REVIEW ARTICLE

# Time-Lapse Imaging (TLI) versus Preimplantation Genetic Testing (PGT): A Scoping Review on Embryo Assessment Strategies

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**Keywords:**
Time-lapse imaging; preimplantation genetic testing; embryo assessment; clinical outcomes

**ABSTRACT**

**Background:** Embryo selection remains a critical determinant in the success of assisted reproductive technologies (ART). While conventional morphological assessment is widely used, it lacks predictive precision and is prone to subjectivity. Two advanced technologies; Time-Lapse Imaging (TLI) and Preimplantation Genetic Testing (PGT) have emerged to enhance embryo viability assessment, yet their comparative effectiveness remains uncertain. This scoping review aimed to evaluate and compare the effectiveness of TLI and PGT in embryo selection for transfer, their impact on clinical outcomes, and the strengths and limitations of each method. **Methods:** A scoping review methodology based on PRISMA for scoping review 2020 guidelines was employed. Four databases PubMed, Scopus, Springer Link, and Cochrane Library were searched for articles published between 2014 and 2024. **Results:** A total of 20 eligible studies were included and analysed. TLI studies reported improved morphological assessment and non-invasive, real-time observation, with pregnancy rates ranging between 27.8% to 68% and live birth rates up to 45.9%. PGT, particularly PGT-A, showed superior outcomes in terms of implantation up to 76.8% and live birth rates up to 78.3%, especially among patients with recurrent pregnancy loss or advanced maternal age. However, PGT carries the risk of embryo damage due to its invasive nature and is associated with higher costs and longer processing times. TLI offers a safer and cost effective option for embryo selection with minimal risk to embryo integrity. TLI's integration with software tools such as iDA scores has further enhanced its diagnostic capability. Nonetheless, in specific clinical scenarios like recurrent miscarriages or known genetic disorders, PGT remains indispensable. **Conclusion:** Both TLI and PGT offer significant advantages in embryo assessment. While TLI is favorable for routine, non-invasive monitoring, PGT provides critical genetic insights.

## INTRODUCTION

Assisted reproductive technologies (ART) have transformed fertility treatment, but the success rate remains challenging, with a 2016 global success rate of 30.9% (Kupka et al., 2024). The conventional method of embryo selection, based on subjective morphological assessments, has limitations in accurately predicting a successful pregnancy. This has led to the development of new technologies, notably time-lapse imaging (TLI) and preimplantation genetic testing (PGT), which aim to improve the identification of viable embryos. While both TLI and PGT are designed to increase implantation rates and reduce miscarriages, they employ different mechanisms, and the debate over their comparative effectiveness is ongoing.

TLI is a non-invasive technology that allows embryologists to monitor embryo development continuously in a stable environment. By capturing images at regular intervals, TLI creates a video record of an embryo's growth, providing detailed insights into its developmental kinetics and morphology (Wang et al., 2023). This method enhances the traditional scoring system, as it allows for a more comprehensive and objective assessment of key parameters like cleavage timing and cell division patterns. Advanced algorithms, such as the Intelligent Data Analysis (IDA) score, further improve TLI's predictive accuracy by using AI to analyze large datasets and reduce human bias (Papamentzelopoulou et al., 2024). However, TLI's limitations include its dependence on high-quality data and a lack of consideration for patient-specific factors or genetic health.

PGT is an invasive procedure that involves screening embryos for genetic and chromosomal abnormalities before they are transferred to the uterus. PGT helps select the healthiest embryos, increasing the likelihood of a successful pregnancy and reducing the risk of genetic disorders and miscarriages, especially for patients with known hereditary risks (Sravya Gudapati et al., 2024). The accuracy of PGT has significantly improved with advancements from older methods like fluorescence in situ hybridization to modern

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techniques such as next-generation sequencing. Despite its benefits in improving outcomes, PGT is an invasive procedure that requires an embryo biopsy, which carries a potential risk to embryo viability (Burks et al., 2021). It also increases the overall cost and complexity of the treatment, making it less accessible for some patients.

The central question in modern ART is which method is more effective in selecting the most viable embryos for transfer. Both TLI and PGT have distinct advantages and limitations. The aim of this review is to provide a comprehensive analysis of the existing literature, synthesizing evidence to evaluate whether one technique demonstrates superiority, or if a combined approach yields the best outcomes. This analysis will offer insights into which embryo selection method is most effective, and whether the invasive nature of PGT is justified by improved results compared to the less invasive TLI. Ultimately, the findings will contribute to the development of more precise, reliable, and patient-centered embryo selection strategies, thereby enhancing success rates.

