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# EFFICACY OF REFERENCE OBJECT CALIBRATION FOR OFF-ANGLE RADIOGRAPHY

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CERTIFICATE OF APPROVAL

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MASTER'S THESIS

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ABSTRACT

EFFICACY OF REFERENCE OBJECT CALIBRATION FOR OFF-ANGLE RADIOGRAPHY
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**Introduction:** Radiography is a critical element in the diagnosis and treatment of endodontic procedures. Periapical radiography, however, has limitations due to distortion caused by sensor and source angulation as well as the penumbra effect. This distortion, if not accounted for, can lead to inaccurate measurements when using in-software digital measuring tools. The purpose of this study is to compare the accuracy of the sensor calibration method to the reference object calibration method when using the digital measuring tool for off-angle radiography.
**Methods:** Radiographs were captured varying the angulation of the radiation source (0°, 15°, and 30°) and sensor (-45°, -30, -15°, 0°, 15°, 30°, and 45°) in relation to a pair of target objects. All radiographs were randomized for review. Preliminary measurements were recorded by a board-certified endodontist using a sensor calibration method, and then re-calibrated using a reference object in the radiograph. **Results:** Utilizing the sensor calibration method a 7.57% magnification was found using a parallel relationship. The range of distortion error for sensor calibration throughout all conditions was between 1.54% and 102.70%. The reference calibration method was significantly better at all angles, having a range of distortion error between 0.22% and 1.30%. **Conclusion:** The use of the reference calibration method was found to greatly improve the accuracy of the measuring tool to less than 1.3% across all angulation conditions.

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## REVIEW OF LITERATURE

Radiology is a critical element in the diagnosis and execution of endodontic procedures. In particular, periapical radiographs remain a standard tool in diagnosis, determination of working length, and documentation of finalized cases. Periapical radiography, however, is limited by the physics of two-dimensional imaging. As a result, improper adherence to basic radiograph principles can greatly affect the diagnostic quality of the resultant image.

An important quality of a diagnostic film is its clarity. Image clarity can be greatly affected by the distance between the focal spot and the object, and the distance between the object and the film (1). The greater the distance of the focal spot to the object, the greater the clarity of the image. This is due to reduction in the number of divergent photons that can hit the sensor (1). Inversely, if the object is closer to the sensor, the clarity of the resulting image will increase (1). The negative effect of divergent photons being able to hit the sensor can be visualized on a radiograph as a diffuse border around the object (1). This ill-defined halo, also known as penumbra, reduces clarity and leads to magnification of the object, diminishing the diagnostic quality of the resultant image (1).

A diagnostic radiograph should also accurately represent the true size and shape of the object being imaged. The paralleling and bisecting angle techniques are invaluable in reducing issues such as distortion and magnification of periapical films, but both are highly technique sensitive. Angle deviation greater than 20 degrees in the paralleling technique revealed a higher incidence of measurement errors (2). The bisecting technique, which can be utilized when off-angle radiographs are required to capture pertinent anatomy, requires an even narrower window to provide a similarly accurate film (2).

Digital technology has allowed for many advancements in the use of radiographs for endodontic procedures. Borg et al. demonstrated that digital sensors showed similar image quality and measuring accuracy to film radiographs at lower radiation exposures (3). In addition to decreasing the radiation exposure to the patient, digital radiography has provided a robust medium that allows for greater post exposure enhancement and interpretation by a measurement calibration module in most radiograph software programs.

There are several different methods of calibrating the digital measurement tool. One method is using the known dimension of the image sensor, referred to as the sensor calibration method (SCM). This allows the software to relate the captured film to the known dimension of the sensor, thereby enhancing the accuracy of the measurement tool. Another method of calibration utilizes a reference object of known dimensions in the same plane as the target structure, recognized as the reference calibration method (RCM). This method has been shown to be effective at correcting for radiographic distortion and magnification caused by the penumbra effect (4).

Lars et al. found that utilization of the RCM led to the selection of a different choice in implant size 58% of the time when compared to an uncalibrated periapicial film (5). Additionally, Loushine et al. found that the RCM was significantly better at correcting for magnification and distortion compared to uncalibrated periapical films when utilizing a paralleling technique (4). Few studies have compared the efficacy of the reference calibration method to the sensor calibration method.

