Review Article

Methodologies used in quality assessment of root canal preparation techniques: Review of the literature

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Received 20 July 2014; revised 4 November 2014; accepted 8 November 2014; Available online 9 January 2015

Abstract

Objectives: To review the dentistry literature regarding methodologies and parameters used to evaluate the quality of performance of root canal debridement techniques and instruments.

Methods: An extensive literature search with pre-defined inclusion and exclusion criteria was undertaken to identify studies that assessed root canal debridement, methodologies and parameters used to assess shaping and cleaning ability of root canal debridement and instruments. The relevant literature in the field of endodontics published from November 1950 to February 2014 was reviewed using PubMed and MEDLINE databases in all languages.

Results: A large number of studies have assessed the quality of root canal instrumentation through the evaluation of cleaning ability (debris, smear layer) using histological sections and Scanning Electron Microscopy (SEM). The majority (71.9%) of studies evaluated the shaping ability. A body of literature has illustrated in-vitro applications of extracted teeth in muffle system and radiographic analysis. Additionally, the majority of studies have used Schneider angle technique as a random criterion. Micro-CT analysis has been increasingly used in the last decade.

Conclusion: Several parameters are employed in the assessment of the post-operative shape or changes in the root canal morphology. Shaping ability of the root canal instrumentation techniques has been more extensively investigated than the cleaning ability. Additional care needs to be taken regarding entire angular changes by combining both Schneider and Canal Access Angel (CAA) methods and their variants. Finally, more concern
regarding micro-computed tomography technique has been expressed.

**Keywords:** Canal area; Canal transportation; Centering ratio; Debridement; Micro-CT; Muffle system

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**Introduction**

The goal of root canal therapy is to eliminate microorganisms and necrotic pulp tissue debris, and to shape the root canal system to facilitate irrigation and placement of medicaments and obturation materials.1

Successful root canal treatments depend on multiple factors such as adequate cleaning, shaping and filling of the root canal system. However, root canal instrumentation is one of the most essential therapeutic procedures in any treatment since it determines the efficacy of all subsequent procedures, in addition to the fact that it includes mechanical debridement, creation of space for medicament delivery, and optimized canal geometries for adequate obturation.2

The literature is replete with studies on various aspects of instruments performance such as: cleanliness of root canals after preparation, shaping ability of instruments, and fracture properties. Several methodologies have been described to evaluate the performance of root canal instrumentation.

When analyzing the quality of root canal instrumentation created by instruments and techniques, several parameters can be considered, including the cleaning and shaping ability.

**Cleaning ability of instruments and techniques**

Cleaning ability of endodontic instruments and preparation techniques is based on the evaluation of the percentage of debris and un-instrumented root canal walls. It was assessed in many studies by histological sections of human root canals (usually curved canals in maxillary and mandibular molars).3,4 This includes histological preparation of specimens, obtaining of serial cross-sections (μm) and assessment of remaining pulp tissue using a morphometric approach.5

Other studies have investigated cleaning ability using the scanning electron microscope.5,6 SEM evaluation includes splitting the specimen into two halves and preparing the most visible section for SEM examination, different parameters evaluated; smear layer, pulpal debris, inorganic debris, surface profile.7 The studies demonstrated that even with most sophisticated instruments, there might be some area that cannot be reached, cleaned or instrumented by instruments or techniques, suggesting that all techniques of root canal instrumentation are unable to completely remove pulpal debris from irregularities such as dentin grooves and depressions.4,7,8

**Shaping ability of instruments and techniques**

The aim of root canal instrumentation is to form a continuously tapered shape with the smallest diameter at the apical foramen and the largest at the orifice to allow effective irrigation and filling.1 This procedure is carried out without any deviations from the original trajectory, in curved and thin canals,3 using techniques and instruments which have the greatest precision and the shortest working time.10

The purpose of studies analyzing post-operative root canal shape is to evaluate the conicity, taper and flow of the prepared root canal, and maintenance of the original canal shape. The ability of an instrument or a technique to allow the prepared canal to stay centered is seen as a positive aspect. Conversely, canal transportation and preparation errors are seen as a negative aspect.11

