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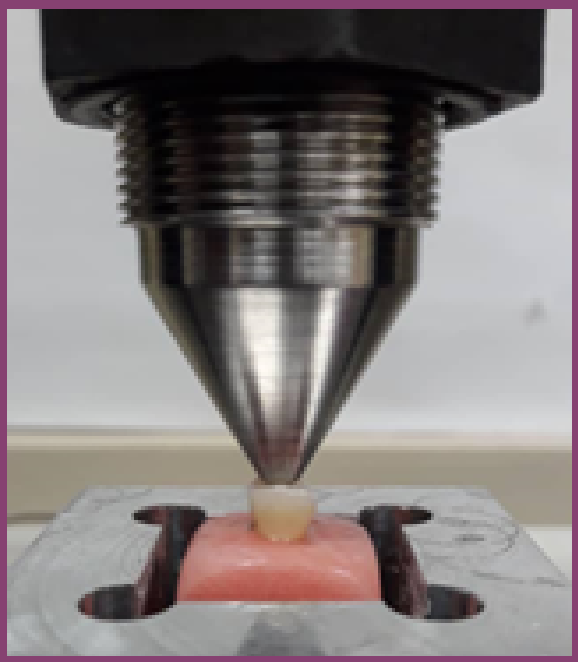

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Aims and scope

IIUM Journal of Orofacial and Health Sciences (IJOHS) is a peer reviewed biannual international journal dedicated to publishing high quality of scientific research in the field of orofacial sciences, health sciences and interdisciplinary fields, including basic, applied and clinical research. The journal welcomes review articles, original research, case reports and letters to the editor. Areas that are covered include but are not limited to dental sciences, oral microbiology and immunology, oral maxillofacial and craniofacial surgery and imaging, dental stem cells and regenerative medicine, dental biomaterial, oral maxillofacial genetic and craniofacial deformities, dental public health and health sciences.

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TABLE OF CONTENTS

EDITORIAL Open Access

Small but significant: behavioural modifications for enhanced oral health and prevention of the tooth death spiral

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The concept of a "tooth death spiral" refers to the progressive decline in oral health that often begins with minor, preventable issues such as early caries or gingivitis. If it is left unaddressed, these initial problems escalate into more severe conditions which requiring restorative interventions, increasing the risk of tooth loss, and compounding systemic health concerns. While technological advancements and professional dental care remain essential, small, evidence-based behavioural changes can play a pivotal role in breaking this cycle and preventing tooth loss. This editorial explores how incremental modifications to daily habits such as oral health care, dietary modifications and technological role, can significantly impact oral health outcomes and halt the tooth death spiral.

The tooth death spiral often begins insidiously. A small cavity or mild gingival inflammation may seem inconsequential, but without timely intervention, these issues can progress into advanced caries, periodontal disease, or endodontic infections (Pitts *et al.*, 2017). The loss of a single tooth exacerbates the problem, leading to functional, aesthetic, and psychological challenges that strain the oral ecosystem (Sheiham, 2001). Adjacent teeth often bear increased load, and without proper care, the cycle repeats, accelerating the path toward further tooth loss. Small, preventive actions can intercept this progression early, offering a cost-effective and sustainable solution to halt the spiral before significant damage occurs.

One of the earliest stages of the tooth death spiral involves plaque accumulation, which leads to demineralisation of enamel and gingival inflammation. Patients often underestimate the significance of proper brushing and flossing techniques in disrupting this process. A two-minute brushing routine, twice daily, ensures thorough cleaning of all tooth surfaces, reducing the risk of plaque retention (Featherstone, 2008). The inclusion of fluoride toothpaste enhances enamel resistance to demineralisation (Pitts *et al.*, 2017). Flossing or using interdental brushes can target areas prone to decay and periodontal issues—preventing interproximal caries and gingivitis that often initiate the death spiral (American Dental Association, 2016). In addition to that, educating patients on identifying early signs of gingivitis, such as bleeding gums, empowers them to seek intervention before the problem escalates (Chapple & Genco, 2013). By reinforcing these foundational

habits, dental professionals can address the initial triggers of the tooth death spiral.

Acidic environments created by frequent sugar intake or poor dietary choices are a key driver of caries progression. The lack of neutralization mechanisms accelerates the decline toward tooth structure breakdown (Dodds *et al.*, 2000). Small but significant interventions include postprandial water consumption which can be done by drinking water after meals. This habit not only clears food debris but also dilutes acids, maintaining a neutral pH and supporting enamel remineralization (Walsh, 2009). Another intervention includes chewing sugar-free gum. It is stated that gum containing xylitol stimulates saliva production, neutralizing acids and creating a protective buffer that halts early demineralisation—a critical step in preventing further decay (Lamont *et al.*, 2018). These actions may seem minor but are instrumental in maintaining the balance required to protect enamel and dentin integrity, preventing small issues from becoming systemic.

Dietary habits are a major contributor to the onset of caries and periodontal issues. Frequent consumption of fermentable carbohydrates feeds acidogenic bacteria, initiating a destructive cycle that leads to demineralization and eventually cavities (Touger-Decker & van Loveren, 2003). On the other hand, cariostatic foods which incorporating calcium- and phosphate-rich foods, such as dairy products, helps strengthen enamel. Leafy greens and fibrous vegetables promote mechanical cleansing of teeth surfaces (Van Loveren, 2000). Another dietary shifts that can be done is snacking modifications by replacing sugary snacks with non-cariogenic options such as nuts or raw vegetables; this reduces the frequency of acid attacks—a critical factor in slowing the progression of caries (Sheiham, 2001). These dietary shifts are not only practical but also cost-effective, making them an accessible strategy for patients across various socioeconomic backgrounds.

One of the most effective ways to prevent the tooth death spiral is through regular professional examinations. These visits provide opportunities to detect early signs of decay, periodontal disease, or occlusal stress that may exacerbate existing conditions (Jepsen *et al.*, 2017).

Small steps to encourage compliance include patient education. Emphasizing the role of routine checkups in identifying and addressing early problems can help patients prioritize preventive care (Pitts *et al.*, 2017). Creating a welcoming environment and employing patient-centred communication which can be done to minimise anxiety can reduce barriers to care, particularly for those with dental anxiety (Preshaw *et al.*, 2012). Early intervention not only addresses minor issues but also reduces the need for invasive procedures, which can disrupt oral function and perpetuate the spiral.

The nighttime oral environment is particularly vulnerable due to reduced salivary flow and prolonged exposure to plaque acids. Poor nighttime hygiene is a common contributor to the tooth death spiral, allowing small issues to escalate during sleep. Encouraging patients to make brushing and interdental cleaning as their final activities before bed, removes debris and plaque, cutting off the bacterial fuel source overnight as pre-sleep oral hygiene routine (Featherstone, 2008). It also can be done by educating patients on the risks of nocturnal sugar consumption can prevent prolonged acid exposure and its cumulative effects on enamel and dentin (Touger-Decker & van Loveren, 2003). These small changes can make an outsized impact on oral health, reducing the progression of caries and periodontal disease.

Modern digital tools offer innovative solutions to monitor and reinforce healthy behaviours that counteract the tooth death spiral. Examples of technology-driven interventions include smart toothbrushes, which the device equipped with sensors provide real-time feedback on brushing technique, ensuring patients maintain proper habits (Pitts *et al.*, 2017). Another example is dental apps that can track oral hygiene routines and send reminders which can encourage consistency in brushing and

flossing. Another great technology is tele-dentistry. Through tele-dentistry, virtual consultations allow patients to address concerns promptly, ensuring early intervention for emerging issues (Jepsen *et al.*, 2017). These tools empower patients to take ownership of their oral health, bridging the gap between knowledge and action.

Tooth loss has profound psychological implications, including diminished self-confidence, impaired social interactions, and reduced quality of life. Breaking the spiral not only preserves oral health but also fosters emotional well-being (Preshaw *et al.*, 2012). Dental professionals should be able to support patients holistically by building confidence through prevention. It can be done by highlighting the role of small preventive measures can instill a sense of control and optimism in patients. Another way is by addressing aesthetic concerns early. Preventing tooth loss through behavioural interventions reduces the need for extensive restorative work, preserving natural aesthetics and function. By focusing on both physical and emotional outcomes, dental professionals can provide comprehensive care that halts the spiral in its tracks.

Dental professionals can play significant role in breaking the cycle. As dental professionals, the role extends beyond clinical interventions to include education, advocacy, and patient empowerment. Short dental appointments often prioritise immediate clinical needs, limiting the opportunity for comprehensive behavioural counselling. Despite these constraints, brief yet impactful chairside education supported by visual aids can reinforce key messages. Providing take-home educational materials or referring patients to digital tools and apps for behaviour tracking can further enhance compliance outside of the clinical setting. By fostering small yet impactful changes in daily oral hygiene routines, dental professionals can contribute to long-term improvements in oral and systemic health. The approach is promisingly can contribute towards sustainable behavioural changes in patient's behavioural modification that we are aiming at.

The tooth death spiral exemplifies how small, preventable issues can snowball into significant oral health challenges. However, this same principle applies in reverse—incremental, evidence-based behavioural changes have the power to disrupt the spiral and restore oral health. Whether it's optimizing brushing techniques, improving dietary habits, or leveraging technology, these small but significant steps offer a pathway to sustainable prevention.

As dental professionals, our role extends beyond clinical intervention. We are educators, advocates, and partners in empowering patients to make these changes. By prioritizing small yet impactful behaviours, we can collectively prevent the tooth death spiral and ensure lasting oral health for generations to come.

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ORIGINAL ARTICLE Open Access

Knowledge and perception of flexible partial dentures among private dental practitioners in Kuantan, Malaysia

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Abstract

Nylon-based thermoplastic dentures offer enhanced flexibility compared to conventional dentures, thus improving patient comfort and acceptance. Despite growing patient demand for flexible dentures, their prescription amongst early-career dental practitioners is poor. This study assessed the levels of knowledge and perception of flexible partial dentures among private dental practitioners in Kuantan, Pahang, Malaysia, with specific attention to potential differences between practitioners with <10 and more or equals to 10 years of clinical practice. A cross-sectional study was conducted using validated, self-administered questionnaires distributed to 73 dental practitioners in Kuantan, yielding 63 responses (38 female, 25 male). Respondents were stratified into two cohorts: Group A (n=28, <10 years' experience), and Group B (n=35, more of equals to 10 years' experience). High knowledge levels and positive perceptions were observed across both groups, with total mean scores of approximately 9 observed in each cohort. Statistical analysis showed no significant inter-group differences in mean scores for knowledge and perception ($p > 0.05$). Furthermore, no significant differences were observed between groups regarding mean knowledge scores or perception agreement frequencies. These findings suggest that private dental practitioners in Kuantan demonstrated substantial understanding and favorable attitudes towards flexible partial dentures, independent of years of clinical experience.

Keywords: *flexible partial denture, Kuantan, private dental practitioners*

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Introduction

Flexible dentures represent a class of metal-free removable partial dentures constructed from ISO 1567-compliant thermoplastic resins, such as polycarbonate acrylic resins and polyamide (nylon) polyaryletherketones (Lim *et al.*, 2021). The clinical application of flexible dentures emerged concurrent with the development of nylon-based thermoplastic resin dentures in 1950 (Rozano *et al.*, 2017). These metal-free removable partial dentures exhibit a significantly reduced flexural modulus compared to conventional polymethyl methacrylate (PMMA) dentures, conferring exceptional breakage resistance to them. Their inherent flexibility facilitates their placement within denture flanges in the buccal vestibule's undercut region (Kapur, 1967). Flexible dentures demonstrate

superior characteristics in terms of comfort, aesthetics and adaptability to the patient's movements in the oral cavity (Singh *et al.*, 2011). Additionally, they provide a viable alternative for patients exhibiting allergic responses to methyl methacrylate monomer or metal components. Contemporary dental practitioners have access to multiple commercial thermoplastic resin options, including Valplast, Flexite, and Acetal, each presenting distinct mechanical and clinical properties (Lim *et al.*, 2021).

The prescription of partial dentures represents a collaborative decision-making process between practitioner and patient. There is a documented preference for flexible dentures, due to enhanced comfort characteristics (Singh *et al.*, 2011). In a study in Rome, 1 out of 5 dentists reported using flexible partial dentures in their clinical practice, citing improved patient comfort and superior aesthetic outcomes (Dragomir, Farcasiu, Pascal, 2021). Higher patient satisfaction rates were observed in flexible dentures when compared against acrylic partial dentures across multiple parameters: aesthetics (53.3% vs. 13.3%), speech function (43.4% vs 20.0%), and comfort (63.6% vs 1.7%) (Akinyamaoju *et al.*, 2019). Furthermore,1 out of 10 expressed a preference for flexible prosthetics over traditional metallic removable partial dentures (RPDs), primarily due to enhanced comfort, superior aesthetics, and favorable cost to the patient (Akinyamaoju *et al*, 2019).

To meet the increasing demand for partial dentures, comprehensive practitioner knowledge regarding flexible prosthetics to optimize treatment outcomes. A previous study reported significant disparities in knowledge levels and perceptions of flexible partial dentures between experienced and novice private dental practitioners in Klang, Malaysia (Rozano *et al.*, 2017). According to the authors, this may be attributed to insufficient coverage of partial denture applications in Malaysian dental curricula (Rozano *et al*, 2017). A previous study by Selvaraj *et al.* in 2023 in Chennai, India revealed significantly higher flexible denture prescription rates among non-prosthodontist dental practitioners compared to general dentists. Notable knowledge gaps hav been identified in undergraduate education, with one study revealing that despite 83% of surveyed dentists reporting awareness of flexible dentures, 77% had never prescribed these dentures to patients (Shivanni *et al.*, 2021).

A study on flexible denture knowledge and perception among private dental practitioners has been reported in Klang Valley, Malaysia (Rozano *et al.*, 2017); however, no comparable study has been performed in Peninsular Malaysia's east coast principal urban center of Kuantan. Situated in the state of Pahang, Kuantan represents a significant healthcare hub, with the Ministry of health data indicating that as of 30 June 2023, the city housed 57.3% (59/103) of Pahang's private dental practices. This concentration of dental healthcare providers presents an opportunity to evaluate the knowledge and perception regarding flexible dentures in a previously unstudied geographical context within Malaysia's healthcare landscape.

The present study aimed to assess knowledge levels and perceptions of flexible dentures among private dental practitioners in Kuantan, Pahang Malaysia, and to investigate potential correlations between duration of clinical experience and practitioner's understanding and attitudes towards flexible partial dentures.

Materials and Methods

This cross-sectional study was conducted under approval by the IIUM Research Ethics Committee (IREC 2022-024). Data collection was performed using previously validated self-administered questionnaires between January 2022 to December 2022 (Rozano *et al.*, 2017). The study population comprised private dental practitioners actively practicing in Kuantan, Malaysia representing diverse demographic characteristics, including ethnicity, gender and duration of clinical experience. The questionnaires were distributed via two modalities: digital dissemination via WhatsApp mobile

application and physical distribution of a printed questionnaires QR codes.

Inclusion and exclusion criteria

The subjects were selected based on purposive sampling methodology. Inclusion criteria was private dental practitioners in Kuantan, Pahang, Malaysia, while exclusion criteria were non- consenting practitioners, employees of the Ministry of Health (MOH), and practitioners operating outside the Kuantan district.

Sample selection

Study participants were grouped into two cohorts based on years of clinical experience: Group A (0-10 years of practice) and Group B (>10 years of practice). Sample size was determined using G*Power software for independent t-test analysis, with parameters set at α= 0.05, power= 0.90, and effect size= 0.8. These parameters yielded a minimum required sample size of 34 participants per group, establishing a total required sample size of 68 participants. Participants were given a set of self-administered questionnaires consisting of 3 sections: demographic details, knowledge on flexible partial dentures, and perceptions of flexible partial dentures. Demographic data collected included age, gender, and duration of clinical practice. The knowledge assessment section consisted of 15 items evaluating participants' understanding of flexible denture characteristics, traits, indications, strengths and weaknesses (Table 1). Knowledge scores were calculated based on correct response frequency. Scores exceeding 50% correct responses indicated higher knowledge levels, and higher mean scores corresponded to greater demonstrated knowledge of flexible partial dentures.

Table 1. Questionnaire on knowledge of flexible denture.

Item	Knowledge on flexible denture		
Q1	Flexible denture is known to be flexible and almost unbreakable	True	False
Q2	Flexible denture is known to be flexible and almost unbreakable	True	False
Q3	Flexible denture material is only made up from Nylon	True	False
Q4	Minimum/no mouth preparation is needed to fabricate flexible denture	True	False
Q5	In ectodermal dysplasia patient, flexible denture may be an option in treatment plan	True	False
Q6	Staining by various ingredient of food, tea and coffee is unlikely to happen	True	False
Q7	Flexible denture can be an alternative for patient that allergic to acrylic denture	True	False
Q8	Flexible denture displaced more soft tissue due to its flexibility	True	False
Q9	Flexible denture is generally used as temporary prosthesis only	True	False
Q10	If patient having limited mouth opening, flexible denture is indicated	True	False
Q11	Undercuts associated with teeth did not pose any problem in insertion or removal of prosthesis	True	False
Q12	Patient with history of repeated denture fractures is indicated to use this prosthesis	True	False
Q13	Patient with lingual tori can use flexible denture without undergoing surgery	True	False
Q14	Flexible partial denture use undercuts in the ridge for retention	True	False
Q15	Technique for insertion and adjustment is same as acrylic partial denture	True	False

Table 2. Questionnaire on perception of flexible denture.

Item	Perceptions on flexible denture	Strongly disagree	Disagree	Agree	Strongly agree
P1	Do you think flexible denture improves digestion?	1	2	3	4
P2	Do you think flexible denture provides more stability during mastication	1	2	3	4
P3	Do you think flexible denture is lighter compared with conventional denture	1	2	3	4
P4	Do you think flexible denture is more reliable for elderly people	1	2	3	4
P5	Do you think flexible denture is easier to wear and remove from mouth compared to conventional denture	1	2	3	4
P6	Do you think your patient will be more comfortable to use flexible denture	1	2	3	4
P7	Do you think flexible denture causes less oral irritation and pain	1	2	3	4
P8	Do you think flexible denture is easier to clean	1	2	3	4
P9	Do you think the cost of constructing a flexible denture is more expensive than conventional denture	1	2	3	4
P10	Do you think flexible denture is easy to construct compared with conventional denture	1	2	3	4
P11	Do you think flexible denture is easy to repair	1	2	3	4
P12	Do you think flexible denture provides more cosmetic solution	1	2	3	4
P13	Do you think flexible denture causes less stress to the remaining teeth and gum	1	2	3	4
P14	Do you think flexible denture will improves general health	1	2	3	4
P15	Do you think flexible denture will improves quality of life	1	2	3	4
P16	Do you think flexible denture is suitable for everyone	1	2	3	4
P17	Do you think flexible denture can be used as permanent prosthesis	1	2	3	4

The perception assessment section consisted of 17 questions evaluated the practitioners'' perception, thoughts and beliefs towards the benefits associated with flexible partial dentures in patients (Table 2). Answers were rated on a 4-point Likert scale (strongly disagree, disagree, agree, strongly agree) as previously established (Rozano *et al.*, 2017). Mean scores for perception were analyzed, with mean values exceeding 50% interpreted as favorable attitudes toward flexible partial dentures, while scores below 50% indicated unfavorable perceptions.

Data was recorded, processed, and analyzed using IBM SPSS Version 25 software. Descriptive statistics were generated, and between-group comparisons of knowledge and perception scores were conducted using independent t-tests to compare for significant differences between dental practitioners with 0-10 years' experience (Group A) and >10 years' experience (Group B). Statistical significance was established at $p<0.05$.

Results

The socio-demographic profile of participating dental practitioners in Kuantan, Pahang (n=63) is presented in Table 3. From 73 distributed questionnaires, 63 responses were received, yielding Gender distribution analysis showed female respondents (60.3%, n=38) outnumbered male respondents (39.7%, n=25). Regarding clinical experience, 44.4% (n=28) of respondents reported <10 years of experience, while 55.6% (n=35) reported more than 10 years of clinical experience.

Table 3. Sociodemographic profile of private dental practitioners in Kuantan, Pahang (n=63).

Sociodemographic profile		n (%)
Gender	Male	25 (39.7)
	Female	38 (60.3)
Years of practicing dentistry	0-10 years (Group A)	28 (44.4)
	More than 10 years (Group B)	35 (55.6)

Knowledge on flexible partial denture

Correct response rate of 63% was found across the 15 knowledge questions in analysis of knowledge assessment. Figure 1 shows the response frequency distribution by item. Eleven items demonstrated higher correct than incorrect response rates. Q1 ("Flexible denture is known to be flexible and almost unbreakable") was answered most correctly (88.9%), while Q13 ("Patient with lingual tori can use flexible denture without undergoing surgery") had the lowest accuracy rates (23.8%). Inter-group comparison of correct response rates is illustrated in Figure 2. Statistical analysis revealed no significant differences in knowledge levels between groups ($p>0.05$) (Table 4).

Analysis of aggregate scores demonstrated high knowledge levels among respondents, with the majority scoring more than 50%. Inter-group comparison of correct responses is shown in Figure 2. Statistical analysis revealed no significant differences in knowledge levels between groups differing in duration of clinical experience ($p>0.05$) (Table 4).

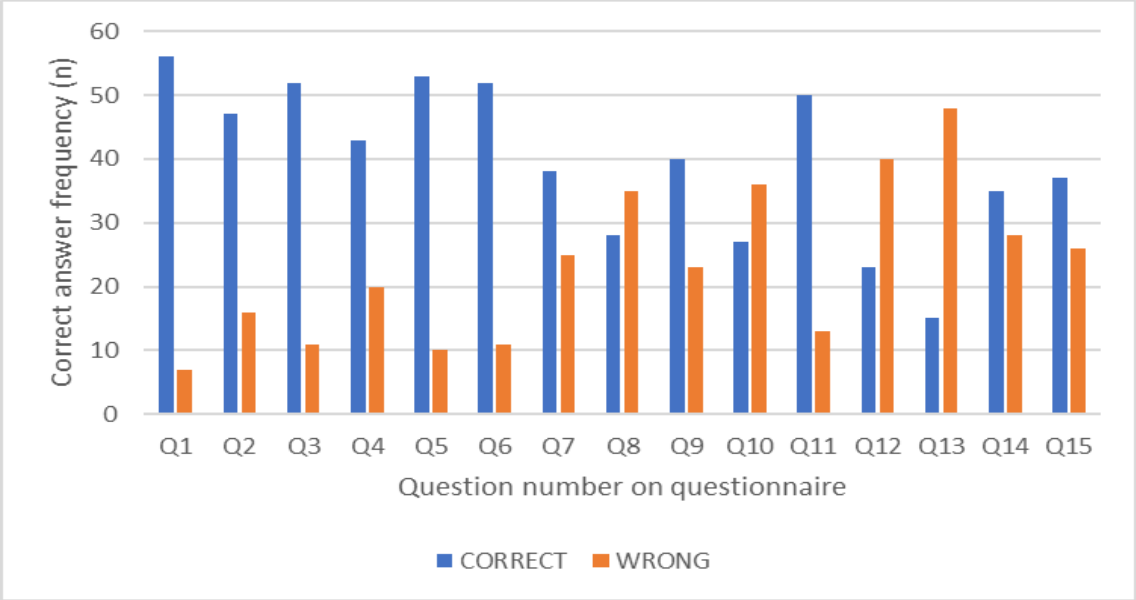

Figure 1. Frequency of the correct answer for knowledge section questions (Q1-Q15).

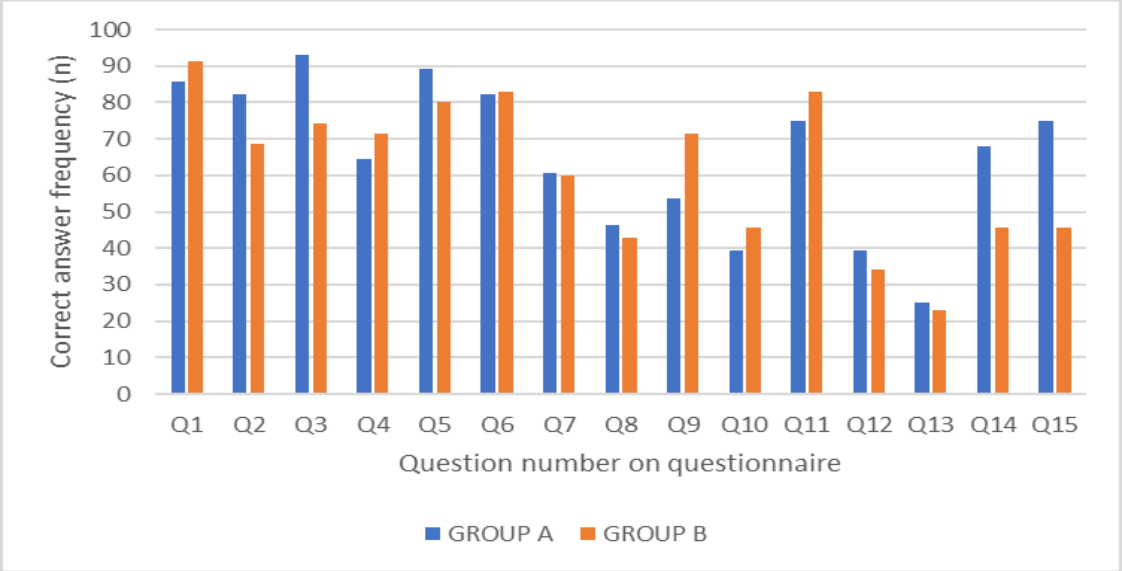

Figure 2. Frequency of correct answers for knowledge section questions. Q1-Q15 indicates item. Group A= ≥10 years' experience, Group B= <10 years' experience

Perception of flexible denture

Frequency of perception response is shown in Figure 3. Overall perception scores demonstrated favorable attitudes toward flexible dentures, with mean scores of 53.5%. Highest agreement frequency was observed for item P3 ("Do you think flexible denture is lighter compared with conventional denture"), with 88.9% of respondents (n=56) indicating agreement. Conversely, only 15.9% (n=10) agreed with item P11 ("Do you think flexible denture is easy to repair").

Comparison of perception response frequencies in groups A and B is shown in Figure 4. In Group A, 92.9% (n=26) of respondents agreed with item P9 ("Do you think the cost of constructing a flexible denture is more expensive than conventional denture"), while 10 out of 28

respondents (10.7%) agreed with item P11 ("Do you think flexible denture is easy to repair"). In Group B, 31 over 35 respondents (88.6%) agreed with item P3 ("Do you think flexible denture is lighter compared with conventional denture"), whereas only 5 over 35 respondents (14.3%) agreed with item P16 ("Do you think flexible denture is suitable for everyone").

Table 4 shows the mean response frequencies for the perception question responses by group. Statistical analysis revealed no significant inter-group differences in perception levels ($p>0.05$), with mean scores of 42.75 and 42.89 for Groups A and B, respectively.

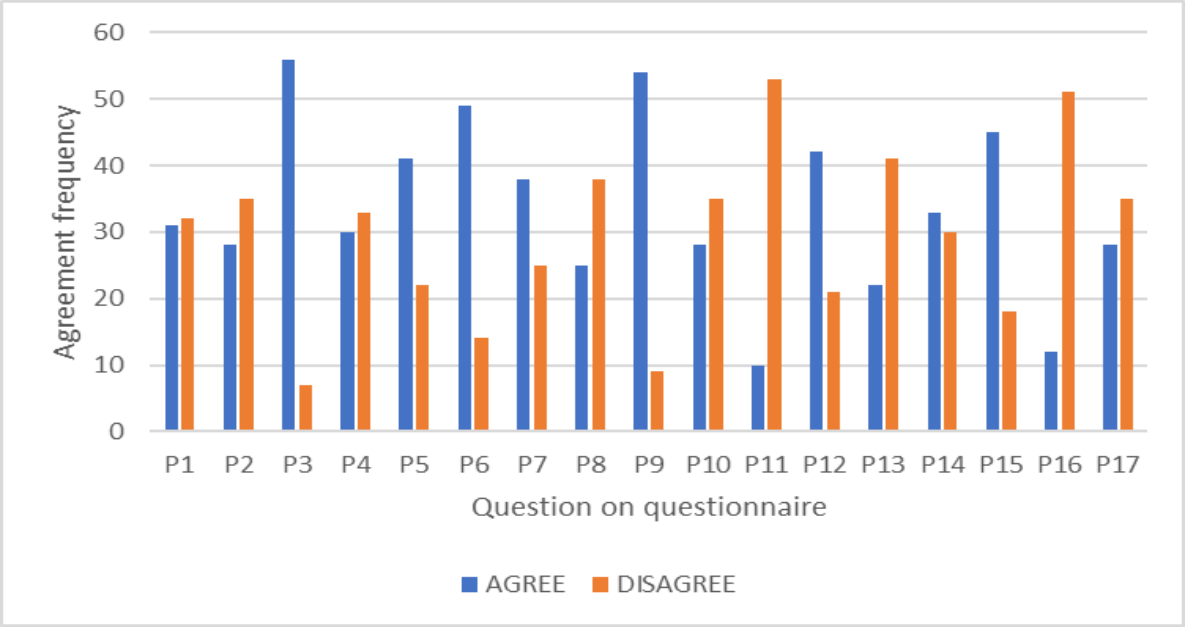

Figure 3. Agreement frequency for each item in the perception section of the questionnaire. P1-P17 indicates item.

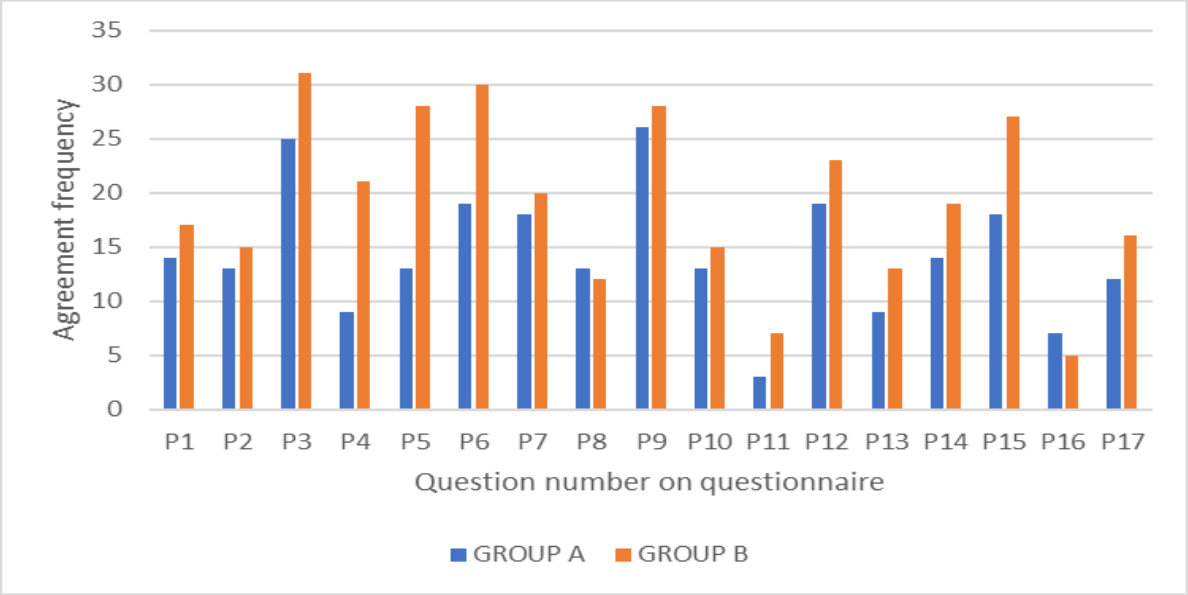

Figure 4. Comparison of agreement frequency for perception questions (P1-P17), by years of practicing (Group A=<10 years' practice; Group B=>10 years' practice).

Table 4. Mean scores for knowledge and perception between Group A and Group B.

Variable	Mean scores		Mean difference (95% confidence interval)	t statistic (df)
	Group A (0-10 years)	Group B (>10 years)		
Knowledge	9.79	9.20	0.585 (-0.291,1.462)	1.336 (61)
Perception	42.75	42.89	-0.136 (-4.170, 3.899)	-0.067 (61)

Discussion

Knowledge of flexible denture

Analysis of the knowledge assessment data revealed high knowledge levels among private dental practitioners in Kuantan, as evidenced by predominantly correct responses patterns across the questionnaire. Statistical analysis revealed no significant differences in mean knowledge scores in practitioners with 0-10 and >10 years of clinical experience.

However, significant variation between Groups A and B was observed for item Q9 ("If patient has limited mouth opening, flexible denture is indicated", correct response: True), suggesting that experience duration may affect understanding of this specific clinical indication. Nevertheless, overall findings indicate that the number of years of experience does not significantly influence comprehensive knowledge of flexible partial dentures. These results align with a previous study by Rozano *et al.* (2017) in the Klang Valley region of Kuala Lumpur, where equivalent knowledge levels among private dental practitioners were observed regardless of gender or years of clinical experience.

A comparative analysis by Daood *et al.* (2022) on removable partial denture curricula across 13 dental schools in Malaysia indicated sufficient educational standards comparable international teaching benchmarks. This standardized educational foundation may account for the observed equivalence in flexible denture knowledge between early-career and experienced practitioners in both the Klang Valley and in Kuantan, Pahang.

Perception of flexible denture

Analysis of perception data revealed generally favorable attitudes towards flexible dentures, with higher agreement scores across most perception items (53.5% agreement, 46.5% disagreement).

Comparison of perception scores in private dental practitioners with less than 10 years' experience (Group A) and more than 10 years' experience (Group B) revealed no significant differences, with three notable exceptions. Significant differences in agreement levels were observed for items addressing elderly patient suitability (P4: "Do you think flexible denture is more reliable for elderly people?"), ease of use (P5: "Do you think flexible dentures are easier to wear and remove from?"), and patient comfort (P6: "Do you think your patient will be more comfortable using flexible dentures?"), with more experienced dental practitioners showing significantly higher agreement rates for these specific aspects. Nevertheless, the overall mean scores for agreement in perception indicate that duration of clinical experience did not influence the perception of flexible partial dentures.

The slightly higher inclination in practitioners with more clinical experience to prescribe flexible dentures is in agreement with a previous study by Rozano *et al.* (2017) indicating a preference for

prescribing flexible partial dentures in practitioners with more than 10 years' experience.

Limitations and further research

This study faced several limitations that warrant consideration in interpreting these findings. First, the minimum sample size was not achieved due to the limited number of private dental practitioners available in Kuantan. Additionally, the study was limited to the town of Kuantan in Pahang, excluding practitioners from other districts and states, which limits the generalizability of findings to broader Malaysian contexts. Furthermore, there was a slight imbalance in the number of dental practitioners across groups, which could have influenced outcomes. Future studies could benefit from expanding the sample size to include practitioners from a broader geographic area, thereby improving sample size and demographic representation.

Conclusion

Private dental practitioners in Kuantan, Pahang exhibited high levels of knowledge and favorable perception of flexible dentures, with no significant association between duration of clinical experience and either knowledge or perception.

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ORIGINAL ARTICLE Open Access

Translation, cross-cultural adaptation and validation of User Mobile App Rating Scale (uMARS)

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Abstract

The user Version Mobile apps rating scale was established to evaluate the mobile apps. However, to date, there is no uMARS in the Malay version. This study aims to develop a Malay language alternative to the existing version of the Mobile Apps Rating Scale. The initial version of uMARS had previously underwent cross-cultural adaptation, and forward-backward translation with synthesis discussion through a development phase. The upgraded Malay version has been screened and rated by 10 respondents for face validation and a total of 36 respondents contributed to the internal reliability assessment by answering the pilot study question. All items and constructs in the uMARS version were fully adapted. All items and constructs from the prior version of uMARS were fully incorporated into the recent version. The Malay language version of uMARS was subsequently assessed for validity as well as reliability after undergoing forward backward translation. Scale level face validity index based on average method (S-FVI/Ave): 0.99, and S-FVI based on universal agreement method (S-FVI/UA): 0.89 showed that uMARS Malay Version has achieved a satisfactory level of response process validity. Whereas all items and construct presented with excellent internal reliability, Cronbach alpha (α) = 0.918, 0.857, 0.984 for objective quality, subjective quality and perceived impact. The Malay language of uMARS represents the outcome produced through proper development and validation of questionnaires; all of which favourably resulted in an updated version of uMARS that has been deemed competent to be utilized for qualitative measurement of mobile health apps in the Malay language.

Keywords: *digital dentistry, digital health records, mobile health, mobile application rating scale, reliability and validity*

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Introduction

Aside from being able to readily provide health care and information to patients, the technology also plays a monumental role in bridging the supply-demand gap between patients and healthcare providers whilst simultaneously enhancing the learning process (Barbosa & Marin, 2009; Sharma *et al*., 2021). The trend of using mobile applications is expected to have an inevitable omnipresence due to the undeniably large fraction of the human population being smartphone owners who are also increasingly mindful about utilizing health-oriented applications (Subramani Parasuraman *et al*., 2017). The use of these mobile apps has benefited both parties in improving communication and service

delivery (Park *et al*., 2016; Zhang *et al*., 2018).

Their triple threat of being popular, mobile and technologically capable propagates the further development of mobile health apps to aid healthcare service providers in solidifying the continuity of care. Mobile technologies are advancing at a rapid rate, suitable for delivering health interventions at the individual level (Perez-Jover *et al*., 2019; Pretlow *et al*., 2015). Several researchers have collectively concluded technology to be a viable aid for health providers in the task of delivering health related information to patients (Heifetz & Lunsky, 2018; Perez-Jover *et al*., 2019; Shao *et al*., 2014; Soler *et al*., 2009; Underwood *et al*., 2015). However, digital product development is faced with two possibilities, success or failure (DeLone & McLean, 1992). Therefore, evaluating such information systems is very important (Delone & McLean, 2003; Mang *et al*., 2022).

Due to the lack of assessment of mobile health apps, it is unknown if the ever-increasing research in health includes the content necessary for health generally or specifically. Therefore, the need for evaluation has become a significant challenge. One way of measuring them is through a valid and reliable questionnaire (Price *et al*., 2015). uMARS is a tool to provide evaluation and measurement scales related to user feedback in evaluating application development from heuristic aspects, user experience and usability to eHealth and mHealth interventions (Stoyanov *et al*., 2016). Numerous scholars have utilized uMARS to evaluate various mobile applications, including contact tracing apps centered on smoking cessation as well as oncological applications (Bendotti *et al*., 2022; Berhanuddin *et al*., 2017; Lu *et al*., 2021; Sereda *et al*., 2019; Sharpe & Kamara, 2018; Strodl *et al*., 2020). The uMARS scale has demonstrated its user-friendliness and may be used as a legitimate and reliable indicator of the app quality. A key challenge in adapting the uMARS to Malay is ensuring that the translated items retain their original meanings. Words, phrases, and health terms often carry different meanings across languages, which could affect how users understand them. Health-related terms, in particular, need careful selection to capture the right nuances and avoid confusion that can result from direct translation (Beaton *et al*., 2000). Cultural context also shapes adaptation; Malay-speaking users may have unique expectations due to their cultural beliefs and habits around health management and information-seeking. Including culturally relevant details in the Malay uMARS can help it better reflect these preferences, leading to more accurate assessments (Sousa & Rojjanasrirat, 2011). Additionally, varied literacy levels in Malay-speaking populations can impact accessibility, so simplifying complex terms or adding clarifications helps ensure that the tool works for all education levels (Cha *et al*., 2007). Adapting the uMARS isn't just about translation, it requires testing to confirm the tool's accuracy and consistency while translating in other language such Malay (Hernández *et al*., 2020). By meeting local standards, the Malay uMARS can help build user trust and remain relevant to Malay-speaking populations (Bardus *et al*., 2020). This version is thus expected to improve health app evaluations, ensuring they meet the cultural, ethical, and usability needs of local users and ultimately support better healthcare through high-quality mobile health solutions (Stoyanov *et al*., 2016).

It is significant to note that the questionnaire showed satisfactory reliability and validity and was brief and easy to use. It's vital to acknowledge the questionnaire's satisfactory level of reliability and validity; both of which further strengthen its existing traits of being user-friendly. uMARS has a good intraclass correlation coefficient (0.66 - 0.70) over a one- to two-month period and great internal consistency = 0.90. Taking into account the risks associated with app inaccuracies as well as the potential exploitation of user data as a result of data breaches. With these factors in mind, it is believed that mobile apps for local use should be appraised using a suitable and understandable tool to gauge the accurate data for app advancement. In addition, the terminology barrier may make it challenging

to effectively capture the local target population's thoughts, feelings, perceptions, behaviours, and attitudes. Studies on the quality of the apps using validated uMARS have been published in a number of languages, including Japanese, Spanish, Italian, and Arabic (Bardus *et al*., 2020; Martin-Payo *et al*., 2021; Morselli *et al*., 2021; Shinohara *et al*., 2022). However, none of these have been developed or adapted and validated to specifically measure the quality of mobile apps in the Malay language. Therefore, this study aims to 1) develop a Malay version of the user version of the Mobile Apps Rating Scale. 2) assess the uMARS Malay version's reliability and validity in evaluating mobile apps. The valid and accurate Malay version of the uMARS questionnaire will be helpful in gauging the calibre of mobile apps among the Malay-speaking populace, particularly in nations like Malaysia, Indonesia, Brunei, and Singapore.

Materials and Methods

Study design

The adaptation and validation of the uMARS Malay Version were conducted using the approach described by (Sousa & Rojjanasrirat, 2011). The approach can be divided into 1) cross-cultural adaptation and translation process, 2) Assessment of Reliability and validity. uMARS is a measurement scale related to user feedback in evaluating application development from heuristic aspects, user experience and usability to eHealth and mHealth interventions (Stoyanov *et al*., 2016). There are 26 items used to evaluate the objective quality, subjective quality and perceived impact. Each uMARS item uses a 5-likert scale (1-Inadequate, 2-Poor, 3-Accepted, 4-Good, 5-Excellent) except item number 13-16, there is a "not applicable" option. Overall, the objective quality of uMARS covers four different structures namely: engagement (items 1–5), functionality (items 6-9), aesthetics (items 10–12), and information (items 13–16). Scores are derived respectively from each item to obtain the average score of each structure (dimension). The total MARS score is also calculated as the mean score for the first four dimensions. The subjective quality score was obtained as the mean score for items 17-22, and perceived impact has six questions in item F and focuses on health impact.

Cross-cultural adaptation and translation process

It was decided that all 26 items and 6 constructs were adapted and maintained for translation. The uMARS structure is illustrated in Figure 1.

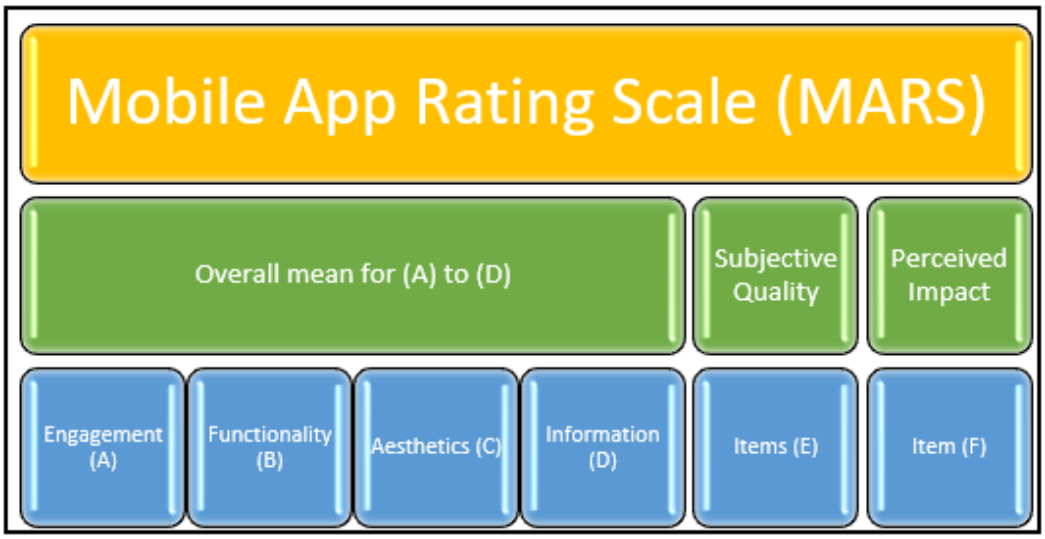

Figure 1. Items in Mobile Apps Rating Scale (MARS).

The translation process for the uMARS involved selected bilingual experts and cognitive interview participants to ensure accuracy and cultural relevance. Bilingual experts included a linguistic specialist and healthcare professionals familiar with mobile health terminology, chosen for their proficiency in both English and Malay, along with experience in translation or cross-cultural adaptation. For cognitive interviews, participants were selected from a broad range of potential users, including healthcare providers, patients, students, and lecturers, to reflect the diversity of the Malay-speaking audience. This approach ensured that the adapted uMARS would be understandable, relevant, and applicable across different user groups.

The adapted uMARS was translate from English to the Malay language by three independent translators, of which one of them is a linguistic expert. All translations were merged into a single version by the committee. The single Malay version was distributed to three independent translators for a back translation process (into English). Comparison between English backward translation and original uMARS was done by the team members and the first Malay Language version of uMARS was produced. The first version was then used for consequent validation. The process of forward-backward translation is demonstrated in Figure 2.

