Development and Evaluation of an Endodontic Simulation Model for Dental Students

Michael Wolgin, DDS; Paul Wiedemann, DDS; Wilhelm Frank, PhD; Karl-Thomas Wrbas, DDS, PhD; Andrej M. Kielbassa, DDS, PhD

Abstract: The aims of this study were to develop an endodontic simulation model able to implement the electronic method of working length determination (electronic apex locators, EALs) in a dental school, to evaluate the practicality of this tool for dental students, and to compare the accuracy of working length measurements achieved by the EAL and the radiographic method. A new simulation model was constructed by embedding extracted human teeth in a self-cured resin, along with a conductive medium. After radiographic and electronic working length determinations, root canal instrumentation was performed by students at a dental school in Austria according to the working lengths obtained from the EAL. Subsequently, root apices (n=44) were longitudinally sectioned using a diamond coated bur. Measurements of the distance between the anatomical root apex (ARA) and the apical constriction (AC) as well as between ARA and the ascertained apical point of endodontic instrumentation were performed using digital photography and a 3D computer-assisted design software. The distance between ARA and the radiologic (ARA-R) or electrometric (ARA-EL) readings of the apical point of endodontic instrumentation was compared with the actual distance ARA-AC. The accuracy of both methods was determined. The difference between the actual distance ARA-AC and the targeted radiological distance was statistically significant (p=0.0001), as was the measured distance between ARA-R and ARA-EL (p=0.016). The electronic method seems to be more precisely referring to the AC (R²=0.0198) than the radiographic method (R²=0.0019). These results suggest that the endodontic simulation model described in this study can be successfully used in preclinical dental education.

Keywords: dental education, endodontics, computer-assisted instruction, root canal treatment, simulation model

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Over the past decades, the use of electronic apex locators (EALs) has been implemented predominantly in the clinical part of endodontic training for dental students.1 In contrast, during the preclinical years of education, dental students often have limited experience in using EALs and endodontic working length determination and have to rely on standard radiographic methods.1,2 The implementation of the EAL in this early stage of dental education is hampered by the lack of appropriate simulation models allowing for extra-oral electrometric working length determination.

Traditionally, endodontic therapy was based on radiographic examination and radiographic working length determination.3,4 The limitations of this method include elongation or shortening of definitive working lengths and the general lack of any 3D information.5 It is commonly recognized that an acceptable root canal filling should terminate exactly at the apical constriction.7,8 This requirement is usually met by subtracting one millimeter from the initially determined radiographic working length.3 However, this rather simple demand experiences some practical problems as the radiographic apex is not necessarily situated at the same location as the anatomical apex (Figure 1).3,5,10 The use of the EAL has become increasingly important because it allows a precise localization of the apical constriction.11 Considering the high reliability, accuracy, and reproducibility of electronic measurements,12-15 this
method is widely accepted by both the scientific community and many practitioners.\textsuperscript{16,17} Under clinical conditions, the EAL alone (or in combination with conventional radiography) can greatly reduce the risk of instrumenting and filling beyond the apical foramen.\textsuperscript{18} To adopt good clinical standards, this approach should be implemented in predoctoral dental education as early as possible.

According to the European Society of Endodontology’s undergraduate curriculum guidelines for endodontology, education should be at a level that ensures an appropriate standard in clinical practice.\textsuperscript{19} At many dental schools, clinical undergraduates are meanwhile expected to treat a defined minimum of root canals. Similar to other treatment modalities, students require intensive practical exercises prior to performing the EAL clinically. In fact, in the early stages of their education, the vast majority of students lack experience in using the EAL.\textsuperscript{2} The first aim of this study was to establish a reliable and validated learning tool, helping the students to create a sense of understanding regarding working length determination.

With respect to preclinical training, many teaching approaches have been introduced, such as use of human skulls, porcine or bovine jaws, and extracted human teeth.\textsuperscript{20-22} The embedding of extracted human teeth into a dental model, followed by the mounting of these models in manikins as well as by the concomitant radiographic working length determination, seems to be a well-established method.\textsuperscript{23} Unfortunately, such a model does not fulfill the conditions for evaluation by means of the EAL. The electronic determination of the apical constriction in vivo is based on the simultaneous measurements of impedance at different frequencies, followed by the calculation of the impedance quotient.\textsuperscript{24-26} To provide conditions allowing impedance measurements in vitro, embedding compounds that surround the tooth apices should be completely or partially made of a conducting medium.

