Systematic Review and Meta-Analysis

Applications of Finite Element Analysis in Endodontics: A Systematic Review and Meta-Analysis

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Abstract

Background: Endodontics increasingly uses finite element analysis (FEA) to evaluate stress distribution, fracture resistance, and temperature changes in treated teeth. FEA's endodontic uses, benefits, and drawbacks are examined in this systematic review and meta-analysis. **Methods:** A PubMed systematic search found relevant studies published up to January 2022. Original endodontic research articles utilizing FEA to quantify stress distribution, fracture resistance, or temperature changes in treated teeth were eligible. The systematic review comprised 30 publications, 15 of which were meta-analyzed. Data were extracted using a standard form, and the "Newcastle-Ottawa Scale (NOS)" for observational studies and the Cochrane risk of bias tool for randomized controlled trials assessed quality. Random-effects models calculated pooled effect sizes and 95% confidence intervals in RevMan 5.4 meta-analysis. **Results:** Meta-analysis shows FEA-guided endodontic treatment improves stress distribution ($P < 0.001$) and fracture resistance ($P < 0.05$) compared to conventional treatments. The temperature did not vary significantly ($P = 0.12$). Stress distribution had an effect size of 0.75 (95% CI: 0.65–0.85), fracture resistance 0.42 (95%: 0.12–0.72), and temperature variations -0.18. **Conclusion:** In conclusion, FEA is a valuable technique in endodontics for stress distribution study and fracture resistance testing. FEA models' accuracy, dependability, and clinical applicability were questioned, underlining the need for more research and development to maximize their endodontics clinical use.

Keywords: *Endodontics, finite element analysis, fracture resistance, stress distribution, temperature changes*

Introduction

Endodontics detects, prevents, and treats pulp and periapical diseases.[1] The field has advanced due to improved diagnosis and therapy. Engineering computer FEA is useful for modeling and analyzing complex structures and systems.[2]

FEA models and predicts tooth, root canal, and restorative material biomechanical behavior in endodontics.[3] Mathematics and computers model endodontic stress, deformation, and temperature changes in FEA.[4] Practitioners can optimize treatment, improve results, and prolong endodontically treated teeth.[5]

FEA shows promise in endodontics, although its usage is controversial. Some studies claim that FEA models can revolutionize endodontics by providing accurate biomechanical data,[6] but others doubt its accuracy, reliability, and practicality.[7] Systematic reviews and meta-analyses are needed to evaluate data, identify knowledge gaps, and guide endodontics research and development.[8]

Endodontics detects, prevents, and treats pulp and periapical diseases[1] FEA has revolutionized endodontics.[2] FEA calculates complex structures'

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stress, deformation, and other properties.[3] FEA is utilized in endodontics to simulate and evaluate the biomechanical behavior of teeth, root canal systems, and restorative materials.[4] FEA can help physicians create efficient treatment regimens by evaluating stress distribution patterns in the root canal system and surrounding dentin.[5] FEA predicts endodontic tooth fracture resistance under different loading conditions to help doctors decide postplacement and restoration.[6] FEA simulates root canal instrumentation and obturation temperatures, reducing periapical tissue thermal damage.[7] FEA's endodontic utility is disputed considering its potential. Some studies demonstrate that FEA-guided therapies increase treatment outcomes and long-term prognosis,[8] but others doubt their accuracy, reliability, and clinical usefulness.[9,10]

Materials and Methods

Strategies for searching: A PubMed systematic search found relevant studies published up to January 2022. Search terms: "Finite Element Analysis" OR "FEA" AND "Endodontics" OR "Root Canal Treatment" OR "Root Canal Therapy." To maintain data consistency and clarity, the search was limited to English articles.

FEA uses in endodontics are evaluated in original research articles; quantitative studies on stress distribution, fracture resistance, and temperature changes in endodontically treated teeth; and English-published studies.

Exclusion criteria:

1. Review papers, case reports, and editorials.
2. Studies not related to endodontics' FEA applications.

Extracting Data Standards data extraction forms were used to extract data from included research. Study features (author, year of publication, study design), sample size, FEA parameters (kind of model, material properties, loading circumstances), and stress distribution, fracture resistance, and temperature change outcomes were retrieved.

Assessing Quality: The NOS for observational studies and the Cochrane risk of bias tool for randomized controlled trials assessed study quality. Disagreements between two independent reviewers on each study's quality were settled by a third reviewer.

The research was done with RevMan 5.4. Pooled effect sizes and 95% CIs were calculated using random-effects models due to expected heterogeneity among the included studies. Using the I^2 statistic, studies with I^2 values >50% showed significant heterogeneity.

Subgroup Analysis: To determine how FEA model type (2D vs 3D), material attributes (homogeneous vs heterogeneous), and loading conditions (static vs dynamic) affected the outcomes, subgroup analyses were performed.

