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Development of a Novel Method for Predicting Root Canals Working Length by Analyzing Dental Radiographs

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Abstract

Accurate working length measurement plays a key role in the success of root canal treatment. In this paper, a novel system is proposed for predicting root canals working length from dental radiographs. The system uses image processing techniques to detect a tooth midline and estimate its length in pixels. The estimated length is then used to predict the working length (in mm) by a weighted linear regression model. The system's performance was evaluated using a database of single- and double-rooted teeth. The mean working length prediction error was 7.3% for single-rooted teeth, and 6.7% and 5.6% for the mesio-buccal and the distal canals of double-rooted teeth, respectively. The system was also successfully used to predict the working length of double-rooted teeth's mesio-lingual canal, which is invisible in the radiographs. The mean prediction error was 6.9% in this case. The accuracy of these working length predictions indicates that the proposed solution could potentially be used to develop practically efficient working length measurement tools that can overcome some problems of the traditional radiographical measurements such as time-consuming repeated measurements and subjective manual adjustments.

Keywords: Working Length Prediction, Root Canal, Dental Radiographs, Image Processing, Weighted Linear Re-Gression.

1. INTRODUCTION

Teeth are complex anatomical structures that have a visible part (the crown) and a hidden part (the root) [1]. They also contain hollow spaces called root canals.

Root Canal Treatment (RCT) is a procedure whereby the infection inside an injured tooth is removed and the root canal area is filled and sealed [2]. One of the important steps in root canal treatment is the

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measurement of root canals' working length [3, 4]. The working length is defined to be the distance from a reference point on the crown to the root canal apical point [4], as shown in Fig. 1.

Inaccurate measurement of the working length during root canal treatment can bring about serious complications such as future reinfections and even root canal treatment failure [3, 5, 6]. This emphasizes the importance of the working length measurement techniques. These techniques include dental K-files, radiography [7–9], Electronic Apex Locators (EAL) [9, 10], and Cone-Beam Computed Tomography (CBCT) [9, 11, 12].

Comparative evaluation of the accuracy and reliability of these techniques have been investigated in various studies [12–16]. In general, there is no consensus among these studies on the optimal technique as there exist important challenges such as the potential of damage to biological tissues by K-files, inaccurate measurements of EALs caused by infection or complex root canal morphology [10, 17], radiation exposure and repeated radiographical measurements due to low image quality [10, 17], and higher expenses and exposure to higher levels of radiation in CBCT [10].

Digital image processing techniques have been widely used in applications such as detection of dental diseases [18–21], enhancement [22, 23], segmentation [24, 25], and edge detection [26, 27] in dental radiographs. Although image processing techniques have the potential to overcome the reviewed challenges of other working length measurement techniques, few studies have used them for that purpose. As an example, Harandi et al. developed a system for measuring the working length [28]. The system performed tasks such as contrast adjustment, image denoising and enhancement, morphological filtering, and edge detection followed by image binarization. The mean error of working length measurements was 8.4%. In another study, an edge map for a dental radiograph was first created [29]. The root canal length (in pixel units) was then estimated by measuring the distance from the tooth's cervical line to the root's apical point and calibrated to millimeters in the end. In the system proposed by Purnama et al., the working length determination was achieved by manual selection of 10 landmark points on the root canal contour, detection of the root canal midline, and estimation of the midline length. The mean error for the working length measurements was reported to be 8.5 mm [30].

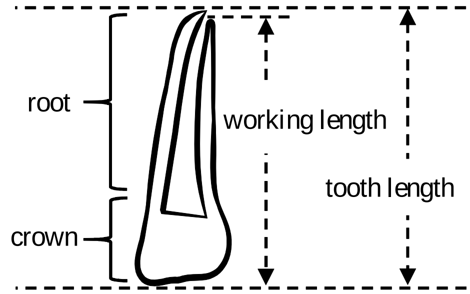

Fig. 1. The anatomy of a single-rooted tooth: the crown, the root, the tooth length, and the root canal working length are demonstrated.

The image-processing-based systems proposed in the reviewed studies do not provide accurate and robust models for working length prediction. In addition, they are not applicable to the root canals that are invisible in dental X-rays. Also, the direct detection of root canals from dental radiographs is very hard, if not impossible, due to low image quality. Therefore, more investigation is required to develop efficient systems. The system proposed in this paper provides a means for predicting the working length from dental radiographs. It is based on the assumption that the length of a tooth and its root canal(s) working length are correlated. The tooth length (estimated using image processing techniques) is used by a weighted linear regression model to predict the root canal working length. The main advantages of the proposed system are the following:

- It avoids the direct detection of root canals which is challenging.
- It is capable of predicting the working length for the root canals that are invisible in the radiographs.
- It is capable of predicting the working length of any tooth, no matter injured or healthy and even before the root canal treatment is started.

