Research Article

Self-Updating Neural Networks for Real-Time Canal Morphology Mapping During Rotary Instrumentation

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Accurate real-time mapping of root canal morphology is critical for safe and efficient rotary instrumentation in endodontic procedures. Traditional imaging methods often fail to provide dynamic feedback during instrumentation, limiting the precision of treatment. This study proposes a self-updating neural network framework capable of continuously learning from intraoperative sensor and imaging data to model canal morphology in real time. By integrating adaptive learning mechanisms, the network updates its predictions as new information becomes available, enabling precise guidance during rotary instrumentation. Preliminary evaluations demonstrate improved mapping accuracy and responsiveness compared to static models, highlighting the potential of AI-driven adaptive systems in enhancing endodontic outcomes. This approach represents a significant step toward intelligent, real-time dental navigation systems.

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Introduction

Accurate understanding of root canal morphology is essential for the success of endodontic treatment, as canal shape and complexity directly influence instrumentation outcomes and clinical prognosis. Variations in canal anatomy, such as curvature, isthmuses, and C-shaped configurations, present significant challenges during both manual and rotary instrumentation, often leading to procedural errors like ledging, perforation, or incomplete debridement (Nagy et al., 1997; Li et al., 2011; Cheung & Cheung, 2008). The selection and performance of instrumentation systems, including manual files and contemporary rotary instruments, further impact canal shaping and preparation quality (de Oliveira Alves et al., 2012; Martins et al., 2022; Zuolo et al., 2018).

Recent advancements in artificial intelligence (AI) have introduced new possibilities for enhancing precision in endodontics, particularly through predictive modeling and real-time guidance systems (Singh, 2022). Self-updating neural networks represent a novel approach that can continuously learn from incoming intraoperative data, enabling dynamic adaptation to complex and variable canal geometries. By integrating AI-driven predictive capabilities with rotary instrumentation, clinicians can achieve more accurate canal morphology mapping in real time, potentially improving procedural safety and treatment outcomes.

Despite promising developments, current approaches often rely on static imaging or preoperative scans, which fail to account for changes occurring during instrumentation. There remains a critical need for intelligent, adaptive systems that can respond instantaneously to the evolving anatomy of the canal. This study explores the design and application of self-updating neural networks for real-time canal morphology mapping, aiming to provide a framework for AI-assisted endodontic navigation that enhances both efficacy and safety during rotary instrumentation.

Methodology

This study aims to develop a self-updating neural network framework for real-time canal morphology mapping during rotary instrumentation. The methodology is structured into four main phases: data acquisition, preprocessing, network design and self-updating mechanism, and evaluation.

Data Acquisition

Root canal morphology data were collected from extracted human premolars and molars, representing a

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variety of canal geometries including oval, C-shaped, and curved canals (Nagy et al., 1997; Li et al., 2011; Cheung & Cheung, 2008). Rotary instrumentation was performed using five commonly employed systems to capture the mechanical interaction between instruments and canal walls (Martins et al., 2022; de Oliveira Alves et al., 2012; Zuolo et al., 2018). Real-time instrumentation data were obtained via torque, force, and micro-imaging sensors integrated into the rotary handpiece.

Data Preprocessing

Collected data underwent preprocessing to ensure consistency and usability for neural network training:

Image normalization

Micro-CT and intraoperative imaging data were standardized to a uniform resolution.

Noise reduction

Gaussian filtering and median filters were applied to remove imaging artifacts.

Segmentation

Canal boundaries were extracted using semi-automated segmentation algorithms to generate 3D canal geometries (Li et al., 2011).

Feature extraction

Geometric and morphological features such as curvature, canal diameter, taper, and cross-sectional shape were extracted for neural network input (Singh, 2022).

Neural Network Architecture and Self-Updating Mechanism

A hybrid convolutional-recurrent neural network (CNN-RNN) architecture was designed to process spatial and temporal features of canal morphology during instrumentation. The CNN component encodes 3D spatial information of the canal, while the RNN component captures sequential changes in morphology as the rotary instrument progresses.

To enable self-updating, the network incorporates an adaptive learning loop:

Initial predictions are generated based on preoperative imaging and historical canal data.

Intraoperative sensor feedback is continuously integrated.

The network updates weights using incremental learning without retraining from scratch, maintaining stability while adapting to new morphologies (Singh, 2022).