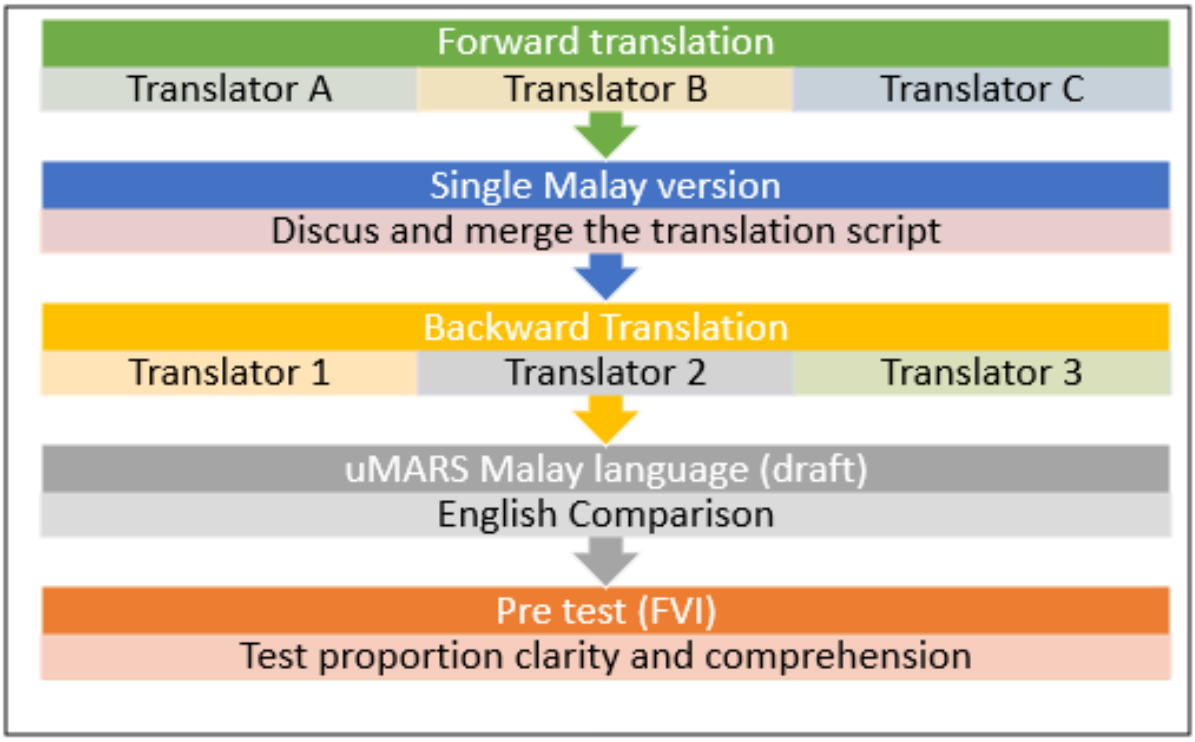

Figure 2. Process forward backward translation.

Assessment of reliability and validity

The face validation process involved ten respondents. Each respondent would remain anonymous to one another during the face validation review procedure, which was carried out independently. The face validation process was conducted to test proportion clarity and comprehension using the Face Validation Index (FVI)(Yusoff, 2019). uMARS Malay version was distributed to ten respondents among the public, patients, students and lecturers. Data management and data analysis were conducted using Microsoft Excel 2016. The face validity assessment was done using the Face Validity Index (FVI) to measure the degree of clarity and comprehension. FVI is a validity method which is widely used by

researchers because its calculation is straightforward, easily understood and informative (Chin *et al*., 2018). Respondents who might be potential users were asked to rate each item on a scale of 1 to 4 based on the degree of clarity and comprehension of the item being assessed (1 = not clear and 4 = very clear). Scores 3 and 4 were re-categorized into 1 (clear and understandable) and others into 0 (not clear and understandable). FVI was calculated based on two components which were Item-FVI (I-FVI) and Scale S-FVI (S-FVI). Since this study used ten respondents as raters, the acceptable cut-off score of FVI is at least 0.83 as mentioned by (Marzuki *et al*., 2018).

Correspondingly, S-FVI is derived from the cumulative scores of items rated as relevant in the tool. The S-FVI can be calculated based on the Universal Agreement (UA) among raters (S-FVI/UA) or based on the average FVI (S-FVI/Ave), with the former being the more conservative method. Calculating the S-FVI/UA is done by adding all items with I-FVI equal to one and dividing it by the total number of items, while S-FVI/Ave can be calculated based on item (I-FVI) and based on proportion clarity and comprehension score across the raters. S-FVI/UA and S-FVI/Ave > 0.8 are considered to represent a satisfactory level of response process validity.

In the validation study for the uMARS Malay version, the sample size was selected to meet statistical power requirements and ensure reliable results. A sample of 36 participants was chosen based on recommendations for achieving adequate internal consistency and validity in cross-cultural adaptation studies. This number aligns with guidelines suggesting a minimum of 30 participants for pilot testing reliability using measures like Cronbach's alpha, which ensures that the tool can be evaluated for consistency across responses (Bujang *et al*., 2018). Additionally, this sample size provides sufficient power to detect any major issues with item clarity, usability, and overall tool functionality, making it a practical choice for a preliminary validation phase.

The reliability of a questionnaire refers to the degree of consistency achieved while producing the result. The reliability of the questionnaire in terms of its internal consistency was determined using Cronbach's alpha. Cronbach's alpha is an essential statistical tool in research because it ensures that the items in a test or survey are consistently measuring the intended construct, contributing to the overall reliability and validity of the study's findings. The uMARS Malay Version (draft) was piloted with 36 respondents using a mobile health app developed for a community health promotion program (Bujang *et al*., 2018). The respondents were selected randomly among undergraduate and postgraduate students at the university and individuals who came to the dental clinic either as patients or accompanying others. An information sheet containing pertinent information about the study was given to eligible participants, and informed consent was obtained. The questionnaire also included a section on participant demographic information. Data management and analyses were conducted using SPSS version 26 (IBM). Analysis was done to assess the reliability of items and construct. The summary of Cronbach's alpha score and the internal consistency is illustrated in Table 1.

Result

Demographics

Out of 36 respondents, 8 (22.2%) were males and 28 (77.8%) were females, and they are in the range of 19 years old – 51 years old. 100% are Malay respondents. Regarding the type of users, 11 (30.6%) were healthcare providers, 24 were derived from a pool of patients (66.7%), and 1 was a (2.8%) student. They were asked about their self-rated level of computer skills. The result showed that 20(55.6%) proclaimed to possess a moderate level of computer skills. The majority of the respondents 25 (69.4%), were android users.

Cross cultural adaptation and translation process

No significant discrepancies were derived when comparing the initial version of uMARS to its successor. Minor changes were carried out to adhere to comments imposed by lay experts; all of which centred on grammar, punctuation, terminology as well as sentence structure. A total of 26 items with five constructs were collectively included to be processed for validation and reliability testing.

Reliability and validity of uMARS Malay Version.

A summary of the entire adaptation and face validation process and findings is illustrated in Table 2.

Validation of Malay Version of uMARS

A summary of the internal reliability findings is illustrated in Table 3.

Cronbach alpha for all constructs is in the range of 0.857 – 0.984 as the result for objective quality domain is 0.918. This result indicated that uMARS Malay version has excellent internal reliability. Eliminating any item would not increase the Cronbach alpha. High corrected item-total correlations indicated significant homogeneity and ranged from 0.65 - 0.98.

Table 1. Cronbach Alpha and internal consistency in dental research proposed by (Jain & Angural, 2017).

Cronbach's alpha	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

Table 2. The FVI indices.

FVI Indices	Formula	Result
S-FVI/Ave (Based on I-FVI)	$\frac{\text{(Sum of I-FVI)}}{\text{Number of items}}$	0.99
S-FVI/Ave (Based on proportion clarity and comprehension)	$\frac{\text{(Sum of Proportion clarity \&comprehension)}}{\text{Number of items}}$	0.99
S-FVI/UA	$\frac{\text{(Sum of UA Scores)}}{\text{Number of items}}$	0.88

Table 3. Internal reliability for Objective Quality uMARS Malay version.

Questions	Mean ± SD	ITC	Cronbach's alpha
A: Engagement			
A1: Entertainment	3.61 ± 1.08	0.83	0.914
A2: Interest	3.78 ± 1.10	0.83	
A3: Customisation	3.33 ± 1.39	0.67	
A4: Interactivity	3.47 ± 1.08	0.86	
A5: Target Group	3.64 ± 1.05	0.77	
B: Functionality			
B6: Performance	3.56 ± 1.10	0.91	0.957
B7: Ease of use	3.71 ± 1.06	0.91	
B8: Navigation	3.78 ± 0.99	0.92	
B9: Gestural Design	3.83 ± 0.97	0.86	
C: Aesthetics			
C10: Layout	3.67 ± 0.93	0.90	0.958
C11: Graphics	3.61 ± 0.93	0.91	
C12: Visual Appeal	3.69 ± 0.95	0.92	
D: Information			
D13: Quality of Information	3.73 ± 0.72	0.72	0.909
D14: Quantity of Information	4.00 ± 0.71	0.81	
D15: Visual Information	4.00 ± 0.71	0.84	
D16: Credibility of source	4.24 ± 0.71	0.81	
Total for Objective Quality			**0.918**
E: App subjective quality			
E17: Recommendation	3.67 ± 1.01	0.67	
E18: Usage	3.03 ± 1.13	0.80	
E19: Interest to pay	2.58 ± 1.16	0.65	
E20: Star rating	3.64 ± 0.93	0.71	
Total for Objective Quality			**0.857**
F: Perceive Impact			
F1: Awareness	3.47 ± 1.34	0.97	
F2: Knowledge	3.47 ± 1.27	0.97	
F3: Attitudes	3.39 ± 1.32	0.98	
F4: Intention to change	3.44 ± 1.32	0.98	
F5: Help seeking	3.53 ± 1.32	0.96	
F6: Behaviour Change	3.56 ± 1.21	0.83	
Total for Perceive Impact			**0.984**

Discussion

The Malay language version of uMARS has thus far proven to be both accurate as well as reliable, the questionnaires of which were further translated into Malay via a standard procedure for cross-cultural adaption to preserve its quality and maintain synchronicity to its predecessor. (Beaton *et al*., 2000). Adapting a questionnaire to meet the requirements of the local context and to fit the local needs are vital steps in ensuring the validity and reliability of the data collected (Sousa *et al*., 2017). Researchers will be able to carry out future studies and assess the quality of mobile health application development by using uMars Malay Versions that are adapted to the local context. It will specifically serve as a guide for developers to strengthen the process of developing apps for planning, managing, and improving the apps and ensuring that the built-in applications can be utilised continually by users to improve their health results. The outcomes showed that the uMARS Malay Version, which was culturally adjusted, is acceptable. Employing rigorous and context-specific translation methods,

along with a combined translation approach, is essential for achieving accurate and culturally relevant adaptations of research tools. This approach helps retain the original meaning while making the tool suitable for the target audience's culture and language, supporting the tool's reliability and validity (Sousa & Rojjanasrirat, 2011). The uMARS Malay version shows a Cronbach's alpha of 0.918 for objective quality and 0.857 for subjective quality, indicating that these scores align well with those found in Arabic language versions that reported internal consistency around 0.88 (Bardus *et al*., 2020), Cronbach's alpha of 0.75–0.85 for Japannese version (Shinohara *et al*., 2022), whereas Cronbach's alpha for original version = 0.90 (Stoyanov *et al*., 2016), showing uMARS Malay Version are comparable reliability across cultural adaptations

This study also presents the results of adaptation, face validation, and internal reliability of the uMARS Malay version. Validity index (FVI) calculations were produced for 26 items, which are five in section A (engagement), four in section B (functionality), three in section C (aesthetics), four in section D (information), four in section E (subjective quality), and 6 in Section F (Perceived impact). The S-FVI/Ave for uMARs Malay version is 0.99, and S-FVI/UA is 0.88, which shows that the uMARS Malay version achieved a satisfactory level (Yusoff, 2019). The Malay uMARS face validity index (S-FVI/Ave) was 0.99, note that it is consistent with scores in Spanish and Japanese versions, which also reported high validity. This consistency shows the thoroughness of the uMARS adaptation (Martin-Payo *et al*., 2021). It demonstrates that the Malay uMARS meets international standards, supporting its reliability and validity for Malay-speaking users.

The newly produced Malay language version of the application was screened by ten lay experts derived from the public population, from groups of students as well as lecturers that had no prior participation in any study phases. It served as a means of establishing the app's clarity and understandability. The expert can ensure that the community for which the questionnaire is being designed is accurately represented by employing possible members of the target group as the subject (Zamanzadeh *et al*., 2015).

Internal consistency was chosen to evaluate the questionnaire based on its widespread use (Bolarinwa, 2015; Taber, 2018) and feasibility. Cronbach's alpha was used to show that the different questions in the questionnaire reliably measured the app quality subscale in the target user. Having the 0.857 – 0.984 for the construct and objective quality domain carried 0.918 as a Cronbach alpha presented with excellent internal reliability for the full scale and good level for the subscale (Jain & Angural, 2017). The Cronbach alpha in this study would definitively meet the criteria if it exceeded 0.7 (Yusoff *et al*., 2021). All items in the uMARS Malay version in the reliability test executed in the range of 0.65 to 0.98 item-total correlation (ITC), which indicates that all items are highly discriminating. The link between an item and the overall score on the other items is defined by the corrected item-total correlation (Zijlmans *et al*., 2019). The scale range of uMARS Malay version is proof of the application's accessibility, validity as well as reliability as a means of defining the quality of mobile apps and the perceived impact imposed on mobile apps though some mobile applications were developed using scientific research, it's still critical to evaluate their contributions to health education (Karlsen *et al*., 2022). It is crucial to bear in mind that user adherence is also influenced by the quality of mobile applications while using them to improve population healthcare.

This study produced a validated questionnaire for the assessment of quality mobile apps by adapting a validated version of uMARS. The development of the uMARS Malay Version has gone through a rigorous translation and validation process involving panels from a wide range of discipline and potential users to help bridge the cultural gap between differing languages. However, this study has some limitations. Firstly, Malay uMARS was developed for mHealth in a specific group which is primary care dental

set-up. Therefore, some testing on a variety of mobile health systems is required. This study only focuses on face validity index. This is because it is regarded as a component of content validity, as face validity is frequently not recognized as a separate validation method. If a questionnaire was administered on its own, the lack of accuracy is necessary to demonstrate its validity. However, combining face validity with other validation tests can be useful (Polit & Beck, 2006). Furthermore, certain nuances may affect the generalizability of findings beyond culturally similar groups in Malaysia, Brunei, Singapore, and parts of Indonesia. The adapted uMARS may be less applicable to Malay speakers in other settings or to other cultural groups, as interpretations of terms or health app usage could vary. To enhance generalizability, future studies could include testing with a more diverse range of Malay-speaking populations or implement additional cultural adaptations.

Conclusion

Employment of this mobile application is sufficient in fortifying the quality of communication in terms of service delivery whilst also ensuring the availability of continuous care. Information material must contain scientifically reliable information and be provided in a form that is acceptable and useful to the patient. It is necessary to educate patients on how to gain quality mobile health apps to adhere users for sustained use and, reach appropriate agreements and adapt to patient health information. Therefore, uMARS Malay version is a valid and reliable tool to help them to measure the quality of the apps.

Future research should expand validation efforts for the Malay uMARS to include a broader demographic, incorporating users from various regions and with different levels of digital literacy. Further studies might also explore the tool's adaptability across other Malay-speaking communities to strengthen its generalizability and address any remaining cultural nuances.

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Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Abbreviation

uMARS : User mobile app rating scale
FVI : Face Validation Index
I-FVI : Item- Face Validation Index
S-FVI : Scale- Face Validation Index
UA : Universal Agreement
S-FVI/UA: Universal Agreement among raters
S-FVI/Ave: Face Validation Index based on the average.

Ethical Approval

Approval was granted by the Research Ethics Committee of Universiti Teknologi MARA (Ref No: REC/06/2021 (MR/400)), (Date 11th June 2021)

Authors' Contributions

Methodology, Tuan Yuswana Tuan Soh, Supervision, Budi Aslinie Md Sabri; Writing – original draft, Tuan Yuswana Tuan Soh; Writing – review & editing, Nik Mohd Nik Mohd Rosy and Budi Aslinie Md Sabri.

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ORIGINAL ARTICLE Open Access

Fracture resistance of direct composite and composite onlay on endo-treated upper premolar with MOD cavity

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Abstract

Endodontically-treated teeth are weaker than vital teeth due to extensive missing sound tooth structure and the endodontic treatment. The restoration choice for an endodontic treatment tooth (ETT) determines the ETT's survival. This study aims to investigate the fracture resistance and mode of direct composite restoration and direct composite onlay with cuspal coverage on endodontically-treated upper premolars with mesio-occluso-distal (MOD) cavity. Twenty sound upper premolars were collected from local dental clinics, mounted in cold-cure acrylic and stored in normal saline. Teeth were subjected to root canal treatment (RCT), followed by MOD cavity preparation. The teeth were randomly and equally divided into two groups (Groups A and B). Group A (n = 10) were restored with direct composite restoration, whereas Group B (n = 10) were prepared occlusally and restored with direct composite onlay restoration. All teeth were subjected to a compressive axial load test using a universal testing machine (Instron 3369, United State) with a metal ball sized 4 mm at 1mm/min of crosshead speed until a fracture occurred. The fracture mode was analysed under a stereomicroscope with 0.68 magnifications. A statistical analysis of fracture resistance and fracture mode was performed using a paired T-test. The mean fracture resistance value was 431.37 N for group A and 1158.34 N for group B, with a statistically significant difference ($p < 0.05$) between these two groups. Endodontically-treated upper premolar with MOD cavities restored with direct composite onlay restoration exhibited higher fracture resistance than direct composite restoration. In addition, the mode of fractures was not affected by the types of restoration.

Keywords: *endodontically-treated teeth, direct composite restoration, direct composite onlay, fracture resistance, MOD cavity*

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Introduction

The success of the endodontic treatment is determined by a combination of optimal quality of endodontic treatment and exceptional coronal seal, which is provided by the final restoration constructed upon completing the root canal treatment (Assif *et al.*, 2003).

Most endodontically-treated teeth are complicated by extensive tooth destruction due to early tooth problems, such as caries, fractures, repeated restorations, and restorative procedures. In addition, further

tooth structure loss occurs during the cavity access of the root canal treatment. Hence, the strength of the tooth and the ability to withstand the occlusal forces is reduced. The strength of the tooth is directly correlated to the quantity of the lost dentine (Faria *et al.*, 2011).

The definitive restoration for ETT should provide adequate retention and maximum fracture resistance. Furthermore, the affected tooth requires a well-sealed restoration to prevent the invasion of intraoral bacteria and toxins to the root canal and periapical area (Hansen, 1988).

In endodontic treatment, a significant amount of dentine is usually removed, causing the tooth to be more brittle (Assif *et al.*, 2003). Tooth brittleness is potentially risky for posterior teeth compared to anterior teeth due to the greater occlusal load exerted on the posterior teeth. Tooth fracture occurs more often on the mandibular molar than the maxillary posterior tooth due to a higher masticatory force (Faria *et al.*, 2011). In addition, the root anatomy also plays a vital role in resisting tooth fracture. For example, the maxillary premolar, with a narrower mesiodistal dimension, exhibits a high tendency for longitudinal root fracture.

To minimise the incidence of fractured teeth, several types of materials and techniques are considered as the definitive restoration after the endodontic treatment. These can be divided into two categories, which are direct and indirect restorations. Direct restoration involves the manipulation of restorative materials at the chairside. Direct restoration includes direct composite onlay, direct composite restoration, and amalgam restoration. On the other hand, indirect restoration requires both chairside and laboratory work, such as ceramic inlay, porcelain-fused-metal crown, and all-ceramic crown.

Fractures were documented as significant issues in a 20-year retrospective analysis of 1638 endodontically-treated posterior teeth restored with amalgam without cusp coverage. Maxillary bicuspids with MOD restorations demonstrated the lowest survival rate overall (28% fractured within three years, 57% after 10 years, and 73% after 20 years) (Hansen, 2019). According to clinical research (McComb, 2008), MOD cavity preparation with composite restoration has a greater fracture resistance compared to amalgam restoration due to the usage of acid etching and a bonding agent. The use of cuspal coverage restoration immediately after completing RCT may prevent tooth fracture and improve the longevity of the tooth (Heling *et al.*, 2002). In contrast, restoration without cuspal coverage, like bonded CAD/CAM ceramic inlays, performed poorly with numerous catastrophic fractures (Hannig *et al.,* 2005). Thus, this type of restoration to restore endodontically-treated teeth should be avoided.

This study compares direct composite restorations and direct composite onlays as the definitive restoration of endodontically-treated upper premolars. Onlay is 'partial-coverage restoration that restores one or more cusps and adjoins occlusal surfaces or the entire occlusal surface and is retained by mechanical or adhesive means (Ferro *et al.*, 2017). Onlay can be made of metals, such as gold, ceramic, and composite. The demand for composite onlays has increased due to their low cost, outstanding esthetical value, mercury-free, and similar mechanical properties to dentine (Jiang *et al.*, 2010). An onlay offers high fracture resistance, given its cuspal coverage and effective stress distribution properties (Assif *et al.*, 2003).

Meanwhile, direct composite restoration replaces lost tooth structure intracoronally with no cuspal coverage involvement. This technique is generally effective in restoring teeth to their normal strength through proper cavity preparation. Nevertheless, the prognosis in endodontic treated teeth is questionable due to higher stresses and cyclic fatigue of the composite bonding (McComb, 2008). Assumably, the direct composite restoration causes a high risk of cuspal fracture.

This study aims to compare the reliability of fracture resistance of direct composite onlay

and direct composite restoration on endodontically-treated upper premolars with mesio-occluso-distal (MOD) cavities. Specifically, the objectives of this study aimed to compare the fracture resistance of direct composite onlay and direct composite restoration as a definitive restoration of an endodontic treated maxillary premolar and to analyse the type of failure that occurs on the restored endodontic treated maxillary premolar. It is hypothesised that direct composite onlay with cuspal coverage would demonstrate better fracture resistance than direct intracoronally composite restoration.

Materials and Methods

Collection and preparation of samples

A total of 20 sound maxillary extracted premolars were collected and cleaned with sodium hypochlorite for 24 hours and rinsed. The sample size was dictated based on the previous study by Assif *et al.*, 2003 which included 10 samples for each study group. Only sound teeth with no carious lesions, previous restoration, and crack lines were included in the study. Then, the teeth were stored in normal saline to maintain the moisture of the tooth structure. The teeth were mounted in Huge Dent (China) cold cure acrylic resin to initiate the sample preparation.

Root canal treatment

Access cavity was conducted on all teeth using a long shank round bur and an Endo Z (Densply Sirona, United State) bur on a high-speed handpiece. After that, the working length of each canal was determined using K-file #15 and confirmed by an intraoral periapical radiograph, as depicted in Figure 1. Cleaning and shaping were performed by crown down technique using hand Protaper sizes S1, S2, F1, and F2. Next, a trial GP (Protaper GP size F2) was placed up to the working length and confirmed by a periapical radiograph. Lastly, obturation was undertaken by a single cone technique, and GP was cut below the cement-enamel junction (CEJ) using a heated Endo plugger. A radiograph was taken to assess the quality of obturation (Figure 1).

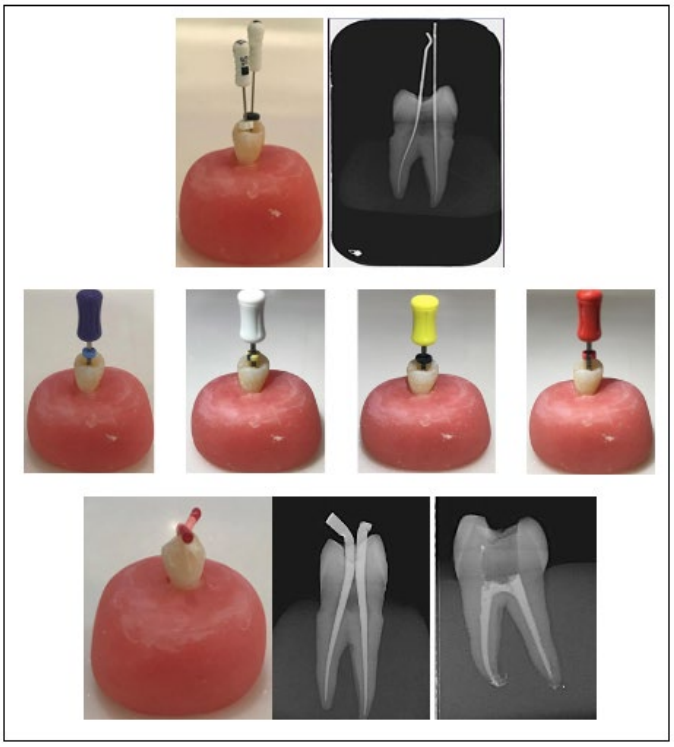

Figure 1. Steps of root canal treatment (RCT) on an upper premolar tooth.

Cavity preparation

All teeth were randomly and equally divided into two groups (A and B), comprising 10 teeth in each group. Group A was prepared for only MOD cavity, whereas Group B was prepared with MOD cavity and onlay preparation. The MOD cavity was prepared on both groups using medium grit diamond straight fissure bur in a high-speed handpiece under the air-water spray. The specific dimension of the cavity was one-third of the buccolingual width, approximately 1 mm, and the depth was 1.5 mm up to the CEJ level. A periodontal probe and a calliper were used to measure the cavity during cavity preparation. For Group B, onlay preparation was performed with the same instruments with a dimension of 2 mm reduction on both buccal and palatal cusps. Three guiding grooves with a depth of 2 mm (measured with a periodontal probe) were made on occlusal (buccal and palatal). The reduction was subsequently performed with the grooves as the marker.

Restoration

A narrow matrix band (Tofflemire type) was placed on each tooth for the preparation of the MOD and onlay restoration. A single layer of 3M ESPE Single Bond Universal bonding agent was applied using a micro brush, and it was blown using a 3-way syringe before being light-cured for 20 seconds. Next, 3M Filtex P60 Posterior Composite was adapted incrementally and light-cured using Planmeca LED light cure for 20 seconds. The composite was carved to the original teeth shape and polished using a white stone bur.

Loading test

The samples were subjected to compressive axial loading under the Universal Testing Machine by a 4 mm-sized crosshead with a 1.0 mm/min speed until fracture occurred (Figure 2). The peak load at fracture is presented in Figure 3, which was recorded in Newton (N) for each specimen, and the mean and standard deviation were calculated for each group.

Once the fracture occurred, the force required to elicit tooth fracture was recorded and analysed. The mode of fracture was examined and analysed using a stereomicroscope. A classification system proposed by Burke *et al.* (1993) was employed to evaluate the fracture mode. Type I fractures were restricted to the restoration, while Type II fractures were limited to the crowns and did not extend to the root. Meanwhile, Type III crown fractures were extended to the root but less than 1 mm below the acrylic line and were restorable. Type IV fractures occurred in the crown and the root, extending more than 1 mm below the acrylic line and were not restorable. Data for the fracture resistance test and mode of fractures were analysed using SPSS Statistic software version 27 and a Paired Sample t-test.

Results

The peak load at fracture measured in Newton are presented in Figure 3.

The mean fracture resistance values for Group A and Group B were acquired and recorded in Table 1. The mean fracture resistance value for onlay restoration (Group B) was significantly higher compared to the teeth that were restored with direct composite restoration (Group A) (Table 2; $p < 0.05$).

Nonetheless, the mode of fractures between direct composite restoration (Group A) and onlay restoration (Group B) was not significantly different ($p > 0.05$).

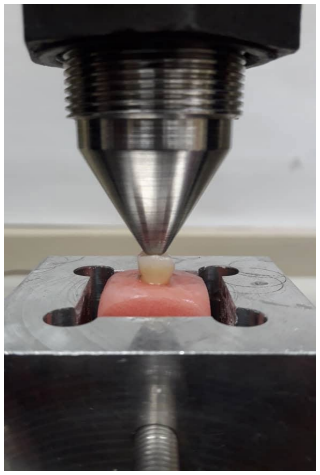

Figure 2. Tooth mounted in acrylic was tested under the loading machine.

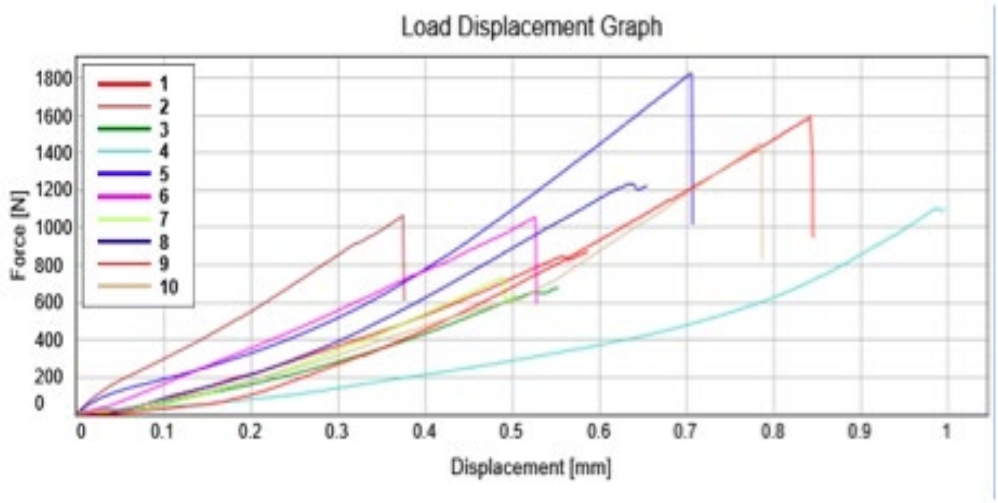

Figure 3. The peak load at fracture for group B. Data was recorded in Newton (N) for each specimen and the mean and standard deviation were calculated for each group.

Table 1. Mean fracture resistance and standard deviation for each group.

Group	*n*	Restoration	Mean of the fracture resistance (N), ± SD
Group A	10	Direct composite restoration	431.37 ± 177.11
Group B	10	Onlay restoration	1158.34 ± 378.69

Table 2. Distribution of mode of fractures for each group.

Group	*n*	Mode of fractures			
		Type I (%)	Type II (%)	Type III (%)	Type IV (%)
Group A	10	5 (50%)	5 (50%)	-	-
Group B	10	6 (60%)	4 (40%)	-	-
Total	20	11 (55%)	9 (45%)	-	-

Discussion

This study investigated the differences in fracture resistance and mode of fractures between endodontically-treated teeth (ETT) that were restored with direct composite restoration and direct composite onlay restoration. The teeth selected for this study were maxillary premolars due to their anatomic position in the middle of the molars and anterior teeth. Sound teeth of standard size, absence of carious lesions, restorations, and crack lines were included in the study. Based on previous studies, ETT has lower strength than sound teeth due to the loss of tooth structure resulting from caries or restorative procedures (Assif *et al.*, 2003; McComb, 2008; Slutzky-Goldberg *et al.*, 2009). ETT are more susceptible to fracture during function. The coronal restoration after endodontics treatment determines the clinical longevity of the teeth (McComb, 2008). Previous studies supported that the teeth with cuspal coverage restoration demonstrated higher success rates (Faria *et al*., 2011; Jiang *et al.*, 2010)

In this study, compressive axial loading was applied parallel to the longitudinal axis of the samples until a fracture occurred, similar to the procedure employed in most previous studies (Assif *et al.*, 2003; Salameh *et al*., 2010). A universal testing machine with a 4 mm-sized crosshead with a speed of 1.0 mm per minute was used in this study, consistent with the testing machine and speed of the crosshead used by Salameh *et al.* (2010).

The average fracture resistance for direct composite restoration obtained in this study was 431.37 N. Previous studies reported that fracture resistance was 655.80 N (Assif *et al.*, 2003) and 607.00 N (Faria *et al.*, 2011). For direct onlay composite restoration, this study's average fracture resistance value was 1158.34 N, consistent with earlier studies, 1006.13 N (Alshiddi & Aljinbaz, 2016), and 1544. 67 N (Salameh *et al.*, 2010). Nevertheless, there is a slight difference between the present study and the other research due to the different types of tested teeth, restoration material and the load angle applied to the samples.

The results obtained in this study depicted a significant difference in fracture resistance between Group A (direct composite restoration) and Group B (onlay restoration). This result parallels the findings of several studies that supported fracture as a significant complication in ETT with MOD restoration without cuspal coverage restoration. This event occurred due to increased cusp deflection during masticatory load, whereby the internal architecture of the tooth was lost (McComb *et al.*, 2008). Fractures were more distinct in maxillary premolars with MOD cavities, and increasing the cavities depth by twofold will increase the deflection by eightfold. The risk of teeth fracture is markedly increased in ETT, where the cavity depth is three to four times deeper than usual restoration in vital teeth. Therefore, it is recommended that the definitive restoration after endodontics treatment includes the cusps in posterior teeth to increase the survival rate of the ETT. This is supported by a previous study in which ETT without a crown was unsuccessful at a six-fold greater than teeth with crowns (McComb *et al.*, 2008).

The fracture modes were categorised into 4 types: Type I, Type II, Type III, and Type IV, similar to the study by Burke et al. 1993. The teeth in this study fracture with mode I and mode II types of fracture. The universal testing machine halted at the early stages of fracture propagation, which explains why only type I and type II fracture modes were observed in this study. The early termination prevented further progression of fractures that might have resulted in more extensive fracture patterns in type III and Type IV (Koosha et al, 2022). No significant difference between Group A and Group B regarding fracture modes was detected. Given the lack of prior studies, the underlying reasons for these results still need to be fully understood.

The limitation encountered in this study was the lack of previous studies that compared MOD composite restoration and direct composite onlay restoration. Information

was also lacking regarding the patients' age from which the teeth were extracted. It was suspected that the older the patients, the more brittle the teeth due to increased mineralised content in the dentinal tubules. Nevertheless, this issue is still debatable, as an earlier study found no significant difference in dentine hardness between patients' ages (Montoya *et al.*, 2015). Future studies should consider obtaining teeth samples from the same age group to address this issue and prevent controversy.

Conclusion

In this in vitro study, it was observed that endodontically treated teeth restored with direct composite onlay restorations demonstrated higher fracture resistance compared to those with direct composite restorations. Therefore, direct composite onlays may provide a mechanical advantage for restoring endodontically treated teeth with MOD cavities. However, since this was a laboratory-based investigation, the findings should be interpreted cautiously when applied to clinical practice. Additionally, the study noted that the type of restoration did not significantly influence the mode of fractures. Further clinical research is necessary to validate these results in the clinical setting.

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ORIGINAL ARTICLE Open Access

Patient satisfaction toward aesthetic and functional outcomes: a comparative study of acrylic vs. cobalt-chrome removable partial dentures

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Abstract

Removable partial dentures (RPD) are effective prostheses for restoring both function and aesthetics following tooth loss. Patient satisfaction with RPD functional and aesthetic outcomes is critical in determining the success of RPD therapy. This study aimed to evaluate and compare patient satisfaction with the function and aesthetics of acrylic and cobalt chrome (Co-Cr) RPD and identify factors affecting patients' satisfaction with RPD. Ninety-one patients who received RPD from undergraduate dental students from Kulliyyah of Dentistry (KOD), IIUM, participated in this study. The number of RPD issued for these patients was 150 units, with 121 (80.7%) acrylic and 29 (19.3%) Co-Cr RPD. Patients completed validated questionnaires consisting of four sections: demographics information, patient satisfaction towards the function of RPD, patient satisfaction towards aesthetics of RPD and patient perception towards retention and stability of RPD. Data analysis was conducted using Microsoft Excel 2016 and SPSS version 25. Mann-Whitney U tests were used to analyse and compare patient satisfaction levels of RPD. A chi-square test was used to examine patients' perceptions of retention and stability of their RPD. Analysis was set as $p<0.05$ with a 95% confidence interval as statistically significant. The majority of patients reported greater functional and aesthetic satisfaction with acrylic removable partial dentures (RPDs) compared to cobalt-chromium (Co-Cr) RPDs. There was no significant relationship between patient satisfaction with retention and stability of RPD. In conclusion, acrylic RPDs were perceived to be superior to Co-Cr RPDs, and patient satisfaction was not influenced by the retention or stability of the RPDs.

Keywords: *acrylic RPD, aesthetics, cobalt-chrome RPD, functions, patient satisfaction*

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Introduction

A removable partial denture (RPD) is a prosthesis replacing the missing teeth in a dental arch while preserving the remaining natural teeth. Its role extends beyond restoring mastication, speech, and aesthetics; it also establishes proper relationships with remaining teeth, periodontal structures, and mucous tissues (Bessadet *et al.*, 2013). RPD can enhance masticatory efficiency in partially dentate patients, improving quality of life by enhancing aesthetics and stomatognathic system functions (Sharma *et al.*, 2018). A

high-quality RPD significantly enhances oral health. Besides the dentist's skill and prosthesis quality, the subjective assessment by the patients is a key factor in determining treatment success (Awawdeh *et al.*, 2024).

Some patients express dissatisfaction with their RPD, even when the dentist graded it as satisfactory (Shala *et al*., 2016). Patient dissatisfaction may occur when the recommended prosthetic designs, despite being clinically evaluated as optimal by the dentist, do not align with the patient's subjective expectations and preferences. Understanding how patients use partial dentures is crucial in guiding the decision-making process for both dentists and patients during treatment. Since patient satisfaction with partial dentures is highly subjective, it can be challenging to quantify and define.

A previous study stated that higher satisfaction scores were significantly associated with older age, upper RPD, and RPD fabricated by prosthodontic residents (Koyama *et al*. 2010). Gender, Kennedy classification, and denture type did not significantly affect patient satisfaction (Shala *et al*. 2016). Despite these findings, there remains a research gap in exploring the differences in satisfaction levels between acrylic RPDs and Co-Cr RPDs, as well as the impact of denture retention and stability on patient satisfaction.

This research aims to evaluate and compare patient satisfaction with acrylic and Co-Cr RPD in terms of function and aesthetics. In addition, it also focuses on assessing patient perceptions of the retention and stability of these two types of dentures and their relationship with patient satisfaction toward RPD.

Materials and Methods

Data collection

The sample size for the patient population using RPD was determined through Raosoft software (Washington, USA). Ethical approval for the study was granted by the IIUM Research Ethics Committee (IREC), under approval number IREC 2023-064. Patient data were retrieved from the patient database at the Prosthodontics Clinic, Kulliyyah of Dentistry (KOD), International Islamic University Malaysia (IIUM). Patients who received RPDs from IIUM undergraduate dental students between 2018 and 2021 were contacted by phone. Those who had not completed the RPD construction or received other types of prostheses were excluded from the study. Those who provided informed consent were invited to complete a set of validated questionnaires. The questionnaires, verified by three Prosthodontics specialists, comprised four sections: demographic information, patient satisfaction regarding the satisfaction towards the function of the RPD, satisfaction with its aesthetics, and perceptions of its retention and stability. Sections B and C utilised a five-point Likert scale, while Section D consisted of binary-type questions.

Data analysis

The collected data were organised and analysed using Microsoft Excel 2016 and SPSS version 25. The normality of the data was assessed using the Kolmogorov-Smirnov test. Descriptive statistics, including means and percentages, were calculated for the demographic data. For bivariate analysis, given that the data were not normally distributed, non-parametric Mann-Whitney U tests were employed to compare patient satisfaction levels and differences in satisfaction between acrylic and Co-Cr RPD. The Chi-square test was utilised to examine patients' perceptions of the retention and stability of RPDs. Statistical significance was set at $p<0.05$, with a 95% confidence interval.

Results

Demographic information

Ninety-one (91) patients consented to participate in this research. 52.8% (48) of

patients were male, and 47.3% (43) were female (Figure 1). The patient's age ranged between 25 to 84 years old, with a mean age of 59.5 ±11.5 years. Patient demographic based on their occupational status: 14.2% were government employees, 37.4% were pensioners, 6.6% were private sector employees, 8.8% were self-employed, and 33.0% were unemployed (Figure 2). The total RPD issued was 150 units, with 80.7% (121) being acrylic RPD and 29 (19.3%) being cobalt-chrome RPD (Figure 3).

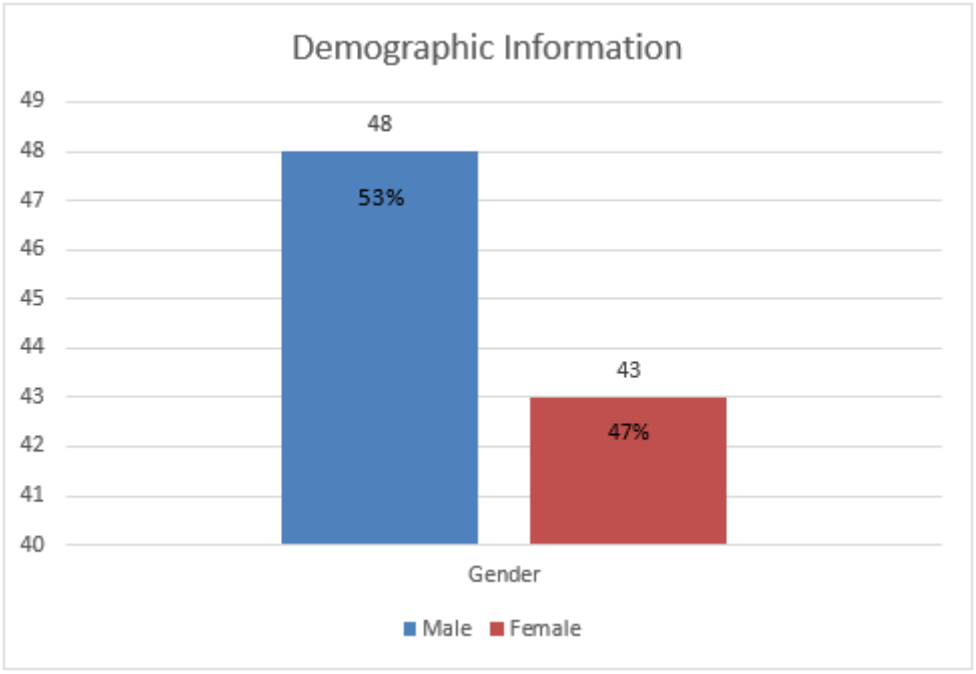

Figure 1. Gender distribution of the patient.

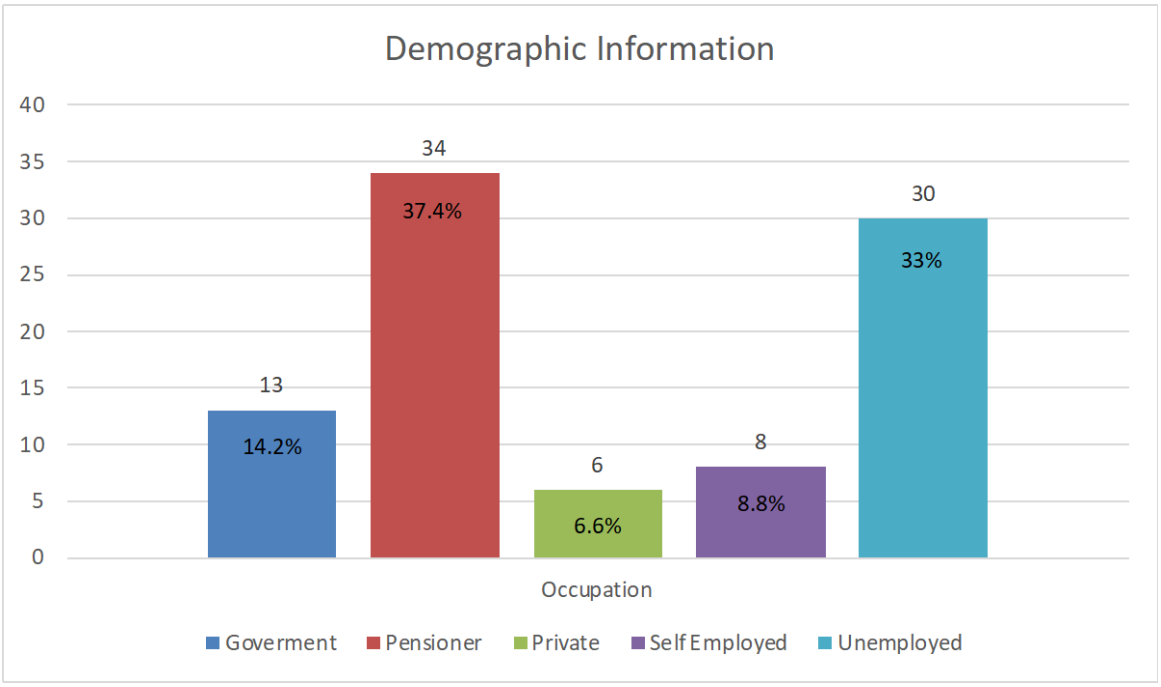

Figure 2. Occupation distribution of the patients.