## MATERIALS AND METHODS

### Study design

This research utilizes a scoping review design to comprehensively map the existing evidence on the effectiveness of TLI and PGT in assessing embryo viability for assisted reproductive technology. The framework included the development of research objectives aligned with the research problems, the selection of articles that met the review's goals, and a screening process to ensure compliance with the inclusion and exclusion criteria, along with the availability of full-text articles.

### Search Method

Relevant research articles were retrieved from four medically and scientifically credible online databases: PubMed, Scopus, Springer Link and Cochrane Library. The following keywords were used to identify relevant publications: 'time-lapse imaging', 'time-lapse monitoring', 'TLI', 'preimplantation genetic testing', 'preimplantation genetic screening', 'PGT', 'embryo assessment', 'in vitro fertilization', 'intracytoplasmic sperm injection', 'invasive', 'embryo selection', 'embryo grading', 'fertilization rate', 'blastocyst rate', 'implantation rate', 'pregnancy rate', 'miscarriage rate', 'live birth rate', 'clinical outcome', 'cost', 'invasiveness', 'time', and 'accuracy'. Additionally, in order to further clarify and broaden the search parameters while using databases, Boolean operators (AND, OR) and asterisks (*) were utilized in combination with the search keywords.

### Inclusion and exclusion criteria

Several criteria were established and considered during the selection of relevant papers for this scoping review. Articles that failed to meet the inclusion criteria outlined in Table 1 were excluded from the analysis.

### Selection of studies

The research papers were selected following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews (PRISMA-ScR) standards. These standards provide guidelines for choosing, evaluating, and synthesizing studies in scoping reviews, and the most recent statement incorporates improvements in these approaches (Page et al., 2021). Articles published between 2014 and 2024 were extracted from online databases and screened. After eliminating duplicates from various sources, the remaining articles underwent title and abstract screening to filter out irrelevant studies. Subsequently, the full-text versions of the selected papers were retrieved. Next, the information in those articles was thoroughly examined to analyze the data on the effectiveness of TLI or PGT in embryo assessment. During the screening process, articles that did not meet the inclusion criteria or conformed to the exclusion criteria were excluded. The PRISMA extension for scoping reviews is presented in Figure 1.

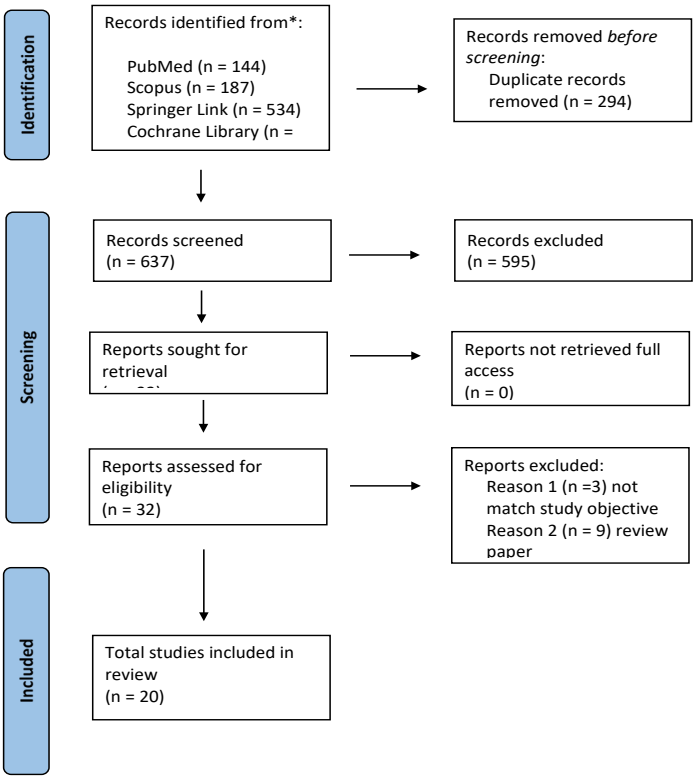


**Figure 1:** PRISMA flow diagram

**Data extraction**

The final phase for methodology is data retrieval from the chosen articles. The data were extracted and analysed through meticulous reading and examination to synthesize key insights of the studies according to objectives and identify advantages and limitations of TLI and PGT. The findings from the final selection were extracted presented in Table 2. Here, the characteristics of each study were summarized and were presented with their references, ordered by publication year (latest to oldest). A primary focus across these studies is the evaluation of embryo viability and clinical outcomes, alongside findings of the strengths and limitations of each technology.