The performance of the proposed system was evaluated using radiographs of single- and double-rooted teeth. The rest of this paper is organized as follows. In section 2, the data used in this study and the proposed system are described. The results for the working length predictions are presented in section 3. The results and constraints of the proposed system are discussed in section 4, and the final conclusions of this study are presented in section 5.

2. MATERIALS AND METHODS

The proposed system and the data used to evaluate its performance are described in this section.

2.1. Data

The data used in this retrospective study were selected from an existing private dental database containing 45 radiographs of both upper and lower second permanent premolars, 28 radiographs of lower first permanent molars, and the clinical measurements for their working lengths. Second molars are often single- rooted teeth having a single canal. Lower first molars are double-rooted teeth having a mesial and a distal root, and a total of 3 root canals. The distal root, which is farther from the face midline, has a single root canal, but the mesial root, which is closer to the face midline, contains 2 root canals called mesio-buccal and mesio-lingual root canals. The mesio-buccal and mesio-lingual root canals are located toward the cheeks and the tongue, respectively. All the data had been collected from adult patients during routine dental care procedures and they had given general consent to the usage of their radiographs in scientific research as long as their identities and personal data remained confidential. Except for the radiographs and the working length measurements, the database owner provided no information about the anonymous patients to the authors.

2.2. The Proposed System

The main purpose of the proposed system is to predict root canals' working length. The block diagram of the proposed system is presented in Fig. 2. After being preprocessed, the dental radiographs are binarized using Bradley's adaptive thresholding algorithm [31]. The target tooth is then manually selected by drawing a closed path around it. In the next step, the tooth midline is detected and its length is estimated. In the final step, the estimated length (in pixels) of a tooth is used to predict its root canal working length in millimeters. The last step is achieved using a weighted linear regression model. The details of the proposed system are presented in sections 2.2.1 to 2.2.4.

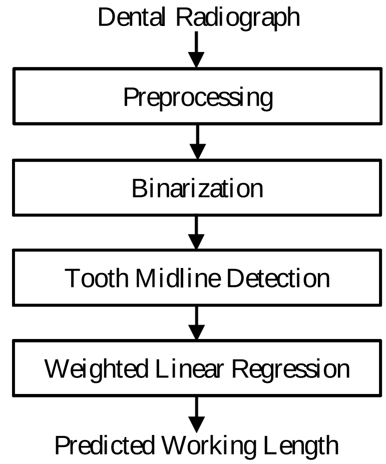

Fig. 2. The block diagram of the proposed system.

2.2.1. Preprocessing

The preprocessing stage includes dynamic range compression, Gaussian filtering, and dynamic range expansion. The dynamic range compression is achieved by:

$$f_C(x, y) = \sqrt{f(x, y)} \tag{1}$$

where $f(x, y)$ and $f_C(x, y)$ represent the original gray scale image before and after dynamic range compression, respectively. The output of the dynamic range compression, $f_C(x, y)$, is then smoothed in the spatial domain using a 2D Gaussian kernel defined by:

$$h(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \tag{2}$$

The size of the square Gaussian kernel, D, is specified as:

$$D = 2\lceil 2\sigma \rceil + 1 \tag{3}$$

where $\lceil \cdot \rceil$ denotes the ceiling function. In our study, a value of 7.5 was selected for σ by trial and error, resulting in $D = 31$. The smoothed image, $f_G(x, y)$, is obtained by convolving the image $f_C(x, y)$ with the kernel $h(x, y)$. Finally, the dynamic range of the smoothed image is expanded by:

$$f_E(x, y) = f_G^4(x, y) \tag{4}$$

where $f_E(x, y)$ is the image after the dynamic range expansion.

2.2.2. Binarization

The second stage of the proposed system is the binarization of the preprocessed image $f_E(x, y)$. For that purpose, Bradly's thresholding method ([31]) is used, where the average intensity of an $R \times C$ window centered on each pixel in image $f_E(x, y)$ is computed. If the intensity of the pixel located at the center of the rectangular window is T percent lower than the computed average, it is set to 0, otherwise, it is set to 1. In this study, T was set to 60% and the window dimensions for an $M \times N$ image were computed as follows:

$$R = 2\left\lfloor \frac{M}{16} \right\rfloor + 1 \tag{5}$$

$$C = 2\left\lfloor\frac{N}{16}\right\rfloor + 1 \quad (6)$$

where $\lfloor\cdot\rfloor$ denotes the floor function. The resulting binary image is defined to be $f_B(x, y)$.