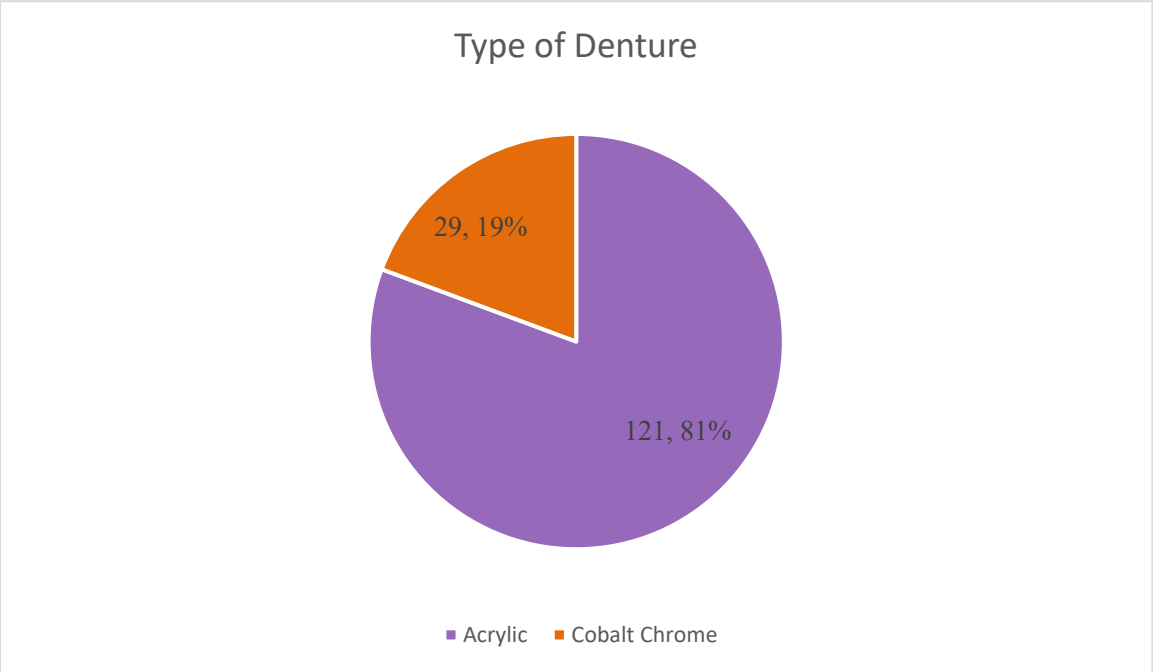

Figure 3. Number of units of RPD according to the type of RPD.

Patient satisfaction towards the function of RPD

The Mann-Whitney U test was used in bivariate analysis to assess the correlation of patient satisfaction with the function of RPD and to differentiate the level of satisfaction between acrylic RPD and Co-Cr RPD (Table 1). Patient satisfaction with acrylic RPD was notably higher, ranging from 56.2% to 64.5% across speaking ability, masticatory function, ease of insertion and removal, and swallowing, while satisfaction with Co-Cr RPD ranged from 27.6% to 51.7% for the same parameters. Statistical analysis demonstrated significantly higher satisfaction with acrylic RPDs for chewing ability ($p = 0.022$), masticatory function ($p = 0.003$), and swallowing ability ($p = 0.005$). However, satisfaction levels for ease of insertion and removal did not differ significantly between the two groups ($p = 0.199$), with 63.6% of patients satisfied with acrylic RPDs and 51.7% satisfied with Co-Cr RPDs.

Patient satisfaction towards aesthetics of RPD

Table 2 indicates a bivariate analysis of patient satisfaction towards acrylic and Co-Cr RPD for aesthetics parameters. Six aesthetic parameters were evaluated, encompassing the shade of artificial teeth, the shape and size of the teeth, the arrangement of the teeth, the compatibility of acrylic teeth with natural dentition, and the facial support provided by the RPD. Patient satisfaction with the aesthetics RPD was generally high for both acrylic and Co-Cr RPD, with satisfaction ranging from 88.4% to 92.6% for acrylic RPD and 79.3% to 86.2% for Co-Cr RPD across all aesthetic parameters. However, satisfaction with acrylic RPD was significantly higher for specific aesthetic parameters, including teeth shade ($p = 0.012$), teeth shape ($p = 0.011$), teeth size ($p = 0.017$), and teeth set-up ($p = 0.005$). No statistically significant differences were observed between the two groups in the compatibility of artificial teeth with natural teeth ($p = 0.057$) or in facial support ($p = 0.637$).

Table 1. Patient satisfaction on functional parameters of RPD.

Function	Type of denture	SD-D	Neutral	A-SA	*p*-value
Speaking ability	Acrylic	18(14.9)	33(27.3)	70(57.85)	0.022*
	Co-cr	8(27.59)	11(37.93)	10(34.48)	
Masticatory function	Acrylic	18 (14.9)	35 (28.9)	68 (56.2)	0.003*
	Co-cr	9 (31.0)	12 (41.4)	8 (27.6)	
Remove and insert the denture	Acrylic	17 (14.0)	27 (22.3)	77 (63.6)	0.199
	Co-cr	6 (20.7)	8 (27.6)	15 (51.7)	
Swallowing	Acrylic	15 (12.4)	28 (23.1)	78 (64.5)	0.005*
	Co-cr	7 (24.1)	10 (34.5)	12 (41.4)	

SD-D: Strongly Disagree - Disagree, U: Unsure, A-SA: Agree - Strongly Agree

Table 2. Patient satisfaction with the aesthetic of RPD.

Aesthetics	Type of dentures	SD-D	Neutral	A-SA	p-value
Teeth shade	Acrylic	2 (1.7)	12 (9.9)	107 (88.4)	0.012*
	Co-cr	3 (10.3)	3 (10.3)	23 (79.3)	
Teeth shape	Acrylic	2 (1.7)	10 (8.3)	109 (90.1)	0.011*
	Co-cr	3 (10.3)	3 (10.3)	23 (79.3)	
Teeth size	Acrylic	2 (1.7)	10 (8.3)	109 (90.1)	0.017*
	Co-cr	3 (10.3)	3 (10.3)	23 (79.3)	
Teeth set-up	Acrylic	2 (1.7)	8 (6.6)	111 (91.7)	0.005*
	Co-cr	3 (10.3)	3 (10.3)	23 (79.3)	
Compatibility with natural teeth	Acrylic	2 (1.7)	12 (9.9)	107 (88.4)	0.057
	Co-cr	3 (10.3)	3 (10.3)	23 (79.3)	
Facial support	Acrylic	3 (2.5)	6 (5.0)	112 (92.6)	0.634
	Co-cr	0 (0.0)	4 (13.8)	25 (86.2)	

SD-D: Strongly Disagree - Disagree, U: Unsure, A-SA: Agree - Strongly Agree

Patient satisfaction towards retention and stability of acrylic and Co-Cr RPD

The chi-square test was used to evaluate patient perceptions of retention and stability for acrylic and cobalt-chromium (Co-Cr) removable partial dentures (RPDs), as shown in Table 3. Patient satisfaction with retention and stability was higher for acrylic RPDs, with 78.4% and 80.3% of patients reporting satisfaction, respectively, compared to 21.6% and 28.9% for Co-Cr RPDs. However, despite these observed differences, the results were not statistically significant.

Relationship between retention and stability of RPD with patient's satisfaction level

The Mann-Whitney U test was used to assess the relationship between patient satisfaction and the retention and stability of RPD. The analysis revealed no significant relationship between patient satisfaction and retention ($p = 0.44$) or stability ($p = 0.633$) of the RPD, as shown in Table 4.

Table 3. Patient satisfaction with retention and stability of the RPD.

	Type of dentures	Yes	No	Chi-Square	p-value
Retention of the denture	Acrylic	29 (78.4)	42 (77.8)	0.005	0.946
	Co-cr	8 (21.6)	12 (22.2)		
Stability of the denture	Acrylic	53 (80.3)	18 (72.0)	0.729	0.393
	Co-cr	13 (28.0)	7 (19.7)		

Table 4. Relationship of overall patient satisfaction with retention and stability of RPD.

Variables	Answer	SD-D	Neutral	A-SA	p-value
Retention	Yes	2 (5.4)	8 (26.1)	27 (72.9)	0.44
	No	6(11.1)	10 (18.5)	38 (70.3)	
Stability	Yes	6 (9.1)	12 (18.2)	48 (72.7)	0.633
	No	2 (8.0)	6 (24.0)	17 (68.0)	

Discussion

The removable partial denture (RPD) remains a viable option in rehabilitating partially edentulous patients, as it restores critical oral functions like mastication and aesthetics while preserving the remaining natural dentition (Campbell *et al*., 2017). Patient satisfaction with RPD is influenced by various factors, including the patient's age, personality, past denture experience, expectations, aesthetics, residual ridge anatomy, denture quality, construction methods, dentist expertise, and the quality of dentist-patient relationships (Čelebić & Knezović-Zlatarić, 2003), (Koyama *et al*., 2010). This study explores and compares patient satisfaction with acrylic and Co-Cr RPD fabricated by undergraduate students at IIUM. Furthermore, it evaluates patients' perceptions of RPD retention and stability and investigates how these factors correlate with overall satisfaction.

This study evaluated four functional parameters of RPD, including speaking ability, masticatory function, ease of removing and inserting the denture, and swallowing. Most patients reported satisfaction with the functional performance of both types of RPD, acrylic RPD (56.2 to 64.5%) and Co-Cr RPD (27.6% to 51.7). Notably, acrylic RPD were found to be superior to Co-Cr RPD in all functional parameters except for ease of insertion and removal. However, this finding contrasts with earlier studies by Almufleh *et al*. (2020), which reported no significant difference in patient satisfaction with the functional performance of acrylic and Co-Cr RPD. This discrepancy highlights the need for further studies to understand the factors influencing patient preferences and satisfaction.

For satisfaction towards the aesthetic appearance of the RPD, six aesthetic parameters were assessed, including the shade, shape, and size of artificial teeth, their arrangement, the compatibility of acrylic teeth with natural dentition, and the facial support provided by the RPD. Most patients expressed high satisfaction with the aesthetic outcomes of RPD, with satisfaction levels ranging from 79% to 92% across all parameters for both acrylic and Co-Cr RPD. Takaichi *et al*. (2022) highlighted that this high level of satisfaction is attributable to the ability to customise the RPD to match the patient's natural teeth in terms of colour, shape, size, and alignment. By achieving a close match with the natural dentition, RPDs can provide a harmonious and aesthetically pleasing smile, enhancing the patient's confidence and self-esteem (Čelebić & Knezović-Zlatarić, 2003).

Furthermore, comparing acrylic and Co-Cr RPD regarding aesthetic outcomes revealed that patient satisfaction with acrylic RPDs

was statistically higher for specific parameters, including teeth shade, shape, size and alignment. Acrylic dentures allow for easier customisation in shape and colour, enabling them to better align with individual patient preferences and enhance satisfaction levels (Nejatian *et al*., 2023). This feature is less feasible with Co-Cr due to the frameworks' rigidity and appearance (Bosînceanu *et al*., 2019). This finding aligns with results from M. Awan *et al*. (2018), who reported that most patients expressed greater satisfaction with acrylic RPD compared to Co-Cr RPD regarding aesthetic appearance. Acrylic resin also offers superior aesthetic blending with surrounding oral tissues due to its colour-matching potential, creating a more natural appearance than the metallic framework of Co-Cr RPDs (Hamze *et al*., 2020). Additionally, acrylic RPDs typically have less visible metal components, making them less conspicuous during speech or smiling. In contrast, Co-Cr RPD often involves noticeable metallic parts, detracting from their aesthetic appeal (Campbell *et al*., 2017).

This study also demonstrated that acrylic and Co-Cr RPD exhibit excellent retention and stability. However, in comparison, the study suggests that while acrylic RPDs demonstrate marginally better retention and stability than their Co-Cr counterparts, this difference does not reach statistical significance. This observation could be attributed to the inherent material properties of acrylic. Acrylic is less firm and has a slightly more elastic nature compared to cobalt-chrome metal, which may allow it to adapt more closely to the contours of the oral tissues (Cortés-Sandoval *et al*., 2015), potentially enhancing the retention and stability of the prosthesis. However, the lack of statistical significance suggests that these differences might not have a substantial clinical impact or may vary depending on individual anatomical and functional factors. Further analysis revealed no positive relationship between overall patient satisfaction with denture retention and stability for both types of dentures. Thus, the retention and stability of dentures do not influence patients' satisfaction with RPD.

Conclusion

Co-Cr and acrylic RPD are associated with high levels of patient satisfaction. However, acrylic RPD demonstrates higher satisfaction than Co-Cr RPD in terms of both functionality and aesthetics. Overall, patient satisfaction tends to favour acrylic RPD over Co-Cr counterparts. Despite both RPD types exhibiting excellent retention and stability, these factors do not significantly influence patient satisfaction with the RPD. Further studies are recommended to explore additional factors influencing satisfaction to better guide in clinical decision-making.

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ORIGINAL ARTICLE Open Access

Association between disease activity and clinico-laboratory parameters in Systemic Lupus Erythematosus patients in Hospital Universiti Sains Malaysia: a retrospective study

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Abstract

Systemic Lupus Erythematosus (SLE) is a prototypic autoimmune disease with multi-system involvement. The clinical manifestations and laboratory parameters in SLE patients vary depending upon the disease severity. SLE affects many organs such as skin, brain, and joints, thus affecting the clinical and laboratory parameters of the patients. This study aims to determine the association between the disease activity and clinico-laboratory parameters among SLE patients at Hospital Universiti Sains Malaysia. A total of 32 medical records of SLE patients from 2010 to 2023 were retrieved. The data of clinical and laboratory parameters were obtained and analysed using SPSS 27.0. Demographic data was analysed descriptively, and the Chi square test was used to evaluate the association between SLE disease activity and the clinico-laboratory parameters. We expect the most common symptoms in SLE include arthritis, malar rash, oral ulcer, and increase anti-dsDNA particularly in active SLE. This study showed the most common symptoms were arthritis (n=14;43.8%) followed by oral ulcer (n=10;31.3%). High level of anti-nuclear antibodies (ANA) was found in 21 patients (65.6%) while 18 (56.3%) patients had elevated erythrocyte sedimentation rate (ESR). Sixteen (50.0%) patients demonstrated low serum C3 and C4 levels. Significant associations were found between the disease activity and arthritis (p=0.033), oral ulcer (p=0.002), prolonged fever (p=0.001), ANA level (p=0.009), and anti-dsDNA level (p=0.022). Arthritis was found to be the most frequent symptoms in SLE patients. High level of ANA, increased ESR and low serum complement levels correlates well with active disease. In conclusion, active SLE patients were more frequently presented with arthritis, oral ulcer, prolonged fever, and demonstrated high ANA and anti-dsDNA levels.

Keywords: *clinical parameters, disease activity, laboratory parameters, systemic lupus erythematosus*

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Introduction

Systemic Lupus Erythematosus (SLE) can be defined as a chronic autoimmune inflammatory disease with multi-system involvement and is associated with high risk of morbidity and mortality (Narváez, 2020). This disease attacks one's own tissues which leads to inflammation of the tissues in the

various organs such as skin, brain, joints, and kidney. The first classification criteria for SLE were formulated in 1971 by the American College of Rheumatology (ACR), followed by revisions in 1982 and 1997. To improve their clinical performance which reflects the new knowledge on autoantibodies, Systemic Lupus International Collaboration Clinics (SLICC) classification criteria was issued. According to SLICC, the patient must satisfy at least 4 of 17 SLICC classification criteria, including at least one clinical and one immunologic criterion (Petri *et al.,* 2012). Recently, the new 2019 EULAR/ACR classification criteria was introduced to maintain the high specificity of the ACR criteria with a sensitivity close to SLICC criteria. The new 2019 EULAR/ACR classification criteria comprise of positive ANA as an obligatory criterion, 7 clinical criteria (constitutional, hematologic, neuropsychiatric, mucocutaneous, serosal, musculoskeletal, renal) and 3 immunological (antiphospholipid antibodies, complement proteins, SLE-specific antibodies) domains, which weighted from 2 to 10 (Aringer *et al.,* 2019).

Based on the Malaysian SLE association, more than 10,000 people over the past 30 years have been diagnosed with SLE. The prevalence of this life-threatening disease affects more females than males with a ratio of 9-10:1, with the age range from 15 to 40 years old (Ramírez Sepúlveda *et al.,* 2019). The disease activity is a manifestation of clinical and laboratory features which reflects the immunologic and inflammatory manifestation of lupus at a certain point of time (Parker & Bruce, 2019). SLE disease activity is assessed using the SLE Disease Activity Index (SLEDAI) score. SLEDAI score is a global score which includes both clinical and laboratory parameters, used to measure the disease severity within the last 10 days. Patients with SLEDAI score of lower than 6 are regarded to have an inactive disease, whereas those with a score of 6 or higher are considered to have an active disease (Shamim *et al.,* 2020). SLEDAI score has been proved to be a good tool in monitoring disease activity in SLE patients since it is concise and easy to use and has demonstrated great psychometric qualities in validation (Shamim *et al.,* 2020). A high disease activity status indicates severe active disease (Koelmeyer *et al.,* 2019) and it has been found to be associated with higher relative risk of mortality (Parker & Bruce, 2019).On the other hand, a low disease activity, remission or inactive disease have been proven to be associated with reduction in disease flare, reduce risk of irreversible end organ damage and improvement in patient outcomes (Golder V & Tsang- A-Sioe., 2020).

Oral ulcers are one of the clinical manifestations in SLE patients. It is one of the listed criteria when classifying SLE patients and it is the most common oral manifestation found in SLE patients which mainly occur on the hard palate, followed by the soft palate and vermilion of the lower lip (Zakeri *et al.,* 2012). Oral manifestations may present at early stage of SLE disease. Therefore, it is crucial for the dentists to be able to detect the ulcers, especially aphthous ulcers, for early diagnosis, treatment and to prevent complications. Chronic cutaneous SLE patients may come with asymmetrically distributed, well-demarcated, red, round, or irregular-shaped, atrophic or ulcerated oral lesions. As for acute cutaneous SLE, patients have a higher prevalence of ulcers and blisters (García-Ríos *et al.,* 2022). Apart from oral ulcers, a study in Qatar had observed that SLE patients have a high prevalence of gingivitis, periodontal disease as well as cavities (Hammoudeh *et al.,* 2018). Additionally, periodontitis is also one of the main clinical manifestations in SLE which is thought to have a similar underlying pathophysiology. Elevated levels of proinflammatory cytokines, B2-glycoprotein 1-dependent anticardiolipin and tissue destruction had been found in SLE and periodontitis (Fosam, 2020).

SLE patients who underwent treatment with immunosuppressive drugs, various antimalarials and biologic agents may experience more oral lesions. For instance, methotrexate which is originally used for treatment of cancer is also used for SLE, since it can reduce joint pain and swelling by blocking folic acid production. However, this

drug is commonly associated with mouth ulcer and an increased risk of oral infection such as fungal and mycobacterium infections. Therefore, a collaboration between dentist and medical practitioners is crucial to shorten the course of the disease, to decrease the disease activity as well as to minimise the complication with the aim of improving patients' quality of life (Fosam, 2020).

The association of disease activity and clinico-laboratory parameters in our local population has not been extensively studied. The clinico-laboratory parameters are important for SLE diagnosis. Therefore, this study aimed to assess the association between SLE disease activity, clinical manifestation as well as laboratory parameters to improve the outcome, disease monitoring and SLE prognosis.

Materials and Methods

This retrospective study was carried out by accessing medical records from Record Unit, Hospital USM. Thirty-two medical records of diagnosed SLE patients between 2010 to 2023 were retrieved. The inclusion criteria include SLE patients within the age range of 18 to 60 years old who was diagnosed with the disease using the SLICC 2012 or EULAR/ACR 2019 criteria. SLE patients who have SLEDAI score of more than 6 were defined as having active disease whereas those with the score of less than 6 were considered to have inactive disease. Pregnant and lactating women, patients who had malignancy or other autoimmune or inflammatory conditions (such as rheumatoid arthritis, ankylosing spondylitis) were excluded. The study protocol was approved by the Ethics Committee of USM (USM/JEPeM/KK/23040319).

Malar rash, arthritis, alopecia, prolonged fever, photosensitivity, oral ulcers, headaches, blurred vision, alopecia, serositis, and vasculitis were among the symptoms and clinical manifestations which were obtained from medical records. Immunological investigations were comprised of antinuclear antibody (ANA), anti-double stranded DNA (anti-dsDNA), complement 3 (C3), and complement 4 (C4). Haematological parameters include full blood count (FBC) and erythrocyte sedimentation rate (ESR).

Data entry and analysis

Data entry was performed and analysed using SPSS Version 27.0 (IBM SPSS, Chicago, IL). Demographic data was analysed using descriptive method. Chi square test and Fisher's Exact test were used to evaluate the association between SLE disease activity, clinical features and laboratory parameters. A p value *of* <0.05 was considered statistically significant.

Results

A total of 32 SLE patients were included in this study, consisting of 16 active SLE patients and 16 SLE patients with inactive disease. Thirty (93.8%) patients were female, and 3 patients (6.3%) were male with the ratio of 15:1. The majority of patients (93.8%) were Malay, the remainder were Chinese and Siamese. The most common presenting symptoms were arthritis (43.8%), oral ulcer (31.3%), followed by malar rash, prolonged fever, and alopecia which showed the same prevalence (28.1%) (Table 1). Twenty-one (65.6%) of SLE patients had high ANA levels with the titer of 1:160 and above, while only 9 (28.1%) patients had high anti-dsDNA levels. Low serum C3 and C4 were found among SLE patients with the prevalence of 20 (62.5%) and 19 (59.4%), respectively. Elevated ESR levels were observed in 18 (56.3%) patients (Table 1).

Clinical features such as arthritis (p=0.033), oral ulcers (p=0.002), and prolonged fever (p=0.001) were significantly associated with high SLEDAI score. ANA is the only laboratory parameter that had a significant association with SLEDAI score (p=0.009), meanwhile there was no significant association between other clinical features and laboratory parameters with SLEDAI score (Table 2).

Table 1. Demographic, clinical features, and immunological parameters of systemic lupus erythematosus patients (n=32).

Variables	n (%)
Gender	
Female	30 (93.8)
Male	2 (6.3)
Race	
Malay	30 (90.6)
Chinese	2 (6.3)
Others	1 (3.1)
SLEDAI Status	
Active (≥6)	16 (50.0)
Inactive (<6)	16 (50.0)
Presenting Symptoms	
Arthritis	14 (43.8)
Malar rash	9 (28.1)
Oral ulcer	10 (31.3)
Prolonged fever	9 (28.1)
Alopecia	9 (28.1)
Blurring vision	4 (12.5)
Headache	6 (18.8)
Serositis	1 (3.1)
Vasculitis	4 (12.5)
LE non-specific lesions	2 (6.3)
LE-specific lesions	2 (6.3)
Both types of lesions	1 (3.1)
Photosensitivity	6 (18.8)
Immunological Parameters	
High level ANA	21 (65.6)
High level anti-dsDNA	9 (28.1)
Low serum C3	20 (62.5)
Low serum C4	19 (59.4)
Haematological parameters	
Elevated ESR	18 (56.3)
Anemia	14 (43.8)
Thrombocytopenia	3 (9.4)
Leucopenia	7 (21.9)

*ANA - antinuclear antibody, Anti-dsDNA - anti-double stranded DNA, C3 - Complement 3, C4 - Complement 4, ESR - erythrocyte sedimentation rate, SLEDAI - Systemic Lupus Erythematosus Disease Activity Index

Table 2. The association of SLEDAI score with demographic, clinical features, and immunological parameters of SLE patients (n=32).

Variables	SLEDAI score		*p*-value
	Active (≥6) n (%)	Inactive (<6) n (%)	
Gender			
Female	15 (46.9)	15 (46.9)	1.000
Male	1 (3.1)	1 (3.1)	
Arthritis			
Yes	10 (31.3)	4 (12.5)	0.033*
No	6 (18.8)	12 (37.5)	
Oral Ulcer			
Yes	9 (90.0)	1 (10.0)	0.002*
No	7 (31.8)	15 (68.2)	
Malar Rash			
Yes	6 (37.5)	3 (18.8)	0.238
No	10 (62.5)	13 (81.3)	
Prolonged Fever			
Yes	9 (100)	0 (0)	0.001*
No	7 (30.4)	16 (69.6)	
Alopecia			
Yes	6 (66.7)	3 (33.3)	0.433
No	10 (43.5)	13 (56.5)	
Blurring Vision			
Yes	4 (12.5)	0 (0)	0.101
No	12 (42.9)	16 (57.1)	
Headache			
Yes	5 (15.6)	1 (3.1)	0.172
No	11 (34.4)	15 (46.9)	
Serositis			
Yes	1 (3.1)	0 (0)	1.000
No	15 (46.9)	16 (50.0)	
Vasculitis			
Yes	4 (12.5)	0 (0)	0.101
No	12 (37.5)	16 (50.0)	
LE-non-specific Lesions			
Yes	2 (6.3)	0 (0)	0.484
No	14 (43.8)	16 (50.0)	
LE-specific Lesions			
Yes	2 (6.3)	0 (0)	0.484
No	14 (43.8)	16 (50.0)	
Both types of Lesions			
Yes	1 (3.1)	0 (0)	1.000
No	15 (46.9)	16 (50.0)	
Photosensitivity			
Yes	4 (12.5)	2 (6.3)	0.654
No	12 (37.5)	14 (43.8)	
ANA			
Low	2 (6.3)	9 (28.1)	0.009*
High	14 (43.8)	7 (21.9)	
Anti-dsDNA			
Low	8 (25.0)	14 (43.8)	0.054
High	8 (25.0)	2 (6.3)	

Serum C3			
Low	11 (34.4)	9 (62.5)	0.465
High	5 (15.6)	7 (21.9)	
Serum C4			
Low	9 (28.1)	10 (31.3)	0.719
High	7 (30.4)	6 (18.8)	
Elevated ESR			
Yes	10 (31.3)	8 (25.0)	0.476
No	6 (18.8)	8 (25.0)	
Anemia			
Yes	8 (25.0)	10 (31.3)	0.476
No	8 (25.0)	6 (18.8)	
Thrombocytopenia			
Yes	3 (33.3)	0 (0)	0.226
No	13 (56.5)	16 (50.0)	
Leucopenia			
Yes	5 (15.6)	2 (6.3)	0.394
No	11 (34.4)	14 (43.8)	

*Significant *p*-value <0.05, ANA (antinuclear antibody), anti-dsDNA (anti-double stranded deoxyribonucleic acid antibody), C3 (complement), C4 (complement 4), ESR (erythrocyte sedimentation rate), SLEDAI (systemic lupus erythematosus disease activity index)

Discussion

The majority of SLE patients in this study were of the Malay ethnicity, which explains the large difference in number of Malays than other ethnicities. The population bias in East Coast Peninsular Malaysia is influenced by the demographic distribution of ethnic groups, with Malays forming the majority. This explains the higher number of Malay SLE patients. This reflects the local demographic distribution rather than a true difference in disease susceptibility, leading to a skewed ratio at the sampling site (Ilias *et al.,* 2017). In this study, 30 patients were female and only 2 patients were male. The female to male ratio was 15:1 which is much higher compared to a study conducted in Qatar (9.5:1) by Hammoudeh *et al.* (2018). Females are more susceptibility to SLE due to of the effects of oestrogen and its hydroxylation and differences in gonadotropin-releasing hormone signalling (Yacoub Wasef, 2004). Oestrogen has a wide range of immunological effects, including modulating the innate and adaptive immune responses, increasing the number of immunoglobulin-secreting cells, effects on antigen presentation by dendritic cells and macrophages, as well as modulating the Th1 and Th2 responses. Although SLE commonly occurs in female at childbearing age and uncommon after menopause, in certain circumstances SLE cases had been reported in pediatric and male patients (Guéry, 2019).

A study in Kuala Lumpur, Malaysia reported that arthritis, malar rash, haematological diseases, oral ulcer, and renal disease were the most common clinical manifestations in SLE patients (Jasmin *et al.,* 2013). Our study showed similar clinical manifestations experienced by SLE patients, with the most common symptoms are arthritis, oral ulcer, and malar rash. Renal and hematological disease were not assessed in this study. Arthritis is one of the earliest clinical manifestations in SLE disease progression which influences the SLEDAI score. According to EULAR/ACR classification, arthritis is a synovitis that affects two or more joints, and it can be characterised by swelling or effusion, or by pain in two or more joints, and associated with morning stiffness for at least 30 minutes. This study shows arthritis is the most common clinical symptom in SLE patients which was present in 14 (43.8%) patients in our cohort. The result is lower compared to a previous study by Ceccarelli *et al.* (2022) which reported that 90% of the patients had arthritis.

Nevertheless, a study by Shamim *et al.* (2020) in Saudi Arabia reported a closer number to our study which is 43.5%. Our study found that there is a significant association between arthritis and disease activity (p=0.033). By contrast, there is no significant association between arthritis and disease activity in these two previous studies.

Oral ulcer was the second most common clinical presentation in our patient cohort (n=10, 31.3%). This finding is comparable with the findings of an earlier study by Hammoudeh *et al.* in 2018 with the prevalence rate of various forms of oral ulcer in SLE patients from 7.0% to 41.0%. Hammoudeh *et al.* (2018) also observed that 72.0% of SLE patients had oral ulcer and the oral manifestations in these patients can be in the form of honeycomb plaque, raised keratotic plaque, and petechiae. We found that there is a significant association between oral ulcers and disease activity (p=0.002) which is comparable to a previous study finding by Nazri *et al.* (2018) (p=0.001). There is established evidence regarding the action of circulating antigen-antibody complexes which degenerate keratinocytes of oral mucosa leading to increase in the number of oral mucosal lesions among SLE patients (García-Ríos *et al.,* 2022). Thus, it is important for dental practitioners to be able to identify oral ulcers during patients' visit as it could be an initial sign of SLE disease progression.

Other frequent clinical features observed in this study were malar rash (28.1%), alopecia (28.1%), and prolonged fever (28.1%). The prevalence of malar rash and alopecia in this study was lower than previous study by Chanprapaph *et al.* (2021), (43.2%) and (36.6%), respectively. The prevalence of prolonged fever in this study was also lower compared to a previous study (43.5%) by Shamim *et al.* (2020). There was a significant association between disease activity and prolonged fever in our study. However, there is no significant association between the two parameters in study by Shamim *et al.* (2020). The significant of presence of common symptoms in SLE such as malar rash, alopecia and prolonged fever is important for early diagnosis and treatment to prevent complications.

In our study, ANA was detected in all patients. Twenty-one patients (65.6%) had high level of ANA with the titre of 1:160 and above. Chanprapaph *et al.* (2021) reported that 69.6% of SLE patients had high ANA level which is consistent with our study. A negative ANA test cannot rule out diagnosis of SLE, since 20.0% of patients may have negative (true negative or false negative) at various stages of the disease, although typically the rate of ANA-negative lupus is much lower. The frequency of ANA negativity ranged from 5 to 23 (4.9% to 22.3%) of 103 samples for immunofluorescence assay (IFA), 12 (11.7%) and 14 (13.6%) for enzyme linked immunofluorescence assay (ELISA) and multiplex assay (Pisetsky *et al.,* 2018). Our study shows that high ANA level was associated with high disease activity (p=0.009) which is consistent with the study finding by Nazri *et al.* (2018) *(*p=0.006). The prevalence of high level of anti-dsDNA was lower in our study (28.1%) as compared to previous study (67.2%) in Thailand (Chanprapaph *et al.,* 2021) as well as study in Malaysia (78.1%) (Nazri *et al.,* 2018). A previous study by Adamichou & Bertsias in 2017 had described an increase in anti-dsDNA levels a few weeks before SLE flare with subsequent reduction during flare of the disease. Anti-dsDNA testing is crucial for accurate classification and diagnosis of SLE which might help in disease activity assessment since it correlates with disease activity particularly in patients with renal involvement (Orme *et al*., 2022).

Serum C3 and C4 were decreased in 20 (62.5%) and 19 (59.4%), respectively. These findings are consistent with previous study findings by Nazri *et al*. (2018), who reported that the prevalence of C3 and C4 levels were 22 (68.8%) and 19 (59.4%) respectively. In general, SLE patients with an active disease usually have low C3 and C4 levels. The most possible cause of decrease in complement levels is due to increase in complement consumption which suggests involvement of the classical complement pathway (Ayano & Horiuchi, 2023). However, our study found

that no significant association between the complement levels and disease activity (C3: p=0.465) and (C4: p=0.719). In contrast, a cross-sectional study conducted in Lahore reported a significant association between a high SLEDAI score and elevated anti-dsDNA titer, ESR, low haemoglobin and low complement levels (Shamim *et al*., 2020). Previous study by Al-Mughales, (2022) reported that patients with organ involvement, particularly renal problems, were found to have decreased levels of serum C3 (p=0.066) and C4 (p=0.003) levels. Eighteen patients (56.3%) had elevated ESR in this study, but the percentage is lower than previous study (78.3%) by Shamim *et al*. (2020).

Conclusion

The most common presenting symptoms in SLE patients in this study were arthritis, oral ulcer, malar rash, prolonged fever and alopecia. Arthritis, oral ulcers, and prolonged fever were found to be significantly associated with the SLE disease activity, whereas for laboratory parameters, only serum level ANA was significantly associated with SLE disease activity. One of the limitations in this study is the small sample size. Larger sample size should be considered in the future study to obtain more conclusive findings.

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ORIGINAL ARTICLE Open Access

Pandemic pressure: the impact of COVID-19 on dental students' oral health and well-being in Malaysia

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Abstract

The COVID-19 pandemic disrupted dental education and affected students' oral health and overall well-being. This study explored the impact of Oral Health-Related Quality of Life (OHRQoL) among Malaysian undergraduate dental students during the pandemic. A cross-sectional study was conducted with 530 students from nine dental schools in Malaysia using the validated Oral Health Impacts Profile-14 (OHIP-14) questionnaire. The OHIP-14 measures functional and psychosocial disabilities caused by oral health issues. The average OHIP-14 score was 10.86 ± 8.47, with 21.3% of students reporting impacts on their OHRQoL. The most affected subscales were psychological discomfort (38.2%), psychological disability (26.9%), and physical pain (22.2%). There were no significant differences in daily performance difficulties between preclinical and clinical students. This study highlights the significant impact of the pandemic on Malaysian dental students' OHRQoL, particularly in psychological and physical aspects. Dental educators and policymakers should prioritize strategies to support students' oral health and overall well-being during such challenging times.

Keywords: *COVID-19, dental student, undergraduate, Oral Health-Related Quality of Life (OHRQoL), Oral Health Impact Profile (OHIP-14)*

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Introduction

COVID-19 has necessitated a paradigm shift in the global educational system with dental schools being no exception. The sudden transition to online learning has posed significant challenges for dental students, who typically require hands-on training in simulation labs and clinical practice (Llanos *et al.*, 2018). Not only did the pandemic hinder dental students from getting adequate hands-on patient training, but preclinical students were also deprived of training on their pre-clinical projects, leaving them unprepared to enter the clinical training years. Learning in dental school could be challenging due to overwhelming clinical and theoretical knowledge.

Oral health is intricately linked with overall health and quality of life (QoL) (Llanos *et al.*, 2018). Several studies consistently demonstrated a correlation between poor oral health and reduced QoL. Good oral health can ensure a good position towards both of the criteria. For example, poor oral

health affects the quality of life and causes psychological stress, contributing to systemic diseases (Vasiliou, 2016). Furthermore, researchers also confirmed that a wide range of severity of periodontal disease could lead to different effects on the quality of life of a person (Llanos *et al.,* 2018).

In recent years, there has been a great interest in researchers finding answers correlating the condition of oral health with a person's quality of life. Oral Health-Related Quality of Life (OHRQoL) is a tool that can evaluate the relationship between oral health and a person's quality of life. OHRQoL considers the subjective point of view of the oral health condition and the personal assessment of the functions, psychology, social, and pain or discomfort (Bennadi & Reddy, 2013). OHIP-14 is a set of questionnaires to appraise the OHRQoL (Skośkiewicz-Malinowska *et al*. 2016).

Quality of life (QoL) is difficult to describe since it should include many facets of life, both subjective and objective, and express a holistic approach to the human person (Bennadi & Reddy, 2013). Several studies on QoL and specific factors comprise this quality in the literature. The literature provides several approaches to this issue, numerous definitions of oral health and QoL, and numerous methods for assessing this concept. The World Health Organization (WHO) defines health as "full physical, mental and social well-being, and not only the absence of disease or illnesses". The WHO defines QOL as "individuals' view of their place in life in the context of the culture and value systems in which they live and in connection to their goals, expectations, standards, and concerns" (Sanders *et al.*, 2009). Oral health-related quality of life is particularly relevant in dentistry (Uzarevic & Bulj,2021). Modern dentistry aims to enhance patients' overall quality of life and dental health. It's crucial to consider the dentist's perspective while evaluating the results of a dental procedure and the patients. This concept has recently emerged in the last several decades and has received minimal attention previously (Gift *et al.*, 1997).

OHRQoL is a multidimensional concept that includes physical, social, and psychological aspects (Slade *et al*., 1998). Clinical evaluations do not examine these features; only the existence and severity of the disease are recorded, which seldom includes the impact of symptoms on QoL (Gherunpong *et al.*, 2006). OHRQoL is assessed using questionnaires that collect information on oral health and the effects of oral health on QoL. The oral health impact profile (OHIP-14) is one such questionnaire used to assess the impact of oral health on OHRQoL dimensions such as functional limitations, physical pain, psychological discomfort, physical disability, psychological disability, social disability, and social handicap (Slade *et al.*, 1997). According to a five-point Likert scale, the responses included 'very often=5', 'fairly often=4', 'occasionally=3', 'hard=2', 'never=1', or 'don't know=0'. The lower the oral health state, the higher the OHIP-14 score (Slade *et al.*, 1997). They are used to assess the quality of life in certain disease entities or groups of illnesses. The term "health" encompasses biopsychosocial well-being, and dental health can influence numerous facets of QoL (Sheiham, 2005). Despite the increasing research on this topic, few have addressed students as a distinct demographic (Acharya & Sangam, 2008). Such studies enable the investigation of OHRQoL in a group of persons who have received intense training in detecting modest deviations from normalcy and preserving oral health (Harsh *et al.*, 2012). Several studies show that students' views and behaviour toward oral health alter as they proceed through their courses (Rong *et al.*, 2006; Idris *et al.*, 2010).

As we all know, dentistry is a challenging course as dental students are perceived to learn intense theoretical and clinical components (Acharya & Sangam, 2008; Dumitrescu *et al.*, 2007). Knowledge acquisition in every subject in dental school is critical for every undergraduate dental student. In the traditional way of learning, face-to-face lectures, and discussions to explain the theory and clinical practice were done before COVID-19 started. New forms of knowledge are forcing educational institutions to make those processes using

online platforms with many limitations that contribute to students' psychological stress (Gherunpong *et al.*, 2006). Therefore, OHRQoL among undergraduate dental students is essential to determine if their oral health condition affected their effort to cope with studying intense subjects during the pandemic. Good OHRQoL is critical among undergraduate dental students since they play a vital role in a country's future growth, eventually becoming future proponents of social advancement. Understanding students' self-perceptions of oral health, particularly OHRQoL, will provide insights into improved teaching approaches. Additionally, knowing OHRQoL can aid in creating measures to enhance the impact of the curriculum attained as well as the student's health (Acharya & Sangam, 2008). This study aimed to evaluate the effect of OHRQoL among undergraduate dental students in Malaysia and assess if preclinical and clinical Malaysian dental students have any different difficulties in their daily performance during the COVID-19 pandemic.

Materials and Methods

Participants

A cross-sectional study was conducted with undergraduate students from selected universities in Malaysia in 2023, with a sample size of 530 participants. All participants were randomly chosen from six public and three private dental schools and are in their first to fifth year of study, representing both genders. The study was carried out to assess the impact of oral health on the quality of life of these students. The study was conducted following the Declaration of Helsinki, ensuring the protection of the subject's identity. Before participation, informed consent was obtained from all participants at the beginning of the questionnaire. All 530 participants responded and agreed to participate and complete the questionnaire, resulting in a final sample size of a 100% response rate.

Methods

The study was a cross-sectional study. The dean's office of the Faculty of Dentistry at Universiti Teknologi MARA confirmed this study as part of the final year project. Data were collected from undergraduate dental students from selected dental schools in Malaysia. The permission to distribute the questionnaire for selected universities was received from each university's Deputy Dean of Research. Online questionnaires were developed using Google Forms and sent to the representatives from each university via email and social media platforms such as WhatsApp or Telegram. The questionnaires used in this research were validated from a previous study.

This research was designed as a questionnaire that comprises four parts. The first part aimed to gather information on the students' demographics, including their gender, ethnicity, year of study, the dental school they attend in Malaysia, qualification for entering the dental school, and monthly family income. Dentistry undergraduate studies comprise pre-clinical training undertaken during Year-1 and Year-2 before students can enter clinical training in Years 3, 4, and 5. The second part of the questionnaire assessed the students' oral health-related behaviour through a set of questions. The third part involved Slade's short-form instrument, the Oral Health Impact Profile (OHIP-14) (Slade *et al.*, 1997), which has been used to measure how different oral health conditions affect quality of life. This tool evaluated functional and psychosocial disability resulting from an oral health condition during the COVID-19 pandemic. The OHIP-14 questionnaire comprises 14 items investigating functional limitation, physical pain, psychological discomfort, physical and social impairment, and perceived handicap. The participants indicated the frequency of discomfort symptoms on a five-point Likert scale, which includes 'very often=5', 'fairly often=4', 'occasionally=3', 'hard=2', 'never=1', or 'don't know=0'. The OHIP-14 score is higher for individuals with poor oral health status and lower for those with good oral health status. Relevant to this study's purpose,

samples of dental students studying for basic dentistry degree, who underwent non-conventional dental teaching during the Pandemic Covid-19, higher OHIP-14 scores, indicating poorer quality of life during a pandemic, compared with pre-pandemic students (Harsh *et. al.* 2012)

In the pilot study, 20 undergraduate students were recruited to test the methods and assess the questions for the main study. The plans were found to be appropriate and required no changes. The participants were asked to complete the questionnaires on their gadgets and provided a contact number to contact the researchers for any queries. Anonymity and confidentiality were assured, and the participants were given a clear explanation of the study's objectives. Once the questionnaires were completed, the data collection process was initiated immediately through Google Forms, with the data being transferred to Google Sheets.

Result

The research data collected through the questionnaire from Google Forms were processed using IBM SPSS Version 29 on a computer and linked from a Google Sheets database application. To assess the data quality, the collected data were analysed descriptively using mean values, standard deviations, medians, lowest and maximum values, and interquartile ranges. Internal consistency dependability was measured using Cronbach's alpha. Pearson's correlation coefficient determined the correlation between the seven subscale scores and the overall OHIP-14 score. To assess the impact of oral health-related quality of life (OHRQoL), the OHRQoL variable was categorised into two groups: no effect (don't know, never, and hardly ever) and impact (occasionally, reasonably often, and very often). It is essential to determine the prevalence of the influence of OHRQoL on the entire OHIP-14, as well as its domains and individual items. This will provide a comprehensive understanding of the factors that affect oral health-related quality of life and help identify areas for improvement in future teaching and learning strategies.

Five hundred thirty respondents, of whom 71.5% were female and the remaining 28.5% were male, were involved in the study, as depicted in Table 1. Regarding ethnicity, data from this study showed Malay students were the highest respondents, followed by Chinese, Indian, Bumiputera (Sabah or Sarawak), and others with 64%, 23.6%, 7.9%, 4.0%, and 0.6%, respectively (Table 1).

Universiti Sains Islam Malaysia (USIM) recorded the highest number of respondents (22.45%), followed by Universiti Teknologi MARA (UiTM) and MAHSA International University (MAHSA) with 14.53% and 12.08%, respectively, as seen in Table 1. Further analysis of the respondents of this study which were among the undergraduates of Bachelor of Dental Surgery in Malaysia, projected the highest number in Year 3, with a response rate of 28.9%, followed by the undergraduates in Year 2, year 4 and Year 1 with 25.5%, 25.3%, and 11.5%, respectively. Year-5 dental students recorded the lowest response rate of only 8.9%. Most of the respondents were from foundation studies (65.3%), followed by matriculation (17.5%), A-level (10.4%), STPM (2.5%), and others (4.3%). 37.4% of the respondents recorded a family income of more than RM10970 monthly, 37.0% between RM4851 to RM10970 monthly, 13.4% with a family monthly income between RM2500 to RM4850, and 12.3% with a family monthly income of less than RM2500.

Table 1. Participants' demographic information.

Variable	Number (N)	Percentage (%)
Gender		
Female	9	71.5%
Male	28	28.5%
Ethnicity		
Malay	339	64.0%
Chinese	125	23.6%
Indian	42	7.9%
Bumiputera Sabah/ Sarawak	21	4.0 %
Other	3	0.6 %
Year of Undergraduate study		
Year 1	61	11.5 %
Year 2	135	25.5 %
Year 3	153	28.9 %
Year 4	134	25.3 %
Year 5	47	8.9 %
Universities		
UiTM	13	14.5%
UKM	11	8.3%
USM	8	8.3%
UM	5	8.3%
UIAM	5	10.6%
USIM	5	22.5%
MAHSA	5	12.1%
IMU	5	9.7%
PIDC	5	5.9%
Entry Qualification		
A-Levels	55	10.4%
Foundation	346	65.3%
STPM	13	2.5%
Matriculation	93	17.5%
Others	23	4.3%
Family Income (Monthly)		
<RM2500	65	12.3%
RM2500- RM4850	71	13.4%
RM4851- RM10970	196	37.0%
>RM10970	198	37.4%

The study samples were then required to provide details regarding their oral hygiene behaviour, whereby 95.8% of the respondents recorded brushing their teeth two or more times a day, 3.8% brushing once daily, and 0.2% for both 1-2 times a week and 4-5 times a week (Table 2). On the duration of each brushing, 63.2% of the respondents brushed their teeth for 3 minutes or less, while 31.5% brushed their teeth between 3 and 5 minutes. 5.3% of the respondents recorded brushing their teeth for 5 minutes or more. Of the 530 respondents, 47.4% use toothbrushes and dental floss as their tools for brushing teeth, followed by toothbrushes (32.1%) and a combination of a toothbrush, dental floss, and an interdental brush (9.6%). Interestingly, 1.9% of the respondents out of 530 claimed to wear dentures, while 98.1% did not use dentures, as seen in Table 2.