**RESULTS**

A comprehensive search yielded, a total of 931 potential articles were identified from the selected database. After removing duplicates, 294 references remained. A total of 32 articles were eligible based on inclusion and exclusion criteria. Among the eligible articles, only 20 publications match with the objective of this study. There are 10 studies specifically discuss TLI, 9 focus on PGT, and 1 observational study compares the costs of both techniques

**Effectiveness TLI and PGT in selecting viable embryos for transfer**

Figure 2 presents a comparative analysis of TLI and PGT across three aspects: fertilization rate, blastocyst formation rate, and embryo quality. PGT demonstrated superior performance in fertilization rate and embryo quality, with a mean fertilization rate of 67.52% compared to 64.02% for TLI, and a significantly higher mean embryo quality score of 78.84% versus 65.08% for TLI. Conversely, TLI showed a slightly higher average blastocyst formation rate at 55.2%, compared to 51.46% in the PGT group.

**Impact of TLI and PGT on clinical outcomes**

Figure 3 presents a comparative analysis of TLI and PGT across four aspects: implantation rate, pregnancy rate, miscarriage rate, and live birth rate. PGT consistently demonstrates superior clinical outcomes in key indicators of ART success. For implantation and pregnancy rates, the mean percentages for PGT are 63.78% and 59.17%, respectively, which are significantly higher than TLI's 33.14% and 47.22%. Furthermore, PGT is associated with a greater likelihood of live birth, with a mean rate of 51.19% compared to 39.6% for TLI. In contrast, the TLI group showed a slightly lower mean miscarriage rate of 8.2% compared to 11.33% for PGT.

**Strength, limitations, and potential drawbacks of both TLI and PGT**

Table 3 presents a comparative analysis of TLI and PGT in terms of time, invasiveness, accuracy, and cost. TLI is a non-invasive, efficient, and relatively affordable method that provides real-time insights into an embryo's developmental kinetics without disrupting its environment. In contrast, PGT is a highly accurate but invasive procedure that genetically screens embryos, a process that is more time-consuming and significantly more expensive. The invasiveness of PGT carries a risk of harming the embryo, potentially compromising its viability. While TLI relies on morphokinetic parameters to predict success, PGT directly assesses chromosomal health; however, its ability to detect complex genetic abnormalities, such as mosaicism, remains limited due to sampling constraints.

**Table 1**: Inclusion and exclusion criteria

| Inclusion Criteria | Exclusion Criteria |
|---|---|
| a) Studies that are published in English. | a) Studies that are published in languages other than English. |
| b) Studies that are published from year 2014 to 2024. | b) Studies that are published before year 2014. |
| c) Studies that are related to embryo assessment with TLI or PGT. | c) Studies that are not related to embryo assessment. |
| d) Full-text articles. | d) Unpublished studies, conference paper, grey literature, letters, editorials, reviews (systematic, scoping, narrative reviews), and meta-analysis. |
| e) Clinical studies that consists of related specific keywords and related with the objectives. | e) Studies that conducted on animals |

**Table 2:** Findings of TLI and PGT in embryo assessment.

| Author | Study Design | Assessment method | Findings | | |
|---|---|---|---|---|---|
| | | | Embryo Viability | Clinical outcomes | Strength & limitations |
| Xu et al., (2024) | Retrospective | PGT-A with NGS | (i)High quality embryo: 67.7%<br><br>(ii)19 mosaic embryo used for transfer | (i)Pregnancy Rate: 64.2%<br><br>(ii)Miscarriage Rate: 17.2%<br><br>(iii)Live Birth Rate: 51.3% | PGT enhanced selection of euploid embryos, and increase the chances of successful pregnancy were enhanced, particularly in patients with a history of recurrent miscarriages |
| Illingworth et al.(2024) | Randomized Controlled Trial (RCT) | TLI with iDA score | (i)Fertilization rate: 60.95%<br><br>(ii)Blastocyst Formation Rate: 68.5%<br><br>(iii)Mean viable embryo iDA score transfer (9.09±0.68) | (i)Pregnancy Rate: 46.5%<br><br>(ii)Live Birth Rate: 39.8% | TLI took only 21.3 seconds to evaluate embryos |
| Bhide et al., (2024) | RCT | TLI | Fertilization rate: 60.66% | (i)Pregnancy Rate: 42.2%<br><br>(ii)Miscarriage Rate: 8.7%<br><br>(iii)Live Birth Rate: 33.7% | TLI only requires monitoring and recording of the embryos over time, which is less labor intensive and requires fewer human resources. |
| Harris et al.,(2024) | Retrospective | PGT-A | Patient age under 35<br>(i)Fertilization rate: 62.94%<br>(ii)Blastocyst rate: 54.03%<br><br>Patient age 35-37<br>(i)Fertilization rate: 63.58%<br>(ii)Blastocyst formation rate: 52.73%<br><br>Patient age 38-40<br>(i)Fertilization rate: 62.96%<br>(ii)Blastocyst formation rate: 46.08% | Patient age under 35<br>(i)Pregnancy rate: 54.3%<br>(ii)Miscarriage rate: 19.5%<br>(iii)Live birth rate: 43.3%<br><br>Patient age 35-37<br>(i)Pregnancy Rate: 64.8%<br>(ii)Live Birth Rate: 43.0%<br>(iii)Miscarriage Rate: 8%<br><br>Patient age 38-40<br>(i)Pregnancy rate: 53.3%<br>(ii)Miscarriage rate: 19.5%<br>(iii)Live birth rate: 43.3% | PGT allows identification and prioritization of chromosomally normal embryos which may lead to better clinical outcomes. |
| Katz-Jaffe et al., | Prospective | PGT-A | (i)Fertilization Rate: 59.42% | (i)Implantation Rate: 76.8% | - |

