A simple mounting model for consistent determination of the accuracy and repeatability of apex locators

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Abstract

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Aim To develop a precise and simple mounting model (MM) for evaluating apex locators and to compare the repeatability of the MM with a conventional visual method (VM).

Methodology Electronic working length determination was performed in 32 maxillary central incisors using two methods: (i) the MM method and (ii) a conventional VM. The MM utilizes a micrometer to determine the distance travelled by the measuring file during working length determination. In the VM, the length of the measuring file (representing the working length) is determined visually using a caliper and a microscope at 6× magnification. Each measurement was repeated once. The repeatability of each method was evaluated by calculating the coefficient of repeatability.

Results The coefficient of repeatability, which includes 95% of the differences between repeated measurements, was 0.04 mm for MM compared with 0.9 mm for VM. The measurement error of MM was significantly lower than VM (0.02 and 0.4 mm respectively). There was a statistically significant difference between the means of absolute difference in repeated measurements: MM 0.01 mm (95% confidence interval (CI): 0.01; 0.02 mm) compared with VM 0.4 mm (95% CI: 0.3; 0.5 mm).

Conclusion The new MM had superior repeatability in comparison with the conventional method where visual interpretation is a source of inaccurate measurement.

Keywords: apex locator, comparative study, equipment design, odontometry, repeatability of results, root canal therapy/methods.

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Introduction

Working length determination is commonly performed using either radiographs or apex locators (Bramante & Berbert 1974). An integral part of both techniques is the adjustment and reading of the length of a measuring file. This is usually done by adjusting the rubber stopper of the measuring file to a coronal reference point then measuring the distance between the stopper and the tip of the file with a measuring gauge. During this procedure inaccurate measurements may occur because of the following:

- Inaccurate adjustment of the stopper to the reference point
- Movement of the stopper during measuring procedure
- Lack of parallelism between the long axis of the measuring file and gauge
- Inaccurate identification of the file length (Reit & Hollender 1983, Cox *et al.* 1991)

Even when computer-aided measurements are performed on digital images, image calibration and identification of the distance to be measured on the monitor, using the cursor or mouse, are another source of measurement error (Geelen *et al.* 1998, Douglas 2004).

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Clinically, these procedural errors can be reduced by adopting techniques to minimize inaccuracy, for example, preparing a definite coronal reference point, using stable stoppers and taking the mean of repeated measurements (Weiger *et al.* 1999). Nevertheless in laboratory studies such procedural inaccuracy may bias and influence study results, especially when different devices are compared or when the repeatability of a device/method is evaluated. Unfortunately, little information is available on the range of procedural inaccuracy that can occur. Determining the repeatability of measuring techniques can help quantify procedural inaccuracy.

Repeatability is the ability of a measuring device/method to provide similar values for the same measurement under the same conditions when repeated several times. To determine the repeatability of a device/method the following conditions should be fulfilled:

- Identical measuring procedure and location
- Identical measuring equipment and conditions
- One experienced and consistent operator
- Repetitions completed over a short period of time

When repeatability is evaluated, the variation of measurements because of device/method is of interest, therefore variations because of the operator, teeth, equipment and materials should be minimized. Procedural inaccuracy of an established conventional method can be quantified by comparing its repeatability with that of a new consistent method.

The aim of this study was to develop a precise and consistent mounting model (MM) that minimizes procedural errors during working length determination and to compare the repeatability of the new MM with that of a commonly used visual method (VM).

Materials and methods

Thirty-two maxillary central incisors with single canals were used to determine the repeatability of two root length measuring methods using the Root ZX apex locator (Morita, Tokyo, Japan). Conventional access cavities into the pulp chamber were prepared. A definite coronal reference plane was achieved by preparing the incisal edge perpendicular to the long axis of the root canal.

In the two tested methods, electronic working length determination of the 32 root canals was repeated once to obtain 64 repeated measurements, thus, there were 32 repeated measurement per method.

The mounting model

The components of the MM are shown in Fig. 1. It consists of:

- A digital micrometer to which any hand file could be fixed to serve as a measuring file
- A 3-dimensional adjustable ring that allowed fixation of teeth and alignment of the long axis of the root canals to that of the measuring file
- A container to hold the electroconductive medium and the lip clip of the apex locator

A clockwise rotation of the micrometer allowed forward movement of the measuring file while an