Table 2. Oral hygiene behaviour.

Variable	Number (N)	Percentage (%)
Frequency of tooth brushing		
1-2 times a week	1	0.2%
2 or more times a day	508	95.8%
4-5 times a week	1	0.2%
Once a day	20	3.8%
Duration of each brushing		
3 minutes or less	335	63.2%
3-5 minutes	167	23.6%
5 minutes or more	28	5.3%
Using Denture		
Yes	10	1.9 %
No	520	98.1 %

Further analysis was done among the ten respondents who wore dentures, four washed their dentures with water and a toothbrush, and four only rinsed with water. One respondent cleaned their dentures using water and a denture cleanser. Another respondent cleaned their dentures with a toothbrush and denture cleanser only.

The study found that 21.3% of the population experienced an adverse impact on their OHRQoL, as seen in Table 3. The mean score on the OHIP-14 was 10.86 ± 8.47, indicating that most oral health conditions did not significantly impact respondents' OHRQoL. The internal consistency of the OHIP-14 score was measured using Cronbach's alpha, which was found to be 0.863, indicating high dependability. The subscales of OHIP-14 also had acceptable internal consistency reliability, with Cronbach's alpha values ranging from 0.424 to 0.712. The total OHIP-14 score was correlated with each of the seven subscales, with a range of correlations from 0.273 to 0.553 (Figure 1). The subscales of psychological discomfort, psychological disability, and physical pain had the most significant impact on the OHRQoL of the respondents, with prevalence rates of the effect of 38.2%, 26.9%, and 22.2%, respectively. On the other hand, the functional limitation subscale had the most negligible impact, with only a 9.5% impact prevalence.

Table 3 presents the prevalence of OHRQoL across individual OHIP-14 items, which ranged from 8.6% (for the OHIP-1 item, "had trouble pronouncing any words because of problems with your teeth, mouth, or dentures" in the functional limitation subscale) to 49.4% (for the OHIP-5 item "felt self-conscious because of problems with

teeth, mouth, or dentures" in the psychological discomfort subscale). Further analysis was done to explore the academic years, preclinical, and clinical influences on Malaysian dental students' daily performance difficulties during the COVID-19 pandemic, as reported in Table 4. It is exciting to note that both clinical and pre-clinical years reported that many respondents for the OHIP-5 item "felt self-conscious because of problems with teeth, mouth, or dentures" in the psychological discomfort subscale with 16.8 % and 32.6%, respectively. However, to emphasise once again, the average OHIP-14 score was 10.86 ± 8.47, suggesting that most oral health issues did not significantly affect respondents' OHRQoL during the COVID-19 pandemic.

OHIP-14 Subscales	Score				Impact on OHRQOL		Cronbach's Alpha	r
	Mean (SD)	Minimum	Maximum	Median (IQR)	No Impact (%) (answer 0&1)	Impact (%) (answers 2&3&4)		
Functional limitation	0.88 (1.27)	0	8	1(0-2)	90.5	9.5	0.452	0.293
Physical pain	1.55 (1.66)	0	8	2(1-3)	77.8	22.2	0.569	0.409
Psychological discomfort	2.56 (2.08)	0	8	3(2-5)	61.8	38.2	0.569	0.409
Physical disability	1.31 (1.65)	0	8	1(0-2)	82.5	17.5	0.712	0.553
Psychological disability	1.87 (1.78)	0	8	1(0-3)	73.1	26.9	0.424	0.273
Social disability	1.39 (1.61	0	8	1(0-2)	82.4	17.6	0.522	0.360
Social handicap	1.28 (1.54)	0	8	0(0-2)	82.9	17.1	0.533	0.385
OHIP-14 TOTAL	10.86 (8.47)	0	56	10(5-17)	78.72	21.3	0.863	

OHIP-14: Oral Health Impact Profile; n: number of participants; SD: standard deviation; IQR: interquartile range; OHRQoL: oral health-related quality of life; r: Pearson's correlation coefficient; *: statistically significant correlation on p < 0.05

Figure 1. Descriptive statistics, internal consistency, and correlation of OHIP-14 subscale scores and total scores among undergraduate dental students from 6 public dental schools and two private dental schools in Malaysia (n = 530).

Table 3. Frequency of impact of each item of the OHIP-14 on OHRQoL among Malaysian university dental students (n = 530).

Response / Subscale/item	0- Never		1-Hardly ever		Cumu-lative	2-Occa-sionally		3-Fairly often		4-Very often		Cumu-lative
	n	%	n	%	%	n	%	n	%	n	%	%
Functional limitation												
1. Have you had trouble pronouncing any words because of problems with your teeth, mouth, or dentures?	395	74.5	89	16.8	91.3	31	5.8	10	1.9	5	1.0	8.6
2. Have you felt that your sense of taste has worsened because of problems with your teeth, mouth, or dentures?	342	64.5	133	25.1	89.6	40	7.5	6	1.1	9	1.8	10.4
Physical Pain												
3. Have you had a painful aching in your mouth?	293	55.2	135	25.5	80.7	74	14.0	19	3.6	9	1.7	19.3
4. Have you found it uncomfortable to eat any foods because of problems with your teeth, mouth, or dentures?	273	51.5	124	23.4	74.9	90	17.0	33	6.2	10	1.9	25.1
Psychological discomfort												
5. Have you felt self-conscious because of problems with your teeth, mouth, or dentures?	162	30.6	106	20.0	50.6	105	19.8	93	17.5	64	12.1	49.4
6. Have you felt tense because of problems with your teeth, mouth, or dentures?	239	45.2	148	27.9	73.1	86	16.2	42	7.9	15	2.8	26.9
Physical disabilities												
7. Has your diet been unsatisfactory because of problems with your teeth, mouth, or dentures?	304	57.4	137	25.8	83.2	65	12.3	18	3.4	6	1.1	16.8
8. Have you had to interrupt meals because of problems with your teeth, mouth, or dentures?	321	60.6	113	21.3	81.9	65	12.3	23	4.3	8	1.5	18.1
Psychological disabilities												
9. Have you found it difficult to relax because of problems with your teeth, mouth, or dentures?	281	53.0	138	26.0	79.0	72	13.6	27	5.1	12	2.3	21.0

10. Have you been a bit embarrassed because of problems with your teeth, mouth, or dentures?	231	43.6	125	23.6	67.2	97	18.3	46	8.7	31	5.8	32.8
<u>Social disabilities</u>												
11. Have you been a bit irritable with other people because of problems with your teeth, mouth, or dentures?	290	54.7	133	25.2	79.9	60	11.3	31	5.8	16	3.0	20.1
12. Have you had difficulty doing your usual jobs because of problems with your teeth, mouth, or dentures?	314	59.2	137	25.8	85.0	58	10.9	14	2.6	7	1.3	15.0
<u>Social handicap</u>												
13. Have you felt that life in general was less satisfying because of problems with your teeth, mouth, or dentures?	281	53.0	120	22.6	75.6	78	14.7	38	7.2	13	2.5	24.4
14. Have you been totally unable to function because of problems with your teeth, mouth, or dentures?	364	68.7	114	21.5	90.2	42	7.9	4	0.8	6	1.1	9.8

OHIP-14: Oral Health Impact Profile; OHRQoL: oral health-related quality of life; n: number of participants

Table 4. Year of studies and frequency of impact of each item of the OHIP-14 on OHRQoL among Malaysian university dental students (n = 530).

Subscale/item \ Response		0- Never	1-Hardly ever	Cumulative	2- Occasionally	3-Fairly often	4-Very often	Cumulative
		n	n	N (%)	n	n	n	N (%)
Functional limitation								
1. Have you had trouble pronouncing any words because of problems with your teeth, mouth, or dentures?	Pre-clinical	141	36	177 (33.4)	11	5	3	19 (3.6)
	Clinical	254	53	307 (57.9)	20	5	2	27 (5.1)
2. Have you felt that your sense of taste has worsened because of problems with your teeth, mouth, or dentures?	Pre-clinical	124	50	174 (32.8)	16	3	3	22 (4.2)
	Clinical	218	83	301 (56.8)	24	3	6	33 (6.2)
Physical Pain								
3. Have you had a painful aching in your mouth?	Pre-clinical	110	45	155 (29.2)	30	9	2	41 (7.7)

	Clinical	183	90	273 (51.5)	44	10	7	61 (11.5)
4. Have you found it uncomfortable to eat any foods because of problems with your teeth, mouth, or dentures?	Pre-clinical	100	43	143 (26.9)	36	14	3	53 (10.0)
	Clinical	173	81	254 (47.9)	54	19	7	80 (15.1)
Psychological discomfort								
5. Have you felt self-conscious because of problems with your teeth, mouth, or dentures?	Pre-clinical	70	37	107 (20.2)	34	33	22	89 (16.8)
	Clinical	92	69	161 (30.4)	71	60	42	173 (32.6)
6. Have you felt tense because of problems with your teeth, mouth, or dentures?	Pre-clinical	88	49	137 (25.8)	37	13	9	59 (11.1)
	Clinical	141	99	240 (45.3)	49	29	6	84 (15.8)

Physical disabilities								
7. Has your diet been unsatisfactory because of problems with your teeth, mouth, or dentures?	Pre-clinical	113	49	162 (30.6)	24	6	3	33 (6.2)
	Clinical	190	88	278 (52.5)	41	12	3	56 (10.6)
8. Have you had to interrupt meals because of problems with your teeth, mouth, or dentures?	Pre-clinical	121	42	163 (30.8)	22	9	2	33 (6.2)
	Clinical	200	71	271 (51.1)	43	14	6	63 (11.8)
Psychological disabilities								
9. Have you found it difficult to relax because of problems with your teeth, mouth, or dentures?	Pre-clinical	102	61	163 (30.8)	25	13	5	43(8.1)
	Clinical	179	77	256 (48.3)	47	14	7	68 (12.8)

10. Have you been a bit embarrassed because of problems with your teeth, mouth, or dentures?	Pre-clinical	84	45	129 (24.3)	37	19	11	67 (12.6)
	Clinical	147	80	227 (42.8)	60	27	20	107 (20.2)
Social disabilities								
11. Have you been a bit irritable with other people because of problems with your teeth, mouth, or dentures?	Pre-clinical	101	50	151 (28.4)	23	15	6	44 (8.3)
	Clinical	189	82	271 (51.1)	37	37	10	8415.8)
12. Have you had difficulty doing your usual jobs because of problems with your teeth, mouth, or dentures?	Pre-clinical	110	55	165 (31.1)	26	4	1	41 (7.7)
	Clinical	204	82	286 (53.9)	32	10	6	48 (9.1)

Social handicap								
13. Have you felt that life in general was less satisfying because of problems with your teeth, mouth, or dentures?	Pre-clinical	98	50	148 (27.9)	23	19	6	48 (9.1)
	Clinical	183	70	253 (47.7)	55	19	7	81 (15.3)
14. Have you been totally unable to function because of problems with your teeth, mouth, or dentures?	Pre-clinical	127	51	178 (33.6)	15	1	2	18 (3.4)
	Clinical	237	63	300 (56.6)	27	3	4	34 (6.4)

Discussion

The assessment of Oral Health-Related Quality of Life (OHRQoL) is a vital tool for understanding how oral health affects individuals' well-being across multiple dimensions, such as pain, discomfort, oral function, and social interactions. During the COVID-19 pandemic, studies worldwide reported significant changes in OHRQoL, particularly in populations already experiencing poor oral health. It is important to recognize that oral health problems are often multifactorial, meaning the observed changes in OHRQoL may not be solely caused by the pandemic. This discussion synthesises findings from multiple studies, including research on university students in Croatian and Malaysian populations. It provides a clearer understanding of the pandemic's impact on OHRQoL while acknowledging that other factors beyond COVID-19 may have influenced the results. OHRQoL assessments, such as the Oral Health Impact Profile (OHIP-14), allow healthcare providers to go beyond standard clinical evaluations by including emotional, psychological, and social aspects of oral health (Gherunpong *et al*., 2006). This comprehensive approach is critical during difficult times like the COVID-19 pandemic when disruptions in dental services and increased stress worsened oral health problems (Tsigarida *et al*., 2021). For example, a study in Italy showed that people with poor oral health before the pandemic experienced a greater decline in their OHRQoL during the pandemic compared to those with better oral health at baseline.

Several studies have consistently shown that psychological discomfort and physical pain are the most affected dimensions of OHRQoL in young adults. However, whether these changes are directly caused by the COVID-19 pandemic or influenced by other factors, such as stress or pre-existing conditions, is unclear. This distinction is important, as the findings might reflect broader issues rather than pandemic-specific impacts. Uzarevic and Bulj (2021) found that Croatian University students frequently reported psychological discomfort and physical pain, a trend supported by studies from Acharya *et al*. (2008), Gonzales-Sullcahuaman *et al*. (2013), and Silva *et al*. (2010). Similarly, our study showed that Malaysian dental students reported significant impacts on psychological discomfort (38.2%), psychological disability (26.9%), and physical pain (22.2%). These findings align with global studies from India, Iran and Turkey (Sanadhya *et al.*, 2015; Khalighi *et al*., 2023; Ustaoğlu, *et al.,* 2020), showing that university students are particularly vulnerable to these dimensions, particularly during the pandemic.

The elevated psychological discomfort among dental students can be linked to their increased awareness of oral health, which comes from their training and education, as well as the stress of dental studies. Priya *et al*. (2011) noted that dental students experience high levels of stress and anxiety, making them more sensitive to even minor oral health problems. While these findings are consistent across Croatian and Malaysian students, certain limitations must be addressed. The OHIP-14 tool, though widely used, may not fully capture the complex and multifactorial nature of oral health issues, particularly during the pandemic. Factors like stress, limited access to care, and lifestyle changes could have also influenced OHRQoL outcomes. Additionally, the cross-sectional study design prevents the identification of a clear cause-and-effect relationship between COVID-19 and OHRQoL changes.

Despite these limitations, this study has strengths. It highlights common trends across different populations and emphasises the positive role of good oral health awareness and behaviours among dental students. However, future studies should consider tools that better reflect the multifactorial causes of oral health problems and ensure the validity and reliability of the assessment methods used. Papagiannopolunou *et al*. (2012) similarly reported that individuals with poorer self-assessed oral health had higher OHIP-14 scores, showing a greater impact on their OHRQoL. In this study, the mean OHIP-14 score of 10.86 ± 8.47 among Malaysian

students, which is below the threshold of 14, indicates a low overall impact on daily activities. This result is consistent with Croatian students (Uzarevic & Bulj, 2021). Nevertheless, the extent to which the OHIP-14 instruments comprehensively capture the complex and multifaceted nature of OHRQoL in this study's context remains uncertain, highlighting the importance of selecting well-validated and context-specific tools to ensure the accuracy and reliability of research findings, particularly in the assessment of oral health-related quality of life.

The COVID-19 pandemic increased psychological and emotional challenges related to oral health, especially during lockdowns and movement control orders (MCO). Studies by Elmer *et al*. (2020) and Kürklü *et al*. (2017) showed that poor oral health during the pandemic often led to more anxiety, depression, and social isolation. Limited access to dental care during the MCO period worsened the situation, with delays or cancellations of treatments causing uncertainty and frustration. Al-Attar *et al*. (2021) emphasized that the stress-inducing effects of the pandemic were particularly severe among dental students, noting that tools like the OHIP-14 were often used to measure Oral Health-Related Quality of Life (OHRQoL). It is important to ensure such tools are properly cited and their validity thoroughly discussed to strengthen the findings. However, to accurately assess the direct impact on oral health and, consequently, Oral Health-Related Quality of Life (OHRQoL), it is crucial to identify specific oral health issues caused or worsened by pandemic-related stress. This can be achieved by employing targeted assessments or validated tools that measure the direct effects of stress on oral health, such as bruxism, periodontal issues, or increased dental caries.

Despite the significant impact of psychological discomfort, functional limitations, social handicaps, and physical disability had minimal effects on OHRQoL among Croatian and Malaysian dental students. Uzarevic and Bulj (2021) reported that Croatian students scored lowest on functional limitations, and Malaysian students similarly indicated that their oral health did not affect their ability to speak, taste, or socialise. These low scores could be due to the students' heightened oral health awareness or limitations in the OHIP-14 questionnaire, which may not capture subtle functional or social issues. The low impact on functional and social dimensions can also be explained by dental education programs that promote good oral health habits and strategies to manage stress (Gherunpong *et al*., 2006). Regular oral care, such as toothbrushing, flossing, and dental check-ups, further contributes to these results (Montero-Martin *et al*., 2009). Strong support systems from family and peers also help reduce the negative effects of oral health problems (Jaafar & Malik, 2021).

In the context of this study, highlights the multidimensional nature of OHRQoL and its varied impact on university students, especially during the COVID-19 pandemic. Psychological discomfort and physical pain were the most affected areas, while functional and social limitations were less noticeable. This phenomenon could be attributed to the protective role of dental education, which instils in students a deep understanding of the importance of oral health and equips them with the knowledge and skills necessary to maintain good oral hygiene practices, as well as the proactive oral health habits that dental students often adopt as a result of their training, such as regular brushing and flossing and healthy dietary habits which can help to mitigate the negative impacts of oral health problems on their overall quality of life. However, the study has limitations. Oral health issues are influenced by many factors, making it difficult to attribute changes in OHRQoL solely to the pandemic. Additionally, the OHIP-14 tool may not fully capture all relevant impacts, especially in dental students. Despite these limitations, the study's strengths include its focus on young adults, who are more vulnerable to psychological stress, and its cross-cultural approach, which improves the relevance of the findings. Future research should use more targeted tools, address confounding

factors, and include longitudinal studies to better understand the long-term effects of pandemic-related disruptions on OHRQoL.
Another limitation of this study is the potential for recall bias among participants, particularly given that the data collection occurred during the endemic phase of COVID-19 in Malaysia. Specifically, some participants may have responded with "Don't know" to certain questions on the Oral Health Impact Profile-14 (OHIP-14) due to difficulties in recalling their experiences during the pandemic. This limitation may be attributed to the challenges of retrospective self-reporting, where participants' ability to accurately recall their past experiences may be compromised. Furthermore, the study's sample population was limited to undergraduate dental students from select dental schools in Malaysia, which may not be representative of the broader population of dental students in the country.

To address these limitations, future studies could consider expanding the sample population to include all undergraduate dental students in Malaysia, as well as postgraduate dental students, to provide a more comprehensive understanding of the impact of COVID-19 on oral health-related quality of life (OHRQoL) among dental students. Additionally, exploring the experiences of postgraduate dental students could provide valuable insights into the potential differences in OHRQoL between undergraduate and postgraduate students, and whether these differences are related to their level of training or other factors. Moreover, conducting similar studies among students from other faculties could provide a more nuanced understanding of the relationship between oral health and quality of life among students in Malaysia, and identify potential areas for targeted interventions. By adopting a more inclusive and diverse sampling strategy, future research could provide a richer and more generalizable understanding of the complex interplay between oral health, quality of life, and the COVID-19 pandemic.

Conclusion

The mean OHIP-14 score obtained in this study suggests that, overall, the oral health of most Malaysian undergraduate dental students did not have a profound impact on their Oral Health-Related Quality of Life (OHRQoL) during the COVID-19 pandemic. This finding is noteworthy, as it implies that despite the challenges and disruptions caused by the pandemic, the oral health of these students did not significantly compromise their daily functioning, social interactions, or overall well-being. Furthermore, the results of this study indicate that there were no significant differences in the difficulties experienced by preclinical and clinical Malaysian undergraduate dental students in their daily performance during the COVID-19 pandemic. This suggests that both preclinical and clinical students were equally resilient in coping with the pandemic-related challenges and that their oral health did not differentially affect their daily activities, regardless of their stage of dental training. These findings have important implications for dental education and practice, as they highlight the importance of promoting oral health awareness and self-care practices among dental students, particularly during times of crisis, to mitigate the potential negative impacts of oral health problems on their quality of life. Overall, this study provides valuable insights into the OHRQoL of Malaysian undergraduate dental students during the COVID-19 pandemic and underscores the need for continued support and resources to ensure the oral health and well-being of this population.

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Conflict of Interest

The authors declared no competing interest in the study.

Ethical Approval

Before participation, informed consent was obtained from all participants at the beginning of the questionnaire. All 530 participants responded and agreed to participate and complete the questionnaire. The ethical approval to conduct this study was obtained from the ethics committee, Universiti Teknologi MARA (UiTM) Faculty of Dentistry Research Ethics Committee, with the ethical approval number: FRC/03/2022(ERP/20/32).

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ORIGINAL ARTICLE Open Access

High-resolution retinal imaging system: diagnostic accuracy and usability

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Abstract

The development of high-resolution retinal imaging systems is critical for enhancing the diagnostic accuracy and usability of tools used in detecting glaucoma and managing other ophthalmic and systemic diseases. This study evaluates a novel high-resolution retinal imaging system by comparing its diagnostic performance in detecting glaucoma with AutoMorph, a leading retinal vessel segmentation tool with available online code for reproducibility. The system's diagnostic accuracy was assessed using Area Under the Curve (AUC) metrics, with our system (HRVIAS) achieving a superior AUC of 0.7048 compared to AutoMorph's AUC of 0.6560. Additionally, a usability study was conducted using the System Usability Scale (SUS), where participants rated the system highly, with the majority of scores clustering around 80 to 85, indicating strong user satisfaction. These findings demonstrate that the proposed system not only improves the diagnostic accuracy of detecting glaucoma but also offers a user-friendly interface, making it a valuable tool for clinical and research applications in retinal imaging.

Keywords: *diagnostic accuracy, glaucoma detection, high-resolution retinal imaging, retinal vessel segmentation, system usability scale*

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Introduction

Retinal vessel segmentation is a critical component in the diagnosis and management of various ophthalmic and systemic diseases, including diabetic retinopathy (Radha & Karuna, 2024), glaucoma (Kortuem *et al.*, 2021), and cardiovascular conditions (Hanssen *et al.*, 2022). Accurate segmentation of retinal vessels enables the extraction of valuable biomarkers that can be used for early diagnosis (Ma *et al.*, 2023), monitoring disease progression (Leontidis *et al.*, 2015), and planning surgical interventions (Zhang *et al.*, 2021). Given the importance of this task, numerous methods have been

developed over the years to improve the accuracy, sensitivity, and specificity of vessel segmentation from fundus images and other retinal imaging modalities (Chen *et al.*, 2021).

Traditional approaches to retinal vessel segmentation have relied on manual techniques or basic image processing methods, which are often time-consuming and prone to human error. However, the advent of deep learning has revolutionized the field, leading to the development of more sophisticated algorithms that can automatically segment retinal vessels with high precision (Chen *et al.*, 2021). Among these, the Full-Resolution Network (FR-UNet) stands out for its ability to outperform state-of-the-art methods in both retinal vessel and coronary angiography segmentation (Liu *et al.*, 2022). This method achieves higher sensitivity and connectivity with fewer parameters by utilizing a multiresolution convolution interactive mechanism and a dual-threshold iterative algorithm (Liu *et al.*, 2022). The FR-UNet method was shown to significantly enhance vessel connectivity and improve segmentation performance across multiple datasets.

In parallel, several other innovative approaches have been proposed. For instance, Muzammil *et al.* introduced a multifilters-based unsupervised method for retinal blood vessel segmentation that effectively segments vessels in fundus images by employing a combination of contrast enhancement and morphological operations. This method provides a reliable tool for ophthalmologists in diagnosing various eye diseases (Muzammil *et al.*, 2022). Similarly, MIC-Net, a multi-scale integrated context network, has been designed to reduce small blood vessel segmentation errors, improving the overall accuracy of retinal vessel segmentation in fundus images (Wang *et al.*, 2023).

Furthermore, the need for enhanced sensitivity in retinal vessel segmentation has led to the development of a phase stretch transform (PST)-based edge detection scheme, which significantly improves sensitivity, especially in high-resolution fundus images (Firdausy *et al.*, 2022). This approach demonstrates a clear improvement over existing methods, highlighting the ongoing need for advancements in this area.

Other notable methods include SS-Net, a U-shaped network based on attention mechanisms, which improves disease diagnosis accuracy by accurately segmenting retinal vessels in optical coherence tomography angiography (OCTA) images (Jiang *et al.*, 2022a), and the use of B-COSFIRE filters for enhanced segmentation performance in fundus images (Li *et al.*, 2022). Additionally, the integration of transformers with convolutional neural networks in the MTPA_Unet model has shown significant improvements in segmentation accuracy across multiple public datasets (Jiang *et al.*, 2022b).

Moreover, AutoMorph, another advanced system, leverages a deep learning pipeline for automated analysis of retinal vascular morphology. This system, which has been made publicly available, has demonstrated its potential in facilitating ophthalmic and systemic disease research, particularly in oculomics (Zhou *et al.*, 2022). AutoMorph's approach to retinal vasculature analysis further exemplifies the ongoing evolution in this domain.

In this study, we aim to enhance retinal vessel segmentation techniques by evaluating and comparing different methods, focusing on their applicability to high-resolution retinal images and their potential clinical impact. Specifically, we compare our approach with AutoMorph, a publicly available method, to ensure reproducibility and consistent benchmarking. The objectives of this study are to (1) assess the diagnostic accuracy of HRVIAS in comparison to AutoMorph and (2) evaluate its usability using the System Usability Scale (SUS) to determine its feasibility for integration into research and clinical workflows.

Materials and Methods

Data selection and image processing methodology

In this study, we utilized a subset of the FIVES dataset (Jin *et al.*, 2022), which is a high-resolution colour fundus image collection. From this dataset, we initially selected 400 images, comprising 200 cases diagnosed with glaucoma and 200 cases with no detectable pathology (Che Azemin *et al.*, 2024). This selection was intended to provide a balanced representation of both pathological and healthy retinal conditions.

To ensure the quality and reliability of the images used for analysis, we employed the built-in AutoMorph quality assessment system (Zhou *et al.*, 2022). This system automatically evaluates the quality of each image, filtering out those that do not meet the necessary standards for accurate analysis. Only images deemed gradable by this assessment were included in the subsequent processing steps, ensuring that our analysis was conducted on images of sufficient quality (Ribeiro Reis *et al.*, 2024).

Following the quality assessment, the images were processed independently by two systems: HRVIAS and AutoMorph. Each system is designed to isolate and analyse the retinal blood vessels, separating them from the background of the fundus image. This vessel segmentation is a crucial step in the analysis, as it allows for a focused examination of the vascular network, which is essential for calculating the fractal dimension (Che Azemin *et al.*, 2024). HRVIAS employed a state-of-the-art high-resolution blood vessel segmentation technique based on IS-Net architecture (Che Azemin *et al.*, 2025).

Both HRVIAS and AutoMorph utilise the box-counting method to determine the fractal dimension of the retinal vasculature (Che Azemin *et al.*, 2016). This method provides a quantitative measure of the complexity and branching patterns of the blood vessels, which can be used to assess differences between glaucomatous and healthy eyes. The output of this analysis provides insights into the structural characteristics of the retinal vessels, which may differ between the pathological and non-pathological cases.

Through this methodology, we aimed to compare the capabilities and outputs of the HRVIAS and AutoMorph systems in analysing high-resolution retinal images, with a focus on the accuracy and reliability of the fractal dimension calculations derived from the FIVES dataset.

Technical specifications

Table 1 presents a comparison of the technical specifications between two systems, AutoMorph and HRVIAS, which are used for analysing retinal vasculature. The comparison focuses on three key aspects: resolution, segmentation capabilities, and the method used for determining the fractal dimension of the vasculature.

Table 1. Comparison of technical specifications between AutoMorph (AM) and HRVIAS systems, focusing on resolution, segmentation capabilities, the method used for calculating the fractal dimensions of retinal vascular, and the interface used.

System	Technical Specifications			
	Resolution (pixels)	Segmentation	Fractal Dimension Method	Interface
AutoMorph	912	Whole vessel and Artery/Vein	Box counting	Google Collab
HRVIAS	2048	Whole vessel	Box counting	GUI

The resolution of the images processed by each system differs significantly. AutoMorph operates with a resolution of 912 × 912 pixels, whereas HRVIAS utilizes a much higher resolution of 2048 × 2048 pixels. This difference in resolution suggests that HRVIAS may capture more detailed images, which could be advantageous for analysing finer structures within the retinal vasculature.

In terms of segmentation, AutoMorph offers more advanced capabilities. It is not only capable of segmenting the entire vessel structure but also differentiates between arteries and veins within the retinal images. On the other hand, HRVIAS is designed to segment the whole vessel structure without distinguishing between the different types of blood vessels. This indicates that AutoMorph may provide more detailed and specific vascular analysis, potentially offering more comprehensive insights into retinal health.

Both systems employ the box counting method to calculate the fractal dimension of the retinal vasculature. The fractal dimension is a crucial metric used to describe the complexity of the vascular network. By using the same method, it allows for a standardized approach to assessing vascular patterns across different systems, even though the resolution and segmentation capabilities differ between AutoMorph and HRVIAS.

For the AutoMorph system, the interface is based on Google Colab, which is a cloud-based platform allowing users to run and interact with code in a web-based environment. This suggests that AutoMorph is likely designed for users familiar with coding or technical environments. On the other hand, HRVIAS uses a Graphical User Interface (GUI) as illustrated in Figure 1, which typically offers a more user-friendly, visual interaction method, making it more accessible to users who may not have technical coding skills.

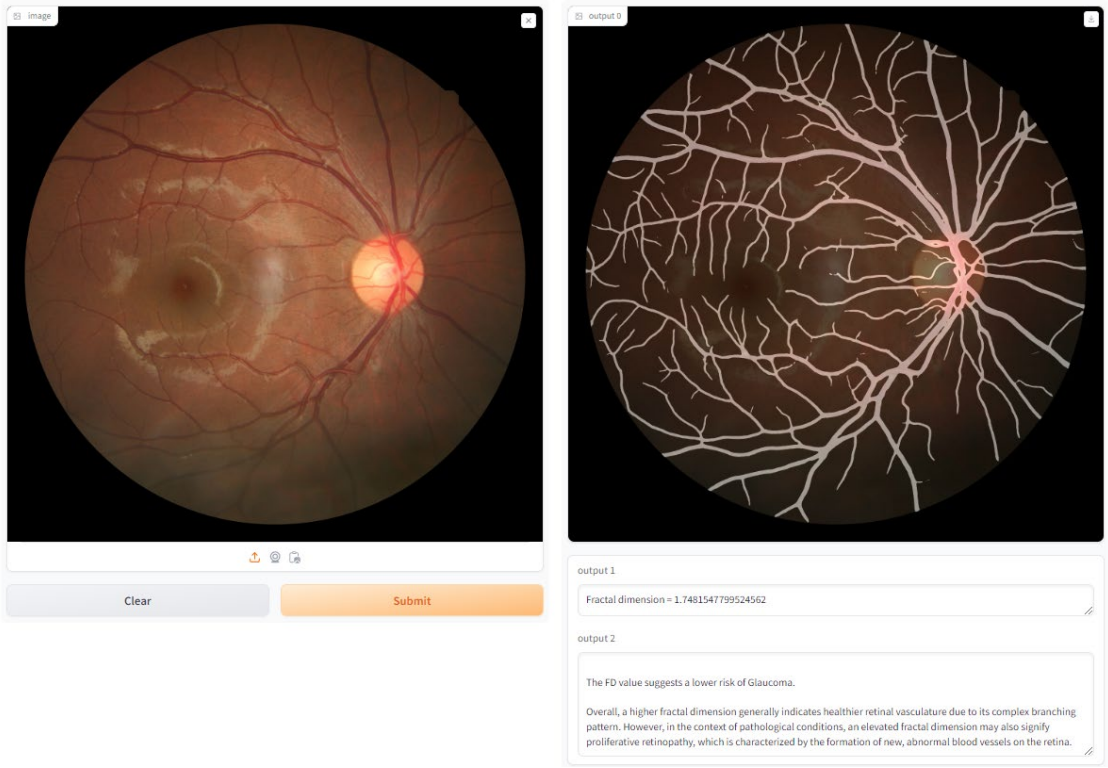

Figure 1. Screenshot of the HRVIAS interface showing a retinal image with its vascular network, along with the calculated fractal dimension and glaucoma risk assessment, indicating a healthy vasculature.

Usability study

To assess the usability of HRVIAS, we conducted a study using the System Usability Scale (SUS). The SUS is a widely recognized tool for measuring the usability of a system and provides a single score that reflects the overall usability of a product or service (Lewis, 2018). For this study, 13 participants were selected, including resident optometrists, visiting optometrists, lecturer optometrists, and non-clinical staff working at an optometry premise. Each participant independently interacted with the system and provided their assessments based on the predefined evaluation criteria. These participants were chosen to ensure that the feedback collected was representative of the system's actual end-users.

In usability studies, small sample sizes are common because the primary goal is to identify major usability issues rather than to statistically generalize findings to an entire population. Nielsen (1994) and Virzi (1992) demonstrated that testing with as few as five participants can uncover approximately 80–85% of usability problems, with additional users often providing diminishing returns in terms of new insights. Moreover, Faulkner (2003) supports the notion that increasing the number of participants beyond a certain threshold typically yields minimal additional benefits. In our study, a sample of 13 participants—which included optometrists and other potential users—was chosen to ensure a diversity of perspectives while still aligning with these established guidelines in usability research. This sample size allowed us to gather robust user feedback and obtain reliable SUS scores that reflect the overall user experience, making it a justified and effective choice for our formative usability evaluation.

Participants were asked to respond to a series of statements regarding their experience using the retinal image analysis tool, and they provided their level of agreement on a 5-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree) (Lewis, 2018; Lewis & Sauro, 2018).

In the SUS evaluation, participants were asked to respond to ten statements regarding the retinal image analysis tool. These statements covered a range of opinions, including their likelihood to use the tool regularly for assessing vascular health; whether they found the tool unnecessarily complex or, conversely, easy to use; and if they believed they would require technical support to operate it. Other statements focused on the integration of the tool's functions, the consistency of its design, the ease with which most users could learn to use it, the degree to which it felt cumbersome, their overall confidence when using the tool, and the initial learning effort required before getting started.

To calculate the SUS score, each participant's responses were converted using a standardized method. For the odd-numbered statements (1, 3, 5, 7, and 9), 1 was subtracted from the participant's score, while for the even-numbered statements (2, 4, 6, 8, and 10), the participant's score was subtracted from 5. The adjusted scores from all ten statements were then summed to yield a total score ranging from 0 to 40. Finally, this sum was multiplied by 2.5 to convert the total into a SUS score out of 100.

The SUS score is interpreted based on a threshold of 68, where a score above 68 is considered to indicate above-average usability, suggesting that the system is generally well-received and user-friendly (Lewis, 2018; Lewis & Sauro, 2018). Conversely, a score below 68 is regarded as below average, indicating that the system may have usability issues or areas that require improvement to meet users' expectations and needs effectively. This scoring system provides a quick and reliable way to assess whether a tool or system is likely to be user-friendly or in need of further refinement.

Result

Figure 2 shows the Receiver Operating Characteristic (ROC) curves for two retinal image analysis systems, AutoMorph (AM)

and HRVIAS. The ROC curve is a plot of the True Positive Rate (sensitivity) against the False Positive Rate (1-specificity) across various threshold settings, providing insight into the diagnostic accuracy of the systems. The Area Under the Curve (AUC) is used to quantify the overall performance, with a higher AUC indicating better discriminative ability.

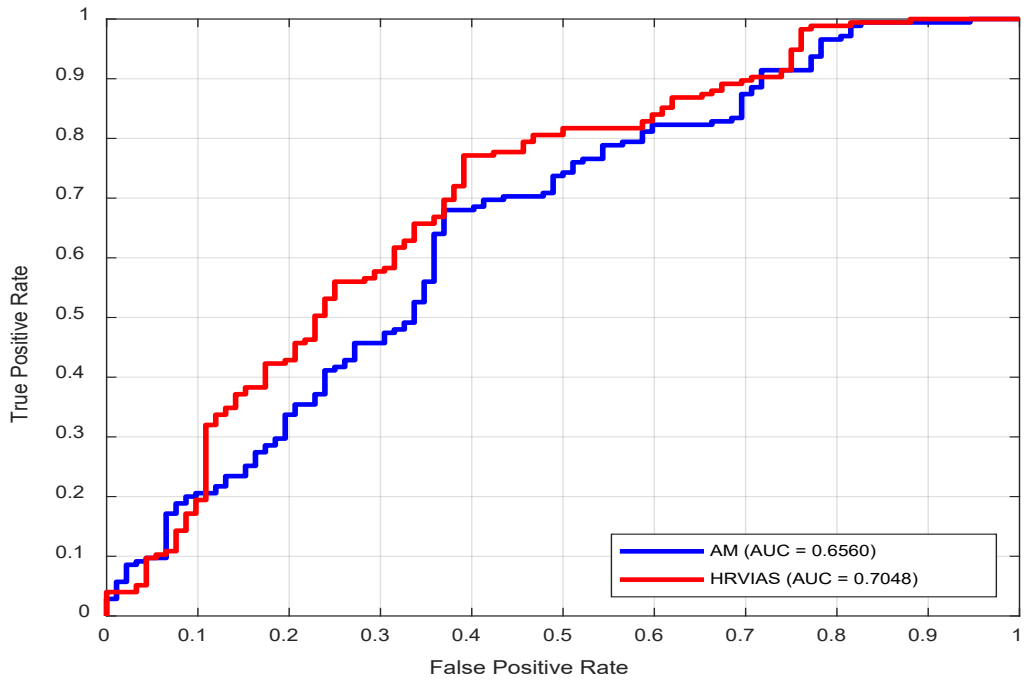

Figure 2. Receiver Operating Characteristic (ROC) curve for differentiating between glaucoma and normal cases using AutoMorph (AM) and High-Resolution Retinal Imaging System (HRVIAS systems).

An AUC of 1.0 represents perfect classification, meaning the system perfectly distinguishes between the positive and negative classes without any errors. Conversely, an AUC of 0.5 indicates a performance equivalent to random chance, where the system has no discriminative ability.

In this figure, the AUC for HRVIAS is 0.7048, which is higher than the AUC for AutoMorph, which is 0.6560. Although the difference did not reach statistical significance, these results indicate that HRVIAS may exhibit a modest advantage in differentiating between positive and negative cases in this dataset. Although both systems show moderate performance, HRVIAS outperforms AutoMorph in this particular analysis, indicating its superior ability to correctly classify retinal images in the context of this study.

As shown in Figure 3, the distribution of System Usability Scale (SUS) scores indicates that most participants rated the usability of the system between 80 and 85, suggesting a generally positive user experience.

Discussion

The findings of this study demonstrate that the proposed high-resolution retinal imaging system offers a modest but meaningful improvement in diagnostic accuracy for glaucoma detection compared to AutoMorph, as evidenced by the higher AUC (0.7048 vs. 0.6560). This aligns with previous research emphasizing the importance of high-resolution imaging in retinal vessel segmentation and its impact on diagnostic precision (Chen *et al.*, 2021; Liu *et al.*, 2022). The superior performance of HRVIAS may be attributed to its higher

resolution (2048 × 2048 pixels) compared to AutoMorph (912 × 912 pixels), which likely enables the capture of finer vascular details critical for accurate segmentation and disease detection (Che Azemin *et al.*, 2024). This is consistent with the findings of Firdausy *et al.* (2022), who highlighted the role of high-resolution imaging in improving sensitivity for retinal vessel segmentation.

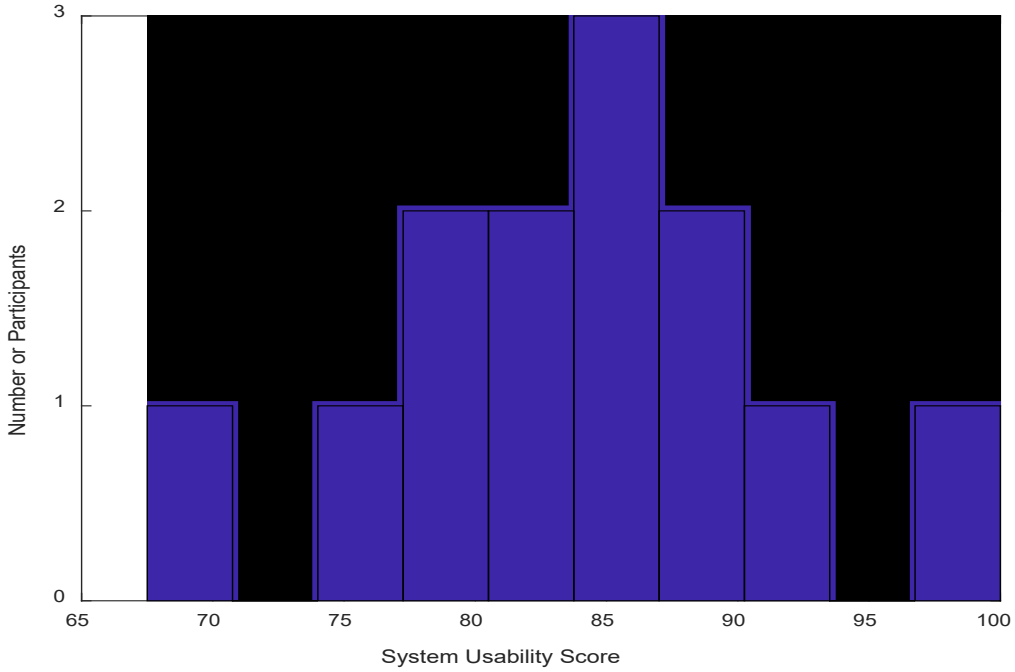

Figure 3. Distribution of System Usability Scale (SUS) scores among participants. The histogram shows the number of participants corresponding to different SUS score ranges. The scores are spread across a range, with the majority of participants scoring around 8.

The usability study further underscores the potential of HRVIAS for clinical adoption. With SUS scores clustering between 80 and 85, the system was rated as highly user-friendly, a critical factor for its integration into clinical workflows. This is particularly important given the increasing reliance on automated tools in ophthalmology, where user satisfaction and ease of use are key determinants of adoption (Lewis, 2018). The graphical user interface (GUI) of HRVIAS, as opposed to the code-based interface of AutoMorph, likely contributed to its higher usability scores, making it more accessible to clinicians without technical expertise (Lewis & Sauro, 2018). This finding is consistent with usability research by Faulkner (2003), which emphasizes the importance of intuitive design in enhancing user experience and reducing the learning curve for new systems.

However, it is important to acknowledge the limitations of this study. While HRVIAS demonstrated a higher AUC, the difference was not statistically significant, suggesting that further validation on larger datasets is necessary to confirm its diagnostic superiority. Additionally, the usability study, though informative, was conducted with a relatively small sample size (n = 13). While small sample sizes are common in usability studies and can effectively identify major usability issues (Nielsen, 1994; Virzi, 1992), future studies should include a broader and more diverse user base to generalize these findings.

The comparison with AutoMorph also highlights areas for improvement. AutoMorph's ability to differentiate between arteries and veins provides a more detailed vascular analysis, which could be beneficial for certain clinical applications (Zhou *et al.*,

2022). Integrating similar capabilities into HRVIAS could further enhance its utility. Additionally, the use of advanced segmentation techniques, such as the Full-Resolution Network (FR-UNet) employed by Liu et al. (2022), could be explored to improve the connectivity and accuracy of vessel segmentation in HRVIAS.

The implications of this study extend beyond glaucoma detection. Retinal vessel segmentation is a critical tool for diagnosing and managing a range of ophthalmic and systemic conditions, including diabetic retinopathy and cardiovascular diseases (Hanssen *et al.*, 2022; Radha & Karuna, 2024). The improved diagnostic accuracy and usability of HRVIAS make it a promising tool for broader clinical and research applications. For instance, its high-resolution capabilities could be leveraged to study subtle vascular changes associated with systemic conditions, as highlighted by Ma *et al.* (2023).

Conclusion

This study evaluated a novel high-resolution retinal imaging system (HRVIAS) for glaucoma detection, demonstrating that it achieved an AUC of 0.7048 compared to AutoMorph's 0.6560. Additionally, usability testing using the System Usability Scale yielded high scores (between 80 and 85), indicating strong user satisfaction. These results suggest that HRVIAS not only enhances diagnostic accuracy through improved retinal vessel segmentation but also offers a user-friendly interface, making it a promising tool for both clinical practice and future research.