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| (2024) | | | | (ii)Miscarriage Rate: 4%<br><br>(iii)Live Birth Rate: 78.3% | |
| Zheng et al., (2023) | Retrospective | PGT-A with NGS | (i)Fertilization rate: 70.75%<br><br>(ii)High quality embryo: 89.92% | (i)Pregnancy Rate: 63.55%<br><br>(ii)Live Birth Rate: 55.26% | - |
| Meng et al., (2022) | RCT | TLI with KID score | Mean top quality embryo: Control (7.15 ± 4.42) vs TLI (5.62 ±3.07) | (i)Pregnancy Rate: 49.18%<br><br>(ii)Miscarriage Rate: 3.33%<br><br>(iii)Live Birth Rate: 45.9% | TLI offer a real-time observation and captures detailed developmental and abnormalities such as direct cleavage and reverse cleavage. |
| Singh et al., (2022) | Retrospective | PGT-A with NGS | Fertilization rate: 69.54% | (i) Implantation Rate: 66.6%<br><br>(ii) Pregnancy Rate: 81.8%<br><br>(iii) Miscarriage Rate: 14.8%<br><br>(iv) Live Birth Rate: 66.6% | (i)Abnormalities detected (Gene mutatiom:40% Chromosal abnormalities; 54.5%<br>Mosaic: 5.45%)<br><br>(ii)The application of NGS in PGT process provides a comprehensive and accurate screening of all 24 chromosomes |
| Sui et al., (2020) | RCT | PGT-A with SNP | Fertilization rate: PGT (70%) | (i)Implantation Rate: 48.51%<br><br>(ii)Pregnancy Rate: 51.3%<br><br>(iii)Miscarriage Rate: 1.74%<br><br>(iv)Live Birth Rate: 43.48% | (i)A significant proportion of cycles (50.27%) and patients (24.27%) in the PGT-A group failed to reach embryo transfer due to the loss of euploid embryos during blastocyst biopsy.<br><br>(ii)PGT-A process, including blastocyst biopsy, genetic screening, embryo vitrification, and counselling, can take a lot of time. This process may slow down embryo transfer and increase stress for patients already facing infertility. wait for results.<br><br>(ii)PGT-A can still miss certain issues like mosaicism where an embryo has a mix of normal and abnormal cells, and errors can |