Having such a suitable simulation model in the preclinical phase, the students would not only be able to determine the working length by means of the EAL. Instead, their awareness of this problem would be increased at an early stage of the curriculum. The main goal of the establishment of such practical simulation models in the preclinical phase of education is to help students to learn about a defined educational complex through problem-solving. The implementation of elements such as a problem-based learning approach could increase collaboration skills and intrinsic motivation of the course participants.

Besides these educational challenges and the evaluation of the practicability of the designated and easily manufactured simulation model, an additional aim of this study was to compare the accuracy of working length measurements. By determining the distance between the anatomical root apex and the ascertained apical point of endodontic instrumentation, we hypothesized that the accuracy of electrometrical

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Experimental set-up}
\footnotesize{Note: Teeth were longitudinally ground until the largest diameter of the root canal was exposed (panel a). Location of minor diameter was determined (panel b). Location of anatomical apex was determined (panel c). Distance minor diameter to anatomical apex was determined (panel d). Working length was determined (panel e). Recommended working length was determined (panel f).}
\end{figure}
Materials and Methods

Based on German regulations for this type of research, no ethical approval was mandatory for this study. All extracted human teeth (Enretex, Velten, Germany) with completely developed root apices and the absence of visible macroscopic damage of the roots were carefully selected. Teeth with existing large restorations, incompletely formed apices, or previously performed root canal fillings were excluded from the sample pool. All teeth were stored in disinfectant solution (Chloramine-T 0.5%, pharmacy-made; Apotheke zum Engel, Krems, Austria) to prevent dehydration and alterations due to storage.

The model fabrication was conducted jointly by the students and the technical personnel of the in-house dental laboratory. Each simulation model was constructed by embedding 12 extracted human teeth in an autopolymerizing resin matrix (Paladur; Heraeus Kulzer, Hanau, Germany). The selected teeth were inserted in these silicone forms, which had been prepared in advance, at their anatomically correct positions. To ensure immobility of the teeth within the model and to seal the root orifices, dental wax (Beauty Pink; Thomas Oertel Dental, Kassel, Germany) was placed around the crowns and apices of the teeth. Additionally, a wax barrier was placed at the root apices serving as an empty chamber at the root apices and the lip electrode (Figure 2). Upon electronic measurement, the rubber stop on the instrument was adjusted to the reference point of the respective teeth, and these working lengths were used as the reference for the instrumentation procedure.

The preoperative digital radiographs were examined for evaluation of the root canal anatomy. The choice of the appropriate RECIPROC file was performed according to the manufacturer’s instructions. Shaping of the apical part of the root canal was performed under supervision to prevent over-instrumentation. Following instrumentation, the root canal was copiously flushed with sodium hypochlorite (2.5%).

For analysis, recollected and disassembled teeth (n=44) were fixed under a microscope OPMI Pico S100 (Carl Zeiss Meditec, Jena, Germany) and evaluated at 21-fold magnification. A diamond bur (Komet, Lemgo, Germany) was used to cautiously grind the apical part of the teeth. Once the root canal was longitudinally exposed, it was further selectively ground until its largest diameter was reached. Digital photography (Canon EOS 450D, Tokyo, Japan; Canon Macro Lens EF 100 mm, Mode MF; Canon MacroRing Lite MR-14 EX) and ImageJ (http://rsbweb.nih.gov/ij/) were used for analysis, and every exposed root apex was photographed without a silverpoint (Figure 3, panel a). Measurements of the distance ARA-AC, as well as the distance ARA, were performed. The distances ARA-R and ARA-EL were compared with the actual distance ARA-AC. Subsequently, the silverpoint with the individually determined radiographic working length was intro-
Using a 3D-computer aided design software (Cerec AC 4.0; Sirona Dental Systems), the anatomical situation of the root apex was investigated (Figure 3, panels d-f). The 3D-model was evaluated with the tools available as part of the Cerec-design phase. Using a distance measuring tool, the distances ARA-R and ARA-EL were compared with the actual distance ARA-AC. The conventionally demanded distance (1 mm short of the apex) was established depicting its 2D radiographical projection by drawing a parallel to the longitudinal axis of the tooth. From this parallel (1 mm short of the base), a perpendicular line was drawn to the lumen of the canal. This was considered...
the starting point for the first measured distance to the anatomical apex of the tooth. The second distance marker was placed 1 mm coronal to this point without regard to the actual anatomical situation. For the second part of the measurement, the distance marker (indicating the most apically located point of the root) was moved to the area of the anatomical root apex, and the distance was recorded again. Subsequently, for the third part of the measurement, the first distance marker was left at the point of the anatomical root apex, and the second distance marker was set to the determined point of the apical constriction, indicating the desired point of instrumentation.