2.2.3. Tooth Midline Detection

In binary image $f_B(x, y)$, a closed path is drawn roughly around the target tooth, i.e., the tooth whose working length should be determined. All the pixels outside the closed path are set to 0, resulting in a binary image $f_R(x, y)$ that includes only one object (i.e., the target tooth). The midline of the target tooth is then detected by fitting a curve to the pixels located in the target tooth region. For that purpose, the tooth midline is approximated by a cubic polynomial defined by:

$$y = ax^3 + bx^2 + cx + d \quad (7)$$

The optimal values for parameters a, b, c, and d are found in a least square sense, that is, by minimizing the residual sum of squares:

$$r = \sum_{i=1}^{N_T}(y_i - ax_i^3 - bx_i^2 - cx_i - d)^2 \quad (8)$$

where the ordered pairs (x_i, y_i) represent the locations of the pixels inside the target tooth region and N_T is the total number of these pixels. To minimize the residual r, The partial derivatives of r with respect to a, b, c, and d must be obtained and equated to 0, resulting in a system of 4 linear equations defined by:

$$a\sum_{i=1}^{N_T} x_i^{m+3} + b\sum_{i=1}^{N_T} x_i^{m+2} + c\sum_{i=1}^{N_T} x_i^{m+1} + d\sum_{i=1}^{N_T} x_i^{m} = \sum_{i=1}^{N_T} x_i^{m} y_i \quad (9)$$

where m should be replaced by all integer numbers in [0, 3]. Having solved the system of equations for a, b, c, and d, all the pixels located on the tooth midline are found using Eq. (7). The length of the tooth midline is finally computed by:

$$z = \sum_{n=1}^{N_m-1} \sqrt{(x_{n+1} - x_n)^2 + (y_{n+1} - y_n)^2} \quad (10)$$

where the ordered pairs (x_n, y_n) are the locations of the midline pixels, N_m is the total number of these pixels, and z is the length of the tooth midline in pixels unit.

2.2.4. Working length prediction

The relationship between the root canal working length (in millimeters) l and the length of the tooth midline (in pixels) z computed by Eq. (10), is supposed to be linear:

$$l = \beta_0 + \beta_1 z + \varepsilon \quad (11)$$

where ε is an error term, and β_0 and β_1 are the linear relationship coefficients. The weighted linear regression algorithm is used to estimate $\beta = [\beta_0, \beta_1]^T$ as follows:

$$\beta = \underset{\beta}{\operatorname{argmin}} \sum_{k=1}^{K_{tr}} w_k(l_k - \beta_0 - \beta_1 z_k)^2 \qquad (12)$$

where K_{tr} is the total number of the radiographs used for training the model. For these radiographs, z_ks are computed by Eq. (10) and l_ks are the clinical measurements of the working lengths. The weights w_k are chosen as follows:

$$w_k = e^{-\frac{(z_k - z)^2}{2\tau^2}}, \quad k = 1, 2, 3, \cdots, K_{tr} \qquad (13)$$

The parameter τ was set to 5 in our study. If the difference between z_k and z is small, w_k approaches 1, but when this difference is large, w_k approaches 0. The parameters z_k and z are the midline lengths for the k^{th} tooth in the training database and the target tooth, respectively. It can be shown that the optimal parameters $\hat{\beta} = [\hat{\beta}_0, \hat{\beta}_1]^T$ are computed by:

$$\hat{\beta} = (Z^T\, W\, Z)^{-1} Z^T W l \qquad (14)$$

where W is a diagonal matrix with $W(k,k) = w_k$, l is a column vector containing l_k's and Z is a $K_{tr} \times 2$ matrix such that its k^{th} row is $Z_k = [1, z_k]$. Once the optimal parameters $\hat{\beta}$ are computed, the target tooth's working length is predicted as:

$$\hat{l} = \hat{\beta}_0 + \hat{\beta}_1 z \qquad (15)$$

It should be added that during the training and testing phases, all z_ks were normalized, as follows, to have zero mean and unit variance:

$$z_k^N = \frac{z_k - \mu_z}{\sigma_z} \qquad (16)$$

where μ_z and σ_z are the mean and the variance of the midline lengths for all the teeth in the training dataset, and z_k^N is the normalized length of tooth k in the database.