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| | | | | | occur due to limitations in trophectoderm biopsy procedures |
| van de Wiel et al.,(2020) | Observational | TLI and PGT | NA | NA | TLI is a relatively inexpensive add-on, with prices ranging from £0 to £795 and PGT A usually costs between £2,100 and £3,295, with an average price of £2,695. |
| Masbou et al., (2019) | Retrospective | PGT-A | - | (i)Implantation Rate: 63.2%<br>(ii)Live Birth Rate: 54%<br>(iii)Miscarriage Rate: 14.5% | PGT is an invasive procedure can lead to cellular damage, potentially affecting the embryo's development and its implantation potential |
| Ozgur et al., (2019) | RCT | PGT-A with NGS | (i)Fertilization Rate: 81.0%<br>(ii)Blastocyst formation Rate: 53.0% | Patient under 35:<br>(i)Pregnancy Rate: 61.3%<br>(ii)Miscarriage Rate: 6.1%<br>(iii)Live Birth Rate: 58.6% | Time for PGT results takes 7 days after the biopsy. |
| Barberet et al., (2018) | RCT | TLI | (i)Fertilization rate: 75.4%<br>(ii)Blastocyst formation rate: 44.8%<br>(iii)Viable embryo rate: 47.8% | (i)Implantation Rate: 35.1%<br>(ii)Pregnancy Rate: 48.6%<br>(iii)Miscarriage rate: 14.9% | By day 3 or day 5, embryologists have a full developmental profile to inform selection and transfer |
| Verpoest et al., (2018) | RCT | PGT-A with aCGH | – | (i)Pregnancy Rate: 38%<br>(ii)Miscarriage Rate: 8%<br>(iii)Live Birth Rate: 30% | PGT involves advanced procedures such as laser polar body biopsy and array comparative genomic hybridization requires specialized lab equipment and reagent such as those for DNA extraction, amplification, sequencing and trained personnel. |
| Goodman et al., (2016) | RCT | TLI with KID score | (i)Fertilization rate: 57.24%<br>(ii)KIDscore TLI (2.6 ± 1.2) | (i)Implantation Rate: 51%<br>(ii)Pregnancy Rate: 68% | TLI allows the identification of multi nucleation and irregular cell divisions, which are linked to reduced implantation success. |
| Kieslinger et al., (2016) | Prospective | TLI with EEVA | (i)Fertilization rate: 67.4%<br>(ii)Top quality embryo: 82.3% | (i)Implantation Rate: 35%<br>(ii)Pregnancy Rate: 40.4%<br>(iii)Live Birth Rate: 32.9% | Embryos remain in a stable incubator environment, avoiding potential stress from handling and environmental changes. |
| Siristatidis et al., (2015) | Prospective | TLI | (i)Fertilization Rate: 65.4% | (i)Pregnancy Rate: 65.7%<br>(ii)Live Birth Rate: 45.71% | TLI helps predict which embryos will reach the blastocyst stage, optimizing transfer timing and improving outcomes for patients. |

| | | | | | |
|---|---|---|---|---|---|
| Park et al., (2015) | RCT | TLI | (i)Fertilization rate: 49.47%<br><br>Mean good quality embryo (2.41±2.3) | (i)Implantation Rate: 27.9%<br><br>(ii)Pregnancy Rate: 33.5%<br><br>(iii)Miscarriage Rate: 33.3% | - |
| Fodina et al., (2015) | Cohort | TLI | Fertilization Rate: 64.4% | Total all clinical outcome rates:<br>(i)Implantation rate: 31.7%<br>(ii)Pregnancy Rate: 39.7%<br>(iii)Miscarriage Rate: 12.1%<br><br>Patient younger than 35:<br>(i)Implantation rate: 35.5%<br>(ii)Pregnancy Rate: 39.8%<br>(iii)Miscarriage Rate: 0%<br><br>Patient older than 35:<br>(i)Implantation rate: 15.8%<br>(ii)Pregnancy Rate: 27.8%<br>(iii)Miscarriage Rate: 10.0% | Non-invasive and stable culture conditions, minimizes exposure to fluctuations in $CO_2$, pH, temperature due to no need to remove embryos from incubator. |
| Rubio et al., (2014) | Prospective | TLI | (i)Fertilization Rate: 75.3%<br><br>(ii)Blastocyst formation rate: 52.3% | (i)Pregnancy Rate: 65.3%<br><br>(ii)Miscarriage rate: 16.6% | The system of TLI has precise timing of embryonic development helps reduce observer subjectivity |

*Note. TLI = Time-Lapse Imaging; PGT = Preimplantation Genetic Testing; NA: Not applicable: PGT-A = Preimplantation Genetic Testing for Aneuploidy; RCT = Randomized Controlled Trial; EEVA = Early Embryo Viability Assessment; NGS = Next-Generation Sequencing; SNP = Single- Nucleotide Polymorphism; aCGH = Array Comparative Genomic Hybridization; iDA = Intelligent Data Analysis; KID = Kinetics Information Data

