Periodontal Blood Flow Protects the Alveolar Bone from Thermal Injury during Thermoplasticized Obturation: A Finite Element Analysis Study

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Abstract

Introduction: The purpose of this study was to investigate the heat transfer during thermoplastic obturation and the cooling capacity of blood flow in the periodontal ligament (PDL) using finite element analysis (FEA). **Methods:** A 3-dimensional digital tooth model was constructed based on micro–computed tomographic scanning of a mandibular first molar after chemomechanical preparation *in vitro*. A layer of PDL with or without simulated blood flow was built on the root portion of the tooth in software. Two heat-assisted obturation techniques (ie, the single-wave condensation technique and the warm vertical compaction technique followed by backfilling with injectable gutta-percha) were examined using an FEA package. **Results:** In the model without blood flow, the highest temperature at the alveolar bony aspect of the PDL was 50.0°C along the distal canal and 52.5°C for the mesiolingual canal when the single-wave technique was used. With the warm vertical compaction technique, the highest temperature was 47.3°C for the distal canal and 47.8°C for the mesiolingual canal. In the model with simulated periodontal blood flow, a notable drop in the peak temperatures at the root surface and at the adjoining alveolar bone was observed for both the distal and mesiolingual canals; all peak temperatures at the PDL fell below 47°C regardless of the obturation techniques used. The greatest rise in temperature was situated at the furcation aspect of the middle third of both roots. **Conclusions:** The cooling capacity of blood flow in the PDL is a factor that must be considered in the investigation of heat transfer during thermoplastic obturation. *(J Endod 2018;44:139–144)*

Key Words

Blood flow, finite element analysis, periodontium, temperature rise, thermoplasticized obturation

Significance

The cooling capacity of periodontal circulation for dissipating heat during root canal obturation cannot be overemphasized. Periodontal blood flow protects the alveolar bone from thermal injury during thermoplasticized obturation.

The final procedure of root canal therapy is to achieve homogenous and 3-dimensional obturation to prevent future invasion of microorganisms into the root canal system (1). Gutta-percha has been used for root canal obturation with a very long track record. Many techniques of introducing and packing the material into position have been proposed. The "cold lateral condensation" technique is commonly taught worldwide. Some studies have pointed out that the cold lateral condensation technique no longer requires a dense and tight seal because of the poor adaptability of cold gutta-percha (GP) (2, 3). Because GP material is thermoplastic (4), various heating methods have been advocated to soften the material during the obturation process. Examples include System B (SybronEndo, Orange, CA), Touch 'n Heat (SybronEndo), Obtura II (Obtura Spartan, Algonquin, IL), and Thermafil (Dentsply Tulsa, Tulsa, OK). Thermoplasticized GP has been shown to be able to flow into irregular spaces, such as the isthmus and lateral canals (5) and, hence, is considered a superior method of filling the canal space.

The issues of heat generation and potential thermal injury to the periodontium during thermoplastic obturation techniques have been a concern (6). In a classic study of implant dentistry by Eriksson and Albrektsson (7) in which rabbit tibia was exposed to a temperature in excess of 47°C, fat cell replacement and irreversible bone resorption were observed. Nowadays, it is generally accepted that any temperature rise on the root surface should be kept to within 10°C to avoid bone injury. Although dentin is a relatively good insulator (8), a temperature rise on the external root surfaces with a consequential alveolar bone reaction has been reported after the use of some common heat-assisted obturation techniques (9). Temperature rises up to 27°C were recorded at the central region of the external root surface during obturation by thermomechanical compaction (6). An elevation of more than 10°C was reported when Touch 'n Heat was used (10). Sweatman et al (11) reported with the use of System B at a setting of 200°C that the greatest temperature rise occurred at about 6 mm from the root apex. In the case of mandibular central incisors, which have relatively thin dentinal walls, when the canal was being filled with injectable GP (Obtura II), a temperature increase of more than 10°C was reported (12).

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A thermocouple is the most frequently used instrument to evaluate the temperature at the external root surfaces because of its low cost and the possibility of applying it both *in vivo* (13) and *in vitro* (14, 15). Two major drawbacks of thermocouples are that they are unable to record temperature changes over the entire length of the root and the accuracy of the readings relies on good contact between the measuring tip and the root surface. Another measurement method is infrared thermography, which is able to measure in real time and over a larger area of the root (16, 17). Limitations of infrared thermography are the high cost of equipment, environmental requirements during measurement, and sample standardization.

Finite element analysis (FEA) is considered a reliable method for simulating various dental procedures and/or cavity preparations (18), especially for stress analysis. In fact, a temperature gradient may be considered as a form of thermal stress. Hence, the application of FEA has been extended to the simulation of warm vertical compaction of GP in a maxillary canine (19). In that early study, the tooth model was built by taking the mesiodistal and the buccolingual view of a canine from a tooth atlas. Later, Zhou et al (20) constructed a model of a mandibular molar using micro–computed tomographic imaging and evaluated the continuous-wave condensation (also known as single-wave condensation) technique followed by injectable GP. The results indicated that the activation (heating) time when using this technique should be limited to no more than 3 seconds; otherwise, thermal damage of the periodontium could occur.