3. RESULTS

The results for the midline detection and the working length predictions made by the proposed system are presented in this section.

3.1. Tooth Midline Detection Results

The process of midline detection for a single-rooted tooth is demonstrated in Fig. 3. As expected, the preprocessed image (Fig. 3(b)) is less noisy and smoother than the original one (Fig. 3(a)). In the binarized radiograph (Fig. 3(c)), the target tooth, i.e. the one in the middle, was manually selected by drawing a closed path around it and setting all pixels outside the path to zero, resulting in Fig. 3(d). Also, the detected midline of the tooth is shown as a dashed black line in Fig. 3(d). As explained in section 2.2, the midline length

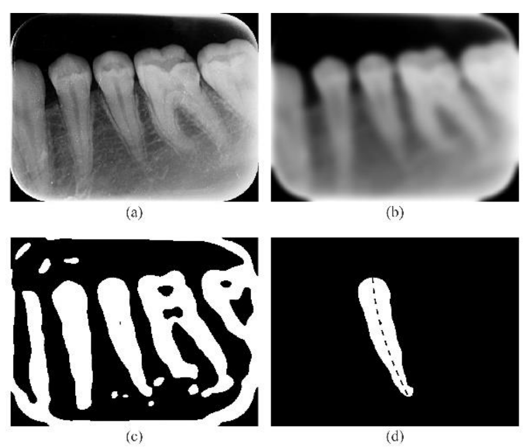

Fig. 3. Midline detection for a single-rooted tooth: (a) the original radiograph; (b) the preprocessed radiograph; (c) the binarized radiograph; (d) the selected single-rooted tooth (the tooth midline is shown as a dashed black line).

(in pixels unit) is computed by Eq. (10) and used to predict the working length by Eq. (15).

Fig. 4 shows the process of midline detection for the two roots of a double-rooted tooth. The original radiograph of the double-rooted tooth is presented in Fig. 4(a). The double-rooted tooth must be divided into 2 halves, each including a root. For that purpose, in the binarized radiograph (Fig. 4(b)), a closed path is drawn around the root on the left side and that part of the crown attached to it, and the pixels outside the closed path are set to 0 (Fig. 4(c)). The same process is repeated for the root on the right side (Fig. 4(d)). The midline detected for each root is shown as a dashed black line. The length of each midline (in pixels unit) is computed by Eq. (10) and used to predict the working length of the respective root canal by Eq. (15).

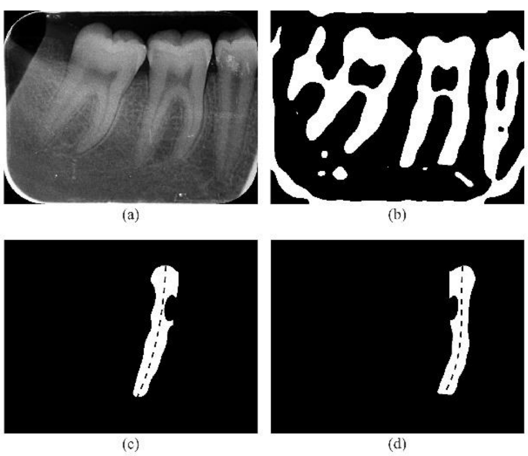

Fig. 4. Midline detection for two roots of a double-rooted tooth: (a) the original radiograph; (b) the binarized radiograph; (c) the selected left part of the tooth in the middle; (d) the selected right part of the tooth in the middle. The dashed black lines are the midlines.

3.2. Results of Working Length Prediction

Several tests were conducted to evaluate the proposed system's performance. In each test, a model based on weighted linear regression was created for a specific root canal (e.g. the distal root canal of first molars). The data described in section 2.1 was used to train and test the model. The Leave-One-Out Cross Validation (LOOCV) strategy was used to find the mean and the 99% confidence interval for the absolute prediction error. In other words, assuming that the total number of radiographs used in a given test is N_D, a weighted linear regression model is created using $N_D - 1$ radiographs and the working length of the target tooth in the remaining radiograph is predicted by this model. This is repeated N_D times, each time a different tooth is considered as the target. The absolute prediction error, ε_k, for a given tooth, the mean absolute prediction error, $\bar{\varepsilon}$, and the standard deviation of the mean absolute prediction error, σ_ε, are computed as:

$$\varepsilon_k = \left|\hat{l}_k - l_k\right| \tag{17}$$

$$\bar{\varepsilon} = \frac{1}{N_D}\sum_{k=1}^{N_D} \varepsilon_k \tag{18}$$

$$\bar{\varepsilon} = \frac{1}{N_D}\sum_{k=1}^{N_D} \varepsilon_k \tag{19}$$

where l_k is the actual working length (measured by the dentist during treatment) for a given root canal of tooth k in the database, and $\hat{l}_k$ is the working length for the same root canal predicted using the weighted linear regression model. The 99% confidence interval (CI) for the mean absolute prediction error was also computed by:

$$CI: \left[\bar{\varepsilon} - \rho_z \frac{\sigma_\varepsilon}{\sqrt{N_D}}, \bar{\varepsilon} + \rho_z \frac{\sigma_\varepsilon}{\sqrt{N_D}}\right] \quad (20)$$

where the Z-score for the 99% confidence intervals is $\rho_z = 2.576$. The results of all the conducted tests are presented in sections 3.2.1 and 3.2.2.

3.2.1. Working Length Predictions for the Visible Root Canals

The first four tests were conducted to predict the working length of all root canals that were visible in the radiographs, i.e., the root canal of single-rooted second premolars, and the distal and mesio-buccal root canals of double-rooted first molars. The results of these tests are presented in Table 1.

In the first test, the proposed system was used to predict the working length for second premolars' root canal. A total of 45 radiographs were used in this test. The mean absolute prediction error ($\bar{\varepsilon}$) was 1.5 mm (99% CI: [1.1, 1.9]). In the second and third tests, the proposed system was used to predict the working length for first molars' distal and mesio-buccal root canals. A total of 28 radiographs were used in these tests. The mean absolute prediction error ($\bar{\varepsilon}$) was 1.1 mm (99% CI: [0.8, 1.4]) and 1.3 mm (99% CI: [0.8, 1.8]) for the distal and the mesio-buccal root canals, respectively. The fourth test was devised to evaluate the proposed system on all radiographs. Therefore, the data for both types of teeth, i.e., single-rooted and double-rooted teeth, were concatenated and used to build the weighted linear regression model. Accordingly, the measurements of 101 visible root canals were used (45 root canals for second premolars, 28 mesio-buccal, and 28 distal root canals for first molars). The mean absolute prediction error ($\bar{\varepsilon}$) was 1.3 mm (99% CI: [1.1, 1.5]).

3.2.2. Prediction Results for The Mesio-Lingual Root Canal of Double-Rooted Teeth

Another round of tests was conducted to predict the working length of double-rooted teeth's mesio-lingual root canal (which is not visible in the radio- graphs). For that purpose, the visible root canals data (actual working lengths and the lengths estimated by Eq. (10))

Table 1. ***The results of working length prediction for visible root canals: $\bar{\varepsilon}$ is the mean absolute prediction error, CI is the 99% confidence interval for the absolute prediction error, and N_D is the number of root canal radiographs.***

Tooth (root canal)	$\bar{\varepsilon}$ (mm)	CI	N_D
single-rooted	1.5	[1.1, 1.9]	45
double-rooted (D)	1.1	[0.8, 1.4]	28
double-rooted (MB)	1.3	[0.8, 1.8]	28
single- and double-rooted	1.3	[1.1, 1.5]	101

Table 2. ***The results of working length prediction for the invisible mesio-lingual (ML) root canal of double-rooted teeth using the estimated lengths of the visible root canals of single- and double-rooted teeth: $\bar{\varepsilon}$ is the mean absolute prediction error, CI is the 99% confidence interval for the absolute prediction error, and N_D is the number of root canal radiographs.***

Tooth (root canal)	$\bar{\varepsilon}$ (mm)	CI	N_D
single-rooted	1.55	[1, 2.1]	45
double-rooted (D)	1.3	[0.8, 1.8]	28
double-rooted (MB)	1.3	[0.8, 1.8]	28
single- and double-rooted	1.3	[0.8, 1.8]	101

were used to train the linear regression model. The visible root canals include the single-rooted teeth's root canal and the double-rooted teeth's distal and mesio-buccal root canals. The results of these tests are summarized in Table 2. The mean absolute prediction error ($\bar{\varepsilon}$) for the mesio-lingual root canal was 1.55 mm (99% CI: [1, 2.1]) using the 45 single-rooted teeth root canals data, 1.3 mm (99% CI: [0.8, 1.8]) using the 28 distal root canals data, 1.3 mm (99% CI: [0.8, 1.8]) using the 28 mesio-buccal root canals data, and 1.3 mm (99% CI: [0.8, 1.8]) using all the 101 visible root canals of all the teeth in the database.