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ORIGINAL ARTICLE Open Access

Patient expectations and satisfaction with non-surgical periodontal treatment provided by fourth-year dental students at the University of Otago, Faculty of Dentistry, Dunedin

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Abstract

Evaluation of patient satisfaction is critical to assessing the quality of care. In New Zealand, there are limited studies evaluating the satisfaction of patients receiving treatment by dental students. The aim of this study was to evaluate the current patient satisfaction levels and the factors that influence patient satisfaction with non-surgical periodontal treatment provided by fourth-year dental students at the University of Otago Faculty of Dentistry, along with areas requiring improvement. This study utilised a mixed-methods approach. A 29-item electronic survey was completed by 41 eligible participants. A five-point Likert scale was used to ascertain respondents' level of agreement with a range of statements related to quality of care. Open text fields were used after each group of questions to allow participants to expand on their responses. Quantitative data was analysed using SPSS and qualitative data was coded and content analysed. 100 percent of respondents agreed that they received good periodontal treatment and 81.6 percent agreed that their dental student appeared competent. Participants further elaborated on areas that can be improved such as logistics, standard of care, patient expectation, prior knowledge, communication, physical and emotional care, personnel, technical skills, and physical space. Despite limitations, this study indicated a high level of patient satisfaction with the periodontal treatment provided. Areas of improvement include access to care, informed consent, and communication. The results of this survey reinforce the excellent standard of care provided by students and highlight areas for improvement in future years.

Keywords: *periodontal, patient, satisfaction, university*

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Introduction

Periodontal disease encompasses a range of inflammatory conditions characterised by the progressive destruction of the periodontium, which includes the gingiva, bone, and periodontal ligament (Gasner, 2024). The disease begins with gingivitis, a localised inflammation of the gingiva caused by the microbial biofilm (Gasner, 2024). If dysbiosis of the oral microbiota and host immune defences continues, gingivitis can progress to periodontitis (Kinane *et al*., 2017). The severity of this disease can ultimately lead to alveolar bone loss and tooth loss and contribute to systemic inflammation (Pragati & Neelam, 2020). A comprehensive review revealed that an estimated 10 percent of the global population suffers from severe periodontitis (Frencken *et al*., 2017).

Non-surgical periodontal therapy (NSPT) is a multi-stage treatment involving professional removal of supragingival and subgingival dental plaque and calculus through scaling and root planning by ultrasonic instruments, hand scalers, and curettes to reduce periodontal inflammation and re-establish periodontal health (Kinane *et al*., 2017). Professional NSPT and oral hygiene instruction (OHI) can improve patient oral health by a mean 50 percent reduction in plaque indices (Salhi *et al*., 2020). The success of NSPT depends on modifiable risk factors, such as smoking, localised defects, and the patient's commitment to following OHI to maintain their oral hygiene (Kinane *et al*., 2017; Salhi *et al*., 2020). Following the initial therapy, a re-evaluation should take place to assess adequate healing of connective tissue, and the patient placed on periodontal maintenance or receive additional cause-related therapy of a non-surgical or surgical nature (Sanz *et al*., 2020).

Evaluating patient satisfaction with NSPT is a crucial process for identifying areas for improvement. Satisfaction involves being well attended to and having expectations met (Klaassen *et al*., 2021). Patients may lack clinical expertise, so non-dental factors may influence their satisfaction. In a dental school setting, patient surveys can pinpoint areas where services can be enhanced, reducing the likelihood of patient complaints and aiding in patient retention, thus providing opportunities for broader clinical experiences for students (Dirham, 2021).

Key themes that commonly arise in the literature assessing patient satisfaction with dental care include communication between the dentist and the patient, cost of treatment, accessibility of dental care, quality of the treatment, pain management, and whether the treatment outcome was as the patient had expected (Luo *et al*., 2018). Cost is a significant barrier that affects the likelihood of people accessing dental services in New Zealand, resulting in a measurable decline in health status (Jatrana *et al*., 2009; Stuart, 2011). The University of Otago Faculty of Dentistry Dunedin clinic is attempting to reduce cost as a barrier by offering reduced fees for dental treatment performed by students under staff supervision. However, patients at the University of Otago Faculty of Dentistry in Dunedin may experience lengthy wait times, with some waiting two years for routine care, negatively impacting patient satisfaction (Miller, 2020; Al Ghanem *et al*., 2023).

One aspect of care that has not been well documented is patients' satisfaction with their dentists' cultural competency. With the increasing cultural diversity in New Zealand, clinicians must practice in a culturally safe manner to improve patient satisfaction with their treatment (Govere & Govere, 2016). Additional aspects reported to affect patient satisfaction include treatment quality, clinical skills, emotional care, whether expectations were met, and pain management (Luo *et al*., 2018).

In New Zealand, no published studies have evaluated the satisfaction of patients receiving dental treatment or non-surgical periodontal treatment from fourth-year Bachelor of Dental Surgery (BDS) students at the University of Otago, Faculty of Dentistry, Dunedin. Similar studies undertaken globally have shown proven benefits in conducting such research, as it allows for continuous improvement of the care provided in the area studied (Chang & Chang, 2013).

This study aimed to evaluate the current patient satisfaction levels and the factors influencing patient satisfaction with the non-surgical periodontal treatment provided by fourth-year BDS students at the University of Otago, Faculty of Dentistry, Dunedin, along with areas within the provision requiring improvement.

Materials and Methods

To separate eligible participants from non-eligible participants, all patients who received non-surgical periodontal therapy (NSPT) by fourth-year dental students in 2023 at the Faculty of Dentistry, Dunedin, were screened manually according to the eligibility criteria below (Table 1). The

Global Burden of Disease study estimates that 9.8 percent of the global population suffers from severe periodontitis (Marcenes *et al*., 2017). Based on an estimated population prevalence of 9.8 percent of individuals having severe periodontitis, a margin of error of five percent, and a confidence interval of 85 percent, a response from 37 individuals was needed from our sample population of 71. Figure 1. outlines the protocol used in this study to establish the eligible sample population.

Table 1. Inclusion and exclusion criteria.

Eligibility Criteria of Participants	
Inclusion Criteria	• Participants >18 years of age who received a full course of non-surgical periodontal treatment in 2023 at the University of Otago, Faculty of Dentistry, Dunedin. • Participants must also be on a recall list for continuation of periodontal treatment and maintenance.
Exclusion Criteria	• Patients who did not have their full course of non-surgical periodontal treatment completed during 2023. • Patients whose treatment was completed outside of the BDS4 specialist periodontal clinic. • New periodontal patients assigned to BDS students for 2024. • Patients whose final appointment of their non-surgical periodontal treatment was before 2023. • Treatment that involved any surgical procedures requiring post-graduate periodontal training such as crown lengthening surgery, guided tissue regeneration, bone grafts, etc.

This study utilised a mixed-method approach, collecting qualitative and quantitative data through a 29-item electronic survey based on a survey validated by Mahrous & Hifnawy (2012). Questions 1-4 assessed patient knowledge and expectations before receiving NSPT. Questions 5-10 assessed patient satisfaction with their dentist, the administrative aspects of treatment, and the quality of treatment received, while questions 11-13 assessed satisfaction with the standard of care and cost.

Quantitative data was collected using a series of statements that aimed to target a range of aspects of treatment, from communication to clinical competence. A five-point Likert scale with the following options: strongly disagree (1), disagree (2), neither agree nor disagree (3), agree (4), and strongly agree (5), was used to assess respondents' level of agreement with each statement (Ilioudi *et al*., 2013). An additional ten open-text questions enabled participants to expand on their answers.

The survey was distributed via Qualtrics XM to all eligible participants and was open for three weeks. Weekly email reminders were sent to complete the survey. The data was stored securely on a university cloud platform, and no identifying participant information was linked to the data collected in this study.

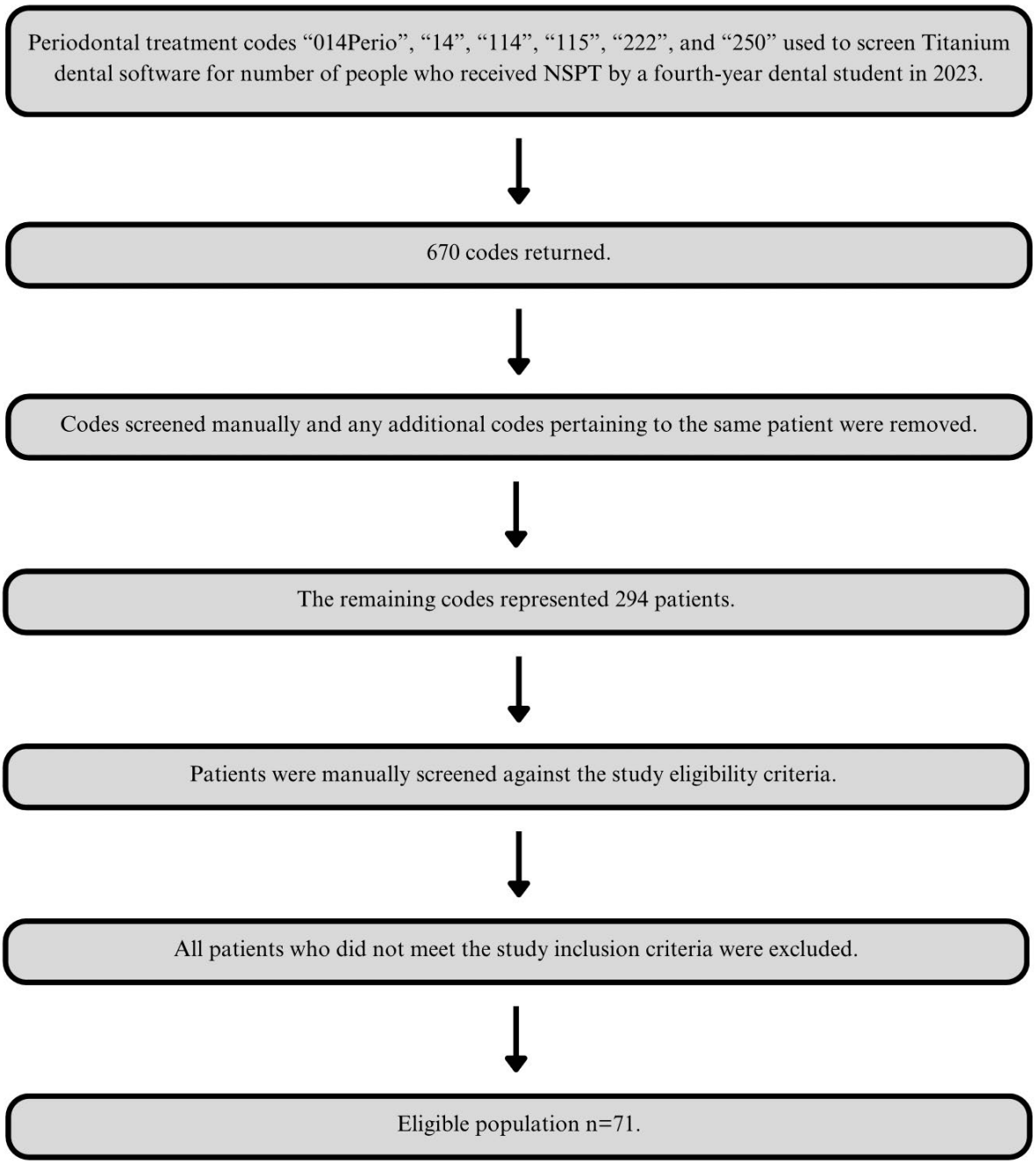

Figure 1. Outline of the process for determining eligible patients to participate in this study.

All qualitative data was coded using the methods from Klaassen *et al*. (2021) by attaching a keyword or phrase to each response. The quantitative data was analysed using IBM SPSS Statistics 2022 version 29.0.0.0 and the mean, median, and standard deviation were calculated for each statement. These figures corresponded to the numerical values attributed to each of the five possible responses provided by the Likert scale. For example, if the median value for a given statement was 5, it would mean that the middle rating in the dataset was 5, indicating "strongly agree" according to the Likert scale. The data was then further simplified into respondents who agreed or disagreed with each statement, where "agree" encompassed both "strongly agree" and "agree" answers, while "disagree"

encompassed both "strongly disagree" and "disagree" answers.

This project (H24/037) was granted ethics approval by the University of Otago Human Ethics Committee (Health) on 27 May 2024.

Results

Of the 71 eligible study participants, 41 responded to the survey, producing a response rate of 57.7%. An average of 78% of respondents completed the open-ended questions in the patient satisfaction survey.

The sample reflects a diverse age range and ethnic composition. The age distribution shows a predominance of respondents in the 60-69 age group (31.7%), with those aged 50-59 being the second most predominant (29.3%). The mean age of respondents was 65.73 years, with a median age of 67. Most respondents identified as New Zealand European (70.7%), with a smaller proportion of Māori, Pasifika, and Asian (4.9% each), and other ethnicities making up 14.6%. These results indicate that patients at the Faculty of Dentistry requiring periodontal treatment are primarily New Zealand European. Age and ethnicity data are shown below in Table 2.

Table 2. Demographic characteristics of the sample for responses (N=41).

Variable	n	%	Mean	Median	SD
Age					
20-29	1	2.4			
30-39	0	0			
40-49	2	4.8			
50-59	12	29.3	65.73	67.00	13.555
60-69	6	14.5			
70-79	13	31.7			
80-89	7	17.1			
Ethnicity					
NZ European	29	70.7			
Māori	2	4.9			
Pasifika	2	4.9			
Asian	2	4.9			
Other	6	14.6			

Participants' prior knowledge of periodontal treatment varied widely. Some were familiar with the treatment due to past experiences or regular recalls (33.3%). Others understood that periodontal treatment involved addressing gum disease and preventing its progression, often learning more about it during their appointment (29.2%). However, many patients had limited knowledge, citing they knew "nothing" or "very little" (37.5%).

When asked about the goals they hoped to achieve through NSPT, three participants primarily focused on achieving better gingival and dental health, preventing further deterioration, and improving their oral hygiene and aesthetics. For example, a patient mentioned *"wanting to keep teeth and gums as healthy as possible and for as long as possible*" [respondent 14]. Three patients with no expectations (8.8%).

When asked about the presence or absence of anxiety before receiving NSPT, most respondents (53.7%) had no degree of anxiety or excitement before treatment. In comparison, 29.3% of respondents felt slightly anxious, as shown below in Table 3.

Table 4 shows that most respondents (90.2%) agreed that their dentist was friendly, and 82.9% agreed that their dentist made them feel comfortable in the chair. 95.4% of respondents agreed that all procedures were explained well before starting. Respondents were generally satisfied when it came to dentist communication. However, 7.3% of respondents neither agreed nor disagreed, and 4.8% disagreed that their dentist communicated effectively. Respondents (82.9%) agreed that their dentist did not criticise the condition of their teeth or gums, with only one respondent expressing disagreement. Many respondents (87.8%) felt their dentist showed concentration on their work, and 75.6% believed their dentist was competent, with no respondents disagreeing. Additionally, 87.8% of respondents felt they received advice during their appointments, while 80.5% believed the student respected their culture and could express it freely.

Table 3. The frequency, percentage, mean, median, and standard deviation for the responses (N=41).

How did you feel when you were about to receive periodontal treatment?					
Response	**n**	**%**	**Mean**	**Median**	**SD**
Severely anxious	1	2.4	2.74	3	0.724
Slightly anxious	12	29.3			
Neither anxious nor excited	22	53.7			
Slightly excited	2	4.9			
Extremely excited	1	2.4			
Missing	3	7.3			

Table 4. The respondents' satisfaction regarding their interaction with the dentist (N=41).

Statement	Responses	n	%	Mean	Median	SD
The dentist was friendly (1)	Strongly disagree	0	0	4.58	5	0.642
	Disagree	1	2.4			
	Neither agree nor disagree	0	0			
	Agree	13	31.7			
	Strongly agree	24	58.5			
	Missing	3	7.3			
The dentist made me feel comfortable in the chair (2)	Strongly disagree	0	0	4.39	5	0.755
	Disagree	1	2.4			
	Neither agree nor disagree	3	7.3			
	Agree	14	34.1			
	Strongly agree	20	48.8			
	Missing	3	7.3			
The dentist explained all procedures before starting (4)	Strongly disagree	0	0	4.54	5	0.691
	Disagree	1	2.4			
	Neither agree nor disagree	1	2.4			
	Agree	12	29.3			
	Strongly agree	23	56.1			
	Missing	4	9.8			
	Strongly disagree	1	2.4			
	Disagree	1	2.4			

The dentist communicated effectively (5)	Neither agree nor disagree	3	7.3	4.30	5	0.939
	Agree	13	31.7			
	Strongly agree	19	46.3			
	Missing	4	9.8			
The dentist did not criticise the condition of my teeth and gums (6)	Strongly disagree	0	0	4.43	5	0.728
	Disagree	1	2.4			
	Neither agree nor disagree	2	4.9			
	Agree	14	34.1			
	Strongly agree	20	48.8			
	Missing	4	9.8			
The dentist was concentrated on their work (3)	Strongly disagree	0	0	4.47	5	0.603
	Disagree	0	0			
	Neither agree nor disagree	2	4.9			
	Agree	16	39.0			
	Strongly agree	20	48.8			
	Missing	3	7.3			
The dentist appeared competent (7)	Strongly disagree	0	0	4.29	5	0.768
	Disagree	0	0			
	Neither agree nor disagree	7	17.1			
	Agree	13	31.7			
	Strongly agree	18	43.9			
	Missing	3	7.3			
The dentist gave me advice following treatment (8)	Strongly disagree	0	0	4.57	5	0.555
	Disagree	0	0			
	Neither agree nor disagree	1	2.4			
	Agree	13	34.1			
	Strongly agree	22	53.7			
	Missing	4	9.8			
The dentist was respectful of my culture and made me feel like I could express my culture freely (9)	Strongly disagree	0	0	4.45	5	0.724
	Disagree	0	0			
	Neither agree nor disagree	5	12.2			
	Agree	11	26.8			
	Strongly agree	22	53.7			
	Missing	3	7.3			

Table 5 shows that wait times at the Faculty of Dentistry were acceptable to most respondents (73.2%). However, 4.8% of respondents felt they had waited too long. 78.1% of respondents thought that their treatment was efficiently completed. While most respondents thought the clinic was situated in a good location, 9.7% believed it was not, with less than half of respondents thinking it was easy to find a park and access the clinic.

Table 5. The respondents' satisfaction regarding the administrative aspects of treatment.

Statement	Responses	n	%	Mean	Median	SD
I didn't have to wait long to be seen for periodontal treatment (1)	Strongly disagree	1	2.4	4.05	4	0.911
	Disagree	1	2.4			
	Neither agree nor disagree	5	12.2			
	Agree	18	43.9			
	Strongly agree	12	29.3			
	Missing	4	9.8			
The appointment times suited my schedule (2)	Strongly disagree	0	0	4.30	4	0.878
	Disagree	3	7.3			
	Neither agree nor disagree	1	2.4			
	Agree	15	36.6			
	Strongly agree	18	43.9			
	Missing	4	9.8			
Periodontal treatment was completed efficiently (3)	Strongly disagree	0	0	4.27	4	0.693
	Disagree	0	0			
	Neither agree nor disagree	5	12.2			
	Agree	17	41.5			
	Strongly agree	15	36.6			
	Missing	4	9.8			
The clinic is situated in a good location (4)	Strongly disagree	1	2.4	4.14	4	1.058
	Disagree	3	7.3			
	Neither agree nor disagree	3	7.3			
	Agree	13	31.7			
	Strongly agree	17	41.5			
	Missing	4	9.8			
It was easy to find parking and I had no trouble accessing the clinic (5)	Strongly disagree	7	17.1	3.08	3	1.362
	Disagree	5	12.2			
	Neither agree nor disagree	9	22.0			
	Agree	10	24.4			
	Strongly agree	6	14.6			
	Missing	4	9.8			

Table 6 shows that respondents' level of satisfaction regarding the periodontal treatment they received indicated general satisfaction. All respondents strongly agreed or agreed that their initial examination was thorough and that they received good periodontal treatment. Additionally, 82.9% strongly agreed or agreed that their treatment was painless or well managed with local anaesthetic, though 7.3% neither agreed nor disagreed. All respondents agreed that the dental environment was clean and sterile. Except for two, all respondents felt better about their teeth and gums after treatment.

Table 6. The respondents' satisfaction regarding the periodontal treatment they received (N=41).

Statement	Responses	n	%	Mean	Median	SD
A thorough initial examination was conducted (1)	Strongly disagree	0	0	4.62	5	0.492
	Disagree	0	0			
	Neither agree nor disagree	0	0			
	Agree	14	34.1			
	Strongly agree	23	56.1			
	Missing	4	9.8			
I received good periodontal treatment (2)	Strongly disagree	0	0	4.57	5	0.502
	Disagree	0	0			
	Neither agree nor disagree	0	0			
	Agree	16	39.0			
	Strongly agree	21	51.2			
	Missing	4	9.8			
The treatment offered was not painful or the dentist managed my pain well (using local anaesthetic) (3)	Strongly disagree	0	0	4.35	4	0.633
	Disagree	0	0			
	Neither agree nor disagree	3	7.3			
	Agree	18	43.9			
	Strongly agree	16	39.0			
	Missing	4	9.8			
The dental environment was clean and sterile (chair/bench/tools etc.) (4)	Strongly disagree	0	0	4.67	5	0.435
	Disagree	0	0			
	Neither agree nor disagree	0	0			
	Agree	9	22.0			
	Strongly agree	28	68.3			
	Missing	4	9.8			
I feel better about my teeth and gums now than I did before treatment began (5)	Strongly disagree	0	0	4.62	5	0.594
	Disagree	0	0			
	Neither agree nor disagree	2	4.9			
	Agree	10	24.4			
	Strongly agree	25	61.0			
	Missing	4	9.8			

The remainder of the qualitative data was analysed using content analysis by two researchers (CL and ML). A total of 229 open-ended comments were received. From these comments, 28 codes were generated based on keywords within each comment. To enhance the reliability and validity of the analysis, a clear research aim was established prior to data collection and analysis. An inductive coding system was also used, based on the framework previously implemented by Klassen et al. (2021). Lastly, the analysis was conducted independently by two researchers (CL and ML), who compared their findings before confirming the final codes.

The codes were then grouped into seven categories to represent the range of data received. The categories, listed from most frequently to least frequently commented on, were logistics (112), standard of care (65), communication (15), physical and emotional care (14), personnel (11), technical skills (7), and physical space (5). Of the 229 comments received, each was also further classified as either satisfied, neutral, or dissatisfied, indicating the tone of the comments in each category (Figure 2). One

hundred sixty-three comments were classified as satisfied (71.2%), with statements such as "*satisfied*", "*pleased*", and "*impressed*" supporting this classification. Twenty-eight comments were coded as neutral (12.2%) based on keywords such as "*okay*" and "*fine*". A final 38 comments were classified as dissatisfied (16.6%), where patients expressed dissatisfaction with aspects of their treatment. Table 7 shows the categories and codes with comment distribution.

Standard of care

The category comments regarding the standard of care encompassed the codes: standard of care, history taking, completeness of care, efficiency, professionalism, and service satisfaction. The periodontal treatment provided by fourth-year students at the Faculty of Dentistry, Dunedin, was generally met with high satisfaction (71.6%). Patients commented that the care they received was thorough, with one respondent citing that "*[...] what I received clinically was what I was expecting. My gums felt healthier, and I was provided with advice for caring for my gums at home. You feel good after these appointments, and it reminds you to preserve your teeth and not go backwards*" [respondent 40]. The care provided often exceeded respondent expectations. Multiple respondents stated that nothing could be improved in the standard of care and highlighted that the students demonstrated professionalism and efficiency in their care. 9.2% of comments received, however, were classified as dissatisfied, with one respondent stating, "*I would like to be treated like a person not a project*", and another saying, "*I felt like I was being used as a major test case because of the [amount] of work to be done and the students were more interested on how it would look on [their] work experience than what I wanted done*" [respondent 19].

Logistics

The category logistics encompassed the codes: appointment scheduling, notice of appointments, number of visits, waiting times, parking, cost, tutor numbers, and general administrative satisfaction. The Faculty of Dentistry, being a teaching institution, brings with it a set of inherent qualities such as longer wait times and an increased number of appointments; therefore, this category possessed a broader distribution of satisfied (55.4%), neutral (19.6%), and dissatisfied (25.0%) responses. Patients were mainly dissatisfied with the notice given for appointment scheduling, *"Notice [times] for appointments were very short, sometimes [a] couple of day[s], [was] lucky to have good employer".* Patients were also dissatisfied with the number of appointments it took to complete their treatment, *"the amount of time to complete treatment from start to finish is slow"* [respondent 28]. Patients also expressed concern regarding a lack of accessible parking, with 100% of responses classed as dissatisfied. Regarding the cost of treatment, the feedback was largely favourable, with 62.5% of responses considered satisfied. There was some dissatisfaction expressed (13.9%), concerning the cost discrepancy between the estimate provided and the invoiced cost following treatment completion. A new fee structure was introduced at the Faculty of Dentistry in 2023, where patients pay per visit rather than per treatment code. Some respondents felt that this could deter patients from completing treatment with the financial burden of multiple visits, *"The new fee structure is clunky and open-ended. Would deter many people from coming back despite really needing dental care. The document on pricing needs rewording at the very least, to indicate time payment [options]"* [respondent 9].

Communication

Communication encompassed the codes: student communication skills, informed consent, and patient education. Feedback received was generally positive, with 93.3% of responses indicating satisfaction. Respondents highlighted the practical and warm communication skills they observed from their students, with one respondent stating that *"everything was explained well"*

[respondent 8]. Others said they felt comfortable asking questions, which were always addressed thoroughly and helped to form rapport and trust throughout the sessions. Regarding cost, many patients appreciated that there were clear explanations around treatment options and the associated costs, which helped to set realistic explanations, with one respondent stating, *"Price was explained at the beginning and was certainly cost-effective"* [respondent 35]. Respondents also praised being able to pay in instalments.

Physical and emotional care

This category encompassed the codes: friendliness, well-mannered, rapport, attentiveness, and comfort, and showed that patients were generally satisfied with their physical and emotional care (92.8%). Patients praised the friendliness and care provided by their students, describing them as "*professional*" [respondent 23] and "*respectful*" [respondent 34]. Many mentioned that their student made them feel at ease during procedures that would typically make them uncomfortable. They felt that their student was attentive and remained calm, providing a positive experience.

Personnel

Personnel referred to the code: student and staff interaction with the patient. Feedback was mainly positive (81.8%), with the remainder being neutral (18.2%). Many noted that the students showed professionalism and care, with the positive influence of tutoring staff members. Although one comment stated the tutor was "*quite abrupt in telling me about the condition of my teeth and gums*" [respondent 40], most responses were positive, with one stating, "*I was completely happy with the treatment I received*" [respondent 38]. Many acknowledged that although the students were still learning, they felt that the quality of care improved with each year; "*the calibre of the student [...] seems to get better as each year goes on*" [respondent 1].

Technical skills

Technical skills encompassed the codes: skills and knowledge, and student competency. Of the comments, 71.4% were satisfied, with patients generally feeling that the fourth-year dental students were willing to learn and improve throughout their treatment. The thoroughness of the examination and the level of informed consent was praised. A significant proportion of patients were dissatisfied (28.6%) with their student's competency, citing that their student was "*[...] confused at what she was doing and had to be told by her assistant*" [respondent 1]. Despite this, most respondents recognised that the Faculty of Dentistry is a training institution for students to learn and develop.

Physical space

The category of physical space represented the code: quality of facilities. There was a 100% satisfaction rate from the respondents who expressed acclaim for the facilities at the Faculty of Dentistry, with the Clinical Services Building opening in 2019. Respondents appreciated the comfort provided, with one respondent saying, "*I like the new building - well really it's the chairs, sooo comfortable*" [respondent 9]. The organisation and cleanliness of the space was commended, contributing to an overall positive experience.

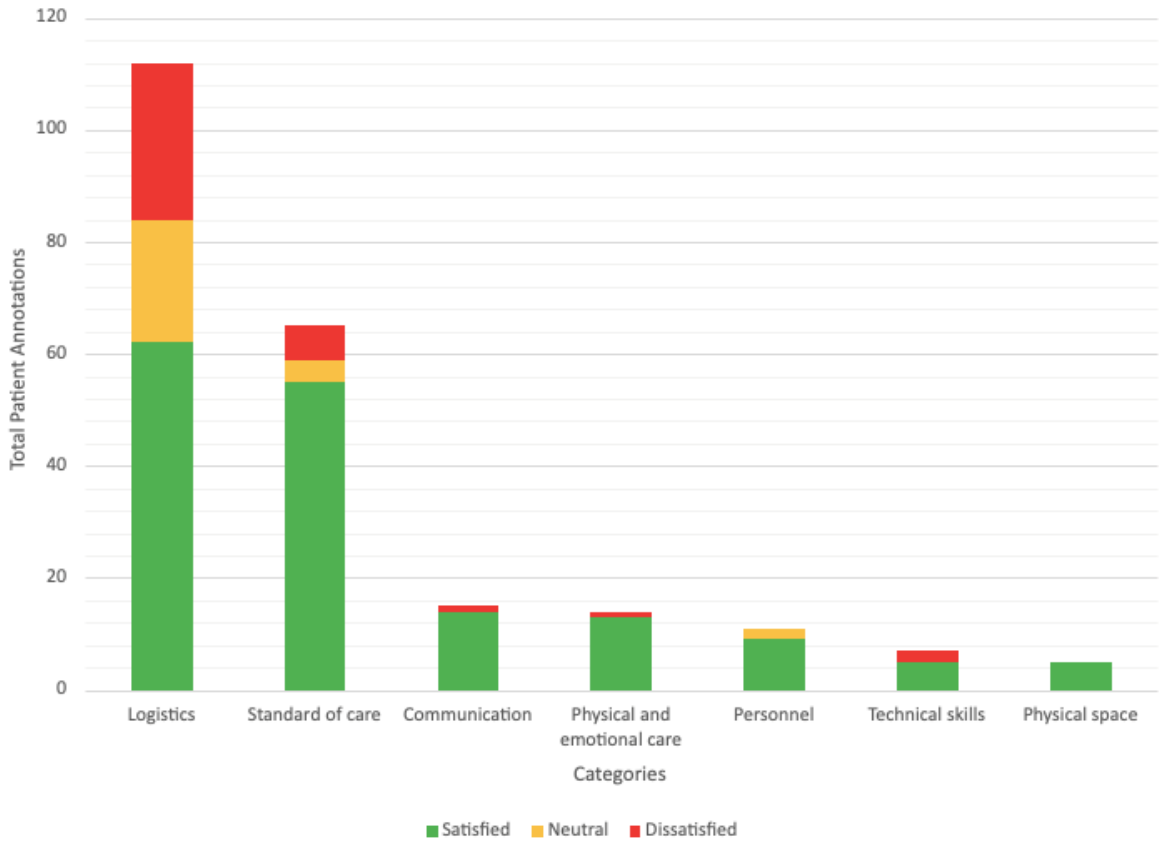

Figure 2. Stacked column graph showing the proportion of satisfied, neutral, and dissatisfied responses within each category.

Table 7. Categories and codes with comment distribution.

Thematic category and codes	Number of times coded from patient responses
Personnel	**11**
Interaction with dentist	9
Staff interaction	2
Physical and emotional care	**14**
Friendliness and care	7
Well-mannered	1
Rapport	1
Attentive	1
Comfort	4
Technical skills	**7**
Skills and knowledge	2
Competency	5
Standard of care	**65**
Standard of care	32
History taking	1
Completeness of care	1
Efficiency	1
Professionalism	5

Service satisfaction	27
Communication	**15**
Clinician communication skills	6
Informed consent	6
Patient education	3
Logistics	**112**
Appointment scheduling	4
Notice of appointment	4
Appointment length	4
Number of visits	4
Parking	8
Wait times	1
Cost	72
Tutor numbers	2
Administration satisfaction	13
Physical space	**5**
Quality of facilities	5

Discussion

This study examined patient satisfaction with non-surgical periodontal therapy by fourth-year students at the University of Otago, Dunedin, using a mixed-method approach. Given the lack of published data regarding patient satisfaction with NSPT at the University of Otago, Faculty of Dentistry, Dunedin, the primary questions in this study provided insight into patient care, cultural competency, and patient-clinician communication. The comments from respondents in each category of satisfied, neutral, and dissatisfied may help to guide the university in improving aspects of care that relate to each category.

The results indicate a generally positive experience with the NSPT provided by fourth-year dental students. With a response rate of 57.7% from the 71 eligible participants, this study reflects a diverse patient demographic predominantly in the 50-69 age range, including many ethnic backgrounds, with the majority being New Zealand Europeans. The respondents captured in this study were reflective of the overall population in Dunedin, for example, the study had a 70.7% New Zealand European respondent percentage, compared to Dunedin having 85.2% and the Māori population of Dunedin being 9.9%, and we had a response rate of 4.9% Māori in our study (Stats N.Z, 2024).

Most comments received in this survey expressed satisfaction (71.2%). It was unsurprising to discover that respondents were generally satisfied with the standard of care provided (71.6% of open-ended responses). Quantitative data supported the notion that the standard of care provided by students at the Faculty of Dentistry is satisfactory and meets the standards set by the Dental Council of New Zealand (DCNZ) (Dental Council New Zealand, n.d.).

Patients expressed higher satisfaction in physical space, physical and emotional care, and communication. All respondents were satisfied with the facilities provided by the Faculty of Dentistry. The emotional care provided by the student played an essential role in increasing patient satisfaction, with 92.8% of respondents in their qualitative comments praising the friendliness and care provided by their student, describing them as “professional” and “respectful”. Empathy can decrease dental anxiety and positively impact patient outcomes (Uziel *et al*., 2019). The results, however, did highlight some areas for improvement, particularly regarding communication and informed consent. While 93.3% of comments relating

to communication were positive, one respondent stated that *"the cost provided by the administrative team did not line up with what the student quoted me"* [respondent 23]. 5.4% of respondents disagreed that their dental student communicated effectively, and 2.7% disagreed that all procedures were explained before starting treatment. These results indicate failure to provide informed consent, as there should be no discrepancy between what is quoted before treatment commences and what the patient pays at the end. Since informed consent is an ongoing process, any changes in cost during treatment should require re-consent. Informed consent is an ethical and legal requirement for all dentists in New Zealand and allows patients to maintain autonomy and make informed choices about the treatment they receive (Nono *et al*., 2024).

The study showed that 86.8% of respondents found their dental student respectful of their culture which is a positive reflection of cultural safety and suggests that students at the Faculty of Dentistry are operating in alignment with the DCNZ cultural safety domains in both education and regulation (Dental Council New Zealand, n.d.).

Respondents generally thought that their dental student was competent, with 81.6% of respondents either agreeing or strongly agreeing with this statement. Respondents supported this as 71.4% of open-ended responses stated that respondents were satisfied with the technical skills of their dentist; *"They demonstrated good competency"* [respondent 5], *"everything was explained well, and treatment was thorough"* [respondent 28]. However, open-ended comments revealed concerns with students' technical skills, suggesting a need for further training and evaluation to ensure that students meet professional standards. A recent study of Otago graduates by Loh *et al*. (2022), showed that while new graduates perceive themselves as confident in diagnosing and treating periodontitis, employers thought that new graduates more frequently misdiagnose periodontal diseases, suggesting that despite patients feeling satisfied with the treatment they receive, their perceptions may not accurately depict the clinical quality of treatment provided.

According to respondents, the logistics of physically accessing the Faculty of Dentistry and finding an appointment time were the most prohibitive factors for accessing care. 8.1% of respondents disagreed that the available appointment times suited their schedules. Fourth-year periodontal clinics were held only on Fridays, acting as a barrier to care for individuals who work or have regular commitments at this time. Fourth-year students are encouraged to see patients with advanced periodontitis in these clinics as they have access to specialist tutors during this time. However, this lack of flexibility may make attendance more difficult for respondents. 10.8% of respondents also disagreed that the clinic was in a good location, and 32.4% disagreed that parking was accessible. Accessibility is a critical aspect to consider for patient satisfaction, however, students and staff at the Faculty of Dentistry have less control over this aspect of care.

This study possessed several strengths. Utilising a mixed-method approach allowed the researchers to analyse the results both statistically and categorically. This enhanced the depth of insights gained, particularly regarding patient expectations, experiences, and the cultural competency of dental care provided by students. Additionally, the response rate for this study (57.7%), was sufficient to ensure a representative sample of participants from diverse ages and ethnic backgrounds. Lastly, the rigorous ethical oversight and systematic data analysis enhanced the credibility of the findings, making this study a valuable contribution to understanding patient satisfaction in dental education settings and the first of its kind in New Zealand.

One limitation of this study was that it was impossible to ensure that respondents were referring solely to the treatment provided in the fourth-year BDS periodontal clinic in 2023. Some participants wrote about treatment provided outside of this clinic,

which was outside the scope of this study. Therefore, it was difficult to be certain which data referred to our population of interest and which did not. Another limitation was the small sample population available after excluding non-eligible participants. Only 71 individuals treated in the fourth-year periodontal clinic in 2023 met the inclusion criteria for this study. Individuals whose treatment was incomplete or was not reviewed, were omitted. Had these groups of individuals been included in the study, the results may be less favourable due to the incompletion of treatment. This study's smaller sample size also reduces the external validity of the results.

Despite the limitations of this study, we recommend that future research spans several years and includes multiple cohorts of students along with a more significant number of participants. Incorporating focus group interviews with patients could offer deeper insights into the factors that most strongly influence patient satisfaction and provide more precise guidance for future improvements. Additionally, including diverse treatment phases, such as initial NSPT and follow-up care, would help clarify how different stages of treatment impact patient perceptions and satisfaction. A final recommendation is to establish a real-time feedback mechanism that enables patients to share their treatment experiences, facilitating the immediate identification of any issues that may require attention.

Conclusion

This study aimed to provide insight into patient satisfaction with non-surgical periodontal treatment at the University of Otago, Faculty of Dentistry, Dunedin. The results indicated a high level of patient satisfaction and standard of care provided by students. While patients expressed overall satisfaction, they recommended improvement in access to care, informed consent, and communication.

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REVIEW ARTICLE Open Access

The effectiveness of lumbar stabilisation exercises on pain and functional disability among patients with non-specific low back pain: a systematic review

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Abstract

Core stability exercises have emerged as a crucial intervention for managing and preventing back pain, a pervasive condition affecting millions globally. Back pain frequently arises and persists due to deficiencies or imbalances in core muscles. As a result, engaging in targeted core-strengthening exercises is thought to not only reduce pain but also greatly boost functional capabilities and improve overall quality of life. A systematic search of electronic databases (PubMed, ScienceDirect, and PEDro) was conducted to find experimental studies focusing on the impact of core stability exercises on back pain and functional independence in adults with nonspecific back pain. Out of 250 identified studies, 228 titles and abstracts were reviewed, resulting in the exclusion of 122. Among the remaining 106 articles, 93 full texts were retrieved and evaluated for eligibility. Ultimately, 8 studies met the criteria and were included in the review. Out of the eight studies, two reported no improvement in pain reduction compared to control groups. For disability, six studies assessed the outcome, of which three reported no improvement compared to control groups. The remaining studies demonstrated greater effectiveness of core stability exercises in reducing both pain and disability. These findings highlight the importance of incorporating core stability exercises into treatment plans for NSLBP and emphasize the need for tailored exercise programs to optimize outcomes.

Keywords: *core stability, exercise training, low back pain*

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Introduction

Low back pain is defined as pain in the posterior aspect of the body, extending from the lower margin of the twelfth ribs to the lower glutaeal folds with or without referred pain into one or both lower limbs, lasting at least one day. It has been recognised as one of the leading contributors to global disability (Hoy *et al.*, 2014). It is a significant global health issue, affecting millions of people and often leading to disability, reduced quality of life, and substantial economic burden (Wu *et al.,* 2020). According to world health organisation in 2020, low back pain (LBP) affected 619 million people globally, a 60% increase from 1990 and it is estimated that the number of cases will increase to 843 million by 2050, driven largely by population growth and aging (GBD, 2021).

Low back pain may be classified as acute (less than 6 weeks), subacute (6-12 weeks)

or more than 12 weeks as chronic (Frizziero *et al.,* 2021). It can be caused by various specific causes, such as muscle strain, poor posture, or degenerative conditions. However, when no specific pathology is identifiable, it is classified as nonspecific low back pain (NSLBP) (Balague F *et al.,* 2012). Management of chronic low back pain has been a topic of discussion among authors of medical fraternity for a long time with physiotherapy playing a vital role in managing the pain and improving functional outcomes through individualized treatment approaches. Research indicates that core musculature activation patterns, particularly in the lumbar multifidi and transverse abdominis, are disrupted in patients with NSLBP. This leads to the abnormalities and puts tremendous load on the stabilisation structures of spine, causing pain and disability (Frizziero *et al.,* 2021). Consequently, clinical approaches now prioritize strategies to restore core muscle function and enhance stability, aiming to alleviate symptoms and minimize the risk of recurrence. Addressing neuromuscular imbalances has become central to the effective management of chronic NSLBP, reflecting a shift toward targeted, evidence-based interventions.

Although core stability exercises are widely used for managing NSLBP, existing research has reported inconsistent findings regarding their effectiveness in reducing pain and functional disability. These inconsistencies may arise from variability in intervention protocols and patient populations. This review aims to systematically analyse existing literature on core muscle activation patterns in NSLBP, identifying gaps in current research and offering evidence-based recommendations for optimizing treatment protocols and tailoring interventions to individual patient needs.

Materials and Methods

Study design

This systematic review was designed using the PICO (Population, Intervention, Comparison, Outcome) framework to formulate the research question (Tawfik *et al.,*2019): *What is the effect of core stability exercises on patients with non-specific low back pain (NSLBP)?* (Table 1). The review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Page *et al.,* 2021)

Search strategy

Online databases, PubMed and Science Direct were accessed for searching without using any filters. The following key words were used: 'Core stabilisation exercises' OR 'Motor Control Stabilization Exercises' OR 'Trunk Stabilization Exercises' OR 'Swiss ball stabilization' OR 'Spinal Stabilization Exercises' AND 'non-specific low back pain' OR 'chronic non-specific low back pain'. A standard search strategy was done in PubMed and was later modified for each database. The search covered studies published from 2008 to 2021.

Table 1. PICOS framework (Tawfik *et al*., 2019).

Population	Adult patients with NSLBP
Intervention	Core stabilization exercises
Control	Other forms of conventional exercises and treatments or placebo
Outcome	Any reliable and valid outcome measure for pain and/or disability
Study Design	Randomised control trials

Inclusion and exclusion criteria

The studies were reviewed by two reviewers based on the inclusion and exclusion criteria to exclude articles which were Two reviewers manually screened the titles and abstracts, excluding 122 articles that did not meet the criteria not relevant. Following criteria was applied:

Inclusion criteria: 1) original research articles (RCTs) published 2008 onwards and must include patients aged more than 18

years; 2) articles must have patients with NSLBP, with varying pain duration (acute, subacute or chronic); 3) articles using core stability exercises as a principal treatment for an minimum of two weeks; 4) studies must have incorporated outcome measures for measuring pain and disability.

Exclusion criteria: 1) studies published in languages other than English; 2) review articles (including systematic reviews, narrative reviews, scoping reviews, and meta-analyses); 4) case reports.

Study selection

The search results were first screened by reviewing the titles and abstracts. Two reviewers independently screened the abstracts to identify potentially relevant studies. Full-text articles of the selected abstracts were then retrieved and reviewed for eligibility based on the inclusion and exclusion criteria. Any disagreements between the reviewers were resolved through discussion or consultation with a third reviewer.

Data extraction

Data were extracted from the included studies using a standardized data extraction form. Extracted data included Study characteristics: authors, year of publication, study design, number of participants in each group, mean age, details of intervention in each group, and comparison, outcome measures used, and results.

Methodological quality

The selected articles were assessed for the quality in their methodology by two independent reviewers using PEDro scale (Paci *et al.,* 2022). PEDro scale assesses the quality in following domains: 1) Random allocation; 2) concealed allocation; 3) baseline similarity; 4) blinding of assessors, therapists & subjects; 5) measure outcome in more than 85% subjects; 6) intention to treat analysis; 7) between group statistical comparison and 8) point measure and measures of variability.

Results

Figure 1 illustrates the results of the database search process. The systematic literature search identified 250 articles from PubMed (68), ScienceDirect (148), and PEDro (34). After removing 22 duplicates, 228 articles were screened by two independent reviewers based on titles and abstracts, leading to exclusion of 122 articles. Of the remaining 106 articles, 13 could not be retrieved, and 85 were excluded for reasons such as non-English publications (4), reviews/meta-analyses (10), non-relevant outcomes (68), and non-RCTs (3). Ultimately, 8 studies met the eligibility criteria and were included in the review.

Study characteristics

All 8 included studies were RCTs involving 390 participants with NSLBP (Ahmadi *et al.,* 2020; Akhtar *et al.,* 2017; Bhadauria *et al.,* 2017; Ghorbanpour *et al.,* 2018; Kim *et al.,* 2020; Kumar *et al.,* 2009; Shamsi *et al.,* 2020; & Sokunbi *et al.,* 2014). The mean participant age of ranged from 20.9 years (Ghorbanpour *et al.,* 2018) to 47.75 years (Kim *et al.,* 2020). Interventions sessions varied from a minimum of 6 sessions (Akhtar *et al.,* 2017) to a maximum of 18 (Ghorbanpour *et al.,* 2018; Kim *et al.,* 2020).

Most studies compared two groups (core stability vs. control), while three studies used three group designs. Bhadauria *et al.* (2017) compared core stability, Pilates, and strengthening exercises. Kim *et al.* (2020) included groups combining core stability with stretching, strengthening, or sham interventions. Sokunbi *et al.* (2014) compared core stability, acupuncture, and their combination.