Canal transportation is defined according to the Glossary of Endodontic Terms of the American Association of Endodontists as: “Removal of canal wall structure on the outside curve in the apical half of the canal due to the tendency of files to restore themselves to their original linear shape during canal preparation; may lead to ledge formation and possible perforation”.12

Various undesirable apical preparation outcomes such as damage to the apical foramen,13 elbow formation,14 and zip formation and perforation,1 have been described as possible results of canal transportation.

Many methodologies were mentioned to assess the changes after instrumentation of root canal; these include silicone impressions of instrumented canals which assess flow, taper, and smoothness of the walls,15,16 superimposing radiographs before and after shaping17,18 and computer manipulation for comparative analysis19,20 via using special software programs like AutoCad21 or Photoshop.22

One of the most popular methods of in-vitro evaluation is the “muffle system”. Bramante et al. were the first to develop this method to evaluate changes in canal diameter.23 The Muffle system provides a plaster block around a resin-indexed experimental tooth. The block can be custom-machined and sectioned in various planes to allow exact repositioning of the complete block or sectioned parts of the tooth. Simultaneous evaluation and measurement of numerous parameters are possible such as canal area, shaped form, and centering ability. Furthermore, Data can be gathered both pre- and post-operatively, and can be compared and statistically contrasted.24

The quantification of post-instrumentation root canal deviation can be measured by “centering ratio” method25,26 modified formulas to calculate transportation or centering ratio26,27 or by measuring pre- and post-instrumentation dentine thickness.24,28 Alternatively, it can be directly calculated by Pythagorean theorem.19,29

Superimposing radiographs before and after shaping17,18 Digital subtraction radiography images, and computer manipulation19,20 are useful methods to evaluate centering ratio. Centering ratio can be calculated using the following formula: (X1−X2/Y), X1 represents the maximum extent of canal movement in one direction, X2 is movement in the opposite direction and Y is the diameter of final canal preparation.25
Other parameters, such as root-canal diameter, working safety (instrument fractures, perforations, apical blockages, loss of working length -WL-), and working time, were considered when investigating the performance of root canal instrumentation created by instruments and techniques.30–32

Many of the parameters mentioned above (canal transportation, centering ratio, postoperative root-canal diameter, loss of working length, and measurements of dentine thickness pre- and post-instrumentation) could be assessed by a non-destructive technology such as micro-computed tomography (micro-CT).

In 1995, Nielsen et al.33 found that micro-CT accurately reproduced internal and external tooth morphology without tooth destruction and demonstrated surface and volume changes after instrumentation and obturation in extracted maxillary molars. Thus, this technology has been advocated for the comparison of pre- and post-instrumentation images. Micro computed tomography can render cross-sectional (cutplane) and 3D images that are highly accurate and quantifiable.2,24,34,35

Recently, Micro computed tomography technique has been used in assessing accumulated hard-tissue debris after preparation procedures specifically in fins, isthmus, irregularities, and ramifications—using free software for image processing and analysis.36

It is well known that when curvatures are present, endodontic preparation becomes more difficult, and there is a tendency for all preparation techniques to divert the prepared canal away from the original axis.37

The morphology of a curved root canal is of great importance to the outcome of root canal instrumentation, with several studies being conducted to describe the curvature.38

In 1971, Schneider et al.39 performed pioneering work on measuring canal angulation. Subsequently, Weine40 developed an alternative method for determining canal angulation. A third method known as the long-axis (LA) technique was first described by Hankins et al.37 In contrast, Kyomen et al. introduced a linear parameter described as the maximum curvature height, which differs from the angular measurement techniques.42 Likewise, Pruett et al. introduced a new parameter described as the “curvature radius” for measuring root canal curvature.43