4. DISCUSSION

The system proposed in this paper provides a novel method for predicting root canals' working length. Working length prediction is achieved in two general steps. In the first step, the tooth length (in pixels) is computed, which is then used in the second step to predict the working length. The purpose of the weighted linear regression model used in the second step is twofold: it predicts the working length and calibrates it to millimeters simultaneously. It should be noted that the systems proposed in [28–30] first detect a tooth's root canal and then determine the working length directly from the detected root canal. By contrast, the system proposed in this paper avoids the direct detection of root canals which is a challenging problem due to the low quality of dental X-rays. Rather, it first measures the tooth length and then uses it to predict the working length. The mean absolute working length prediction error was 1.5 mm (7.3%) for the single-canal single-rooted teeth in the database, and 1.3 mm (6.7%) and 1.1 mm (5.6%) for the double-rooted teeth's mesio-buccal and distal root canals, respectively. Also, the mean absolute error for the prediction of the double-rooted teeth's mesio-lingual working length was 1.3 mm (6.9%) when the mesial or the distal root lengths were used to train the weighted linear regression model. These error values are much less than the 8.5 mm working length determination error for the image-processing-based system developed by Purnama et al. [30]. Overall, the considerable reduction of the prediction error values obtained in this study validates the assumption that the tooth length estimated by the proposed system is a reliable predictor of the working length. In the traditional method which is based on radiography, the dentist inserts a dental file into the root canal and measures the working length using the markings on the file. To make sure that the file tip extends to the canal's apical point, an X-ray image is taken. The working length may need to be adjusted depending on the actual positioning of the file tip, which can be inspected in the X-ray image. This can, of course, be time-consuming as sometimes more X-rays are needed. In contrast, the system proposed in this paper provides a straightforward method to measure the working length. It is faster (as it uses only the X-rays routinely performed during dental care and/or treatment, and requires no more adjustments or X-rays) and can be more accurate (as it doesn't require a lot of experience).

The performance of electronic apex locators (EALs), reported in the studies reviewed in [10], varies from generation to generation, from study to study, and from tooth to tooth. In general, the combined accuracy reported for EALs varies from 60% to 100%±0.5 mm from the apical point. The performances of the EALs and CBCT radiography were compared in [11] and [12]. While the accuracy of CBCT and EALs was reported to be 70%±0.5 and 40%±0.5 mm, respectively in [11], no significant difference was found between them in [12].

The combined accuracy of the proposed system for single-rooted teeth, double-rooted teeth's distal, mesio-buccal, and mesio-lingual root canals was 22% ±0.5, 22% ±0.5, 27% ±0.5, and 22% ±0.5 mm from the actual values measured by the dentist. Although the EALs and CBCT measurements seem to be more accurate, in practice, there are constraints affecting their performances. For instance, presence of blood or infection inside the tooth leads to inaccurate measurements with EALs [10, 17]. Sometimes short-circuits caused by saliva or other instruments result in malfunction of EALs [10, 17]. Another problem that can limit the use of EALS is that they might interfere electromagnetically with some cardiac pacemakers [10, 17], possibly raising other health issues. Finally, the application of CBCT for working length determination is not a common practice because of the radiation risks associated with it [17].

It should be noted that the proposed system has two advantages over EALs and the traditional radiographic method. Not only does the proposed system eliminate the need for dental files, but it also has the capability to accurately predict the working length for healthy teeth or injured ones before the root canal treatment is started. However, more investigations are needed to develop a practical tool. For instance, application of other image preprocessing techniques and especially morphological features of the roots might lead to the improvement of the working length prediction accuracy. Also, it is necessary to evaluate the performance of the proposed system using larger dental X-ray datasets including all different types of teeth. A major constraint of this study was the lack of benchmark dental datasets, which should be the focus of future research studies. For comparison purposes, these datasets should provide the actual working lengths as measured by both EALs and the traditional method, which uses K-files and radiography.

Although in this study the model created based on the data obtained from the single-rooted teeth was able to make almost accurate predictions about the mesio-lingual working length of the double-rooted teeth, it sounds quite necessary to investigate whether each type of teeth requires a unique model for measuring the working length. It is also necessary to mention that the clinical working length measurements used in this study for training the weighted linear regression model were not necessarily accurate themselves due to the constraints of the measurement technique. To overcome this problem, it might be beneficial to collect the training data ex vivo from extracted teeth. The working lengths of the extracted teeth can be measured using different techniques resulting in more accurate training data.