The accuracy of the EAL was compared with the accuracy of the conventional radiographic method by means of Altman-Bland analyses. Student’s t-test was used for computing significant differences (a=0.05).

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Results

The developed endodontic simulation model was able to implement the electronic method of working length determination and proved to be a practical tool for the students. Analysis according to Altman and Bland revealed sufficient accuracy with a tendency to estimate the electronically (ARA-EL) determined apical point of endodontic instrumentation short (y=0.0844 x + 0.0747 mm; R²=0.0298) of the anatomical apex. The difference between the actual distance ARA-AC and the targeted radiological distance of 1 mm (conventional radiological approach) was statistically significant (p=0.0001) (Figure 4, panel a). The distance between ARA-R and ARA-EL (Figure 4, panel b) was also significantly different (p=0.016). The linear regressions (Figure 5) between actual distances ARA-AC, distances ARA-R, and ARA-EL were R²=0.0019 and R²=0.0198, respectively.

Discussion

This study was conducted using a newly developed simulation model. The objectives were to implement the EAL and to investigate the accuracy of electrometric measurements by simulating clinical conditions in a preclinical setup. After a thorough training of the students, a single rooted tooth included in the simulation model was selected for instrumentation and consideration in this study. Furthermore, the investigation addressed the measurement of the distance ARA-AC (the distance between the anatomical root apex and the determined apical point of endodontic instrumentation). These measurements were obtained by means of digital photography and a dedicated software-supported analysis, followed by scanning of the specimens by means of an image-capturing digital system and subsequent analysis with 3D CAD software.

The statistical evaluation performed according to Altman and Bland revealed most precise measurements for the distance ARA-EL in case of the 3D CAD evaluation when compared to conventional image analysis. Correlation analysis according to Altman and Bland is a suitable method to evaluate the differences between two measurement procedures. When the different experimental procedures reveal the same result, the correlation coefficient will be zero, and the regression line will run nearly horizontal through zero where the results have a high correspondence. In case the regression line deviates from zero, the measurement procedures differ.

The high precision achieved by using the CAD evaluation was not unexpected. The CAD/CAM system used in this study was originally designed for manufacturing all-ceramic restorations, with an overall precision of up to 19 µm. According to our literature review, our study is the first successful attempt to implement this system in endodontic research. The crucial advantage of this system compared to the conventional image analysis software is based on its ability to construct a 3D virtual model of a specimen, allowing for a precise determination of the apical constriction.

Various attempts have already been made to construct a suitable model that could fulfill the prerequisite of a closed circuit needed for the EAL. To provide appropriate conditions, the embedding compound surrounding the tooth apices should be made of a conducting medium. A recently published study described the manufacturing of a similar endodontic teaching model, which also was able to implement the electrometric method of working length determination. That interesting approach had a semi-closed reservoir for conductive fluids surrounding the root apices, but admittedly was not underpinned by comparing the accuracy of working length measurements achieved by the EAL and radiographic methods.

In our study, a simple simulation model was constructed by embedding extracted human teeth
in a self-cured resin matrix. Additionally, an empty chamber for the conductive medium (alginate) was formed around the teeth apices. In previous investigations, alginate showed the highest accuracy when comparing different conductive substances.\textsuperscript{30-32}

The model we used (Figure 2) represents a suitable device for high-quality undergraduate traineeship environments.

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**Figure 4. Analyses to determine statistically significant differences**

*Note:* Panel a shows the difference between the actual distance ARA-AC (1) and the targeted radiological distance (2) of 1 mm (conventional radiological approach) was statistically significant. Panel b shows the distances between ARA-EL (1) and ARA-R (2) were also significantly different. Panel c shows the difference between the actual distance ARA-AC (1) and the actual radiological distance (2) was statistically significant.
Figure 5. Linear regressions according to Altman-Bland

*Note:* If the different experimental procedures lead to the same result, the correlation coefficient will be zero, and the regression line will run nearly horizontal through zero where the results have a high correspondence. In case the regression line deviates from zero, the measurement procedures differ. Panel a shows distance between foramen physiologicum (apical constriction) and foramen anatomicum (apical foramen) according to electrometric length determination. Panel b shows distance between foramen physiologicum (apical constriction) and foramen anatomicum (apical foramen) according to radiographic length determination. Panel c shows distance between foramen physiologicum (apical constriction) and foramen anatomicum (apical foramen) combined.
The results showed significant differences regarding the accuracy of working length determination between the EAL and radiographic methods. With respect to the apical constriction, the EAL seems to be more precise than the conventional radiographic method, even in the hands of preclinical students. A recently published study with 482 root canals in 160 maxillary and mandibular teeth demonstrated that radiographs located the minor foramen correctly in 20% of the cases in anterior and premolar teeth and only in 11% of cases in molar teeth.\(^{14}\) In contrast, in that study, the EAL located the apical constriction correctly in 68% in anterior and premolar teeth and 58% of cases in molar teeth.