The purpose of the present study is to compare the accuracy of using the RCM and the SCM for correction of distortion caused by off-angle radiography.

## MATERIALS AND METHODS

**Stereotaxic Jig**. To ensure proper and consistent alignment of the sensor, target, and radiation source, a stereotaxic jig was designed using 3d CAD software and printed in ABS plastic using the Stratasys Fortus 250mc printer. The body of the jig allowed for independent precise 15-degree incremental changes of both the sensor and the radiation source relative to a target slide.

The target slide was comprised of a plastic scaffold that fit into the body of the jig. There were two designated locations for fixation of a reference object and a target object. The reference object was a 5.0mm x 5.0mm x 0.1mm piece of tin, and the target object, was a 8.5mm x 8.5mm x 0.1mm 3D printed piece of tin. Each was then fixed to the scaffold using cyanoacrylate.

**Radiograph Protocol.** Digital radiographs were exposed with the radiation source perpendicular to the target and the sensor oriented -45°, -30°, -15°, 0, 15°, 30°, and 45° relative to the target (Diagram 1). The source was then placed at 15° and 30° relative to the target, and exposures were taken satisfying all sensor conditions (-45° to 45°) (Diagram 2 and Diagram 3, respectively). The radiograph with the source at 30° and the sensor at 45° could not be included due to excessive geometric distortion.

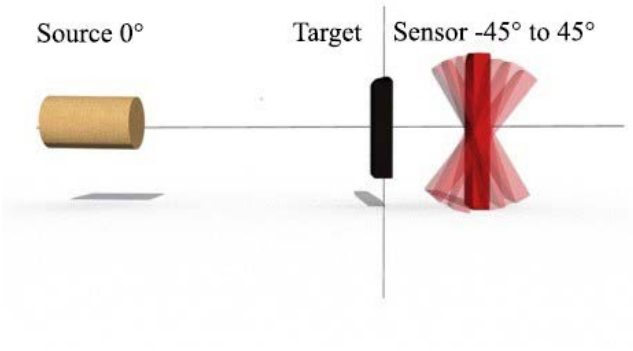


**Diagram 1. Stereotaxic Jig Source Zero Degrees Relative to Target**

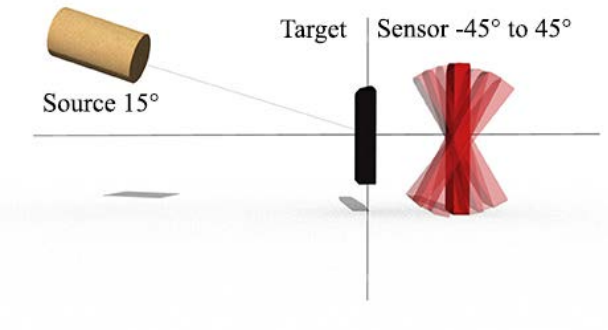


**Diagram 2 Stereotaxic Jig Source Fifteen Degrees Relative to Target**

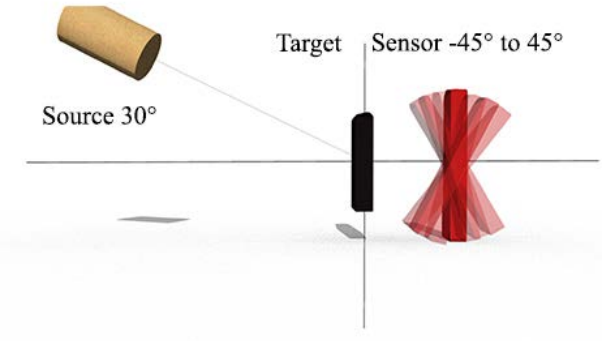


**Diagram 3 Stereotaxic Jig Source Thirty Degrees Relative to Target**

**Radiograph Evaluation**. All radiographs were interpreted by a board-certified endodontist. Prior to radiographic interpretation, the evaluator was given verbal and written instructions on the procedure for collecting the calibration data points within Kodak Apteryx XrayVision 4. Each of the twenty radiographs was duplicated ten times and calibrated for the sensor used. The radiographs were then reviewed in a randomized order, totaling two hundred reviewed images. The evaluator was blinded to the actual dimension of the target object and was given only the known length of the reference object.