Pain and functional disability were consistently reported as primary outcomes using tools like the Visual Analog Scale (VAS), McGill Pain Questionnaire, Oswestry Disability Index (ODI), Roland Morris Disability Questionnaire (RMDQ), and Quebec Low Back Pain Disability Questionnaire. However, Akhtar *et al.* (2017) and Kumar *et al.* (2009) assessed only pain

score. Detailed characteristics of the included studies are summarized in Table 2.

Quantified improvements in pain and functional disability

To provide clarity on the effectiveness of core stability exercises, statistical significance was reported using p-values, presented in Table 2. Mean differences and Cohen's d effect sizes were calculated to assess the intervention effects and are presented in Table 3, for pain and Table 4, for disability, each accompanied by the authors' narrative analysis.

To summarize the findings, Ahmadi *et al*. (2020) and Shamsi *et al*. (2020) reported smaller or no significant effects for pain reduction in experimental groups compared to control groups. However, remaining studies demonstrated significant improvements in pain and disability, with moderate to very large effect sizes. For disability, three studies (Ahmadi *et al*., 2020; Shamsi *et al*., 2020; Ghorbanpour *et al*., 2018) found no significant improvements.

Methodological quality

The methodological quality of the included studies is summarized in Table 5. According to the PEDro scale, a score of 4 is considered 'poor', 4 to 5 is considered 'fair', 6 to 8 is considered 'good', and 9 to 10 is considered 'excellent' (Adian *et al*., 2020). All included studies scored within the 'good' range (6-8) except for the study by Shamsi *et al*. (2020), which scored 5 points, indicating 'Fair' quality. Most of the studies failed to blind the subjects and therapists.

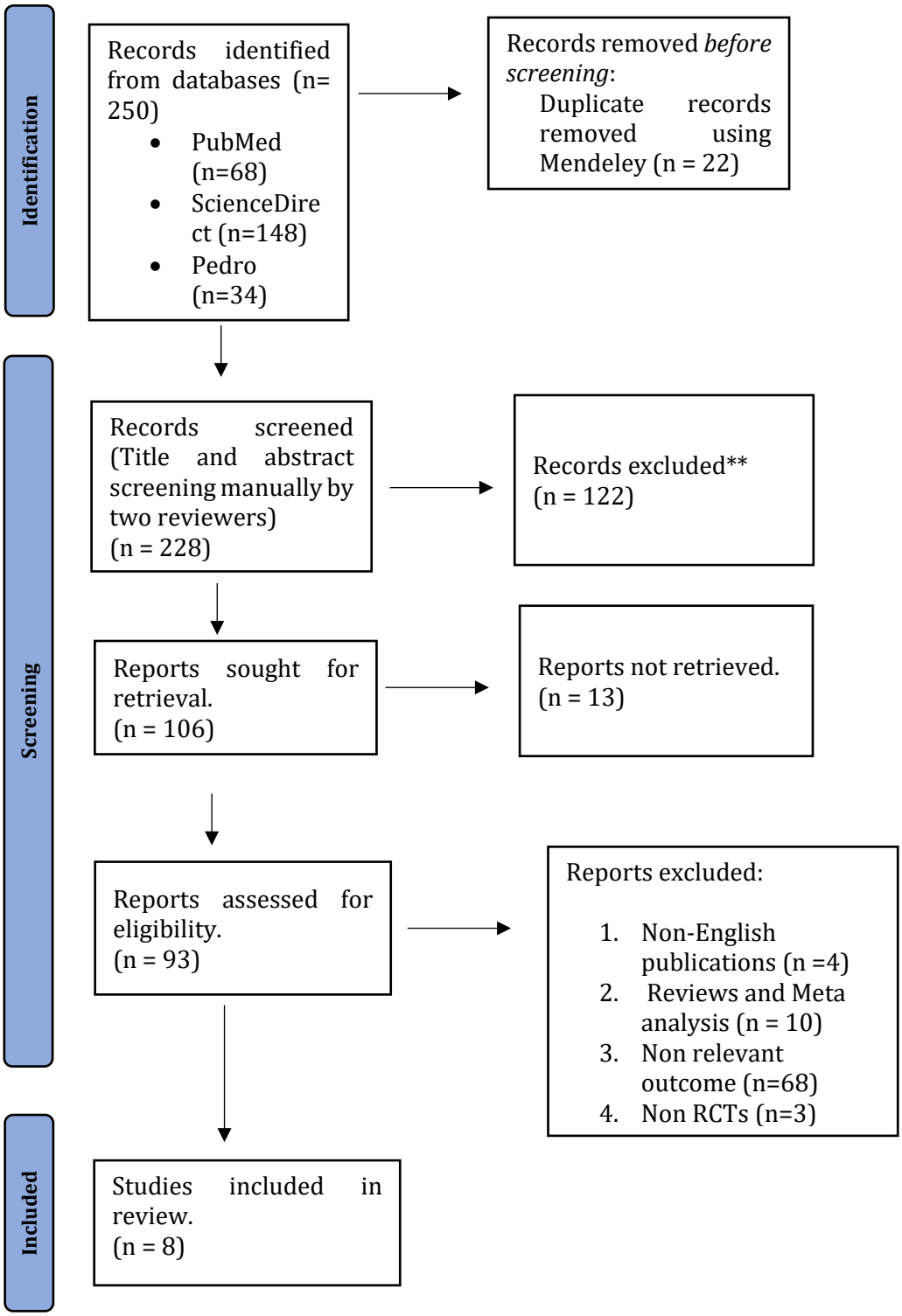

Figure 1. Prisma flow diagram (Page *et al.,* 2021).

Table 2. Characteristics of included studies.

Author/ Year	Study Design	Number of Participants/ Inclusion Criteria	Interventions and mean age	Outcome measures	Findings
Ahmadi *et al.,* (2020)	RCT	n =59 Inclusion Criteria Patients with NSLBP aged between 18-65 years old.	Group A(NCSG) (n= 30, mean age= 42.6± 11.6) This group received therapy utilising the Feldenkrais method. (30-45mins per session/ 2 times per week). Group B (CSG) (n=29, mean age= 38.89.6± 12.52) This group received an educational programme and home-based core stability exercises.	McGill pain questionnaire ODI	Pain score significantly decreased in both groups but there were no significant between group differences (p= 0.16). A significant difference between the groups for disability in favour of Feldenkrais method (p=0.021).
Akhtar *et al.,* (2017)	Single-blinded RCT	n= 108 Inclusion Criteria Patients with CNSLBP aged between 20-60 years.	Group A (CSG) (n= 53, mean age=46.39 ± 7.43) Participants performed core stabilisation exercises (6 weeks,40mins per session, 1 session per week) and received TENS. Group B(NCSG) (n=55, mean age=45.50 ± 6.61) Participants were given a baseline treatment of US and TENS and conventional exercises. back extensor exercises in prone and hip extensor exercises in prone.	VAS	Both treatment groups displayed statistically significant differences in pain at 2nd, 4^{th,} and 6th week of intervention (p < 0.05). However, there was a significant reduction in pain symptoms in intervention group compared to control group (p<0.01).

Bhadauria *et al.,* (2017)	Study Design Single-blinded RCT	n= 36 <u>Inclusion Criteria</u> Patients with CNSLBP aged between 20-60 years.	<u>Group A(CSG)</u> (n=12, mean age= 32.75± 11.73) 16 lumbar stabilisation exercises were prescribed and were performed consecutively for 10 total sessions. <u>Group B(NCSG)</u> (n=12, mean age= 36.67± 10.74) Pilates exercises. Patients were taught to perform isometric contractions of the deep trunk muscles before proceeding with a Pilates programme. <u>Group C(PG)</u> (n=12, mean age= 35.33± 12.88) Dynamic Strengthening. Participants performed 14 exercises targeting the erector spinae and rectus abdominis muscle groups. All participants received hot moist pack and IFT therapies as part of the conventional treatment. Treatment Duration= 3 weeks (60mins per session/3-4 sessions per week).	VAS MODQ	Lumbar stabilisation group reported significant differences in VAS (p=0.0001) and MODQ (p=0.0001) scores within the group and compared to other groups.

Ghorbanpour A *et al.,* (2018)	Study Design RCT	n=30 <u>Inclusion Criteria</u> Patients with CNSLBP aged between 20-40 years.	<u>Group A(CSG)</u> (n=15, mean age= 23.8 ± 3.5) Patients performed core stability exercises such as curl-ups, side-bridge and bird-dog. <u>Group B (NCSG)</u> (n=15, mean age= 20.9 ± 1.2) Exercises for the patients included conventional exercises like single and double knee to chest, prone lying with pillow with one leg sliding, cycling in supine and bridging exercises. All exercises were done for 6 weeks, 3 times per week.	VAS QLBPDSQ	McGill stabilization exercises led to significant improvements in pain ($p<0.05$) and disability ($p<0.05$) in the CSG group, with greater benefits (pain: 15%, disability: 13%) compared to NCSG (pain: 6%, disability: 7%). However, no significant differences were observed between the two groups ($p>0.05$)
Kim & Yim, 2020	RCT	n= 66 <u>Inclusion Criteria</u> Participants with CNSLBP between 30-65 years.	<u>Group A (CSG + stretching)</u> (n=24, mean age= 47.50 ±9.70) Participants underwent core stability exercises followed by 15 minutes of hip muscle (hamstring, iliopsoas, piriformis, TFL) stretching. (30s hold for 3 reps). <u>Group B (CSG+strengthening)</u> (n=22, mean age=47.04± 9.48) Participants underwent core stability exercises followed by 15 minutes of hip strengthening exercises (abductor and extensor strengthening). Positions are held for 30 seconds at maximal isometric contraction and repeated 3 times.	VAS ODI	All groups had significant differences for pain intensity and disability between the baseline and post-intervention ($p < 0.05$). Both the Stretch and Strengthen groups ($p< 0.05$) experienced a greater impact on pain intensity and disability than the Sham group ($p < 0.05$)

			Group C (sham) (n=20, mean age= 47.75± 8.51) Participants underwent Core stability exercises followed by 15 minutes of gentle palpation of skin over lumbosacral spine. All groups performed exercises for 6 weeks (45mins per session/3 sessions per week). All groups carried out core stabilisation exercises (CSE) for 30 minutes followed by different exercises.		
Kumar *et al.,* (2009)	RCT	n= 30 Inclusion Criteria Hockey players with subacute or chronic NSLBP aged 18 -28 years.	Group A (CSG) (n=15, mean age=23.40± 6 3.27) Patients performed lumbar strengthening exercises such as spinal extension and trunk extensor exercises (10 repetitions per exercise) and received ultrasound and diathermy. Group B(NCSG) (n=15, mean age=24.07 ±6 2.89) Core stability exercises in the form of dynamic muscular stabilisation Techniques (DMST) were given in 4 stages (Drawing in of abdomen in supine hook lying, repositioning of limbs while performing drawing in, abdominal hollowing and high-speed phasic exercises)	VAS	The mean levels of pain were significantly lower in the CSG group compared to the conventional treatment group on days 21 and 35 ($p < 0.01$). However, at day 21, the pain levels were similar between the two groups ($p > 0.05$)

Shamsi *et al.,* (2020)	Quasi-randomized controlled trial	n= 46 Inclusion Criteria Adult patients with CNSLBP aged between 18-60 years.	Group A(CSG) (n=22, mean age=38.9±12.2) This group core stabilisation exercises, where patients were first taught the abdominal "drawing in" manoeuvre and progressed to isometric contraction of the muscles in minimally loading positions. Participants then progress to performing light functional tasks while co-contraction stabilising muscles. Finally, participants progress to heavier-load functional tasks. Group B(NCSG) (n=24, mean age=47.0 ± 9.9) Participants performed general exercises which activate the extensor (paraspinal) and flexor (abdominal) muscles. These exercises were performed in the supine-lying position. Treatment duration= 5 weeks (20 mins per session/3 times per week).	VAS ODI	Both groups demonstrated a significant reduction in disability levels ($p < 0.001$) and pain intensity ($p < 0.001$). However, no significant differences were observed between the CSE and GE groups in terms of disability ($p = 0.14$) or pain ($p = 0.72$).
Sokunbi *et al.,* (2014)	Pilot RCT	n=15 (42.1±9.3) Inclusion Criteria Adult patients with acute forms of NSLBP, 18-65 years old.	Participants were divided into 3 groups: Acupuncture Group (ACG), Core stability exercises group (CSG) and exercise with acupuncture group (EACG). Group A (ACG) (n=5, mean age= 40.3±8.2) The participants received acupuncture treatment at selected sites for 20	VAS RMDQ	Pain intensity decreased in all groups. Group C showed significant reductions at both the 6th week and 3-month follow-up ($p < 0.08$), while Group B showed significance only at 3 months ($p < 0.008$). Disability scores

	minutes. Disposable stainless-steel needles were inserted into the muscles to a depth of 10 mm or until the participant feels the acupuncture sensation. Group B(CSG) (n=5, mean age= 42.1±9.3) Participants were shown how to locate and activate the main core stability muscles and exercises were then performed for 20 minutes. Group C(CSG+ACG) (n=5, mean age= 41.4±10.3) Participants received 20 minutes of acupuncture treatment, followed by 20 minutes of core stability exercise treatments. Treatment was given for 6 weeks with 3 months follow up.	decreased in all groups, but only Group C had significant reductions at both time points ($p < 0.008$).

RCT= Randomised control trial, NSLBP= Nonspecific low back pain,ODI=Oswestry disability Index, VAS= Visual analogue scale, MODQ= Modified Oswestry disability questionnaire, QLBPDSQ= Quebec low back pain disability questionnaire, RMDQ= Rolan Morris disability Questionnaire, NCSG= Non-core stability group, CSG= Core stability group, PG= Pilates group, ACG= Accupuncture group, EACG= Exercise with Accupuncture group.

Table 3. Mean differences and effect sizes for pain outcomes following core stability exercises.

Study	Pain measuring tool	Baseline Pain score (Mean & SD)	Post intervention pain score (Mean& SD)	Mean difference in pain within groups	Mean difference in pain between groups	Effect size	Analysis
Ahmadi *et al.,* (2020)	McGill pain questionnaire	CSG = 13.1 ± 6.6 NCSG = 15.3 ± 7.2	CSG = 4.17 ± 4.56 NCSG = 3.63 ± 3.71	-8.93 -11.67	2.74	0.37	The difference between the two groups is small and in favour of NCSG but may not be practically significant.
Akhtar *et al.,* (2017)	VAS	CSG = 5.77 ±1.08 NCSG = 5.40 ± 1.24	CSG = 2.69 ± 0.93 NCSG = 3.69 ± 0.79	3.08 1.71	1.37	0.77	The difference between the two groups indicates moderate to large effect size in favour of CSG, which is substantial and practically significant.
Bhadauria *et al.,* (2017)	VAS	CSG= 7.17± 1.27 NCSG= 6.67± 1.56 PG= 6.42± 1.00	CSG= 1.17± 0.72 NCSG= 2.00± 1.35 PG= 1.33± 0.98	6.00 4.67 5.08	CSG vs. NCSG = 1.33 CSG vs. PG = 0.91 NCSG vs. PG = 0.42	CSG vs. NCSG = 0.79 CSG vs. PG = 0.55 NCSG vs. PG = 0.24	Overall, the CSG group demonstrated the largest improvement, followed by the PG group, and

							then the NCSG group.
Ghorbanpour A *et al.,* (2018)	VAS	CSG = 29.5 ± 4.8 NCSG = 28.3 ± 6.5	CSG = 25.0 ± 4.9 NCSG = 26.5 ± 7.8	4.5 1.7	2.7	0.45	The results indicate moderate effect size in favour of CSG.
Kim & Yim, (2020)	VAS	CSG +stretching= 5.95 ± 1.09 CSG+ strengthening = 6.12± 1.02 Sham= 5.85 ± 1.16	CSG +stretching= 2.37 ± 0.67 CSG+ strengthening = 2.37 ± 0.69 Sham= 2.92 ± 0.61	3.58 3.75 2.93	CSG + Stretching vs. Sham = 0.65 CSG + Strengthening vs. Sham: = 0.82 CSG + Stretching vs. CSG + Strengthening = 0.17	CSG + Stretching vs. Sham = 0.72 CSG + Strengthening vs. Sham = 0.89 CSG + Stretching vs. CSG + Strengthening = 0.19	CSG + Stretching and CSG + Strengthening showed moderate to large pain reductions respectively compared to Sham. The CSG + Strengthening group demonstrated slightly better outcomes.
Kumar *et al.,* (2009)	VAS	CSG = 7.07 ± 0.96 NCSG = 7.00 ±1.07	CSG = 1.47 ± 0.99 NCSG = 4.33 ± 0.82	5.6 2.67	2.93	3.02	CSG showed a substantial reduction in pain group compared to the NCSG group, with a

							very large effect size.
Shamsi *et al.,* (2020)	VAS	CSG = 51.36 ± 9.02 NCSG = 52.86 ±9.02	CSG = 15.09 ± 12.4 NCSG = 15.10 ±13.80	36.27 37.76	1.49	0.09	Result indicates no clinically significant difference between the CSG and NCSG groups.
Sokunbi *et al.,* (2014)	VAS	ACG=62.8±15.7 CSG=60.0±18.5 ACG+CSG= 62.7±17.8	ACG=58.0±22.5 CSG= 50.9±10.4 ACG+CSG=36.6±5.3	4.8 9.1 26.1	ACG vs. CSG = 4.3 ACG vs. ACG+CSG = 21.3 CSG vs. ACG+CSG = 17.0	ACG vs. CSG = 0.16 ACG vs. ACG+CSG = 0.79 CSG vs. ACG+CSG =0.63	The ACG+CSG group showed a large improvement in pain compared to both the ACG and CSG groups.

SD=standard deviation, CSF=core stability group, NCSG= non-core stability group, PG=Pilates group, ACG= Acupuncture group, ODI=Oswestry disability Index, VAS= Visual analogue scale, MODQ= Modified Oswestry disability questionnaire, QLBPDSQ= Quebec low back pain disability questionnaire, RMDQ= Rolan Morris disability Questionnaire

Table 4. Mean differences and effect sizes for functional disability outcomes following core stability exercises

Study	Pain measuring tool	Baseline Pain score (Mean & SD)	Post intervention pain score (Mean& SD)	Mean difference in pain within groups	Mean difference in pain between groups	Effect size	Analysis
Ahmadi *et al.,* (2020)	ODI	CSG =27 ± 8.5 NCSG =27.2 ± 6.5	CSG = 19.31 ± 5.79 NCSG = 14.50 ± 3.38	-7.69 -12.7	5.01	0.79	The NCSG experienced a greater improvement in disability compared to the CSG, with moderate to large effect.
Akhtar *et al.,* (2017)	Did not assess disability						
Bhadauria *et al.,* (2017)	MODQ	CSG= 39.75± 10.11 NCSG= 37.75± 9.27 PG= 28.17± 13.55	CSG= 6.92± 2.47 NCSG= 23.42± 11.01 PG= 8.42± 5.14	32.83 14.33 19.75	CSG vs. NCSG =18.50 CSG vs. PG= 13.08 NCSG vs. PG = 5.42	CSG vs. NCSG= 1.93 CSG vs. PG =1.37 NCSG vs. PG = 0.58	CSG group demonstrated significantly better outcomes in disability compared to the NCSG and PG groups, with very large to large effect sizes.

Ghorbanpour A *et al.,* (2018)	QLBPDSQ	CSG = 25.6 ± 9.7 NCSG = 30.1 ± 11.6	CSG = 22.4 ± 9.0 NCSG = 28.0 ± 10.1	3.2 2.1	1.1	0.10	The results show a small effect size in Favor of the CSG group.
Kim & Yim, (2020)	ODI	CSG +stretching= 57.67± 6.50 CSG+ strengthening =56.91± 6.92 Sham= 58.20 ± 5.27	CSG +stretching= 29.25± 7.66 CSG+ strengthening = 30.18 ± 7.66 Sham= 36.70± 5.12	28.42 26.73 21.50	CSG + Stretching vs. Sham = 6.92 CSG + Strengthening vs. Sham = 5.23 CSG + Stretching vs. CSG + Strengthening = 1.69	CSG + Stretching vs. Sham = 0.68 CSG + Strengthening vs. Sham = 0.51 CSG + Stretching vs. CSG + Strengthening = 0.17	Both CSG + Stretching and CSG + Strengthening groups showed significant improvements in disability compared to the Sham group, with moderate effect sizes. Difference between intervention groups was small.
Kumar *et al.,* (2009)	Did not assess disability						
Shamsi *et al.,* (2020)	ODI	CSG = 50.55 ±12.08 NCSG = 50.67 ±10.41	CSG = 32.77 ±11.0 NCSG = 37.62 ±10.87	17.78 13.05	4.73	0.29	The CSG group showed a small but statistically significant improvement in disability compared to the NCSG group.

Sokunbi *et al.,* (2014)	RMDQ	ACG =8.2±3.7 CSG=8.0 ± 3.1 ACG+CSG= 9.0 ± 4.5	ACG=7.5±2.6 CSG= 4.1 ± 2.4 ACG+CSG= 3.3 ± 0.3	0.7 3.9 5.7	ACG vs. CSG = 3.2 ACG vs. ACG+CSG = 5.0 CSG vs. ACG+CSG= 1.8	ACG vs. CSG = 0.75 ACG vs. ACG+CSG = 1.21 CSG vs. ACG+CSG= 0.45	ACG+CSG showed greater improvement than ACG (moderate-large effect). CSG also improved more than ACG, but with a smaller effect.

SD=standard deviation, CSF=core stability group, NCSG= non-core stability group, PG=Pilates group, ACG= Acupuncture group, ODI=Oswestry disability Index, VAS= Visual analogue scale, MODQ= Modified Oswestry disability questionnaire, QLBPDSQ= Quebec low back pain disability questionnaire, RMDQ= Rolan Morris disability Questionnaire

Table 5. Methodological quality (PEDro scale).

Study	1	2	3	4	5	6	7	8	9	10	11	Score
Ahmadi *et al.,* 2020	√	√	√	√	×	×	×	√	√	√	√	**7**
Akhtar *et al.,* 2017	√	√	√	√	×	×	×	√	√	√	√	**7**
Bhadauri *et al.,* (2017)	√	√	√	√	×	×	√	×	√	√	√	**7**
Ghorbanpour *et al.,* 2018	√	√	√	√	×	×	×	√	√	√	√	**7**
Kim & Yim, 2020	√	√	√	√	√	√	×	√	×	√	√	**8**
Kumar *et al.,*2009	√	√	√	√	×	×	×	√	√	√	√	**7**
Shamsi *et al.,* 2020	√	√	×	√	×	×	×	×	√	√	√	**5**
Sokunbi *et al.,* 2014	√	√	×	√	×	×	√	√	√	√	√	**7**

1: Eligibility criteria, 2: Random allocations 3: Concealed allocation, 4: Comparability at baseline, 5: Patient blinding, 6: Therapist blinding, 7: Assessor blinding, 8: At least 85% follow-up, 9: Intention to treat analysis, 10: Between-group statistical comparisons, 11: Point measures and measures of variability. Item 1 not counted in PEDro score.

Discussion

The present study intended to investigate the effects of core stability exercises on pain and disability among patients with non-specific low back pain. All the studies used pain score as an outcome tool and six studies reported that use of core stability exercises improved the low back pain symptoms significantly among patients with NSLBP. However, Ahmadi *et al.* (2020) reported that both core stability group and Feldenkrais group has a significant reduction in pain scores but there was no significant difference between the two groups. Similarly, Shamsi *et al.* (2020) also reported no significant difference in decreased pain scores between core exercise group and general exercise group, even though both groups showed a significant with-in group differences in pain scores. In rest all the studies core stability exercises were found to be more effective than the other treatments in reducing pain in patients with NSLBP.

In the context of functional impairment, only six out of eight studies (Ahmadi *et al.,* 2020; Bhadauria *et al.,* 2017; Ghorbanpour *et al.,* 2018; Kim *et al.,* 2020; Shamsi *et al.,* 2020; Sokunbi *et al.,* 2014) assessed the subjects in terms of functional disability. These studies utilized various metrics and assessment tools following core stability exercise interventions to measure the degree of functional impairment among the subjects, providing insights into how different conditions or interventions impact daily activities and overall quality of life. However, three studies (Ahmadi *et al.,* 2020; Shamsi *et al.,* 2020; Ghorbanpour *et al.,* 2018) did not report improved functional independence in the core stability exercise group compared to conventional treatment groups.

These findings underscore the dual benefits of core stability exercises, alleviating pain and improving patients' ability to perform daily tasks, thereby enhancing their overall quality of life. The consistent results across the studies (Akhtar *et al.,* 2017; Bhadauria *et al.,* 2017; Ghorbanpour *et al.,* 2018 Kim & Yim, 2020; Kumar *et al.,* 2009; Sokunbi *et al.,* 2014) highlight the effectiveness of core stability exercises in addressing both functional impairment and pain management.

This aligns with the understanding that core muscles are crucial for stabilizing the spine and maintaining proper posture, thereby alleviating the mechanical stress that contributes to pain. The effectiveness of these exercises can be attributed to the targeted strengthening of key muscles, such as the lumbar multifidi and transverse abdominis, which are often weakened or improperly activated in individuals with NSLBP. By improving the activation patterns of these muscles, core stability exercises help to distribute spinal loads more effectively, reducing strain on the lower back and thereby alleviating pain.

A very important observation was made by reviewers was that in two studies, the core stability exercise was combined with other interventions, like stretching, strengthening and acupuncture (Kim & Yim, 2020; Sokunbi *et al.,* 2014). It was observed that when core stability exercises combined with stretching was compared to core stability exercises combined with strengthening exercises, the earlier combination was more effective in reducing pain and improving functional capacity (Kim & Yim, 2020). Similarly, it was reported that core stability exercises, combined with acupuncture therapy demonstrated significant reduction in pain and improvement in functional capabilities compared to core stability exercises alone. These observations underscore the importance of a multimodal approach to treatment. By integrating core stability exercises with other therapeutic interventions like stretching and acupuncture, patients may experience more substantial improvements in pain relief and functional capacity. This comprehensive approach can be particularly beneficial for individuals with chronic pain and functional impairments, offering a more effective pathway to recovery and enhanced quality of life.

The methodological quality of the included studies was generally good, with most studies scoring between 7 and 8 on the PEDro scale. Only one study received a score of 5, indicating fair quality (Shamsi *et al.,* 2020). While all studies lost points due to the lack of blinding of subjects and therapists, the nature of the interventions made blinding of therapist impractical because each study involved different therapists treating each group, which reduces the need for blinding and minimizes the potential bias that could arise from this factor. However, the lack of blinding of the subjects may still have introduced some bias, as participants were aware of the intervention they received. Additionally, assessor blinding could have further reduced bias, and this was implemented in only two studies (Bhadauri *et al.,* 2017; Sokunbi *et al.,* 2014).

One of the primary limitations of this review was the heterogeneity in study designs, which included variability in exercise protocols as well as differences in outcome measures. Variations in the type, duration, frequency, and intensity of core stability exercises made it challenging to compare results across studies and draw definitive conclusions about the most effective protocols. Additionally, discrepancies in sample sizes, with some studies having relatively small populations, may have limited the statistical power and generalizability of the findings. The use of diverse outcome measures for functional disability further complicates the synthesis of results for disability improvement, emphasizing the need for standardized methodologies in future research. Another limitation of this review is the restricted generalizability of the findings, as the inclusion of only English-language studies excluded potentially relevant research published in other languages, which may have provided additional insights or differing perspectives. As a result, the

findings may not be fully generalizable to other demographic groups, such as those from non-English speaking regions or different cultural contexts.

The review highlights the importance of personalized exercise programs for NSLBP patients, as variations in core muscle strength, activation patterns, and overall physical condition necessitate tailored approaches to maximize the effectiveness of core stability exercises. Customized programs are better able to target specific neuromuscular imbalances, thereby enhancing treatment outcomes. Future studies should focus on developing standardized protocols for core stability exercises, potentially integrating other therapeutic interventions. Additionally, including studies from diverse populations and non-English-language sources would improve the generalizability of the findings, addressing a limitation in this review and helping refine treatment strategies for a wider range of patients.

Conclusion

This systematic review offers substantial evidence supporting the integration of core stability exercises into the treatment plans of patients with NSLBP. The analysis of studies revealed that core stability exercises significantly improve pain and functional outcomes in individuals with NSLBP. The inclusion of multimodal approaches, combining core stability exercises with other treatments like stretching, strengthening, and acupuncture, demonstrated more promising improvements in pain relief and functional capacity.

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REVIEW ARTICLE Open Access

Tools to evaluate the impact of nutrition delivery on muscle and physical-related outcomes in critical care: a scoping review

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Abstract

Understanding the impact of nutrition delivery on critically ill patient-centered outcomes is crucial. Patient-centered outcomes should be physical-related due to the natural course of catabolism experienced during critical illness. This review aims to map the existing tools used in research to evaluate the impact of nutrition delivery on muscle and physical-related outcomes among intensive care unit (ICU) patients. A search was conducted in PubMed and Scopus, initially yielding 502 articles published since 2010 on the topic using search terms related to ICU patients, muscle and physical outcomes, and nutrition delivery. Articles were screened based on inclusion criteria, resulting in 45 articles included in the analysis. Findings indicated that the outcome domains used ranged from muscle strength, muscle mass, to function. Imaging techniques and performance-based measures were the most used type of tools, with varying comprehensiveness, precision, simplicity, and feasibility. Despite most studies using repeated measurements throughout ICU stays, challenges in performing comprehensive assessments were reported. This review provides an overview of the assessment tools utilized in ICU nutritional research, highlighting the variability of choice that can be suited with researcher's objectives and the availability of resources. To improve consistency and comparability across studies, future research should focus on developing standardized protocols for selecting appropriate tools to measure the effects of nutrition delivery on muscle and physical-related outcomes.

Keywords: *critical care, functional outcomes, nutrition therapy, scoping review*

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Introduction

A critically ill patient will often experience a shift towards hypercatabolism due to the metabolic changes triggered by high stress levels (Hsu *et al*., 2021). The state of critical illness leads to metabolic instability, where tissue breakdown fuels survival mechanisms in response to physiological stress (Preiser *et al*., 2016). This stress response triggers several metabolic consequences such as insulin resistance due to uncontrolled catabolism and blunted anabolic signalling. Energy production and cellular functions are also compromised, forcing reliance on alternative substrates. This hypercatabolic response can lead to rapid skeletal muscle loss, with up to 5% of lean body mass loss daily (Preiser *et al*., 2014). The muscle wasting often persists in longer duration after intensive care unit (ICU) discharge, negatively impacting survivors' quality of life and physical function for months or even years (de Carvalho *et al*., 2023; Hofhuis *et al*., 2015; Jubina *et al*., 2023; Latronico *et al*., 2017).

Adequate nutrition is essential for critically ill patients to counteract catabolism and promote muscle regeneration through medical nutrition therapy (Hill *et al*., 2021; Van Zanten *et al*., 2019). The revised European Society for Clinical Nutrition and Metabolism (ESPEN) guidelines recommend adjusting energy dosage based on the phases of critical illness and calculation methods, with a gradual delivery of 1.3g/kg protein equivalents per day in the ICU (Singer *et al*., 2023).

Consequently, a consensus statement recommends that research on nutritional interventions in critically ill patients focus on outcomes involving physical function, muscle mass, and muscle function, especially when guided by indirect calorimetry (Sundström-Rehal *et al*., 2023). Moreover, further evaluation of the impact of nutritional therapy on functional outcomes after ICU and hospital discharge is required (Wischmeyer *et al*., 2023; Wittholz *et al*., 2020). Other than that, patients' quality of life (QoL) is also a crucial outcome measure that requires further exploration, as data on QoL outcomes from dietary interventions remain scarce (Barth *et al*., 2023; Bear *et al*., 2017; Wischmeyer, 2016).

A previous systematic review by Taverny *et al*. (2019) found that critically ill nutrition randomized controlled trials (RCTs) rarely use patient-important outcomes, missing the opportunity to elucidate the positive effects of nutritional interventions. As suggested by Bear *et al*. (2018) in their review, compared to mortality, outcome measures related to function and muscle mass are potentially becoming more important. This is consistent with another statement by Taverny *et al*. (2019), highlighting that clinical outcomes such as mortality are decreasing in relevance compared to muscle strength or quality of life, due to the advancement in intensive care. Another review by L. S. Chapple *et al*. (2020) reported that out of 73 trials, only 2 utilized physical, cognitive, or mental health outcomes as primary endpoints. As secondary or tertiary outcomes, only 7 trials used physical function. Therefore, there is a need to understand the impact of nutrition on muscle and physical function and the tools available to measure them.

This scoping review was conducted to identify and classify the assessment tools used in nutrition delivery research evaluating the impact of nutrition delivery on patients' muscle and physical-related outcomes. Understanding the assessment tools utilized in nutrition research is essential for standardizing methodologies, enhancing the comparability of studies, and improving the quality of evidence in clinical nutrition research. This review may help to identify gaps in the current research, guiding future studies, and contributing to more robust and consistent evaluations of nutritional interventions in critical care settings. The following research question was formulated using the PCC (population-concept-context) model: What assessment tools have been used in research to evaluate the impact of nutrition delivery on muscle and physical-related outcomes among critically ill patients?

Materials and Methods

Protocol

The methodology of this scoping review was drafted and revised using the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) protocol (Tricco *et al*., 2018).

Eligibility criteria and search strategy

To be included in the review, articles need to report on energy and/or protein delivery research conducted among critically ill adult patients with at least one outcome related to muscle or physical function. The articles were searched in PubMed and Scopus databases, limited to English publications from 2010 to August 2024. Articles were excluded if muscle or physical-related outcomes were measured only after patients' discharge from the ICU. All types of study addressing the target topic except qualitative, review, and conference abstracts

were eligible for inclusion to consider different aspects of outcome measurements.

The search strategy was built by selecting groups of keywords and subject headings for each part of the PCC model, covering the population (adult critically ill patients aged 18 years or older), concept (muscle and physical-related outcomes assessment tools in ICU), and context (nutrition delivery study). Afterwards, each group of keywords was combined using the Boolean operator AND (Table 1). The final search results were exported to Endnote where duplicates were removed.
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Table 1. Search strings.

Strings	Database
((muscle* OR "muscle function*" OR "muscle mass" OR "muscle strength" OR "muscle weakness" OR "muscle wast*" OR "muscle loss" OR "functional outcome*" OR "physical rehab*" OR "physical function*") AND ("energy intake" OR "calor* intake" OR "protein intake" OR "nutrition therapy"[Mesh])) AND ("intensive care units"[Mesh] OR "critical Illness*"[Mesh] OR "critical care"[Mesh])	PubMed
(TITLE-ABS-KEY (muscle* OR "muscle function*" OR "muscle mass" OR "muscle strength" OR "muscle weakness" OR "muscle wast*" OR "muscle loss" OR "functional outcome*" OR "physical rehab*" OR "physical function*") AND TITLE-ABS-KEY ("energy intake" OR "calor* intake" OR "protein intake" OR "nutrition therapy") AND TITLE-ABS-KEY ("intensive care units" OR "critical Illness*" OR "critical care")) AND PUBYEAR > 2009 AND (EXCLUDE (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "English"))	Scopus

Study selection and data collection

The initial articles underwent a title and abstract review, resulting in several articles selected for full-text evaluation. Disagreements on study selection and data extraction were resolved by consensus and discussion. Data were extracted using a customized data collection sheet to record the article characteristics (e.g., year published, study type), objectives, type of population, duration, assessment tools and frequency of measurement, other outcome measures, and findings (Table 2). Variables to extract were determined based on the research question and piloted on several articles with modifications made accordingly until a consensus was reached on the final format. No methodological quality criteria were considered.

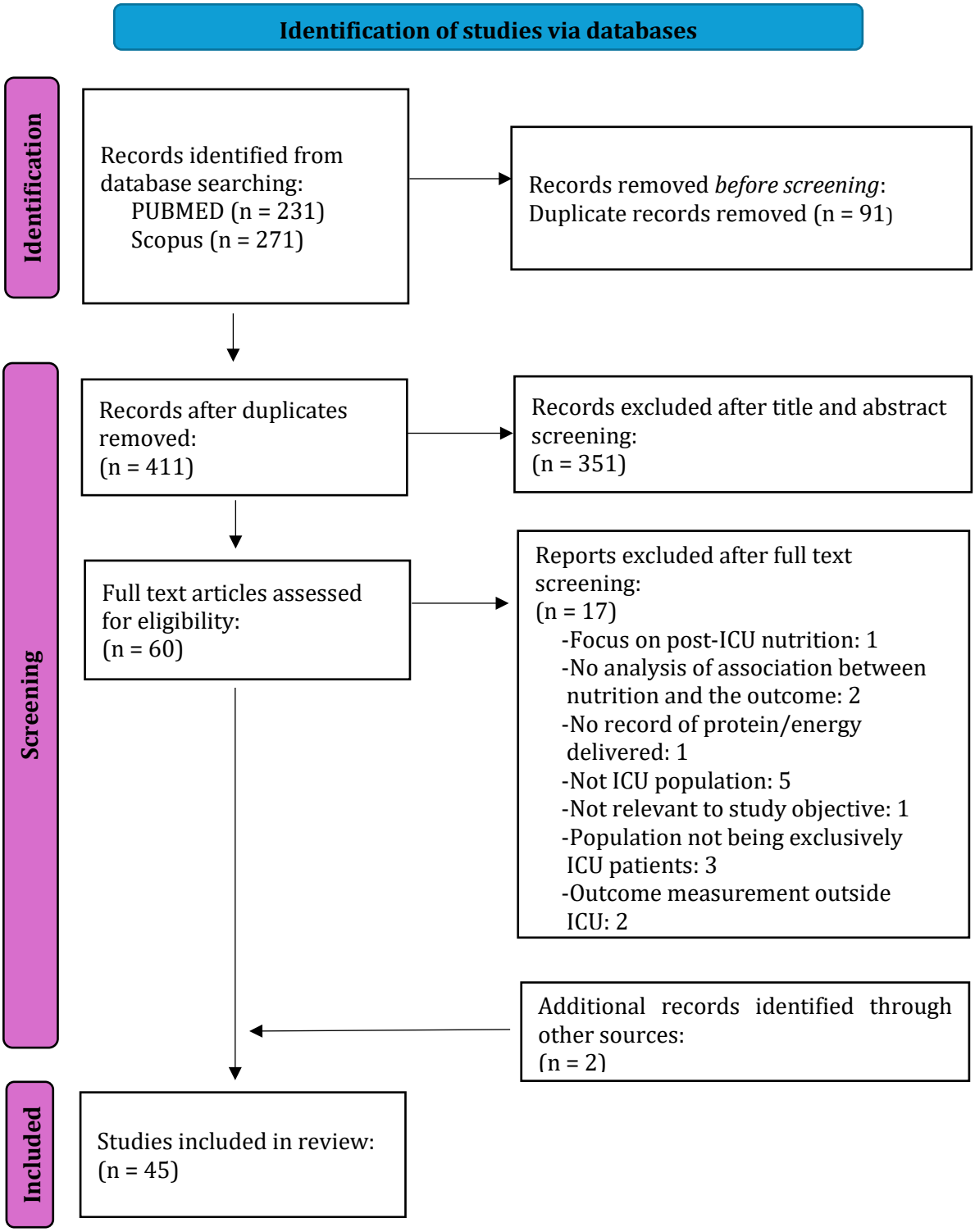

Figure 1. Flow chart of the article search and selection process (Tricco *et al*., 2018).

Results

Search results, study selection, and data extraction

From the literature search, 502 articles were initially identified using the search terms from both databases. After removing duplicates, the articles underwent title and abstract screening, resulting in 60 articles eligible for full-text screening. Following full-text screening, 17 articles were excluded for reasons reported in Figure 1. Another 2 additional articles were identified from the reference lists of included studies. As a result, 45 articles were qualified to be included in the review (Figure 1).

Study characteristics

The 45 articles included primarily consist of randomized controlled trials (RCTs), with the rest being pilot RCTs, subanalysis of RCTs, observational, and comparative studies published between 2010 to 2024. The number of participants varied widely, ranging from 21 to 1,372. A summary of the key characteristics of the included studies is reported in Table 3.

Most studies (84%) repeatedly assessed muscle and physical-related outcomes while in ICU to capture the changes over time in relation to the nutrition delivered. In the studies with a single timepoint outcome assessment, the measurements were mostly conducted at ICU discharge. While most studies enrolled general ICU patients, certain studies focused on specific subpopulations, such as surgical patients, those with COVID-19, indicating targeted approaches to understanding the association between nutrition and outcomes in these groups.

Assessment of muscle and physical-related outcomes

Overall, the findings from this scoping review indicate that the outcomes assessed by researchers can be categorized into three major domains: muscle mass, muscle strength, and function. Table 4 categorizes the various assessment tools used across the included studies into their respective domain, reflecting different aspects of muscle and physical-related outcomes relevant to be examined concerning nutrition delivery. This categorization was performed to investigate which outcomes were used. The most commonly used domain was muscle mass, utilized in 78% of the studies. Conversely, the domain function was less frequently used, with only 16% of studies using the tests categorized under this domain.

Additionally, the assessment tools employed can be further classified by types, as detailed in Table 5. This classification provides a more detailed look at how the outcomes were measured. Overall, the assessment tools were categorized into 7 types: performance-based test, imaging techniques, anthropometric assessment, physical examination, body composition, biochemical, and disability scale. Imaging techniques which include ultrasound and computed tomography (CT) scan, as well as performance-based measures, particularly the Medical Research Council (MRC) scale and handgrip/quadriceps strength, were predominant across the included studies. On the other hand, some types of tools, although less common, were utilized in specific subpopulations. For example, the disability scale, specifically the Modified Rankin Scale, was used in a study involving critically ill patients with subarachnoid haemorrhage.

Association between nutrition delivery and muscle/physical-related outcomes

In addition to identifying and categorizing the measurement tools employed in the studies, findings on the association between nutrition delivery and the outcomes were also charted. Various associations were identified, including positive, negative, mixed, and null. Several studies (n=14) reported significant positive associations, where higher energy and/or protein intake was associated with improved muscle and physical-related outcomes. Conversely, negative associations were reported in only a few studies (n=2) in which higher nutrition delivery resulted in poorer muscle and physical outcomes.

Table 2. Data collection sheet.

No.	Author (Year)	Objective	Population (n)	Study type	Duration	Physical-related measurement in ICU	Frequency of measurement	Other outcome measure	Finding

Table 3. Characteristics of the included studies (n = 45).