The importance of hemodynamics in homeostasis cannot be overemphasized. Blood flow in the periodontal vessels can have a remarkable cooling capacity that must not be neglected. However, no FEA study has taken the blood flow into consideration, as was commented by Ulusoy et al (21). No *ex vivo* experiments have ever investigated the cooling effect of blood flow in the periodontal ligament (PDL) during thermoplasticized obturation of human teeth, probably because of the difficulty of imitating blood flow *ex vivo*. Thus, the aim of this study was to use FEA to examine the effect of PDL blood flow on any temperature increase at the root surface or alveolar bone during thermoplasticized root canal obturation.

Materials and Methods

Establishment of an FEA Model

An intact mandibular first molar, extracted for untreatable periodontitis, was donated by a patient after informed consent. The tooth had 2 mesial canals and 1 distal (D) canal as verified by radiographic examination. After access cavity, all 3 canals were prepared using ProTaper Universal (Dentsply Maillefer, Ballaigues, Switzerland) hand files. The mesiobuccal and mesiolingual (ML) canal were prepared to F2 (MAF size of 25) and the D canal to F3 (size 30). Then, the whole tooth was scanned by micro–computed tomographic imaging (μCT80; SCANCO Medical AG, Zurich, Switzerland) at a pixel size of 20 $\times$ 20 μm and a slice thickness of 20 μm. Over 1000 images were exported as Digital Imaging and Communications in Medicine files and imported into 3-dimensional (3D) reconstruction software (Mimics 14.1; Materialise, Leuven, Belgium) to establish a preliminary 3D model. Three distinguishable segments (ie, enamel, dentin, and root canal) were generated and exported as a STereoLithography file. The thin layer of cementum was neglected because it could not be differentiated from the root dentin in many images. The 3D model was refined by reverse engineering software (Geomagic Studio 12; Raindrop Geomagic, Rock Hill, SC) to facilitate nonuniform rational B-spline modeling and modification of complex features, such as the apical foramen and the dentin-enamel junction (DEJ). The refined model was saved in the Initial Graphics Exchange Specification format.

A 250-μm-thick layer surrounding all roots from the DEJ to the apical foramina was created using CAD software (Solidworks 2013; Dassault Systems, Waltham, MA) to mimic the PDL. Then, a cube of alveolar bone was modeled around this (Fig. 1*A–C*). For modeling the blood flow within the periodontium, a 100-μm-thick layer of fluid (blood) was created in the center of the PDL with the fluid flowing from the apex of the tooth toward the DEJ. The perfusion rate in this simulated PDL was assumed to be the same as that of the gingiva (150 perfusion units) in humans (22). The thermal parameters of various biological structures and dental materials involved were collected from the literature (19, 20, 23–26); these values are summarized in Table 1. The room temperature was assumed to be 22°C.

Simulating the Obturation Process

The obturation process was simulated in FEA software (Abaqus/CAE 6.10, Dassault Systems). Two obturation protocols were simulated in the tooth and PDL model described previously, with or without blood flow. Briefly, a matched GP cone (apical size 25 and apical taper 0.08) was positioned to 0.5 mm short of the working length in the ML canal and, similarly, a matched GP cone (size 30 and taper 0.09) for the D canal. Obturation of the MB canal was omitted because the result was expected to be similar to that of the ML canal. The temperature of the

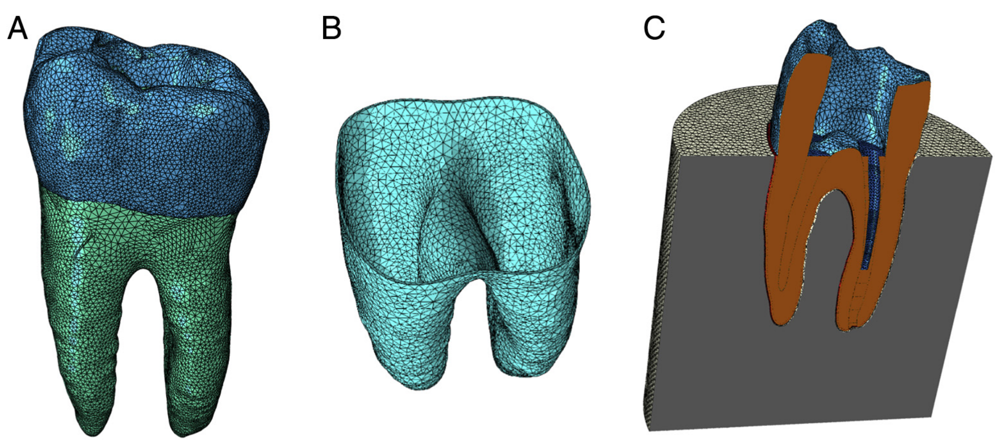

Figure 1. Establishment of the FEA model for various components in this study. (*A*) The mandibular first molar, including the enamel (*dark blue*), dentin (*dark green*), and pulp canals (not shown). (*B*) The PDL (*light blue*) as a 250-μm-thick layer, like a scaffold, to surround all roots from the DEJ to the apical foramina. (*C*) The FEA model of the tooth and its supporting alveolus (*gray*) with periodontal blood flow (*red color*).