In 2005, Günday et al. introduced the term CAA and two new curvature parameters pertaining to the coronal zone of curved root canals: the curvature starting distance (y) and the curvature height (x). They compared the new technique with Schneider method and reported that CAA evaluates the root canal curvature more effectively.38

The Schneider method involves first drawing a line parallel to the long axis of the canal, in the coronal third; a second line is then drawn from the apical foramen to intersect the point where the first line left the long axis of the canal. The Schneider angle is the intersection of these lines.38

In the Weine technique, a straight line is drawn from the orifice through the coronal portion of the curve, and a second line is drawn from the apex through the apical portion of the curve. Weine angle is the intersection of these lines. The LA technique involves drawing a line passing through the apical one-third of the canal, the angle formed by the intersection of that line with the long axis of the tooth is known as the LA angle (Figure 1a).38

Canal access angle (CAA) was described and compared with Schneider angle technique. The canal orifice (A) and apex (B) points were connected with a line. The angle formed by the intersection between this line (AB) and one drawn parallel to the long axis of the canal from the coronal part (AC) (used in the Schneider method), is defined as the CAA (Figure 1b). At the point (C) where the parallel line described in the Schneider method leaves the root canal a perpendicular line was drawn to AB. The point that the perpendicular line intersects AB is D. CD gives the curvature height (x), and the distance from A to point D is the curvature distance (AD/y).38

Most studies that evaluated the quality of canal preparation techniques have been conducted in-vitro. The Preparation of root canals may be evaluated using extracted teeth2,4,44 or simulated root canals in resin blocks.45,46

The aim of this study is to highlight the most important methodologies and parameters for assessing the quality of instruments and techniques used in root canal instrumentation.

Materials and Methods

A literature search for relevant published articles on methodologies used in the assessment of the quality of root canal instrumentation in the context of endodontics between November 195047 and February 201448 in all languages using PubMed and MEDLINE database searches.

The search was performed using different keywords (‘preparation of root canal’, ‘root canal instrumentation’, ‘root canal debridement’, ‘cleaning ability of instruments and techniques’, ‘shaping ability of instruments and techniques’, ‘changes in root canal diameters’, ‘canal transportation’ or ‘centering ratio of root canal’). Peer-reviewed studies of the quality of preparation and endodontic instruments have been identified through PubMed. Articles in which keywords do not match the subject of the search and case reports and non-English language studies have been excluded. After removing duplicates, the remaining papers were retrieved, and their reference lists checked to identify any other articles/textbooks relevant to the topic, which might have provided additional information. The data have been analyzed, and weighted averages have been determined for each of the following: shaping ability, root canal debridement, simulated canals and extracted teeth.

Results

The search through PubMed has shown primarily a huge number of articles (3855). After exclusion of duplicates, articles in which key words do not match the subject of the search, case reports and non-English language studies 528 published papers relevant on instrumentation of root canals were checked.380 (71.9%) studies evaluated shaping ability and 148 (28.1%) studies assessed cleaning ability.

- The majority of studies/492 (95.2%) used extracted teeth while/36 (6.8%)/studies used simulated root canals in resin blocks.

In addition to the studies that have been retrieved, there are several methodologies and parameters used to evaluate the performance of root canal instrumentation.
The methodologies used to evaluate the performance of root canal instrumentation in most studies are:
- For cleaning ability: histological sections, scanning electron microscope, and micro computed tomography technique.
- For shaping ability: silicone impressions. Radiographs and images and computer analysis, muffle system, modified formulas, and micro-computed tomography technique and its breakthroughs.

The parameters used to evaluate the performance of root canal instrumentation in most studies are:
- For cleaning ability: percentage of debris (pulpal debris, inorganic debris,), un-instrumented root canal walls, smear layer, surface profile, and apically extruded debris.

Figure 1: Techniques to measure the angulation of root canals. 
- Schnieder(S), canal access angle (CAA), Weine(W), and Long Aaxis (LA) angles. 
- CAA variables, (x) height and (y) starting distance of the root canal curvature. 
- Root canal curvature can have same (S) and different CAA.
To evaluate the cleaning ability of instrumentation using extracted teeth, Table 1 shows in-vitro studies:

Table 1: In vitro studies evaluating the cleaning ability of instrumentation using extracted teeth.