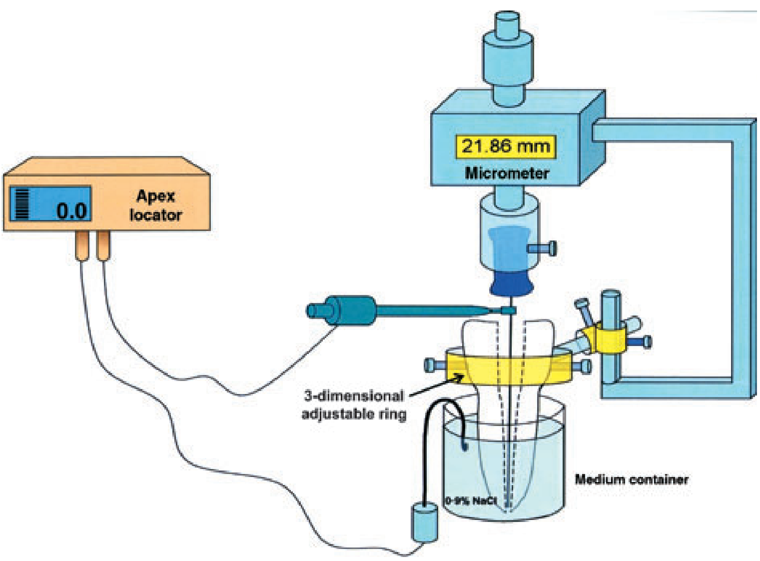

Figure 1 Schematic presentation of the mounting model and study set-up.

anticlockwise rotation allowed backward movement. The reading of the digital micrometer indicated the position of the file/file tip with a precision of 0.01 mm. Any distance travelled by the file/file tip could be determined by calculating the difference between two consecutive readings of the digital micrometer (at initial and end position of the file/file tip). In this way the MM eliminated procedural errors arising from stopper adjustment and reading of the file length on a measuring gauge.

Mounting model method

A size 15 reamer (Dentsply Maillefer, Ballaigues, Switzerland) was attached to the micrometer to serve as a measuring file (Fig. 1). A tooth was fixed in the ring and the long axis of the root canal was aligned to match that of the measuring file. Movement of the measuring file was performed by rotating the micrometer either clockwise (to advance) or anticlockwise (to withdraw). The tip of the measuring file was adjusted to the level of the coronal reference point and the reading of the micrometer (r_{ref}) was recorded. The Root ZX apex locator was connected as shown in Fig. 1. The measuring file was advanced apically into the root canal until the reading of the Root ZX displayed two indicating bars beyond '0.5'. The file was then withdrawn coronally until the reading displayed '0.5'. At this position (Root ZX display at '0.5') the reading of the micrometer was recorded ($r_{0.5}$). The distance travelled by the file tip from r_{ref} to $r_{0.5}$ represented the working length and was calculated by subtracting r_{ref} from $r_{0.5}$. To obtain a repeated measurement, a second working length determination in the same root canal was performed. For this purpose the file was withdrawn from the root canal until the indicating bars on the display of Root ZX disappeared, then the same procedure described above was repeated. In the repeated measurements, recording the micrometer reading at the coronal reference plane (r_{ref}) was unnecessary because the tooth was fixed in the ring and r_{ref} remained unchanged. The operator performing the measurements was unaware of the readings of the micrometer, which were recorded by another operator.

Conventional visual method

The same Root ZX device and experimental settings were used as in MM (Fig. 1), but the size 15 reamer was not fixed to the micrometer. In the VM all movements of the measuring file were performed manually. The measuring file was advanced into the root canal until the level '0.5' in the Root ZX display was surpassed. A stable silicon stopper 3 mm thickness and 6 mm diameter was then adjusted to the incisal edge (coronal reference point). The silicon stopper was held in place against the coronal reference and the measuring file was moved in a coronal direction until the reading displayed '0.5'. The position of the silicon stopper was checked visually for fit against the coronal reference point at 3× magnification. The measuring file was then carefully removed from the canal. The distance between the silicon stopper and the tip of the measuring file was determined visually using a digital caliper and a Stemi 2000-C microscope (Carl Zeiss, Göttingen, Germany) at 6× magnification. The operator who performed the measurements was unaware of the readings of the digital caliper, which were recorded by another operator. A repeated measurement was obtained by using the same procedure described above.

Statistical analysis

The coefficient of repeatability of each method was calculated (Bland & Altman 1986). This corresponds to two standard deviations of the differences between each repeated measurement.

The measurement error for each method was calculated (Bland & Altman 1996). This is the within-subject standard deviation.

Additionally, for each method the mean of the absolute differences and the corresponding 95% confidence interval (CI) were calculated.

Results

The coefficient of repeatability of the MM method was significantly lower than that of the VM (0.04 and 0.9 mm respectively). For each repeated measurement, the mean was plotted against the difference (Fig. 2). The differences showed no relation to the magnitude of the measurement.

The measurement error for the MM method was 0.02 mm in comparison with 0.4 mm for the VM.

The mean of absolute differences of the MM was 0.01 mm (95% CI: 0.01; 0.02 mm). Statistically, this was significantly different from the 0.4 mm mean of absolute differences of the VM (95% CI: 0.3; 0.5 mm).