The sequence for radiograph interpretation involved the evaluator first measuring the target object and recording this value as the SCM data point. Without adjusting the measurement

points on the target object, the radiograph was re-calibrated by using the reference object, and the updated length of the target object was recorded as the RCM data point.

**Statistical Analysis.** Two-sample t-tests were used to compare the mean percent error obtained from the 10 reads from the arbitrary method versus the 10 reads from the reference method, within each experimental (source:sensor) condition. Scatterplots were used to display variation in percent error from each read within and between conditions. Within-rater reliability was evaluated for the standard and reference methods by the intra-class correlation coefficient (ICC) under a one-way random effects model, in which observations are repeated within each experimental condition. The estimated ICC represents the proportion of variation in mean percent error that is explained by variation between conditions. Analyses were done in R version 3.6.1 (Vienna, Austria).

## RESULTS

Measurements were collated and analyzed for all conditions. The data revealed an inter-observer reliability of 0.99 showing high reproducibility of measurements throughout all conditions.

**TABLE 1: Source Zero Degrees Relative to the Target**

| X-ray Sensor | Sensor Calibration Avg Error | Reference Calibration Avg Error |
|---|---|---|
| **-45°** | 43.08% | -0.91% |
| **-30°** | 23.73% | -0.22% |
| **-15°** | 10.05% | -0.65% |
| **0°** | 7.57% | -0.81% |
| **15°** | 12.97% | -0.74% |
| **30°** | 26.19% | -0.77% |
| **45°** | 49.91% | -0.92% |