No.	Author (year)	Objective	Population (n)	Study type	Frequency of outcome measurement
1	Arabi *et al.* (2021)	To assess the feasibility of a large randomized controlled trial testing higher versus lower protein intake in critically ill patients.	Adult critically ill patients ≥18 years receiving enteral feeding and expected to stay ≥1 week in the ICU (704).	Pilot RCT	Repeated
2	Azevedo *et al.* (2019)	To evaluate differences in outcomes for an optimized calorie and high protein nutrition therapy versus standard nutrition care in critically ill adult patients.	Patients expected to stay in the ICU for at least 3 days (57 intervention; 63 control).	RCT	Once
3	Badjatia *et al.* (2020)	To study whether NMES and HPRO in the first 2 weeks after SAH could preserve neuromotor and cognitive function.	SAH subjects with a Hunt Hess grade>1, modifed Fisher score>1 and BMI<40 kg/m2 (12 intervention; 13 control).	RCT	Repeated
4	Berger *et al.* (2019)	To investigate the potential mechanisms underlying the reduction of infectious complications observed in the SPN group of the initial trial in a similarly selected study population, whose gut was not enabling feeding to measured energy target while requiring further ICU treatment.	Critically ill patients on day 3 of admission to the ICU who were fed less than 60% of their energy target by EN alone (23).	RCT	Repeated

5	Braunschweig *et al.* (2014)	To determine if CT scans completed for diagnostic purposes in a heterogenous population of ICU patients could be exploited to measure changes in abdominal skeletal muscle and fat depots; to assess the association between the amount of estimated energy and protein needs received and changes in these depots.	Patients admitted to the medical or surgical ICUs with respiratory failure requiring MV (33).	Retrospective observational	Repeated
6	Bury *et al.* (2020)	To determine the rate of LBM loss in critically ill SICU patients using bedside US compared with that of age-, gender-, and BMI–matched HCs; to correlate energy and protein delivery with the rate of muscle loss.	Surgical ICU patient fed solely via nutrition support for at least 3 consecutive days (52); Healthy control (15).	Observational	Repeated
7	Casaer *et al.* (2013)	To assess the effect of early administration of PN on muscle volume and composition by repeated quantitative CT.	EPaNIC study neurosurgical patients requiring prescheduled repeated follow-up CT scans (15); Healthy volunteers matched for age, gender, and BMI (6).	Substudy of RCT	Repeated
8	Chapple *et al.* (2020)	To quantify intake and nutrition-related outcomes of non-IMV critically ill patients; to establish feasibility of methods to measure nutrition-related outcomes in this population.	Non-IMV adult patients expected to remain in the ICU for ≥24 h (23).	Pilot observational	Repeated
9	Chapple *et al.* (2022)	To assess the effect of augmented calorie delivery on muscle mass, strength, and function.	Patients in TARGET randomised to 1.5 kcal/ml or 1.0 kcal/ml enteral formulae at a single centre (80).	Substudy of RCT	Repeated
10	de Azevedo *et al.* (2021)	To evaluate the efficacy of high protein intake and early exercise versus standard nutrition care and routine physiotherapy on the outcome of critically ill patients.	Mechanically ventilated patients expected to stay in the ICU for 4 days (87 in HPE group; 94 in control group).	RCT	Once

11	Deana *et al.* (2024)	To evaluate muscle mass changes with BIA during the first 7 days after ICU admission; to correlate between muscular loss and caloric and protein debt.	Patients with an expected ICU-stay ≥72h and the need for artificial nutritional support (72).	Secondary analysis of prospective observational	Repeated
12	Doig *et al.* (2013)	To determine whether providing early PN to critically ill adults with relative contraindications to early EN alters outcomes.	Critically ill adults with relative contraindications to early EN who were expected to remain in the ICU longer than 2 days (686 to standard care; 686 to early PN).	RCT	Repeated
13	Dresen *et al.* (2022)	To calculate the intake of individual amino acids and to evaluate the potential associations of amino acid patterns with muscle mass loss during the ICU stay.	Long-term immobilized, critically ill patients receiving medical nutrition therapy (21 intervention; 21 control).	Secondary analysis of RCT	Repeated
14	Dresen *et al.* (2021)	To evaluate the effect of two different quantities of protein as part of a standardized energetically controlled nutrition therapy for the preservation of muscle mass in the later phase of critical illness.	Mechanically ventilated critically ill patients (42).	RCT	Repeated
15	Dreydemy *et al.* (2021)	To determine the association between CLCR and urinary nitrogen loss to better determine the targeted daily protein intake in critically ill trauma patients with or without ARC; to explore the relationship between ARC and muscle wasting in critically ill trauma patients.	Critically ill trauma patient admitted in Surgical and Trauma (ICU), with length of stay ≥ 10 days, no history of CKD and no need for RRT (162).	Retrospective pilot study	Repeated
16	Elizabeth *et al.* (2024)	To test the hypothesis that with optimal nutrition and early physical therapy acting in synergism, muscle mass loss can be reduced, and functional outcomes can be improved.	Older ICU patients (10 intervention; 11 control).	Pilot RCT	Repeated
17	Ferrie *et al.* (2016)	To use a wide range of quantitative and qualitative measures to compare a	Patients requiring PN in ICU (60 intervention; 60 control).	RCT	Repeated

		standard intake of amino acids (0.8 g/kg) with guideline recommendations (1.2 g/kg) in critically ill patients receiving PN while controlling for energy intake.			
18	Fetterplace *et al.* (2019)	To explore the associations between cumulative energy deficits (using indirect calorimetry and estimated requirements), nutritional and functional outcomes.	Mechanically ventilated for at least 48 h (60).	Prospective observational	Repeated
19	Fetterplace *et al.* (2018)	To determine whether a high-protein volume-based enteral feeding protocol with additional protein supplementation delivered more protein and energy than a standard hourly-rate-based nutrition protocol without protein supplementation; to evaluate whether this intervention attenuated muscle or weight loss or the prevalence of malnutrition at ICU discharge.	Adult, mechanically ventilated, on EN feeding (30 intervention; 30 control).	Pilot RCT	Repeated
20	Hermans *et al.* (2013)	To assess whether late PN and early PN differentially affect muscle weakness and autophagic quality control of myofibres.	EPaNIC study participants (305 late PN; 295 early PN).	Subanalysis of RCT	Repeated
21	Kangalgil *et al.* (2024)	To determine the factors associated with acute skeletal muscle loss in critically ill patients.	Patients who were expected to stay in the ICU for at least a week (44).	Prospective observational	Repeated
22	Kim *et al*. (2011)	To assess the nutritional status of patients receiving enteral tube feeding in the ICU at admission; to evaluate its effects on nutritional status over the 7 days after admission; to understand the contribution of energy intake during	Adult medical patients who had been admitted to the medical ICU, started EN after admission to the ICU, had not received preoperative or postoperative care, did not have do-not-resuscitate orders, had received NBM	Prospective descriptive	Repeated

		hospitalisation to the changes in nutritional status during the ICU stay.	since admission, and had not received TPN (48).		
23	Lakenman *et al.* (2024)	To assess body composition during acute and late phase of illness in these patients in relation to clinical outcome and secondary to tailored nutrition support.	Adult critically ill patients with COVID-19 (70).	Prospective observational	Repeated
24	Lambell *et al.* (2021)	To describe changes in CT–derived SMA and SMD across different weeks of critical illness and investigate associations between changes in these parameters and energy and protein delivery.	Adults ICU patients who had ≥2 CT scans at the third lumbar area performed ≥7d apart, if the predominant nutrition route was enteral and/or parenteral (planned >70% requirements), due to oral intake not being routinely recorded in a quantifiable manner (32).	Retrospective observational	Repeated
25	Liu *et al.* (2020)	To explore the therapeutic effects of EEN on patients with sepsis on mechanical ventilation.	Patients with sepsis on mechanical ventilation in the medical ICU (35 EEN; 28 DEN).	RCT	Once
26	Matsushima *et al.* (2021)	To examine the effects of protein intake on physical performance in critically ill adult patients admitted to the ICU.	Adult patients mechanically ventilated over 48h in the ICU (20 pairs).	Retrospective cohort propensity-matched analysis	Once
27	McNelly *et al.* (2020)	To evaluate whether intermittent enteral feed decrease muscle wasting compared with continuous feed in critically ill patients.	Mechanically ventilated adult patients with multiorgan failure (121).	RCT	Repeated
28	Nakamura *et al.* (2020)	To evaluate the efficacy of HMB complex on muscle volume loss during critical care.	ICU patients for whom EN could be performed (43 control; 45 HMB).	RCT	Repeated
29	Nakamura *et al.* (2021)	To assess high-protein and medium-protein delivery under equal total energy delivery with and without active early rehabilitation.	Patients admitted to the ICU (25:31 without EMS, 35:26 with EMS).	RCT	Repeated

30	Nakano *et al.* (2021)	To verify the efficacy of the protocol to ameliorate muscle injury in ICU-AW.	Adult patients admitted to the ICU (45 control; 56 intervention).	Historical control	Repeated
31	Nickel *et al.* (2023)	To assist clinicians to identify critically ill patients at greatest risk of acute muscle loss; to analyse the associations between protein intake and exercise on acute muscle loss.	Adult patients expected to be mechanically ventilated for greater than 48 h and expected to remain in the ICU for more than 2 days after study enrolment (72).	Secondary analysis of RCT	Repeated
32	Pardo *et al.* (2018)	To assess the evolution of the quadriceps muscle during the first 3 weeks after ICU admission and its possible association with nutritional intake.	Patients expected to stay more than 7 days in the ICU (29).	Observational	Repeated
33	Ridley *et al.* (2018)	To determine if an individually titrated supplemental PN strategy commenced 48-72 hours following ICU admission and continued for up to 7 days would increase energy delivery to critically ill adults compared to usual care EN delivery.	Mechanically ventilated adults with at least one organ failure and EN delivery below 80% of estimated energy requirement in the previous 24 hours (100).	Pilot RCT	Repeated
34	Umbrello *et al.* (2021)	To compare the time course of the size and quality of both rectus femoris and diaphragm muscles between critically ill, COVID-19 survivors and non-survivors; to explore the correlation between the change in muscles size and quality with the amount of nutritional support delivered and the cumulative fluid balance.	Patients admitted to ICU for acute hypoxemic respiratory failure, undergoing invasive MV for ≤48 h and with confirmed SARS-CoV-2 infection (36).	Prospective observational	Repeated
35	Uyar *et al.* (2023)	To demonstrate the effect of high protein on diaphragm muscle thickness; to evaluate the correlation of diaphragm thickness fraction with rectus femoris muscle thickness in high protein patients.	Mechanically ventilated patients (49).	RCT	Repeated

36	Verceles *et al.* (2023)	To assess the effectiveness of combined NMES+HPRO+PT in mitigating sarcopenia as evidenced by CT volume and cross-sectional area when compared to usual ICU care.	Older (>50-year-old), mechanically ventilated participants (≥24 hours) with pre-admission Barthel Index of ≥70, ability to follow commands and able to perform physical therapy testing prior to ICU admission (23 control; 16 intervention).	RCT	Repeated
37	Viana *et al.* (2021)	To determine whether HMB, a metabolite of leucine, can attenuate wasting process.	ICU patients depending on mechanical ventilation on day 3 having a functional gastrointestinal tract (30).	RCT	Repeated
38	Wang *et al*. (2024)	To assess the influence of higher early protein intake on the prognosis of critically ill patients.	Critically ill patients aged above 18 years admitted to ICU and EICU, with mNUTRIC score > 5 and an anticipated ICU stay ICU/EICU of more than 7 day (86 intervention: 87 control).	RCT	Repeated
39	Wischmeyer *et al.* (2017)	To test the hypothesis that increased nutrition delivery via SPN + EN to underweight and obese ICU patients would improve 60-day survival and QoL versus usual care (EN alone).	Adult ICU patients with acute respiratory failure expected to require mechanical ventilation for >72 hours and with a BMI of <25 or ≥35 (125).	Pilot RCT	Once
40	Wittholz *et al.* (2023)	To determine feasibility of administering a blinded nutrition supplement in the ICU and continuing it after ICU discharge.	Patient after traumatic injury necessitating admission to ICU (26 intervention; 24 control).	Pilot RCT	Repeated
41	Yatabe *et al.* (2019)	To investigate the impact of nutritional management and rehabilitation on physical outcome.	Patients who received mechanical ventilation for at least 24h and those admitted to the ICU for > 72 h (389).	Observational	Once
42	Yeh *et al.* (2018)	To explore whether psoas CSA and density (HU) are associated with nutritional adequacy and clinical outcomes in surgical intensive care unit patients.	Subjects with at least one CT scan within 72h of ICU admission (140).	Observational	Repeated
43	Yousseff *et al.* (2022)	To evaluate the effect of parenteral proteins on ICU outcome; to compare the	Acute critically ill patients who had PN during their ICU stay (60).	Prospective comparative	Repeated

		effect of two different protein concentrations on handgrip strength in critically ill patients.			
44	Zaragoza *et al.* (2023)	To assess the incidence and determinants of ICUAW in adult patients with EN during the first 7 days in the ICU and mechanical ventilation for at least 48 hours.	ICU patients receiving invasive mechanical ventilation for at least 48 hours and EN the first 7 days of their ICU stay (319).	Prospective cohort	Once
45	Zhang *et al.* (2022)	To evaluate the effect of high protein to the target of 2.0 g/kg/d on diaphragm atrophy and clinical prognosis of patients receiving prolonged MV.	Patients who were treated with ≥7 days' MV (41).	RCT	Repeated

RCT: randomized controlled trial, NMES: neuromuscular electrical stimulation, HPRO: high protein supplementation, SPN: supplemental parenteral nutrition, EN: enteral nutrition, SAH: subarachnoid hemorrhage, CT: computed tomography, LBM: lean body mass, SICU: surgical ICU, US: ultrasound, BMI: body mass index, HCs: healthy controls, CLCR: creatinine clearance, ARC: augmented renal clearance, CKD: chronic kidney disease, RRT: renal replacement therapy, EPaNIC: Early Parenteral Nutrition Completing Enteral Nutrition in Adult Critically Ill Patients, IMV: invasive mechanical ventilation, TARGET: The Augmented versus Routine approach to Giving Energy Trial, HPE: high protein and early exercise, BIA: bioimpedance analysis, PN: parenteral nutrition, NBM: nothing by mouth, TPN: total parenteral nutrition, SMA: skeletal muscle area, SMD: skeletal muscle density, EEN: early enteral nutrition, DEN: delayed enteral nutrition, HMB: β-Hydroxy-β-methylbutyrate, ICU-AW: ICU-acquired weakness, EMS: electrical muscle stimulation, SARS-CoV-2: Severe acute respiratory syndrome *coronavirus 2,* PT: mobility and strength rehabilitation, EICU: emergency ICU, mNUTRIC: modified Nutrition Risk in the Critically Ill, QoL: quality of life, CSA: cross sectional area, HU: Hounsfield units, MV: mechanical ventilation

Table 4. Domains of outcome assessment.

Domain	Specific tests	Author
Muscle mass	Ultrasound of muscle cross-sectional area/thickness	Berger *et al*. (2019) Bury *et al*. (2020) Chapple *et al*. (2020) Chapple *et al*. (2022) Dresen *et al*. (2022) Dresen *et al*. (2021) Elizabeth *et al*. (2024) Ferrie *et al*. (2016) Fetterplace *et al*. (2018) Kangalgil *et al*. (2024) McNelly *et al*. (2020) Nickel *et al*. (2023) Pardo *et al*. (2018) Umbrello *et al*. (2021) Uyar *et al*. (2023) Viana *et al*. (2021) Wang *et al*. (2024) Wittholz *et al*. (2023) Yousseff *et al*. (2022)
	Mid-upper arm circumference/calf circumference/triceps skinfold thickness	Chapple *et al*. (2020) Doig *et al*. (2023) Kim *et al*. (2011) Yousseff *et al*. (2022)
	CT imaging	Badjatia *et al*. (2020) Braunschweig *et al*. (2014) Casaer *et al*. (2013) Dreydemy *et al*. (2021) Lambell *et al*. (2021) Nakamura *et al*. (2020) Nakamura *et al*. (2021) Nakano *et al*. (2021) Verceles *et al*. (2023) Yeh *et al*. (2018) Zhang *et al*. (2022)
	Bioimpedance analysis	Chapple *et al*. (2020) Deana *et al*. (2024) Fetterplace *et al*. (2019) Lakenman *et al*. (2024)
	Subjective Global Assessment (SGA) item scoring muscle wasting	Doig *et al*. (2023)
	Level of butyrylcholinesterase (BChE)	Zhang *et al*. (2022)
Muscle strength	Medical Research Council (MRC) scale	Arabi *et al*. (2021) Elizabeth *et al*. (2024) Fetterplace *et al*. (2019) Fetterplace *et al*. (2018) Hermans *et al*. (2013) Liu *et al*. (2020) Matsushima *et al*. (2021) Nakano *et al*. (2021) Zaragoza *et al*. (2023)
	Handgrip/quadriceps strength	Chapple *et al*. (2022)

		de Azevedo *et al*. (2021) Elizabeth *et al*. (2024) Ferrie *et al*. (2016) Fetterplace *et al*. (2018) Matsushima *et al*. (2021) Nakano *et al*. (2021) Ridley *et al*. (2018) Wischmeyer *et al*. (2017) Yousseff *et al*. (2022) Azevedo *et al*. (2019)
	Sit to stand test & bed to chair transfer test	McNelly *et al*. (2020)
Function	Chelsea Critical Care Physical Assessment Tool (CPax)	Elizabeth *et al*. (2024)
	Physical Function in Intensive Care Test-scored	Fetterplace *et al*. (2019) Fetterplace *et al*. (2018)
	Functional Status Score for the Intensive Care Unit (FSS-ICU)	Nakamura *et al*. (2021) Nakano *et al*. (2021)
	ICU Mobility Scale	Nakano *et al*. (2021)
	Physical status (more than end sitting/bed rest and sitting)	Yatabe *et al*. (2019)
	Modified Rankin Scale (mRS)	Badjatia *et al*. (2020)
	Short Physical Performance Battery (SPPB)	Badjatia *et al*. (2020)

Table 5. Type of outcome assessment tool.

Type	Specific tests	Author
Performance-based	Medical Research Council (MRC scale)	Arabi *et al*. (2021) Elizabeth *et al*. (2024) Fetterplace *et al*. (2019) Fetterplace *et al*. (2018) Hermans *et al*. (2013) Liu *et al*. (2020) Matsushima *et al*. (2021) Nakano *et al*. (2021) Zaragoza *et al*. (2023)
	Handgrip/quadriceps strength	Chapple *et al*. (2022) de Azevedo *et al*. (2021) Elizabeth *et al*. (2024) Ferrie *et al*. (2016) Fetterplace *et al*. (2018) Matsushima *et al*. (2021) Nakano *et al*. (2021) Ridley *et al*. (2018) Wischmeyer *et al*. (2017) Yousseff *et al*. (2022) Azevedo *et al*. (2019)
	Sit to stand test & bed to chair transfer test	McNelly *et al*. (2020)
	Chelsea Critical Care Physical Assessment Tool (CPax)	Elizabeth *et al*. (2024)
	Short Physical Performance Battery (SPPB)	Badjatia *et al*. (2020)

	Physical Function in Intensive Care Test-scored	Fetterplace *et al*. (2019) Fetterplace *et al*. (2018)
	Functional Status Score for the Intensive Care Unit (FSS-ICU)	Nakamura *et al*. (2021) Nakano *et al*. (2021)
	ICU Mobility Scale	Nakano *et al*. (2021)
	Physical status (more than end sitting/bed rest and sitting)	Yatabe *et al*. (2019)
Imaging techniques	Ultrasound of muscle cross-sectional area/thickness	Berger *et al*. (2019) Bury *et al*. (2020) Chapple *et al*. (2020) Chapple *et al*. (2022) Dresen *et al*. (2022) Dresen *et al*. (2021) Elizabeth *et al*. (2024) Ferrie *et al*. (2016) Fetterplace *et al*. (2018) Kangalgil *et al*. (2024) McNelly *et al*. (2020) Nickel *et al*. (2023) Pardo *et al*. (2018) Umbrello *et al*. (2021) Uyar *et al*. (2023) Viana *et al*. (2021) Wang *et al*. (2024) Wittholz *et al*. (2023) Yousseff *et al*. (2022)
	CT imaging	Braunschweig *et al*. (2014) Casaer *et al*. (2013) Dreydemy *et al*. (2021) Lambell *et al*. (2021) Nakamura *et al*. (2020) Nakamura *et al*. (2021) Nakano *et al*. (2021) Verceles *et al*. (2023) Yeh *et al*. (2018) Zhang *et al*. (2022) Badjatia *et al*. (2020)
Anthropometric assessment	Mid-upper arm circumference/calf circumference/triceps skinfold thickness	Chapple *et al*. (2020) Doig *et al*. (2023) Kim *et al*. (2011) Yousseff *et al*. (2022)
Physical examination	Subjective Global Assessment (SGA) item scoring muscle wasting	Doig *et al*. (2023)
Body composition assessment	Bioimpedance analysis	Chapple *et al*. (2020) Deana *et al*. (2024) Fetterplace *et al*. (2019) Lakenman *et al*. (2024)
Biochemical assessment	Level of butyrylcholinesterase (BChE)	Zhang *et al*. (2022)
Disability scale	Modified Rankin Scale (mRS)	Badjatia *et al*. (2020)

Mixed associations were demonstrated in 6 studies with multiple outcomes related to muscle or physical function, where each outcome varied in their relationship with the amount of nutrition. On the other hand, most of the studies (n=22) reported the absence of a significant association between nutrition and the outcomes. Interestingly, in one study, the improvement in muscle outcomes due to higher protein delivery was reported to be substantial only if combined with active early rehabilitation, while another study reported no significant impact of such treatment combination. Details on the results of each included study are illustrated in Table 6.

Table 6. Findings on the association between nutrition delivery and muscle or physical-related outcomes.

	Author (year)	Findings	Type of association
1	Arabi *et al.* (2021)	No significant differences over time in MUAC and MRC sum-score.	0
2	Azevedo *et al.* (2019)	No significant difference in handgrip strength in the OCHPN group versus the Control group	0
3	Badjatia *et al.* (2020)	Reduction in quadriceps muscle atrophy by PBD 14 in NMES+HPRO as compared to SOC group.	+
4	Berger *et al.* (2019)	Total loss of muscle surface tended to be less in SPN compared to EN group with no significant difference.	0
5	Braunschweig *et al.* (2014)	Amount of energy received significantly reduced SKM loss.	+
6	Bury *et al.* (2020)	Changes in QMLT were not associated with nutrition support received.	0
7	Casaer *et al.* (2013)	Early parenteral nutrition did not prevent the pronounced wasting of skeletal muscle observed over the first week of critical illness.	0
8	Chapple *et al.* (2020)	Sample size and ICU LOS were not sufficient for analysis of changes in nutrition-related outcomes.	0[a]
9	Chapple *et al.* (2022)	No difference in QMLT and handgrip strength at any timepoint between intervention and control group.	0
10	de Azevedo *et al.* (2021)	A trend that ICUAW was higher in the control group compared to high protein intake group (borderline significance).	+
11	Deana *et al.* (2024)	Total amount of nutrition delivered does not correlate with changes in muscle mass and phase angle.	0
12	Doig *et al.* (2023)	Significantly greater muscle wasting in standard care compared to early PN group. MUAC differences did not remain significant over the entire ICU stay.	+-

13	Dresen *et al.* (2022)	No statistically significant association between quantitative intake and the skeletal muscle changes after terminating intervention phase.	0
14	Dresen *et al.* (2021)	No statistically significant impact on the loss of muscle mass between higher and standard protein group.	0
15	Dreydemy *et al.* (2021)	No statistically significant difference in changes of muscle psoas CSA and % changes of CSA in patients who received low vs. high protein intake.	0
16	Elizabeth *et al.* (2024)	A trend towards decreased muscle loss in higher protein compared to control group, but no significant difference.	0
17	Ferrie *et al.* (2016)	Handgrip strength was improved at day 7 and muscle thickness was greater in the group receiving the higher compared to lower level of amino acids. No significant difference between groups in handgrip strength at ICU discharge and leg circumference.	+-
18	Fetterplace *et al.* (2019)	Cumulative energy deficit from artificial nutrition support was associated with the development of ICUAW, reduced physical function at ICU discharge and greater loss of fat-free mass.	+
19	Fetterplace *et al.* (2018)	Higher protein was associated with less QMLT loss at discharge compared to standard nutrition, but both groups showed similar muscle strength and physical function.	+-
20	Hermans *et al.* (2013)	Tolerating a substantial macronutrient deficit early during critical illness did not affect muscle wasting, but reduced weakness.	-
21	Kangalgil *et al.* (2024)	The adequacy of energy and protein intake was not associated with the rate of change in RFCSA.	0
22	Kim *et al*. (2011)	Both adequately fed and underfed group had decreased TSF, MAC, and MAMC.	+-
23	Lakenman *et al.* (2024)	Increase in administrated protein intake resulted in <1% difference (40g) of FFM, of which 20g SMM.	+
24	Lambell *et al.* (2021)	Nutrition delivery and adequacy were not associated with muscle loss.	0
25	Liu *et al.* (2020)	Early enteral nutrition can reduce the incidence of ICUAW compared to delayed enteral nutrition.	+

26	Matsushima *et al.* (2021)	High-protein group had significantly higher muscle strength than low-protein group at the time of discharge from the ICU.	+
27	McNelly *et al.* (2020)	Intermittent feeding (higher achievement of nutritional target) in early critical illness is not shown to preserve muscle mass or affect the sit-to-stand or first transfer before ICU discharge, compared to continuous feeding.	0
28	Nakamura *et al.* (2020)	HMB complex supplementation from the acute phase of intensive care does not inhibit muscle volume loss.	0
29	Nakamura *et al.* (2021)	High protein delivery provided better muscle volume maintenance compared to medium protein delivery, but only with active early rehabilitation. FSS-ICU were not significantly different between groups.	+-
30	Nakano *et al.* (2021)	Early mobilization combined with high-protein nutrition prevented femoral muscle volume loss compared to standard protein. The number of days to achieve IMS 1, MRC scores and FSS-ICU at ICU discharge did not significantly differ between the two groups.	+-
31	Nickel *et al.* (2023)	No observed relationship between combined protein delivery and in-bed cycling and muscle loss.	0
32	Pardo *et al.* (2018)	No correlation was found between muscle loss and caloric or protein debt over the first week	0
33	Ridley *et al.* (2018)	Handgrip strengths were similar between the supplemental PN and usual care EN groups.	0
34	Umbrello *et al.* (2021)	The change in both RFCSA and diaphragm end-expiratory thickness was inversely related to the cumulative protein deficit.	+
35	Uyar *et al.* (2023)	Diaphragmatic muscle thicknesses were higher in patients who received protein supplement.	+
36	Verceles *et al.* (2023)	The addition of physical therapy, neuromuscular electric stimulation and high protein nutritional supplementation to standard critical care resulted in an increase in lower extremity muscle volume and cross-sectional area when compared to standard medical care.	+

37	Viana *et al.* (2021)	HMB treatment did not significantly reduce muscle wasting.	0
38	Wang *et al*. (2024)	The atrophy rates of RFMLT and RFCSA in the high early protein group were both significantly lower than the low early protein group.	+
39	Wischmeyer *et al.* (2017)	Potential non-significant tendency to improved handgrip strength at ICU discharge in the SPN + EN group compared to usual care (EN only) group.	0
40	Wittholz *et al.* (2023)	Marked loss of quadriceps muscle thickness occurred in both groups, with the point estimate favouring attenuated muscle loss in the intervention group, albeit with wide CIs.	0
41	Yatabe *et al.* (2019)	Patients might benefit from low caloric intake (less than 10 kcal/kg/day) until day 3 and rehabilitation during ICU stay.	-
42	Yeh *et al.* (2018)	Early nutritional deficits were correlated with muscle quality deterioration.	+
43	Yousseff *et al.* (2022)	High parenteral protein intake was associated with better handgrip strength and significant improvement of muscle thickness.	+
44	Zaragoza *et al.* (2023)	Energy intake during days 3–7 was similar among patients who did and did not develop ICUAW, no effect of energy or protein intake on the onset of ICUAW.	0
45	Zhang *et al.* (2022)	INT improved the diaphragm atrophy and muscle mass of critically ill patients receiving prolonged MV compared to SNT.	+

Abbreviations: MUAC: mid-upper arm circumference, MRC: Medical Research Council, OCHPN: optimized calorie-high protein nutrition, PBD: post bleed day, NMES: neuromuscular electrical stimulation, HPRO: high protein supplementation, SOC: standard of care, SPN: supplemental parenteral nutrition, EN: enteral nutrition, SKM: skeletal muscles, QMLT: quadriceps muscle layer thickness, LOS: length of stay, ICUAW: ICU-acquired weakness, PN: parenteral nutrition, CSA: cross sectional area, RFCSA: rectus femoris cross sectional area, TSF: triceps skinfold thickness, MAMC: mid-arm muscle circumference, MAC: mid-arm circumference, FFM: fat free mass, SMM: skeletal muscle mass, HMB: β-Hydroxy-β-methylbutyrate, FSS-ICU: Functional Status Score for The Intensive Care Unit, IMS: ICU Mobility Scale, RFMLT: rectus femoris muscle thickness, CI: confidence interval, INT: intensive nutrition treatment, SNT: standard nutrition treatment.
0: No association, +: Positive association, -: Negative association, +-: Mixed association
[a] Insufficient data for statistical analysis.

Discussion

The primary aim of this scoping review was to map the broad range of assessment tools used by researchers in examining the association between nutrition delivery with muscle and physical-related outcomes among critically ill adult patients. The identified domains and types of tools allow an overview of the current landscape of critical care nutrition research.

A notable trend was the frequent use of the muscle mass domain, suggesting its significance and a preference for an objective measure in assessing nutrition-related outcomes. Monitoring muscle mass to guide adequate nutritional support during the changing phases of critical illness is helpful (De Rosa *et al*., 2023), as patients were reported to experience muscle loss at a rate of 2% daily during their first week of ICU stay (Fazzini *et al*., 2023). Objective muscle quantifications are potentially sensitive to small changes over short periods, allowing evaluation of nutrition interventions (Umbrello *et al*., 2023). In addition, the assessment of muscle mass by imaging techniques demonstrated great intra- and inter-observer reliability (Pardo *et al*., 2018). This agreement may improve result validity, reproducibility, and bias reduction, both in research, and clinical settings.

On the contrary, the domain function was less frequently used among the included studies, which may suggest a lesser focus on functional ability or challenges to be implemented in the ICU setting. Possible explanation might be the limited feasibility of conducting these ability-to-function tests among the critically ill patients who may not be alert, conscious, or have enough strength. Patients' heterogeneity in their ability to conduct function assessment was reflected in a study by Nordon-Craft *et al*. (2014) where 14 patients could not perform the sit-to-stand and marching-in-place components of the PFIT-s (Physical Function in Intensive Care Test). Effort from the patients would be required to perform the tests for function (Parry *et al*., 2017). In addition, measurements are prone to subjectivity, as reported by Denehy *et al*. (2013), scoring the amount of assistance in the sit-to-stand test relied on researchers' subjective assessment. Nevertheless, measuring functional ability in the ICU is valid and may greatly contribute to informing further rehabilitation strategies.

Other than that, this review revealed that a few assessment tools such as performance-based tests and imaging techniques are commonly utilized and favoured by most of the included studies. For instance, the handgrip strength test, a performance-based, may be commonly employed due to its simplicity, apart from serving as an accurate substitute for other tests in diagnosing ICU-acquired weakness (ICUAW) (Bragança *et al*., 2019; Özyürek *et al*., 2017; Zhang *et al*., 2024). On the other hand, imaging techniques such as computed tomography (CT) scan and ultrasound allows accurate, reliable, and objective evaluation of the muscle cross sectional area, volume, and quality (Mourtzakis *et al*., 2017; Umbrello *et al*., 2023), given that sufficient and proper training is given to research personnel (Mourtzakis *et al*., 2017). These imaging technologies can be greatly useful to evaluate muscle in critically ill populations as they do not require patients' effort, cooperation, or compliance, compared to the tests which require patients to participate actively. Nonetheless, it comes with certain limitations, such as using resources and medical risks to transport patient for a CT scan (Rooyackers & Wernerman, 2014). Nevertheless, the variation in the assessment tool types portray the diverse strategies available for researchers to capture the outcomes of nutritional interventions, depending on study design, target population, and resources available.

It is also important to highlight that the association between nutrition delivery with muscle and physical-related outcomes was inconsistent among the included studies, with many of the included studies reported no significant association. Bels *et al*. (2023) stated that no significant effect of protein supplementation was observed on muscle strength or function in most of the previous

trials, despite a few reports of reducing muscle volume loss particularly with muscle activation. The inconsistencies may be due to differences in sample size, study design, methodology, or assessment tools. The broad range of domain and types of assessment tools underscores the complexity of precisely capturing the influence of nutrition on muscle and physical in the critically ill setting. While certain tools are highly validated, reliable, or precise, their use in the ICU setting may be limited due to significant resource constraint, compared to other affordable measures, though subjective and prone to measurement bias.

Furthermore, challenges exist in the measurement of the muscle and physical-related outcomes for critically ill patients. Fetterplace *et al*. (2018) reported that the quadriceps muscle layer thickness (QMLT) readings were not measured at baseline and discharge in 23% of participants from the intervention group and 27% from the control group. This is due to participant unavailability, change of focus to comfort care, death, other medical issues, or participants being discharged from the ICU when the primary investigator was not available. Other circumstances hindering complete observations include participants being uncooperative with the voluntary strength assessment, patients being too debilitated or ill to perform tests, and difficulties in scheduling of measurements by research personnel (Arabi *et al*., 2021; Wischmeyer *et al*., 2017).

This review identified a significant gap which is the lack of a universally accepted standard to measure muscle and physical-related outcomes in the ICU, specifically concerning nutrition delivery. The broad range of tools used in previous studies, while allowing flexibility for researchers according to the available resources, might lead to contradictory findings on the association between nutrition and outcomes. This may indicate the need to develop guidelines or standardization in the field. In agreement with previous reviews, a broad range of outcomes are used in critical care nutrition trials, affecting the comparison of datasets across studies, and indicating the lack of consensus on where nutrition exerts its most significant benefit (L. S. Chapple *et al*., 2020; Taverny *et al*., 2019).

This review is limited by the scope of the included studies, which primarily focused only on assessing muscle and physical-related outcomes while patients are still in the ICU. Furthermore, categorizing tools into specific domains and types may have introduced subjectivity in interpretation. Nevertheless, this review uniquely categorizes the tools used in relation to nutritional delivery, providing a more focused analysis of their applicability and limitations.

Future research may focus on developing standardized protocols for selecting the tools to measure muscle and physical-related outcomes in critical illness nutrition studies. In addition, the tools currently available for measuring long-term effects of nutrition beyond ICU stay should be systematically mapped to allow a more comprehensive understanding of survivors' trajectories.

Conclusion

A diverse range of assessment tools has been identified for measuring muscle and physical-related outcomes in research evaluating the impact of nutrition delivery among critically ill patients. These tools vary significantly in their approaches, reflecting differences in researchers' objectives, resource availability, and the specific outcomes targeted. The variability in tool selection emphasizes the need for careful consideration when aligning methodologies with study goals. In order to improve consistency and comparability across studies, future research should focus on developing standardized protocols for selecting appropriate tools to measure the effects of nutrition delivery on muscle and physical-related outcomes. Standardization will ensure that findings are reliable and

reproducible, contributing to improved patient outcomes in the ICU.

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TECHNICAL REPORT Open Access

Digital fabrication of flanges in removable partial dentures: a step-by-step workflow

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Abstract

The fabrication of flanges in removable partial dentures (RPD) traditionally entails labour-intensive manual manipulation of materials such as wax to sculpt and shape the flanges according to the patient's oral anatomy. This method requires a high level of skill and precision from dental technicians to ensure the final prosthesis fits comfortably and functions effectively. While most RPD framework designs are now executed digitally, the arrangement of artificial teeth and flanges often remains a manual process. This is primarily due to the scarcity of suitable software capable of designing flanges using computer-aided design (CAD) technology. This report addresses this challenge by presenting an alternative approach to flange design using the CAD software of 3Shape Dental System. By utilizing the software's function for custom tray design, we developed the flanges with the aid of abutment teeth, artificial teeth and framework, thereby improving the accuracy of gingival anatomy in flange fabrication.

Keywords: *computer aided design, dental technique, flanges, removable partial denture*

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Introduction

In recent years, there has been a significant transformation in the fabrication of dental prostheses with the widespread adoption of digital technologies. Despite these advancements, the fabrication of removable partial dentures (RPD) using digital techniques is still evolving (Akl & Stendahl, 2022, Piao *et al*., 2022). The digital design process for RPD utilizes computer-aided design (CAD) software, which integrates patient-specific data obtained from intraoral scans or digital impressions (La Russo *et al*., 2023). However, due to the diverse shapes and irregularities of RPD parts (such as major and minor connectors, rests, clasps and base plates), creating a 3D design for the framework is often challenging and time-consuming. Additionally, a notable gap exists in current computer-aided design (CAD) software, which is the lack of dedicated functions and commands for designing flanges within RPD frameworks.

Flanges, which are extensions of the denture base are crucial components of RPD, providing support, stability, and retention for the prosthesis (Mousa *et al*., 2021). Their proper design is essential for the functionality and comfort of the patient. Yet,

the absence of specialized tools within CAD software means that dental professionals often resort to traditional manual interventions to achieve the desired flange configurations. This reliance on manual methods not only consumes time but also introduces opportunities for human error, potentially compromising the fit and effectiveness of the RPD (Akl & Stendahl, 2022; Bilgin *et al*., 2016). Furthermore, the lack of this specialized functions within CAD software hinders the full potential of digital technologies in the design and manufacturing processes of RPD.

In the traditional workflow, technicians depend on manual manipulation of materials, such as wax, to sculpt and shape the flanges and abutment teeth according to the dentist's prescription and the patient's oral anatomy, by means of the occlusal rim adjusted during maxillo-mandibular relationship and trial denture procedure. This process is often time-consuming, and heavily relies on the technician's experience to ensure the final prosthesis fits comfortably and functions effectively in the patient's mouth (Ismail & Al-Moghrabi, 2023; Touchstone *et al*., 2010). While current software includes a custom tray function, it primarily focuses on facilitating the construction of custom trays for impressions rather than directly addressing the design of RPD flanges. Due to a lack of information from current literature on the technical aspects of digital fabrication and the absence of specialized functions for RPD flange design, repurposing and improvisation of existing tools within the software is necessary to meet the needs for designing flanges. The objectives this technical report was repurpose existing tools within CAD software to develop a digital workflow that utilizes the artificial teeth, as a guide for designing flanges in RPD..

Technical Notes

This report outlines a digital workflow that uses the abutment teeth as a guide when designing flanges in RPD cases. In order to design the flanges, the artificial teeth and framework must first be designed. Artificial teeth are the prosthetic components of the RPD that replace missing natural teeth. In contrast, abutment teeth are the patient's existing natural teeth that support and stabilize the RPD framework, often through the use of clasps, rests, or other attachments. The abutment and artificial teeth cohesively to inform the design of the flanges within the RPD framework. After the extra- or intra-oral scanning, use CAD software (3Shape Dental System) to process and export the scan in order to design the components of the denture. The step-by-step workflow is explained in the following paragraphs:

Artificial teeth and framework design

Artificial teeth design involves digitally creating replacement teeth to restore the function, aesthetics, and occlusion of missing teeth within the RPD. The design process includes selecting appropriate tooth shapes from a digital library, positioning them to align naturally with the patient's existing dentition, and customizing their appearance to blend with the natural teeth. Once the artificial teeth are properly planned, the framework is designed to incorporating elements like saddle, major connector, rest and clasps.

1. Create an order for the RPD design. Set the order to create the "framework" and "artificial teeth."
2. Initiate the design process by designing the artificial teeth and RPD framework, adhering to established guidelines.
3. Once completed, generate the standard tessellation language (STL) output for both the designed artificial teeth and framework using the standard functions within the CAD software program.

Denture flange design

1. Due to the absence of a specific command within the 3Shape Dental System software for flange design, a modification approach was employed utilizing a "custom tray" function. Utilizing the same scanning model,

proceed by generating an order for a “custom tray” (Figure 1).

2. The artificial teeth, abutment teeth and framework are used as guides for the next step, which is to design the flanges. Use the "additional scans" loading function to add the STL files of these parts to the workflow. Use the "move" function to realign the framework and artificial teeth as necessary (Figure 2). These artificial teeth will serve as guides to optimize the design of the denture flanges, particularly in proximity to the natural abutment teeth.
3. Initiate the design (as seen in blue dotted line) of the denture flanges utilizing the custom tray mode. If the design involves both quadrants, ensure that the flanges extend across the midline as necessary (Figure 3).
4. Use the sculp toolkit and wax knife setting to fill the space between the abutment teeth and framework to aid in accurately sculpting the gingival anatomy. Adjust the filling as necessary to achieve the desired results (Figure 4. a-b).
5. The final design is depicted in Figure 5. Upon completion, generate the STL output for the denture flanges (Figure 6).

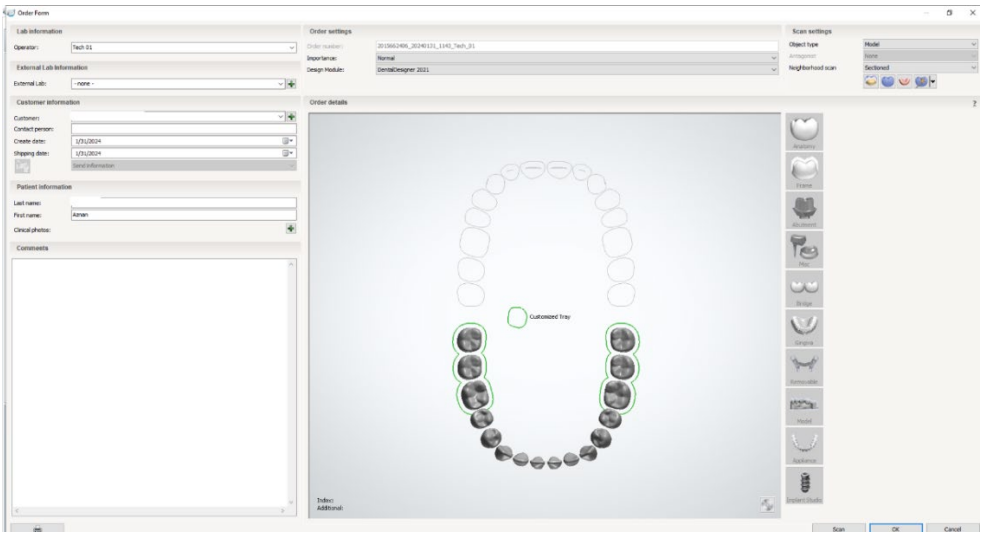

Figure 1. Creating order using “custom tray” function.

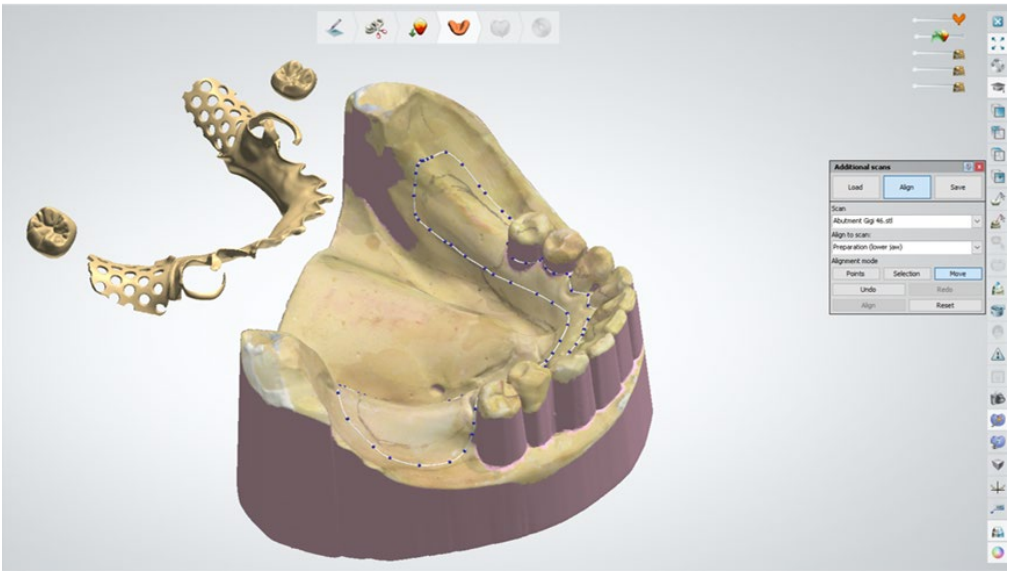

Figure 2. Alignment of framework, artificial teeth with abutment teeth using the 'move' function for integration into the workflow.

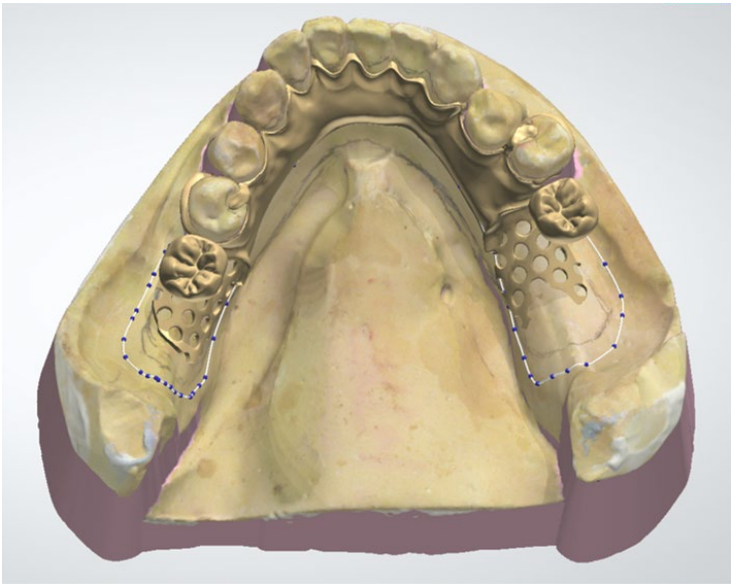

Figure 3. Initiation of denture flange design depicted by blue dotted lines, employing custom tray mode. Flanges extend across the midline for cases involving both quadrants.

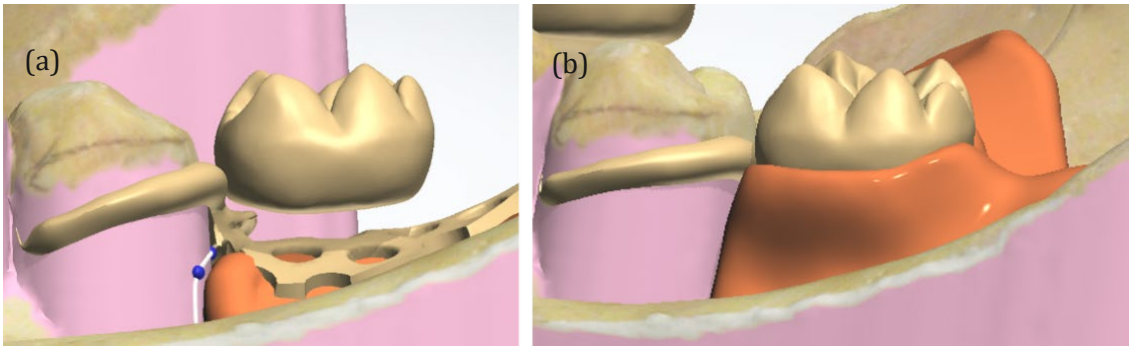

Figure 4. (a) Initial design (b) Utilizing the sculp toolkit, the space between the artificial teeth and framework is filled, with the artificial teeth aiding in sculpting the gingival anatomy.