Discussion

Maxillary central incisors were used in this study because they normally possess relatively straight and

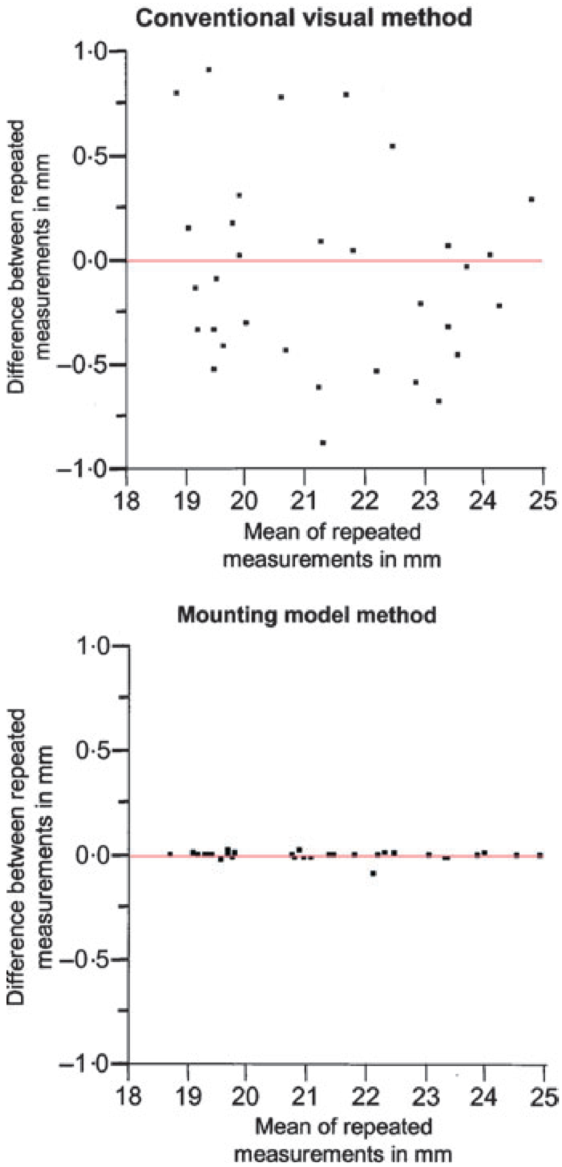

Figure 2 Repeatability plot. For each repeated measurement, the mean was plotted against the difference.

wide root canals, thus variation in measurements as a result of complicated root canal anatomy was minimized. Furthermore, preparing the incisal edge to be perpendicular to the long axis of the root canal offered a stable and reproducible coronal reference plane for all the VM measurements. Also the use of a large dimension silicon stopper provided more stability and better adaptation to the reference plane.

The Root ZX apex locator was used because of its good repeatability (ElAyouti *et al.* 2005). The micrometer and the caliper were pre-calibrated and were of known high accuracy. Therefore, variation of measurements owing to the measuring equipment was minimized. This was demonstrated by the superior repeatability of the MM (Fig. 2).

Measurements were performed by moving the measuring file in a coronal direction, to avoid inaccuracy that may result from bending of the file. This may take place when a small file is advanced apically through a narrow root canal or against root canal wall irregularities.

The coefficient of repeatability was determined as it provides sufficient information on the limits of measurement variation; 95% of the differences between repeated measurements are expected to be below the coefficient of repeatability. The superior repeatability of the MM (0.04 mm) reflects the consistency of the MM and the Root ZX device. The difference between the coefficient of repeatability of the MM and VM (0.04 and 0.9 mm respectively) represents mainly procedural differences between the two methods (adjustment of the silicon stopper and reading of the file length), as the same equipment and teeth were used in both methods. Consequently, in the MM the measurement error (0.02 mm) and the mean of absolute differences (0.01 mm) were significantly different from that of the VM (0.4 mm). Clinically, such favourable circumstances for adjusting the stopper and measuring the file length as occurred in the VM are not available; therefore a higher measurement error is expected. Although the 0.4 mm measurement error using the VM may not be relevant clinically, it could tend to influence the results of laboratory studies, especially when the readings are categorized in 0.5 mm increments or when a target point in the root canal is investigated (e.g. apical constriction or foramen) (ElAyouti *et al.* 2002). Common methodological approaches to reduce measurement error are: using the mean of repeated measurements or considering all measurements around a target point to be correct, e.g. ± 0.5 mm (Lauper *et al.* 1996, Pommer *et al.* 2002, Welk *et al.* 2003). Not all studies make use of these methodological approaches, which may explain the high variability of the results of studies addressing the accuracy of measuring devices (Gordon & Chandler 2004). Accordingly, the results have to be interpreted carefully in studies that use a method/device of unknown repeatability and do not use methods to reduce measurement error.

When closeness of the results of two measuring methods is determined, a method with poor repeatability will not agree with a method that has perfect repeatability. Furthermore, the agreement will be worse when both methods have poor repeatability (Bland & Altman 1986). Therefore, it is imperative in studies that compare measuring devices to use a method of good repeatability and pre-evaluate the repeatability of each device tested.

Conclusions

The mounting model developed in this study was simple to construct, provided a superior repeatability and minimized procedural errors.

Measurement error in the conventional visual method was due mainly to procedural errors such as adjustment of the stopper and reading of the length of the measuring file.

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