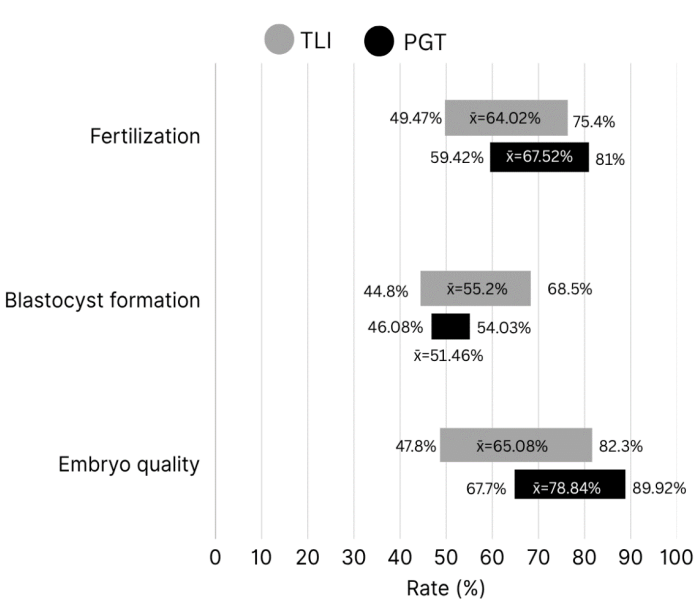


**Figure 2:** Horizontal Bar Chart comparing TLI and PGT effectiveness in selecting the most viable embryos in terms of fertilization rate, blastocyst formation rate and embryo quality

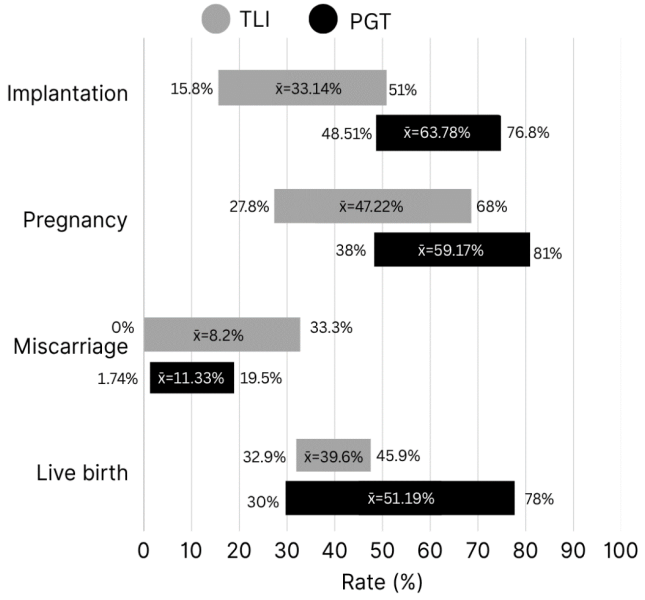


**Figure 3:** Horizontal Bar Chart comparing TLI and PGT effectiveness in clinical outcomes in terms implantation rate, pregnancy rate, miscarriage rate and live birth rate

**Table 3**: Strength and limitation of TLI and PGT in terms of time, invasiveness, accuracy and cost

| Aspect | TLI | PGT |
|---|---|---|
| **Time** | • Very quick takes only 21 seconds to check embryos (Illingworth et al., 2024).<br>• By day 3 to 5, gives a full growth profile for transfer (Barberet et al., 2018).<br>• Can predict which embryos reach blastocyst stage (Siristatidis et al., 2015). | • Slower because includes biopsy, genetic testing, freezing, and counselling (Sui et al., 2020).<br>• Results usually take around 7 days (Ozgur et al., 2019). |
| **Invasiveness** | • Non-invasive as embryos stay in incubator, no disturbance (Fodina et al., 2015).<br>• Stable culture, no stress from handling (Kieslinger et al., 2016). | • Invasive because embryo biopsy may cause cell damage (Masbou et al., 2019).<br>• Many cycles fail to reach transfer due to embryo loss (Sui et al., 2020). |
| **Accuracy** | • Detects abnormal cell divisions linked to poor outcomes (Goodman et al., 2016).<br>• Tracks exact timing of divisions, reducing subjectivity (Rubio et al., 2014).<br>• Spots problems like direct/reverse cleavage in real-time (Meng et al., 2022). | • Next generation sequencing gives detailed chromosome analysis (Singh et al., 2022).<br>• May miss mosaicism (Sui et al., 2020).<br>• Errors possible from biopsy limitations. |
| **Cost** | • Cheaper around £0 to £795 with median £478(van de Wiel et al., 2020).<br>• Requires monitoring and recording of the embryos over time, which is less labor-intensive and require fewer human resources (Bhide et al., 2024). | • Much more expensive around £2,100 to £3,295 with median £2,695 (van de Wiel et al., 2020).<br>• Full package may cost more £9,500 (van de Wiel et al., 2020).<br>• Requires advanced labs & procedures (Verpoest et al., 2018). |

## DISCUSSSION

### Effectiveness of TLI and PGT in selecting the most viable embryos for transfer, in terms of fertilization rate, blastocyst formation rate, and embryo quality