<table>
<thead>
<tr>
<th>Reference (chronologic order)</th>
<th>Type of study</th>
<th>Samples</th>
<th>Methodology/parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walton 1976</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>histological sections (debris)</td>
</tr>
<tr>
<td>Moodnik et al. 1976</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>SEM (debris)</td>
</tr>
<tr>
<td>Conningham et al. 1982</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>histological sections (debris)</td>
</tr>
<tr>
<td>Mandel et al. 1990</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>SEM (debris)</td>
</tr>
<tr>
<td>Myers and Montgomery 1991</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>assessment of apically extruded debris</td>
</tr>
<tr>
<td>Hülsmann et al. 1997</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>SEM (debris)</td>
</tr>
<tr>
<td>Prati et al. 2004</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>SEM (debris, smear layer)</td>
</tr>
<tr>
<td>Zmener et al. 2005</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>SEM (debris)</td>
</tr>
<tr>
<td>Liu et al. 2006</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>SEM (debris)</td>
</tr>
<tr>
<td>De-Deus et al. 2010</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>assessment of apically extruded debris</td>
</tr>
<tr>
<td>Taha et al. 2010</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>histological sections (debris)</td>
</tr>
<tr>
<td>Fornari et al. 2010</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>histological sections (debris)</td>
</tr>
<tr>
<td>Arya et al. 2011</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>histological sections (debris)</td>
</tr>
<tr>
<td>Bürklein and Schäfer 2012</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>assessment of apically extruded debris</td>
</tr>
<tr>
<td>Chandra et al. 2013</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>SEM (debris)</td>
</tr>
<tr>
<td>De-Deus et al. 2014</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>micro-CT (debris)</td>
</tr>
</tbody>
</table>

- For shaping ability: flow, taper, smoothness of the walls, original canal shape, changes in curvature angulation, apical transportation, canal area, centering ratio, thickness of remaining root structure, working time, fractured instruments, aberrations and working length.

Table 2 shows studies evaluating the shaping ability of instrumentation:

### Discussion

The understanding of endodontic therapy concepts leads to great advance in instruments and techniques, which is the reason why, many studies to assess the performance and quality of these instruments and techniques have been undertaken. It has been noted that studies using extracted teeth to evaluate the quality of root canal instrumentation were more than their counterparts using simulated canals in resin blocks.

The major advantage of extracted human teeth is to reproduce the clinical situation. However, it is difficult to standardize some variables such as root canal length and width, dentine hardness, calcification and pulp stones, location and nature of canal curvatures.

On the other hand, simulated resin root canals allow to use greater forces than those used in natural teeth. The size of resin chips and natural dentine chips may not be identical, resulting in frequent blockages of the apical root canal space and difficulties to remove the debris in resin canals. In consequence, data on working time and working safety from studies using resin blocks may not be transferable to the clinical situation.

Noteworthy, some concern has been expressed regarding the differences in hardness between dentine and resin. Microhardness of dentine has been measured as 35–40 kg/mm² near the pulp space, while the hardness of resin materials used for simulated root canals is estimated to range from 20 to 22 kg/mm² depending on the material used.

For the removal of natural dentine, double the force had to be applied than that for resin. Additionally, critics reported that the size of resin chips and natural dentine chips may not be identical, resulting in frequent blockages of the apical root canal space and difficulties to remove the debris in resin canals.

The studies on root canal curvature have shown that several techniques were conducted to describe canal curvatures. Schneider angle was routinely used. Schneider technique mainly emphasizes the canal curvature in the apical region, and Weine technique considers the apical region, and the LA technique considers only the apical curvature of the canal and does not evaluate the overall root canal curvature. CAA together with height and distance of curvature provide more information about the coronal geometry of root canal curvatures. Few studies have used Schneider angle in combination with the radius of curvature. Others claimed that the shape of root canal curve is more accurately described using Schneider in combination with CAA and the related parameters including radius, length, distance and height of curvature. This combination provides more accurate guidelines for both coronal and apical parts of canal curvature.