Evaluation

The network's performance was evaluated against static models and traditional canal mapping approaches. Metrics included:

Mapping accuracy

Comparing predicted vs. actual canal geometries from micro-CT scans.

Responsiveness

Time lag between sensor feedback and network update.

Instrument safety

Assessment of canal wall deviation and procedural errors during rotary instrumentation (Nagy et al., 1997; Li et al., 2011; Cheung & Cheung, 2008).

This methodology allows the neural network to dynamically adapt to previously unseen canal geometries while providing real-time guidance, potentially reducing procedural errors and improving endodontic outcomes.

Table 1: summarizes the major components of the proposed methodology

Component	*Description*	*References*
Data Sources	Extracted premolars and molars with diverse canal morphologies	Nagy et al., 1997; Li et al., 2011; Cheung & Cheung, 2008
Imaging Modalities	Micro-CT, intraoperative sensor imaging	Zuolo et al., 2018
Rotary Systems	Five commonly used rotary instruments for curved and oval canals	Martins et al., 2022; de Oliveira Alves et al., 2012
Preprocessing Steps	Normalization, noise reduction, segmentation, feature extraction	Li et al., 2011; Singh, 2022
Neural Network Architecture	CNN-RNN hybrid for spatial and temporal feature extraction	Singh, 2022
Self-Updating Mechanism	Incremental learning loop with real-time sensor integration	Singh, 2022
Evaluation Metrics	Mapping accuracy, real-time responsiveness, canal wall deviation	Cheung & Cheung, 2008; Zuolo et al., 2018

Table 2: summarizes the comparative advantages of self-updating neural networks over traditional static models in real-time canal morphology mapping

Feature	*Static Models*	*Self-Updating Neural Networks*	*Clinical Impact*
Adaptability to canal variation	Low	High	Reduces risk of procedural errors
Real-time feedback	Limited	Continuous	Guides rotary instrumentation dynamically
Handling complex canal shapes (C-shaped, oval, curved)	Moderate	High	Improves shaping accuracy and reduces ledging
Integration with sensor data	Minimal	Yes	Enhances precision and safety
Learning from intraoperative updates	No	Yes	Improves future predictions and patient-specific modeling

Discussion

The integration of self-updating neural networks for real-time canal morphology mapping represents a significant advancement in endodontic practice. Traditional rotary instrumentation relies on static preoperative imaging and clinician experience, which may not fully capture the dynamic variations in root canal geometry (Nagy et al., 1997; Li et al., 2011). Complex canal shapes, such as C-shaped or oval canals, pose particular challenges, as demonstrated in prior studies evaluating rotary and manual instrumentation methods (Cheung & Cheung, 2008; de Oliveira Alves et al., 2012; Zuolo et al., 2018). In this context, the adaptive capability of self-updating neural networks allows continuous refinement of canal models based on intraoperative feedback, reducing the risk of procedural errors and improving shaping accuracy (Singh, 2022).

Our findings suggest that the network's real-time adaptation enhances its ability to model morphological variations that may not have been apparent in preoperative scans. This capability is particularly beneficial in managing canals with high curvature or irregular cross-sections, where conventional instrumentation may lead to ledging, transportation, or incomplete shaping (Martins et al., 2022). Furthermore, the network's capacity to integrate multi-modal data including tactile sensor input and imaging signals—enables more precise guidance, which could potentially reduce operative time and improve overall treatment outcomes.

While these results are promising, several limitations warrant discussion. The performance of self-updating networks depends on the quality and resolution of intraoperative data; insufficient or noisy sensor inputs can reduce mapping accuracy. Additionally, the computational demands of continuous network updates may necessitate specialized hardware, which could limit immediate clinical deployment (Singh, 2022). Future work should focus on optimizing lightweight architectures, improving sensor integration, and validating performance across diverse canal morphologies.

In conclusion, self-updating neural networks have the potential to transform endodontic practice by providing adaptive, real-time mapping of root canal morphology. When compared with static models, these networks offer superior adaptability, precision, and clinical safety, particularly in challenging canal geometries (Nagy et al., 1997; Li et al., 2011; Martins et al., 2022). Their integration with rotary instrumentation systems represents a promising step toward AI-driven intelligent dental navigation systems capable of improving patient outcomes.

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