PGT generally demonstrates a better performance in fertilization rate and embryo quality. The mean fertilization rate for PGT is 67.52% (Harris et al., 2024; Katz-Jaffe et al., 2024; Zheng et al., 2023; Singh et al., 2022; Sui et al., 2020; Ozgur et al., 2019), which is higher than TLI's 64.02% (Bhide et al., 2024; Illingworth et al.,2024; Barberet et al., 2018; Goodman et al., 2016; Kieslinger et al., 2016; Fodina et al., 2015; Park et al., 2015; Siristatidis et al., 2015; Rubio et al., 2014), and it quite falls within the normal range of fertlization rate for this procedure (Thamarai Fertility, 2018). While some studies show modest improvements with PGT (Sui et al., 2020), others report more significant gains (Singh et al., 2022), indicating that PGT offers more stable and predictable fertilization outcomes compared to the widely varying results seen with TLI. Additionally, PGT shows a higher average embryo quality score of 78.84% (Xu et al., 2024; Zheng et al., 2023) compared to TLI's 65.08% (Barberet et al., 2018; Kieslinger et al., 2016). This can be attributed to several factors, including the fact that patients undergoing PGT may be in more advanced IVF centers with highly skilled embryologists and optimized lab conditions.

When it comes to blastocyst formation rate, TLI shows a slight advantage with an average of 55.2% (Illingworth et al.,2024; Barberet et al., 2018; Rubio et al., 2014) compared to PGT's 51.46% (Harris et al., 2024; Singh et al., 2022; Ozgur et al., 2019). The blastocyst formation rate is the percentage of fertilized eggs that develop into blastocysts (Day 5 or 6 embryos), and the the success of PGT in this area is highly dependent on maternal age, with some younger women under 35 years old showing a higher blastocyst formation rate of 54.03% (Harris et al., 2024). It's also important to note that a cohort of some embryos intended for PGT will inherently contain aneuploid or mosaic embryos, which can influence the overall observed blastocyst formation rate. In contrast, TLI has shown the potential for more significant improvements in blastocyst development in specific contexts (Illingworth et al., 2024).

### Impact of TLI and PGT on clinical outcomes, including implantation rates, pregnancy rates, miscarriage rates, and live birth rate

PGT consistently demonstrates superior clinical outcomes compared to TLI across several critical aspects. For instance, PGT's average implantation rate is 63.78% (Katz-Jaffe et al., 2024; Singh et al., 2022; Sui et al., 2020; Masbou et al., 2019; Ozgur et al., 2019), significantly higher than TLI's 33.14% (Barberet et al., 2018; Goodman et al., 2016; Kieslinger et al., 2016; Fodina et al., 2015; Park et al., 2015). This pronounced difference is largely attributed to PGT's ability to identify and select genetically healthy, or euploid, embryos, which directly addresses a primary cause of implantation failure. Similarly, PGT shows a higher average pregnancy rate of 59.17% (Harris et al., 2024; Xu et al., 2024; Zheng et al., 2023; Singh et al., 2022; Sui et al., 2020; Verpoest et al., 2018) compared to TLI's 47.22% (Bhide et al., 2024; Illingworth et al.,2024; Meng et al., 2022; Barberet et al., 2018; Goodman et al., 2016; Kieslinger et al., 2016; Park et al., 2015; Fodina et al., 2015; Siristatidis et al., 2015; Rubio et al., 2014) and a greater likelihood of a live birth, with a mean rate of 51.19% in PGT (Harris et al., 2024; Katz-Jaffe et al., 2024; Xu et al., 2024; Zheng et al., 2023; Singh et al., 2022; Sui et al., 2020; Masbou et al., 2019; Ozgur et al., 2019; Verpoest et al., 2018) versus TLI's 39.60% (Bhide et al., 2024; Illingworth et al., 2024; Meng et al., 2022; Kieslinger et al., 2016; Siristatidis et al., 2015). While TLI selects morphologically normal embryos, it does not evaluate genetic health, a key factor in achieving ongoing pregnancy, which may explain its lower success rates.

Conversely, while PGT excels in the majority of success aspects, TLI shows a slightly lower average miscarriage rate. TLI studies reported an average miscarriage rate of 8.2% (Bhide et al., 2024; Meng et al., 2022; Barberet et al., 2018; Fodina et al., 2015; Park et al., 2015; Rubio et al., 2014), whereas PGT studies had an average of 11.33% (Harris et al., 2024; Katz-Jaffe et al., 2024; Xu et al., 2024; Singh et al., 2022; Sui et al., 2020; Masbou et al., 2019; Ozgur et al., 2019; Verpoest et al., 2018). This unexpected finding may be due to the differing patient populations studied; PGT studies is often utilized for patients with a higher baseline risk of miscarriage, such as those with advanced maternal age or a history of recurrent pregnancy loss, which could skew the average higher despite PGT's effectiveness in preventing genetic miscarriages. PGT's targeted approach of screening for chromosomal abnormalities is highly effective, leading to a reduction in miscarriage rates in many studies (Singh et al., 2022; Xu et al., 2024), but this benefit is not universally reported, which contributes to the observed range and average.