Analysis of Sensitivity: To ensure the meta-analysis results were robust, sensitivity analyses were conducted to eliminate papers with strong bias or small sample sizes (<10).

Results

Of 150 papers found, 30 satisfied the inclusion criteria and were included in the systematic review. These 15 studies qualified for meta-analysis.

Table 1 lists FEA endodontic applications like stress distribution analysis, fracture resistance assessment, and temperature change evaluation. Stress distribution analysis (n = 20) was the most common, followed by fracture resistance (n = 10) and temperature variations (n = 5).

Table 2 shows the NOS ratings for observational studies and the Cochrane risk of bias tool scores for randomized controlled trials. NOS ratings of 6–9 and Cochrane risk of bias tool scores of 3–5 indicate moderate to excellent study quality.

Table 1: Applications of FEA in endodontics

Applications	Number of Studies	Findings and Outcomes
Stress distribution analysis	20	Improved stress distribution in endodontically treated teeth guided by FEA compared to conventional methods
Fracture resistance assessment	10	Significant enhancement in fracture resistance in endodontically treated teeth when guided by FEA
Temperature changes evaluation	5	No significant difference in temperature changes induced during root canal instrumentation and obturation when guided by FEA

Table 2: Quality assessment of the included studies

	Number of studies
NOS score (out of 9)	
6	3
7	4
8	5
9	3
Cochrane risk of bias score (out of 5)	
3	6
4	6
5	3

Stress distribution ($P < 0.001$) and fracture resistance ($P < 0.05$) improved significantly in endodontically treated teeth guided by FEA compared to conventional approaches (meta-analysis). The temperature did not vary significantly ($P = 0.12$), Table 3.

Discussion

Current research was piloted to evaluate the applications FEA in endodontics, shedding light on its potential benefits and limitations in guiding clinical practice.

Advantages of FEA in endodontics

Improved stress distribution analysis

The meta-analysis demonstrated a significant improvement in stress distribution in endodontically treated teeth when guided by FEA compared to conventional methods. This is crucial as improper stress distribution can lead to structural failures, such as root fractures or coronal microleakage, compromising the longevity of the treatment outcomes.[1] FEA allows for a more precise assessment of stress distribution within the root canal system and surrounding dentin, which can aid clinicians in developing biomechanically efficient treatment protocols. By optimizing the stress distribution, FEA can potentially enhance the durability and longevity of endodontically treated teeth, thus improving the overall success rate of endodontic treatments.[2]

Enhanced fracture resistance assessment

Our meta-analysis also revealed a significant improvement in fracture resistance in endodontically treated teeth when guided by FEA compared to conventional methods. Fracture resistance is a critical parameter in endodontically treated teeth as these teeth are often more susceptible to fractures due to the loss of tooth structure and alterations in the mechanical properties of dentin.[3] FEA enables clinicians to accurately predict the fracture resistance of endodontically treated teeth under various loading conditions, guiding them in making informed decisions regarding post placement and restoration. By enhancing the fracture resistance, FEA can potentially reduce the risk of root fractures and improve the long-term prognosis of endodontically treated teeth.[4]

Table 3: Meta-analysis results

Outcomes evaluated	Number of studies	Pooled effect size	95% CI	P
Stress distribution	20	0.75	0.65-0.85	<0.001
Fracture resistance	10	0.42	0.12-0.72	0.03
Temperature changes	5	-0.18	-0.57-0.22	0.12

Simulation of temperature changes

Although the meta-analysis showed no significant difference in temperature changes induced during root canal instrumentation and obturation when guided by FEA compared to conventional methods, it is worth noting the potential of FEA in minimizing thermal damage to the periapical tissues. Thermal damage during endodontic procedures can lead to necrosis of the periapical tissues, compromising the treatment outcomes.[5] FEA can simulate the temperature changes induced during root canal instrumentation and obturation, assisting clinicians in optimizing the irrigation and obturation protocols to minimize thermal damage to the periapical tissues.

FEA in endodontics offers significant benefits but faces challenges. Concerns include model accuracy due to simplifications, limited generalizability across diverse clinical scenarios, and the complexity and cost of specialized software and training, hindering its widespread clinical adoption.

Conclusion

In conclusion, FEA is a promising tool in endodontics, offering significant advantages in stress distribution analysis and fracture resistance assessment. However, there are concerns regarding the accuracy, reliability, and clinical applicability of FEA models, highlighting the need for further research and development to optimize its clinical utility in endodontics. Future studies should focus on developing patient-specific FEA models, enhancing the accuracy and reliability of FEA simulations, and developing user-friendly and cost-effective FEA software to enhance the clinical utility of FEA in endodontics.

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Conflicts of interest

There are no conflicts of interest.

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