5. CONCLUSION

The image-processing-based system proposed in this paper has the capability to accurately predict endodontic working lengths. The system was successfully validated using a database including single- and double-rooted teeth. The mean working length prediction error was 7.3% for the single-rooted teeth, and 6.7% and 5.6% for the double rooted teeth's mesio-buccal and distal canals, respectively. The trained weighted linear regression model was used to predict the working length for the double-rooted teeth's mesio-lingual root canal (which is invisible in the radiographs), resulting in a mean prediction error of 6.9%. In general, the system was able to provide diagnostically valuable information that can increase the chance of successful root canal treatments. This study paved the way for the development of practically efficient tools that can eliminate the complexities and costs associated with the current technology. However, it is necessary to validate the proposed system on larger dental datasets and then improve it accordingly. Its performance should also be compared against other common techniques such as radiographical measurements and electronic apex locators in future investigations.

REFERENCES

[1] R. C. Scheid, G. Weiss, WOELFEL's Dental Anatomy, enhanced ninth ed., Jones & Bartlett Learning, 2020.

[2] A. L. de Carvalho Felippini, Introductory Chapter: Some Important Aspects of Root Canal Treatment, In: Root Canal, IntechOpen, 2019, doi:10.5772/intechopen.83653.

[3] M. Hülsmann and W. Hahn, Complications During Root Canal Irrigation–Literature Review and Case Reports, INT ENDOD J, Vol. 33, No. 3, pp. 186–193, 2000.

[4] M. Sharma and V. Arora, Determination of Working Length of Root Canal, Med J Armed Forces India, Vol. 66, No. 3, pp. 231–234, 2010.

[5] U. Sjogren, B. Hagglund, G. Sundqvist, K. Wing, Factors Affecting the Long-term Results of Endodontic Treatment, J ENDOD, Vol. 16, No. 10, pp. 498–504, 1990.

[6] M. Farzaneh, S. Abitbol, H. P. Lawrence, S. Friedman, Treatment Outcome in Endodontics, the Toronto Study, Phase II: Initial Treatment, J

ENDOD, Vol. 30, No. 5, pp. 302–309, 2004.

[7] A. Olson, A. Goering, R. Cavataio, J. Luciano, The Ability of the Radiograph to Determine the Location of the Apical Foramen. INT ENDOD J, Vol. 24, No. 1, pp. 28–35, 1991.

[8] A. ElAyouti, R. Weiger, C. Löst, Frequency of Overinstrumentation with an Acceptable Radiographic Working Length. J ENDOD, Vol. 27, No. 1, pp. 49–52, 2001.

[9] A. Bhatt, V. Gupta, B. Rajkuma, R. Arora, Working Length Determination-the Soul of Root Canal Therapy a Review. Inter J Dent Med Sci Res, Vol. 2, No. 1, pp. 105–115, 2015.

[10] M. Gordon, N. Chandler, Electronic Apex Locators. INT ENDOD J, Vol. 37, No. 7, 425–437, 2004.

[11] C. Yildirim, A. Murat Aktan, E. Karataslioglu, F. Aksoy, O. Isman and E. Culha, Performance of the Working Length Determination using Cone Beam Computed Tomography, Radiography and Electronic Apex Locator, in Comparisons to Actual Length, Iran J Radiol. Vol. 14, No. 1, pp. e13468, 2017.

[12] P. S. Kamaraj, H. Parandhaman, V. Raguganesh, Comparison of Five Different Methods of Working Length Determination: An ex Vivo Study. Endodontology, Vol. 32, No. 4, 187–192, 2020.

[13] M. Martınez-Lozano, L. Forner-Navarro, J. Sanchez-Cortes, C. Llena-Puy, Methodological Considerations in the Determination of Working Length. INT ENDOD J, Vol. 34, No. 5, pp. 371–376, 2001.

[14] L. Kqiku, P. Städtler, Radiographic Versus Electronic Root Canal Working Length Determination. INT ENDOD J, Vol. 22, No. 6, pp. 777–780, 2011.

[15] I. Tsesis, T. Blazer, G. Ben-Izhack, S. Taschieri, M. Del Fabbro, S. Corbella, The Precision of Electronic Apex Locators in Working Length Determination: a Systematic Review and Meta-analysis of the Literature. J ENDOD, Vol. 41, No. 11, pp. 1818–1823, 2015.