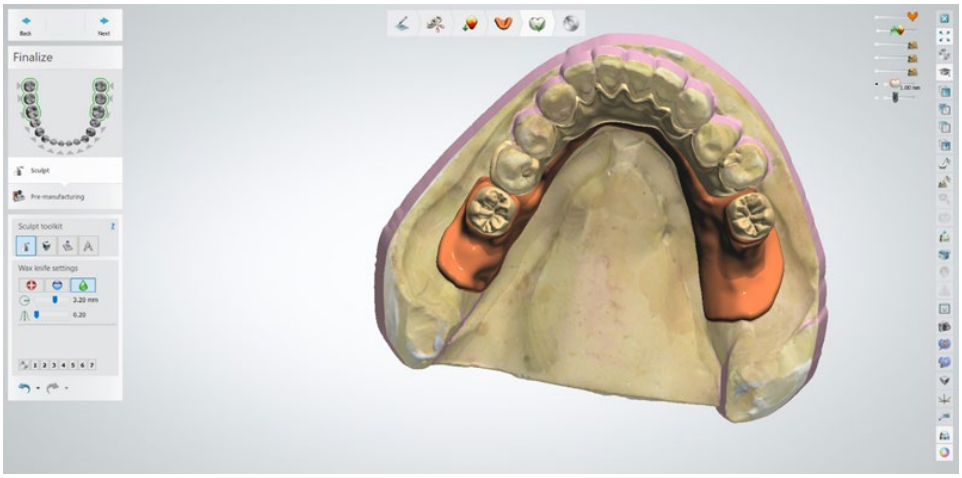

Figure 5.The final design.

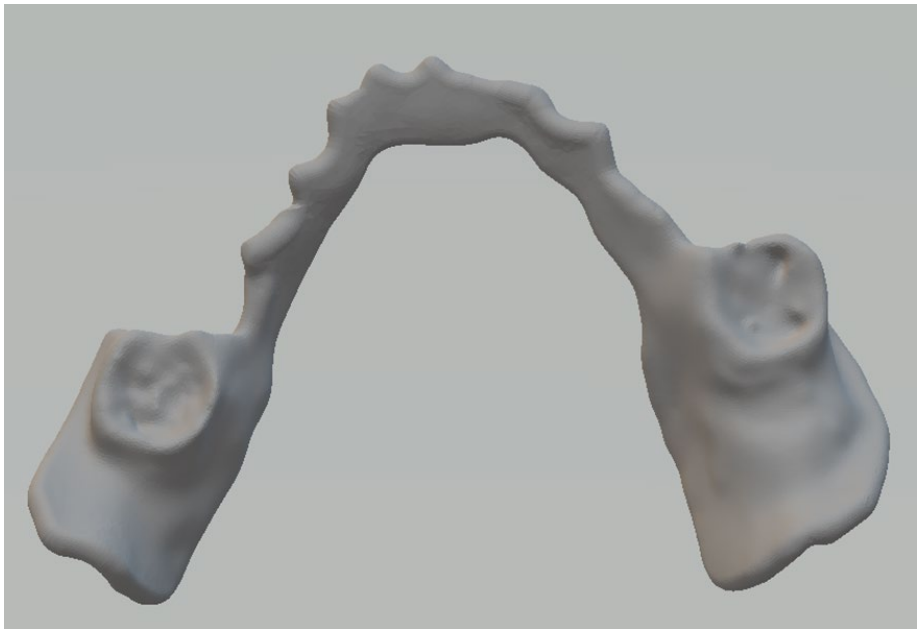

Figure 6. The final design of the flanges, which can be manufactured using either subtractive or additive methods.

Discussion

In the absence of a dedicated function within CAD software for designing flanges within RPD frameworks, traditional methods have typically been relied upon. However, in our study, the alternative approach was employed, utilizing the "custom tray" order function guided by the arrangement of abutment teeth and framework. While traditional methods necessitate manual adjustments and shaping, our utilization of new technology offers an alternative method to fully utilize the digital technology system. Despite the current lack of a dedicated command, our findings highlight the potential for software updates to enhance CAD capabilities in this regard.

A recent systematic review makes two main suggestions: first, it is important to create automatic CAD software that can make framework designs while taking into account the condition of the abutment teeth; second, it is important to create software that can plan predictable prosthetic treatments (Takaichi *et al*., 2022). Only one study has currently presented a novel software application that automates the creation of RPD designs. The software integrates artificial intelligence (AI) technology with clinical decision support principles to generate comprehensive two-dimensional diagrams that illustrate the RPD design. These findings offer valuable insights into the potential for AI-driven solutions in prosthodontic practice (Chen *et al*., 2020).

Through digital fabrication, flange design becomes precisely controllable and adjustable using CAD software, offering numerous advantages. Consequently, this enables more consistent and precise flange shaping, ultimately leading to enhanced comfort and stability for the patient. Moreover, the customization of artificial teeth based on digital data ensures a more precise occlusal surface, enhancing both aesthetics and function compared to the standardized nature of conventional methods (Bilgin *et al*., 2016). Apart from reducing manual labor and potential errors, digital fabrication facilitates easier storage and retrieval of design data, fostering enhanced collaboration (Fueki *et al*., 2014).

However, transitioning to digital workflows may entail certain challenges. Training technicians to proficiently utilize CAD software requires time and investment,

while initial setup costs for software and hardware can be significant (Villias *et al*., 2021). Moreover, technological dependencies may introduce vulnerabilities, such as software compatibility issues or reliance on external support services. To address these challenges and enhance digital workflows, particularly in the domain of flange design, software developers could focus on improving user interfaces for in-built navigation and incorporating features specifically tailored for flange design, such as automated algorithms for contouring based on anatomical parameters which can further enhance accuracy. Furthermore, ongoing software updates and technical support services can help mitigate potential vulnerabilities and ensure smooth operation within digital workflows.

Conclusion

Even though RPD framework designs are often performed digitally, the manual arrangement of artificial teeth and flanges continues because there is a scarcity of appropriate CAD software. This article introduces a different approach to designing flanges using the 3Shape Dental System's CAD software, initially developed for custom tray design with the help of artificial teeth, abutment teeth and the framework.

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CASE SERIES Open Access

Orthodontic and periodontal health interplay: insight from a case series

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Abstract

Orthodontic treatment improves dental aesthetics and function but may presents challenges in patients with compromised periodontal health. This case series highlights the importance of interdisciplinary care and patient compliance in managing these complexities. Three female patients aged 27 to 42 years old with histories of orthodontic treatment were referred to Periodontology Postgraduate Clinic for further periodontal management. All patients showed periodontal deterioration post-orthodontic treatment, with complications such as gingival inflammation, deep probing pocket depth (PPD), increased tooth mobility and severe bone loss involving lower incisors. Improper plaque control and non-compliance with retainers may contributed to these outcomes. All patients reported being unaware of their periodontal issues prior to this except the ones affected by tooth mobility. Following thorough periodontal examination, each patient was informed about the importance of proper plaque control and regular maintenance visits especially in patients with any appliance intraorally, as these appliances would promote bacterial plaque retention. The patients were then received non-surgical periodontal therapy, with regular follow-ups before periodontal stability achieved. This case series emphasizes the need for early periodontal screening, continuous monitoring, and interdisciplinary collaboration between orthodontists and periodontists. Patient compliance is crucial to prevent periodontal complications and to achieve optimal functional and aesthetic results during orthodontic therapy.

Keywords: *complication, maintenance therapy, orthodontic treatment, periodontitis, vertical defect*

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Introduction

Periodontal disease or periodontitis is a chronic inflammatory condition associated with dental plaque biofilm dysbiosis (Papapanou *et al.*, 2018). It leads to the destruction of the complex tooth-supporting structures, including the periodontal ligament, cementum, and alveolar bone (Lindhe *et al.*, 2022). This loss of periodontal support may lead to pathological tooth migration (PTM), affecting both aesthetics and function, and significantly impacting the patient's quality of life (Chapple, 2014).

In patients with pre-existing periodontal conditions, orthodontic appliances can further aggravate the disease, causing increased tooth mobility, bone loss, gingival inflammation, and root resorption (Feller *et al.,* 2015a). These complications may arise during or after orthodontic treatment, leading to both aesthetic and functional challenges.

Interdisciplinary care between orthodontists and periodontists is crucial for managing these complexities and ensuring successful outcomes. Early diagnosis, plaque

control, and comprehensive periodontal monitoring are essential to preserving periodontal health and dental aesthetics (Doulkeridou *et al.,* 2020).

Orthodontics treatment, while effective in addressing malocclusion and dental crowding (Erbe *et al*., 2022), involves the movement of teeth through a biological response in periodontal tissue caused by applied forces (Feller *et al.,* 2015b; Maltha *et al.,* 2021). In healthy periodontal patients, this process is generally safe, but in those with compromised periodontium, it presents additional risks (Jepsen *et al*., 2023). Maintaining a healthy periodontium is vital for optimal orthodontic outcomes and preventing relapse after treatment (Gkantidis *et al*., 2010).

A crucial component in managing these risks is early and through periodontal assessment before starting orthodontic treatment, followed by continuous monitoring throughout the treatment process. The collaboration between orthodontists and periodontists is critical in ensuring optimal outcomes, particularly for patients with existing periodontal concerns. Inadequate communication between these specialties, along with poor patient compliance, can lead to undesirable outcomes, such as relapse of alignment, gingival recession, and compromised aesthetic results.

Therefore, this case series explores the clinical and aesthetics outcomes in three female patients who underwent orthodontic treatment in the presence of varying degrees of periodontal disease. Each patient experienced complications ranging from bone loss to tooth mobility and gingival recession, all of which negatively affected both function and aesthetics. The report aims to highlight the importance of early periodontal screening, interdisciplinary care, and patient compliance in managing these complex cases and achieving successful outcomes.

Case 1

A 27-year-old female patient complained of mobile teeth and sudden exfoliation of lower anterior tooth and seeking for appropriate treatment in 2022 at our periodontal clinic. The patient noticed the symptoms 1-2 years ago, however, due to the movement restriction during the Pandemic Covid-19, she was unable to seek treatment earlier. The patient was medically healthy. She had undergone orthodontic treatment at a private clinic twelve years ago at the age of fifteen to address crowding in the lower incisors. All first premolars were extracted prior to the treatment, which lasted within 2 years, and she was provided with a removable retainer.

Upon visiting the periodontal clinic, she presented with a 4mm space between the central incisor and canine (Figure 1) due to the exfoliation of the lower right lateral incisor a few months before her first visit to our periodontal clinic. Clinically, the patient had minimal localized gingival inflammation and bleeding on probing (BOP), predominantly in interdental areas. The plaque score of 21.3% was noted, mostly in interdental areas. Deep probing pocket depths ranging 5-9mm were observed in several teeth included 17, 23, 25,45,46 and 47. The radiographs revealed severe bone loss, up to two-thirds of root length, particularly at teeth 25, 41, 45 and 47. Bone loss of about half of the root length or less was noted at teeth 17, 23 distal and 43 mesial (Figures 2 and 3). Tooth mobility was observed, with grade I detected at most of the teeth and grade II was detected at teeth 45 and 41. There was no occlusal interference detected.

Based on the clinical and radiographic findings, the patient was diagnosed with localized periodontitis stage III grade C. Management would focus on addressing the deep periodontal pockets and bone loss, with potential regenerative procedures and regular monitoring/ maintenance being essential.

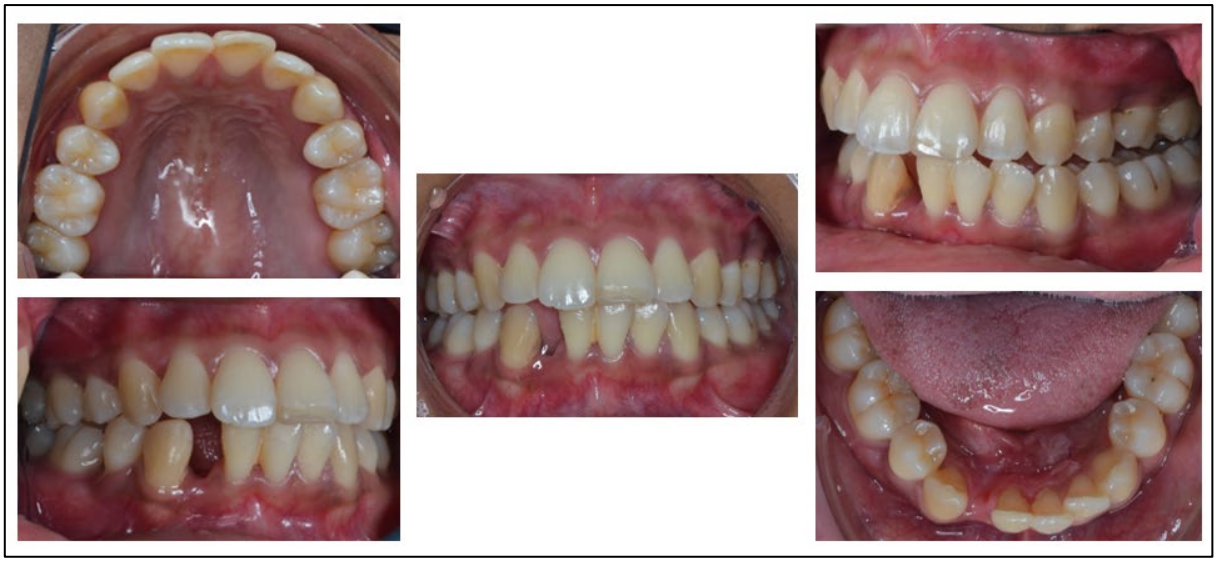

Figure 1. Intraoral photographs of Case 1.

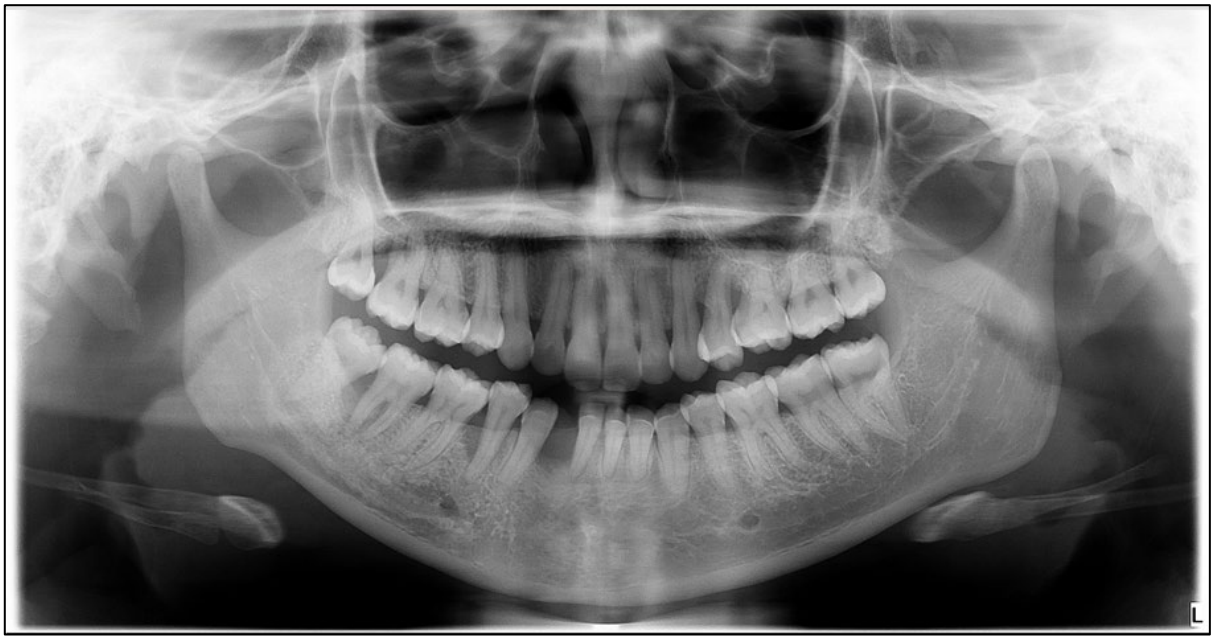

Figure 2. Panoramic radiograph (Orthopantomography) of Case 1.

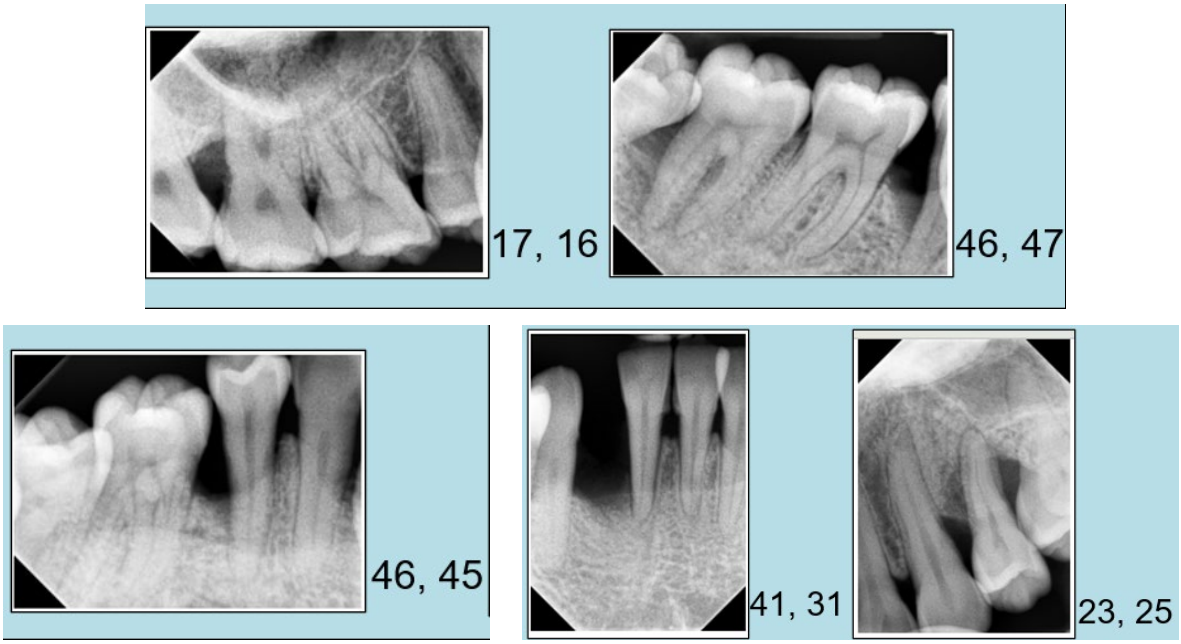

Figure 3. Intraoral periapical radiograph of Case 1.

Timeline-based summary of this first case of 27-year-old patient as below:

- **Year 2010 (age 15):** The patient underwent orthodontic treatment to correct lower crowding. All first premolars were extracted before the treatment. The treatment lasted for 2 years and was given a removable retainer.
- **Year 2020-2021**: The patient noticed mobile teeth and a worsening of symptoms over 1-2 years but could not seek treatment due to pandemic restrictions.
- **Early 2022**: The lower right lateral incisor was exfoliated a few months before visiting the clinic.
- **Year 2022 (age 27)**: The patient visited the periodontal clinic.
    - **Clinical findings**: A 4mm space between the lower left central incisor and canine, minimal gingival inflammation, deep PPD (5-9mm) at several teeth (17, 23, 25, 45, 46, and 47), and bone loss up to two-thirds of the root length at teeth 25, 41, 45 and 47.
    - **Diagnosis**: Localized periodontitis, stage III, grade C.
    - **Treatment**: Focused on managing deep pockets and bone loss with potential regenerative procedures, along with regular monitoring.

Case 2

A 42-year-old female patient complained of loose upper anterior teeth in year 2023 at our periodontal clinic, a problem she had noticed before starting orthodontic treatment in 2016 but had not sought treatment for. The patient is medically healthy. She began orthodontic treatment in 2019 in a private clinic, which involved the extraction of 3 teeth (first premolars except tooth 24) prior to the treatment. The treatment was completed in less than 2 years. She was provided with removable retainers, however, the patient admitted non-compliance, which led to relapse within a year.

Upon presentation in our periodontal clinic, in general, she exhibited inflamed gingiva (Figure 4) with a bleeding on probing (BOP) score of 59.6% and a plaque score of 36.5%. Deep PPD of 5-6mm were observed in several teeth included teeth 46, 12-22, 25, 26, 42 and 43. Teeth mobility was noted, with grade I was detected at teeth 11, 21, 23, 26, 37, 36, 31-43, and 45; and grade II was detected at teeth 12 and 22. Tooth 12 was also affected by buccal gingival recession of

2.5 mm. Occlusal interference was detected at tooth 12 upon closing and opening the mouth.

The radiographs findings showed severe bone loss, up to two-thirds of root length at tooth 12. Bone loss of about half of the root length or less was noted at teeth 17, 13, 11, 35, 32, and 31 (Figures 5 and 6). Apart from that, periapical radiographs showed apical root resorption was noted at all upper anterior teeth, teeth 42 and 43.

Based on the clinical and radiographic findings, the patient was diagnosed with localized periodontitis stage IV grade C without any risk factors. Treatment would aim to stabilize the mobile teeth and manage deep pockets and bone loss, with occlusal adjustments to correct interference which may help in reducing further damage. Comprehensive periodontal therapy, along with regular follow-ups, would be required. A possible advanced periodontal intervention would be necessary in managing this case.

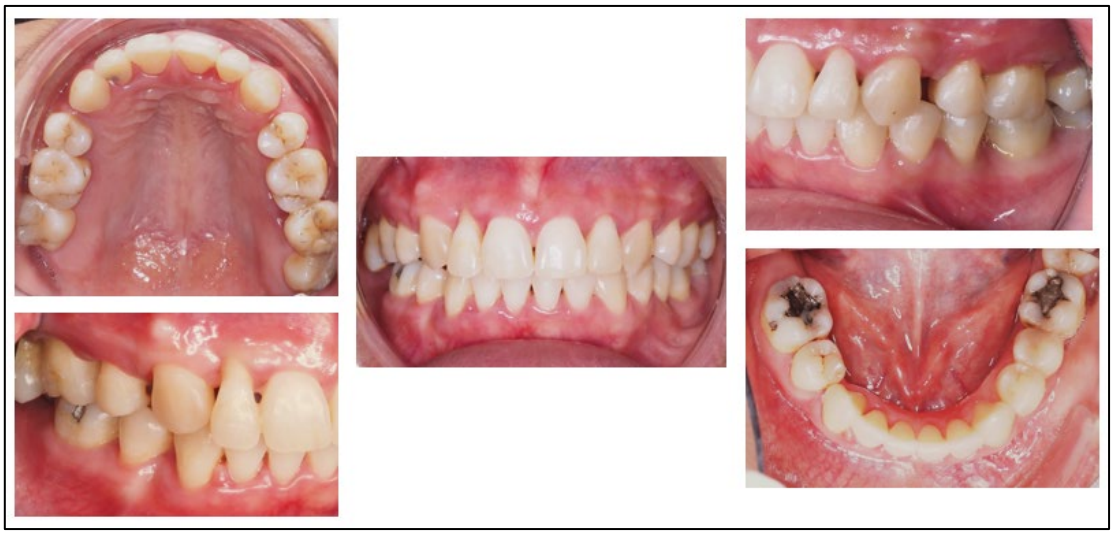

Figure 4. Intraoral photographs of Case 2.

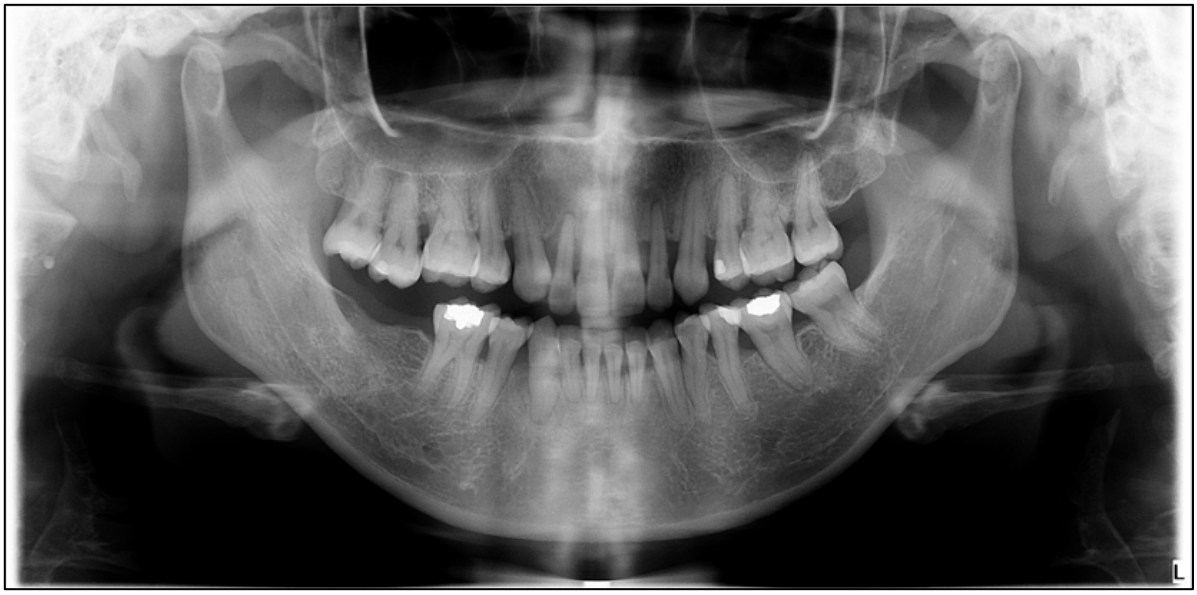

Figure 5. Panoramic radiograph (Orthopantomography) of Case 2.

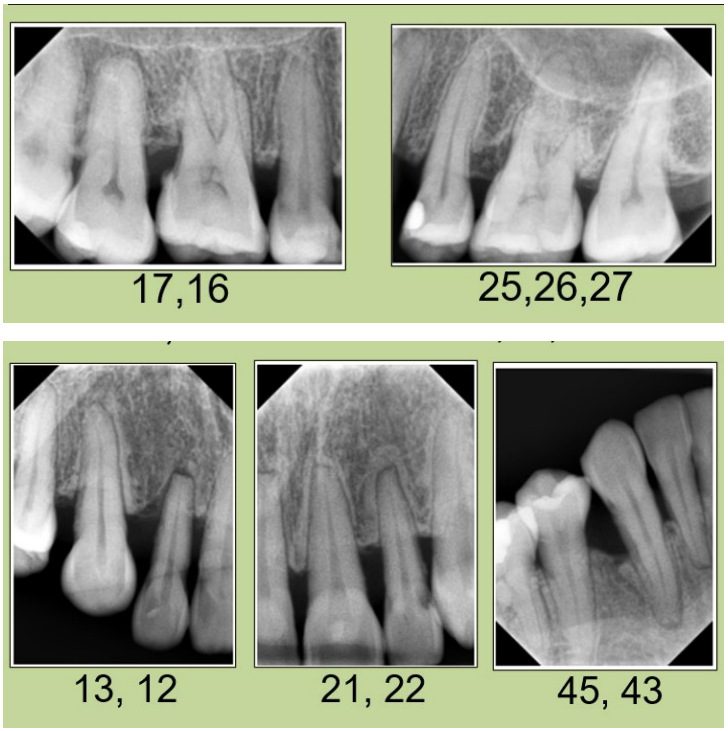

Figure 6. Intraoral periapical radiograph of Case 2.

Timeline-based summary of this second case of 42-year-old patient as below:

- **Year 2016 (age 35):** The patient noticed loose upper anterior teeth but did not seek treatment.
- **Year 2019**: The patient started orthodontic treatment, with the extraction of 3 premolars (except 24). She was provided with removable retainers.
- **Year 2020**: Non-compliance with the retainer led to a relapse in alignment.
- **Year 2023 (age 42)**: The patient visited the periodontal clinic.
    - **Clinical findings**: Inflamed gingiva with a BOP score of 59.6%, deep PPD (5-6mm) in several teeth (46, 12-22, 25, 26, 42, and 43), mobility of several teeth and occlusal interference at tooth 12. Severe bone loss was noted, particularly at tooth 12, and apical root resorption in several upper anterior teeth.
    - **Diagnosis**: Localized periodontitis, stage IV, grade C.
    - **Treatment**: Aimed at stabilizing mobile teeth, managing deep pocket, and addressing occlusal interference. Periodontal therapy and possibly advanced interventions were recommended.

Case 3

A 38-year-old medically healthy female patient complained of food impaction in the upper left posterior teeth during the first visit in our periodontal clinic in 2022. In the past dental history, the patient claimed that she had two extractions involving lower right and upper left first molars while pregnant due to mobility without any post-extraction complication. The patient also had undergone orthodontic treatment in a private clinic six years ago, in 2017, due to anterior teeth crowding, without any prior tooth extractions. The orthodontic treatment was completed in 3 years. The patient was provided with a retainer; however, she did not comply with the retainer provided.

Upon examination in our periodontal clinic, inflamed gingiva was noted with a BOP score of 41.8% and a plaque score of 42.5%. Deep PPD of 5-6mm were found in several teeth included at teeth 17, 16, 23, 38, 37, 36, 35, 32, 45, and 47. Tooth mobility was detected,

with grade I at tooth 36, grade II at tooth 31, and grade III at tooth 32.

The radiographic analysis confirmed the severe alveolar bone loss until the apical of tooth 32 (Figures 7 and 8), deemed to have a hopeless prognosis. Other areas showed minimal bone loss, which were less than one-third of the root length included at teeth 36 and 35. There was no occlusal interference detected.

Based on the clinical and radiographic findings the patient was diagnosed with localized periodontitis stage III grade B without any risk factors. The management approach would involve extraction of tooth 32 due to its hopeless prognosis, periodontal therapy to address inflammation and pocket depths, and careful prosthodontic planning for tooth replacement.

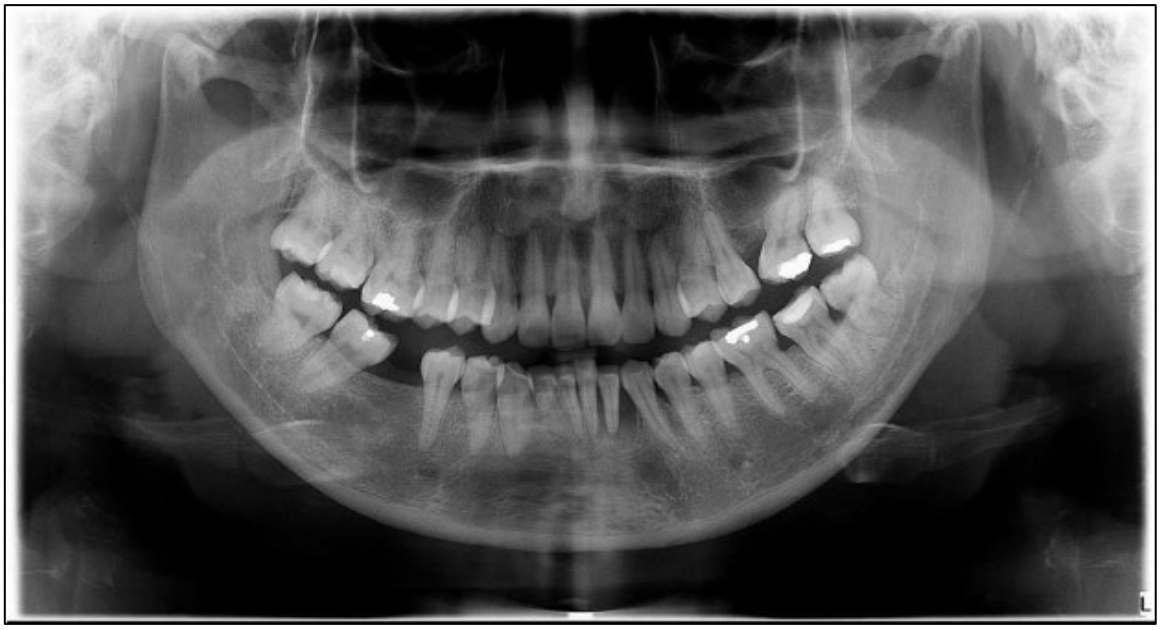

Figure 7. Panoramic radiograph (Orthopantomography) of Case 3.

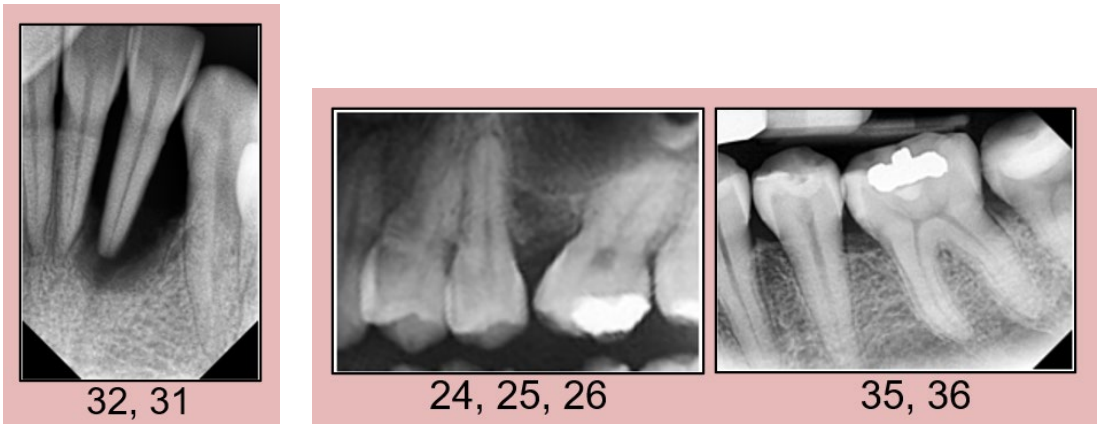

Figure 8. Intraoral periapical radiograph of Case 3.

Timeline-based summary of this second case of 38-year-old patient as below:

- **Before year 2017:** The patient had teeth extractions (lower right and upper left first molars) while pregnant due to mobility without any post-extraction complication.
- **Year 2017 (age 33):** The patient underwent orthodontic treatment for anterior crowding, which lasted 3 years without extractions. She was provided with a retainer, but non-compliance led to relapse.
- **Year 2022 (age 38)**: The patient visited the periodontal clinic.
    - **Clinical findings**: Inflamed gingiva with a BOP score of 41.8%, deep PPD (5-6mm) in several teeth, severe alveolar bone loss and mobility grade III at 32, and clinically missing of 46. Radiographic findings confirmed a hopeless prognosis for teeth 32.
    - **Diagnosis**: Localized periodontitis, stage III, grade B.
    - **Treatment**: Extraction of tooth 32 due to its hopeless prognosis, periodontal therapy, and prosthodontic planning for tooth replacement.

Discussion

Orthodontic intervention is recognized as an effective treatment modality for addressing issues related to both aesthetics and function (Erbe *et al.,* 2022). However, when periodontally compromised teeth are involved, orthodontic treatment become considerably more complex and challenging. Due to compromised supporting tooth structures, improper orthodontic intervention may lead to a range of undesirable consequences (Jepsen *et al*., 2023), including heightened bone loss, increased tooth mobility, exacerbated gingival inflammation, and root resorption (Feller *et al.,* 2016). These adverse effects emphasize the need for interdisciplinary collaboration between orthodontists and periodontists to prevent complications and ensure proper management of periodontally compromised patients undergoing orthodontic therapy.

A key observation across the cases is the lack of effective communication between healthcare providers and patients regarding the importance of maintaining periodontal health during orthodontic treatment. There was a failure to gather data on whether the patient underwent periodontal screening prior to orthodontic treatment, despite patients' history of tooth mobility before orthodontic treatment as seen in Case 2 and Case 3, which is often a significant indicator of potential periodontal issues (McGuire & Nunn, 1996a, 1996b). Without a clear record of whether periodontal evaluation took place, it is difficult to determine if any pre-existing periodontal conditions were identified or addressed before orthodontic intervention began. This lack of information raises concerns about the potential for missed opportunities to prevent or manage underlying periodontal disease, which could have contributed to the progression of the condition during treatment. If a periodontal screening had been conducted, and the patient's mobility had been properly evaluated, it would have warranted appropriate referrals to a periodontist for further management and care. Unfortunately, in this instance, such referrals do not appear to have been made.
Minor radiographic bone loss may be observed in patients with a healthy periodontium following orthodontic treatment. However, this bone loss generally does not lead to significant periodontal compromise. Research suggests that even in patients with stable-treated periodontitis, the slight bone loss seen on radiographs after orthodontic therapy does not have a meaningful impact on periodontal health or clinical outcomes (Martin *et al*., 2022). This indicates that, in properly managed cases, orthodontic treatment can be safely conducted without causing notable harm to the periodontium.

In these cases, deep infrabony defects and periodontal pockets were evident, indicating significant periodontal deterioration. Notably, Case 2 exhibited significant severe vertical bone defects, which were closely

associated with inadequate plaque control, as supported by earlier research (Årtun & Urbye, 1988). These findings underscore the critical role that plaque control and proper oral hygiene play in maintaining periodontal health, particularly in patients undergoing orthodontic treatment. Failure to adhere to stringent oral hygiene practices can lead to the accumulation of microbial biofilm, which exacerbates inflammation and accelerates the progression of periodontal disease. This highlights the need for comprehensive patient education and regular monitoring to ensure that oral hygiene is maintained optimal levels before, during, and after orthodontic treatment. By minimizing the microbial burden, the risk of further periodontal destruction, including deepening periodontal pockets and bone loss, can be significantly reduced, ultimately safeguarding both the patient's periodontal and orthodontic outcomes.

Apical root resorption was another notable complication as presented in Case 2 where shortened apical roots were observed in both the upper and lower anterior teeth. Apical root resorption is recognized as an unavoidable and undesirable iatrogenic consequence following orthodontic intervention (Feller *et al.,* 2016), often caused by heavy continuous orthodontic force and prolonged treatment duration (Bayir & Bolat Gumus, 2021). Without baseline data in this case, the extent of resorption could not be fully quantified.

Apical root resorption is typically categorized into three levels: mild (resorption less than 2mm of the original root length), moderate (resorption exceeding 2mm but remaining below one-third of the original root length), and severe (resorption exceeding 4mm or one-third of the original root length). According to existing literature, root resorption in orthodontically treated patients with healthy periodontium has been reported within the range of 1 to 1.5mm (Corrente *et al.,* 2003; Heravi *et al.,* 2011; Melsen *et al.,* 1989). In patients with periodontitis, the reported range of root resorption following orthodontic treatment varies from 0.2 to 3.0mm (Harris & Baker, 1990; Zasčiurinskienė *et al*., 2018, 2019a, 2019b). It is imperative to inform both patients and their parents about the risk of apical root resorption associated with orthodontic treatment before orthodontic treatment begins. Precautionary measures to mitigate this risk should be carefully considered, and any instances of root resorption should be promptly addressed to prevent further damage.

In addition to the well-known complications such as alveolar bone loss and tooth mobility or loss, orthodontic treatment in periodontally compromised patients can also result in gingival recession, alterations in gingival phenotype, gingival clefts, and loss of interdental papilla (Jepsen *et al.,* 2023). These conditions not only affect aesthetics but also impair function and reduce the patient's quality of life. Careful consideration and tailored management strategies are crucial when planning orthodontic treatment for patients with periodontal concerns.

Retainer non-compliance is a major cause of orthodontic relapse (Littlewood *et al*., 2017) and can worsen periodontal issues. Without retainer use, teeth tent to shift back, leading to crowding, plaque accumulation, which increases the risk of gingival inflammation, periodontal pockets and bone loss. In patients with a history of periodontitis, relapse can strain weakened periodontal structures, exacerbating tooth mobility and bone loss. Maintaining proper oral hygiene becomes difficult with relapse crowding, further aggravating the periodontal health. Therefore, strict adherence to retainer protocols and regular periodontal maintenance is crucial to prevent relapse and protect periodontal health.

The cases presented raise important questions about the qualifications and expertise of the healthcare providers at the private clinics where these patients received orthodontic care, specifically whether they were treated by trained orthodontists or general dentists performing orthodontic procedures. The absence detailed periodontal evaluations prior to orthodontic treatment, despite clear indicators such as

tooth mobility, suggests a potential lack of specialized knowledge in managing complex dental cases involving extensive training to manage cases that may involve compromised periodontal support, ensuring that treatment plans account for any underlying conditions that could be exacerbated by orthodontic forces. In contrast, general dentists may not have the same level of expertise in recognizing and addressing these challenges, particularly when interdisciplinary care involving a periodontist is required. The failure to make appropriate referrals for periodontal management in these cases further suggests that the provider may not have fully understood the risks associated with treating patients with periodontal concerns. This highlights the importance of ensuring that orthodontic treatment is conducted by a qualified orthodontist who has the skill and knowledge to manage complex cases and collaborate with other specialists as needed to prevent adverse outcomes.

Established guidelines must be followed diligently by practitioners when evaluating orthodontic therapy options for their patients. Initially, it is recommended to perform a Basic Periodontal Screening (BPE) during the initial examination, as suggested by Greer *et al*. (Greer *et al*., 2018). It is important to note that a BPE does not provide a definitive periodontal diagnosis, instead, it guides the clinician towards an appropriate diagnostic and treatment course. The British Society of Periodontology (BSP) offers a readily accessible online flowchart that demonstrates how BPE codes can guide clinicians to achieve an accurate diagnosis (BSP, 2018). Patients who score a code of 3 or 4 required a comprehensive examination which includes radiographic assessment to evaluate the crestal bone level, periodontal pocket depth, infrabony defect and furcation involvement. Additionally, it is crucial for practitioners to consistently record patients' plaque scores and bleeding scores to monitor plaque control and gum inflammation effectively throughout the treatment process.

As highlighted earlier, effective communication between the orthodontist and periodontist is vital in enhancing the treatment outcomes and reducing the likelihood of periodontal complications. To facilitate this communication, Table 1 outlines recommended protocols for periodontal screening, maintenance, and follow-up. It's essential to recognize that these protocols may differ for each patient based on factors such as age, medical background, dental history and periodontal condition. Therefore, the clinician must customize the protocol accordingly.

Table 1. Recommended Protocols.

Before Orthodontic Treatment	
Orthodontist	➢ Periodontal screening: basic periodontal examination (BPE) ➢ Refer the patients who score 4 or * to periodontists. ➢ Refer the patients who score 3 which not responding to the treatment to the specialist. ➢ Evaluate the site with the risk of mucogingival deformity. ➢ Refer the patients with a risk of mucogingival deformity to periodontist.
Periodontist	➢ Comprehensive (full mouth) periodontal assessment clinically and radiographically. ➢ Diagnose, plan and treat active periodontal diseases. ➢ Diagnose, plan and treat mucogingival deformity as necessary. ➢ Evaluate the periodontal condition after active therapy. ➢ Repeat the periodontal therapy if the condition persistent. ➢ Refer the patient who periodontally stable to the orthodontist.

Both	➢ Motivation/ Education: ▪ Explain the risk of developing periodontal disease during an active orthodontic treatment. ▪ The importance of adequate plaque control with proper oral hygiene home care. ▪ The importance of regular check-up 6 monthly for prevention and early intervention if necessary. ➢ Oral hygiene instruction: ▪ Proper toothbrushing. ▪ Interdental cleaning using interdental brush or floss. ▪ The uses of mouthwash and tongue cleaner. ▪ The uses of single tufted toothbrush if necessary.
During Orthodontic Treatment	
Orthodontist	➢ Start orthodontic when fulfilling the well-established endpoints of periodontal therapy (Sanz *et al.,* 2020). ➢ Monitor patient's plaque control and gingival inflammation regularly via plaque and bleeding scores. ➢ Monitor BPE score regularly (3- or 6-month intervals). ➢ Refer the patient as necessary. ➢ Tailored orthodontic treatment for periodontally compromised patients: avoid excessive orthodontic stress.
Periodontist	➢ Continuously monitor periodontal conditions. ➢ Update the periodontal parameters every 3 or 6 months including radiographic assessment as needed. ➢ Professional supragingival debridement regularly. ➢ Periodontal treatment when needed. ➢ Tailored a preventive regime.
Both	➢ Remotivate the patients. ➢ Reinforcement of proper oral hygiene care. ➢ Continuously monitor the compliance with recommended home care therapy. ➢ Monitoring and addressing apical root resorption.
After Orthodontic Treatment	
Orthodontist	➢ Remind the patient regarding the importance of compliance to the retainer prescribed. ➢ Remind about the risk of relapse.
Periodontist	➢ Periodontal re-evaluation (clinical and radiographic evaluation). ➢ Decide the appropriate therapy (if needed) and maintenance interval according to the periodontal risk assessment. ➢ Assess mobility once periodontal attachment has fully healed subsequent to recent orthodontic treatment completion.
Both	➢ Remotivate the patients. ➢ Reinforcement of proper oral hygiene care.

Conclusion

In conclusion, it is evident that improper orthodontic intervention may jeopardize the integrity of periodontal structures, potentially exacerbating undiagnosed and untreated periodontitis and leading to undesirable consequences. The cases presented highlight how the absence of comprehensive periodontal screening and inadequate referrals for periodontal management contributed to the progression of periodontal disease in these patients. Issues such as deep infrabony defects, severe bone loss, and tooth mobility could have been mitigated with early intervention, better oral hygiene management, and closer coordination between healthcare providers. However, when conducted to an acceptable standard, orthodontic treatment has proven to be an effective intervention for enhancing both the function and aesthetics, particularly in patients experiencing pathological tooth migration.

Therefore, periodontal screening and necessary referral to a periodontist are imperative prerequisites before initiating orthodontic intervention. This ensures that any underlying periodontal concerns are addressed and managed appropriately. Strong interdisciplinary collaboration between the periodontist and orthodontist is crucial for ensuring the success of orthodontic treatment and preventing unwanted complications. Ensuring proper patient education, adherence to treatment guidelines successful long-term outcomes for patients undergoing orthodontic therapy.

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