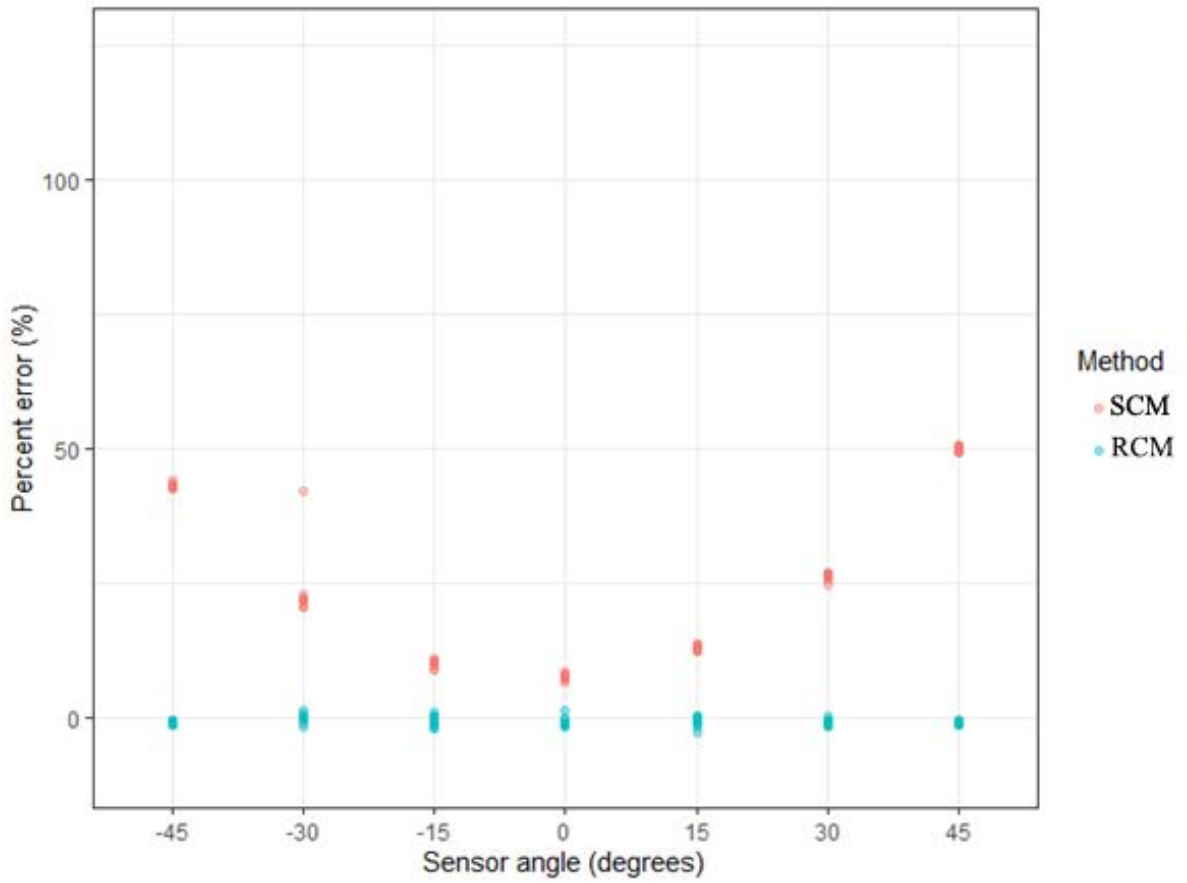


**FIGURE 1: Source Zero Degrees Relative to the Target.** X-axis represents the angle between sensor and target object. Y-axis represents the observed percent error ([observed length/ known length] x 100)

Table 1 lists the comparison of the RCM to the SCM. The RCM had significantly better accuracy (P=≤0.001) across all sensor conditions. In review of the SCM, a minimum error of 7.57% and a maximum error of 49.91% were observed when the sensor was at 0° and 45°, respectively. In contrast, the RCM had a minimum error of -0.22% and maximum error of 0.92%.

**TABLE 2: Source Fifteen Degrees Relative to the Target**

| X-ray Sensor | Sensor Calibration Avg Error | Reference Calibration Avg Error |
|---|---|---|
| **-45°** | 14.41% | -0.69% |
| **-30°** | 5.76% | -0.75% |
| **-15°** | 3.67% | -0.81% |
| **0°** | 8.61% | -1.30% |
| **15°** | 24.32% | -0.36% |
| **30°** | 52.51% | -0.75% |
| **45°** | 108.28% | -0.57% |