Our results support those of previous studies,\(^{13,14,17}\) and the null hypothesis was rejected. These findings show a high practicability of the proposed endodontic simulation model for undergraduate dental students, in particular because the results of this study are in agreement with the previously published clinical trials.\(^{12,15,18,28}\) This clearly allows the sustainable, scientifically based implementation of this simulation model for future use during preclinical endodontic training.

In multiple cases, an accurate working length could be determined by means of conventional radiography. These findings seem to be in agreement with a previously published in vitro study showing that the conventional radiographic method (parallel method) was accurate with 90% of the investigated teeth.\(^{18}\) However, this does not mean that the radiographic method, in principle, achieves an equivalent accuracy compared to the EAL. Instead, it should be kept in mind that the apparent accuracy of the radiographic method could have occurred by chance. In addition, within a clinical setting, the accuracy of the radiographic method might be affected by various limitations, such as presence of rubber dam, superimposed anatomic structures on the radiograph, and/or limited compliance of the patient for taking radiographs under clinical conditions.\(^{18}\) Due to the complex anatomy of dental roots, radiography seems to be suitable for adequate working length determination only to a limited extent. The existence of curved roots often leads to problems in assessing radiographs. Further limitations might occur due to films or sensors not being aligned parallel to the tooth axis.\(^{33}\)

It should be mentioned that the electronic working length determination, performed by the students, did not always lead to the exact determination of the apical constriction. The inaccuracy of the electronic measurement observed in a few cases could be attributed to various reasons. These errors might be caused by air entrapment within the alginate around the teeth apices, inadequate moistening of the teeth prior to the measurement, or various intrinsic alterations of the root canal system. Despite meticulous supervision of the entire manufacturing process and carefully performed determination of the working length, potential divergences or errors could not be ruled out. As for now, a rigorous supervision of the student by the faculty seems to be indispensable during instrumentation. These limitations of the EAL underline the importance of the additional radiographic investigation during undergraduate education, and a diagnostic radiograph should be a mandatory prerequisite prior to the initiation of the root canal treatment.

Concerning the educational environment, it is generally accepted that learning progress is strongly oriented towards the understanding of theoretical backgrounds.\(^{34}\) If the students are familiar with the various aspects of root canal anatomy, they also know much better how to proceed. In this specific case, students have to address the problem of adequate working length determination with regard to the apical constriction aiming at improving the quality of the root canal treatment. Within the understanding of the basic idea beyond the root canal anatomy, students would be able to better internalize all the treatment related processes.

Stimulating students’ curiosity for a learning objective seems to be beneficial, as has been confirmed by our findings in this study. The students exhibited great interest in participating in a scientific study and showed significant enthusiasm to reach a precise result of the instrumentation of the study tooth. In cases in which their selected teeth did not meet the study conditions for various reasons, the students were strongly interested in obtaining an alternative tooth that would fulfill the stated requirements to still be able to participate in the study. During the study, it became apparent that working on a scientific task seemed to create a great deal of commitment and involvement from the students. The common efforts of staff and students toward the study goal created an in-depth understanding for the issue of working length determination. Active and autonomous work on a defined task also resembles the ideas of the problem-based learning approach. At present, the problem-based working concept is mostly implemented as part of the theoretical education. Suitable models for the implementation of this
concept as part of the practical training seem to be only scarcely used. The collective understanding and involvement on a defined scientific problem may be a suitable approach to introduce this concept from the seminars to the laboratory.

Conclusion

Within the limitations of this study, the following conclusions can be drawn. The endodontic simulation model for preclinical dental students was successfully established and seems to represent a suitable learning tool with a sound scientific basis. The electronic method of working length determination seems to be more precise with regard to the apical constriction than the conventional radiographic method, and this is considered clinically relevant. The exact location of working length with respect to the apical constriction can only be determined by histological means.

REFERENCES