### Strengths and limitations of TLI and PGT in terms of cost, invasiveness, time, and accuracy

TLI has high efficiency, non-invasive nature, and cost-effectiveness. The process is rapid, with embryo assessment taking as little as 21.3 seconds using Intelligent Data Analysis (iDA) algorithms (Illingworth et al., 2024). This

non-invasive approach avoids direct embryo manipulation, minimizing the risk of damage and maintaining a stable culture environment, which is crucial for embryo integrity (Kieslinger et al., 2016). Furthermore, TLI is more affordable, with costs ranging from £0 to £795, making it a more accessible option for many patients (van de Wield et al., 2020). However, TLI's primary limitation is its inability to directly assess genetic health. While it can identify morphological abnormalities like multi-nucleation and irregular cell divisions, embryos with ideal appearance may still carry genetic defects such as aneuploidy, which can compromise their viability despite appearing healthy (Meng et al., 2022).

In contrast, PGT excels in accuracy and genetic analysis but is limited by its invasiveness, cost, and time-consuming nature. PGT utilizes advanced techniques such as next-generation sequencing and array comparative genomic hybridization to provide a comprehensive genetic profile of the embryo, enabling the detection of chromosomal abnormalities like Down syndrome (Singh et al., 2022). This high level of genetic screening is crucial for patients with known hereditary risks or advanced maternal age, as it significantly reduces the risk of miscarriage and improves the likelihood of a successful pregnancy. The procedure is invasive, requiring a blastocyst biopsy, which can potentially damage the embryo and result in a failure to transfer in some cases (Sui et al., 2020). The process is also time-intensive, with results taking about 7 days to become available, and it is significantly more expensive, with costs ranging from £2,100 to £9,500 depending on the package (van de Wield et al., 2020). While PGT offers superior genetic insight, it may also yield false positives or negatives due to mosaicism, where some cells are normal and others are not, potentially leading to the discarding of viable embryos (Sui et al., 2020)

**Limitation of study**

A major weakness is the absence of direct, head-to-head comparative studies between TLI and PGT, forcing the review to evaluate each technology independently. This approach may not accurately reflect their combined effectiveness in clinical practice. The study's conclusions are also limited by the significant variability across the included literature, including differences in protocols, patient populations, and success metrics. The inconsistent nature of embryo assessment methods further complicates direct comparisons. Additionally, the review is susceptible to selection bias, as differences in patient populations also contribute to this bias which TLI is often used in broader, healthier populations, while PGT is typically reserved for cases with a poorer prognosis, like advanced maternal age. Finally, the review notes that PGT studies may report more favorable outcomes because they are often conducted in highly specialized IVF centers with more skilled staff and optimized lab conditions, which is a factor not consistently present in TLI studies.

**Future research directions**

Future research on embryo selection for in vitro fertilization should focus on direct comparisons between TLI and PGT to better understand their combined effectiveness. While existing studies often examine these technologies in isolation, or focus on how they complement each other, there's a critical need for large-scale, methodologically rigorous studies, such as randomized controlled trials, to provide more definitive evidence on their performance in clinical settings. Furthermore, the integration of artificial intelligence is rapidly advancing both TLI and PGT, with AI-driven algorithms analyzing time-lapse data to predict embryo viability and ploidy (Barnes et al., 2023). Similarly, non-invasive PGT is revolutionizing genetic screening by analyzing cell-free DNA, potentially eliminating the need for a biopsy and reducing associated risks (Cengiz Cinnioğlu et al., 2023). These technological advancements make direct comparative studies even more crucial for refining assisted reproductive practices and improving patient outcomes.

**CONCLUSION**

This scoping review highlights TLI and PGT are two distinct but complementary tools used in ART to improve embryo selection. TLI provides a non-invasive, continuous assessment of embryo development, which is particularly effective for predicting blastocyst formation and improving embryo quality. However, its impact on overall pregnancy and live birth rates is modest. In contrast, PGT is a more invasive but highly effective genetic screening method that significantly improves live birth rates by identifying and preventing the transfer of chromosomally abnormal embryos, which is especially beneficial for older patients or those with a poor prognosis. The decision to use either technology depends on individual patient factors, such as the need for genetic screening and the balance of associated costs and risks.

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