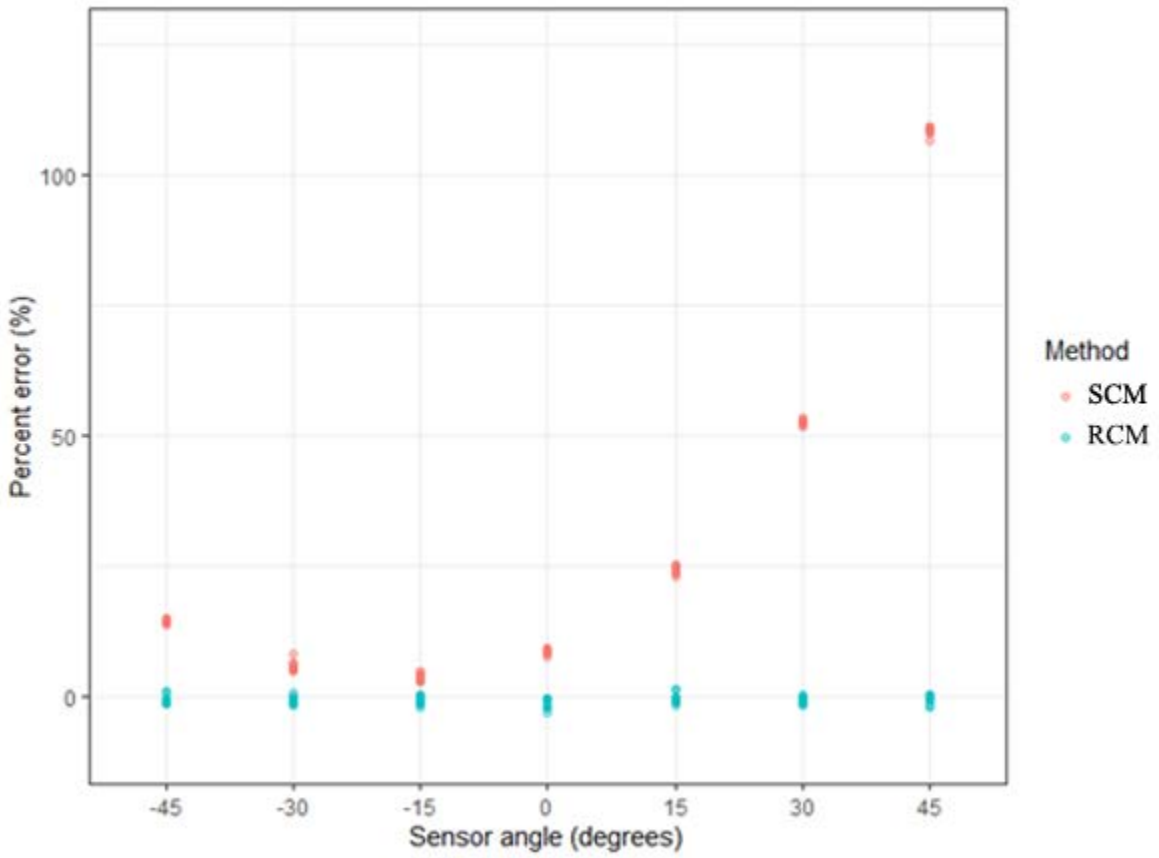


**FIGURE 2: Source Fifteen Degrees Relative to the Target.** X-axis represents the angle between sensor and target object. Y-axis represents the observed percent error ([observed length/ known length] x 100)

Table 2 lists data comparing the SCM and the RCM with the source angled fifteen degrees relative to the target. The RCM had significantly better accuracy (P=<0.001) across all sensor conditions. The range of error observed for the SCM showed a minimum error of 3.67% and a maximum error of 108.28% at -15°and 45°, respectively. The RCM had a minimum and maximum error of -0.36% and -1.30% at 15° and 0°, respectively.

**TABLE 3: Source Thirty Degrees Relative to the Target**

| X-ray Sensor | Sensor Calibration Avg. Error | Reference Calibration Avg. Error |
|---|---|---|
| **-45°** | -6.25% | -0.79% |
| **-30°** | -6.76% | -1.22% |
| **-15°** | -1.54% | -0.53% |
| **0°** | 11.90% | -0.52% |
| **15°** | 41.92% | -0.70% |
| **30°** | 102.70% | -0.87% |