[16] T. G. Wolf, A. Krauß-Mironjuk, R. J. Wierichs, B. Briseno-Marroquın, Influence of Embedding Media on the Accuracy of Working Length Determination by Means of Apex Locator: an ex Vivo Study. Sci Rep, Vol. 11, No. 1, pp. 1–10, 2021.

[17] K. Dutta, P. D. Desai, U. K. Das, S. Sarkar, Comparative Evaluation of Three Methods to Measure Working Length-Manual Tactile Sensation, Digital Radiograph, and Multidetector Computed Tomography: An in vitro study. J Conserv Dent, Vol. 20, No. 2, pp. 76–80, 2017.

[18] A. E. Rad, M. S. M. Rahim, H. Kolivand, A. Norouzi, Automatic Computer-aided Caries Detection from Dental x-ray Images Using Intelligent Level Set. Multimed Tools Appl, Vol. 77, No. 21, pp. 28843–28862, 2018.

[19] J. H. Lee, D. H. Kim, S. N. Jeong, S. H. Choi, Detection and Diagnosis of Dental Caries Using a Deep Learning-based Convolutional Neural Network

Algorithm. J Dent, Vol. 77, pp.106–111, 2018.

[20] A. A. Al Kheraif, A. A. Wahba, H. Fouad, Detection of Dental Diseases from Radiographic 2d Dental Image Using Hybrid Graph-cut Technique and Convolutional Neural Network. Measurement, Vol. 146, pp. 333–342, 2019.

[21] M. G. Endres, F. Hillen, M. Salloumis, A. R. Sedaghat, S. M. Niehues, O. Quatela, Development of a Deep Learning Algorithm for Periapical Disease Detection in Dental Radiographs. Diagnostics, Vol. 10, No. 6, 430, 2020.

[22] S. A. Ahmad, M. N. Taib, N. E. A. Khalid, H. Taib, An Analysis of Image Enhancement Techniques for Dental x-ray Image Interpretation. INT J Mach Learn 385 Comput, Vol. 2, No. 3, pp. 292–297, 2012.

[23] J. W. Choi, W. J. Han, E. K. Kim, Image Enhancement of Digital Periapical Radiographs According to Diagnostic Tasks. Imaging Sci Dent, Vol. 44, No. 1, pp. 31– 35, 2014.

[24] M. Ali, M. Khan, N. T. Tung, Segmentation of Dental x-ray Images in Medical Imaging Using Neutrosophic Orthogonal Matrices. Expert Syst Appl, Vol. 91, pp. 434–441, 2018.

[25] Y. Zhao, P. Li, C. Gao, Y. Liu, Q. Chen, F. Yang, TSASNet: Tooth Segmentation on Dental Panoramic x-ray Images by Two-stage Attention Segmentation Network. Knowledge-Based Systems, Vol. 206, 106338, 2020.

[26] J. Naam, J. Harlan, S. Madenda, E. P. Wibowo, The Algorithm of Image Edge Detection on Panoramic Dental x-ray Using Multiple Morphological Gradient (MMG) Method. Int J Adv Sci Eng Inf Technol, Vol. 6, No. 6, pp. 1012–1018, 2016.

[27] K. Lakhani, B. Minocha, N. Gugnani, Analyzing Edge Detection Techniques for Feature Extraction in Dental Radiographs. Perspect Sci, Vol. 8, pp. 395–408, 2016.

[28] A. A. Harandi, H. Pourghassem, A Semi-automatic Algorithm Based on Morphology Features for Measuring of Root Canal Length. In: 2011 IEEE 3rd International Conference on Communication Software and Networks. IEEE, pp. 260–264, 2011.

[29] K. Padma Vasavi, N. Udaya Kumar, M. Madhavi Latha, E. V. Krishna Rao. An Edge Detection Scheme for Endodontic Working Length Measurement in Root Canal Treatment for Succedaneous Teeth. In: Latest Trends in Cicuits, Systems, Signal Processing and Automatic Control. WSEAS Press, pp. 306–133, 2014.

[30] I. K. E. Purnama, I. Kurniastuti, M. Rinastiti, M. H. Purnomo, Semi-automatic Determination of Root Canal Length in Dental x-ray Image. In: 4th International Conference on Instrumentation, Communications, Information Technology, and Biomedical Engineering (ICICI-BME). IEEE, pp. 49–53, 2015.

[31] D. Bradley, G. Roth, Adaptive Thresholding Using the Integral Image. J Graph Tools, Vol. 12, No. 2, pp. 13–21, 2007.