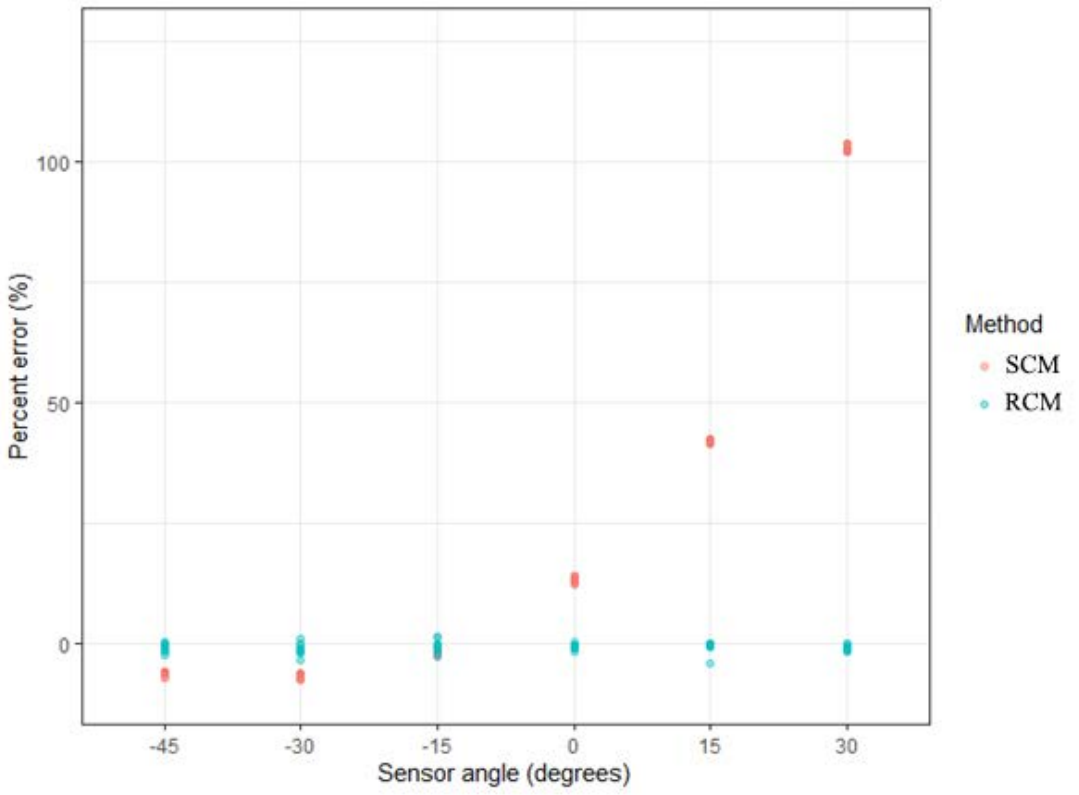


**FIGURE 3: Source Thirty Degrees Relative to the Target.** X-axis represents the angle between sensor and target object. Y-axis represents the observed percent error ([observed length/ known length] x 100)

Table 3 lists the data comparing SCM and RCM with the source angled thirty degrees relative to the target. The RCM method had significantly better accuracy ($P=\leq 0.001$) across all sensor conditions except at the -15° (P=0.49). The range of error observed for the SCM showed a minimum error of -1.54% and a maximum error of 102.70% at -15° and 30°, respectively. The RCM had a minimum and maximum error of -0.52% and -1.22 % at 0° and -30°, respectively. In this set, a measurable radiograph could not be achieved for the 30° source and 45° sensor relationship due to excessive distortion.

## DISCUSSION

The distortion observed with periapical radiography is a combination of several factors. We observed in our parallel relationship a 7.57% magnification when using the SCM. Larheim found a similar magnification with periapical films indicating the need to use a 1.05 magnification factor to correct periapical apical film distortion (6). This magnification is attributed to the relationship between the distance between source and sensor and between target and sensor and is not corrected when using the SCM.

The SCM revealed a greater range of efficacy compared to the RCM. The degree of error was positively correlated to the total angle relationship between the source and the sensor. The greater the angle, the more distortion was observed. Additionally, experimental conditions that approximated an ideal bisecting angle technique reduced errors. When the source was at 15° and the sensor was at -15° relative to the target, 3.67% error was observed. Similarly, the lowest observed error in the 30° source-to-target relationship was when the sensor was angled at -15°, achieving -1.57% error.

Our data suggest limitations in the SCM. Namely, the SCM was unable to effectively correct for the penumbra effect or for moderate to severe angle deviations. For this reason, caution should be used when applying this calibration technique clinically.

When comparing the two calibration techniques, the RCM proved to be superior in all conditions tested. The overall range of error across the RCM groups was between -0.36% and -1.30%. The superior accuracy of the RCM reaffirmed the findings of Loushine (4) and expanded its superiority to include correction for off-angle radiography. Additionally, it was noted that the RCM produced measurements that were significantly more accurate. This increased accuracy should lessen the potential for over-instrumentation when approximating working lengths.

Clinically, however, care should still be taken. Due to the off-centered relationship of apical foramina an appropriate radiographic working length may still lead to over instrumentation (7).

In our experimental model, the benefits of the RCM method were apparent. However, the efficacy of this tool is limited to straight targets and may be less useful for canals with a high curvature (8). For the RCM, any deviation toward or away from the sensor would not be accounted for in the image, which would decrease accuracy. The utilization of this method clinically may also prove to be challenging as it requires the use of a radiopaque object in the same plane as the object being measured.

## CONCLUSION

In summary, the RCM was able to achieve significantly more accurate results correcting angular distortion in comparison to the SCM. Further investigation should identify possible clinical solutions for implementing reference objects into the endodontic armamentarium.

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