Lately, many investigators have been more concerned with micro-computed tomography technique and its
breakthroughs (multislice computed tomography, cone-beam computed tomography). A major factor for this concern is that the radiographs are two-dimensional representations for three-dimensional structures causing certain anatomical features not to be reflected in radiographic changes. In the late 1980s, radiographs were digitized to provide control over the quality of the film and reduce the radiation dosage. These digitized radiographs have an advantage of controlling contrast and brightness by the operator,\textsuperscript{87} although they still provide a 2-dimensional picture. Conversely, micro-CT provides a 3-dimensional picture. It allows pre-instrumentation and post-instrumentation measuring of several parameters to evaluate the quality of root canal instrumentation techniques without using complicated procedures, destructive sectioning of the specimens, or loss of the root material during sectioning. There are no instrumentation problems passing through sections or around curvatures that could affect the instrumentation outcomes. Also, CT scans allow easy measurement of canal changes, because each image has an accurate scale, decreasing the potential of a radiographic orphotographic transfer error.\textsuperscript{88} However, a cone-beam computed tomography scan can expose the patient to two to eight times more radiation than that of a panoramic radiograph and about one third of a full mouth radiographic series.\textsuperscript{89} It should also be noted that cone-beam computed tomography scanning needs complex devices,\textsuperscript{90} and is more expensive than periapical and panoramic radiography.

<table>
<thead>
<tr>
<th>Reference (chronologic order)</th>
<th>Type of study</th>
<th>Samples</th>
<th>Methodology/parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schneider 1971\textsuperscript{79}</td>
<td>in-vitro, ex-vivo, clinical</td>
<td>extracted teeth</td>
<td>cross sections (shaped form)</td>
</tr>
<tr>
<td>Jungmann et al. 1975\textsuperscript{60}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>cross sections (shaped form)</td>
</tr>
<tr>
<td>Abou-Rass et al. 1982\textsuperscript{44}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>silicone impressions (apical design, aberration removal, flow, taper, uniformity, and smoothness of preparation)</td>
</tr>
<tr>
<td>Stadler et al. 1986\textsuperscript{62}</td>
<td>clinical</td>
<td>patients</td>
<td>radiographic analysis (breakage, lateral deviation, overfilling, root perforation, Loss in working length).</td>
</tr>
<tr>
<td>Southard et al. 1987\textsuperscript{63}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>drawings and projected radiographic images (original canal shape) Radiographs and computer analysis (Canal enlargement, apical transportation)</td>
</tr>
<tr>
<td>Luiten et al. 1995\textsuperscript{17}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>muffle system (canal area, centering ratio)</td>
</tr>
<tr>
<td>Deplazes et al. 2001\textsuperscript{76}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>muffle system, modified formulas (centering ratio) muffle system, computer analysis (degree of curvature, working length, straightening of curved root canals, working time, time for changing the instruments)</td>
</tr>
<tr>
<td>Gluskin et al. (2001)\textsuperscript{24}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>radiographic analysis/Wiener angle (shaping ability, working time, canal form, working safety)</td>
</tr>
<tr>
<td>Schäfer &amp; Lohmann 2002\textsuperscript{64}</td>
<td>in-vitro</td>
<td>simulated canals</td>
<td>micro-CT (cervical dentin thickness, Canal volume)</td>
</tr>
<tr>
<td>Song et al. 2004\textsuperscript{77}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>micro-CT (canal diameter, remaining thickness of the dentin wall) Radiographic analysis/Schneider’s angle (working time, canal curvature, working length)</td>
</tr>
<tr>
<td>Guelzow et al. 2005\textsuperscript{66}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>micro-CT (amount of dentine removed, canal roundness, transportation correlation between prepared apical root canal and final instrument used) images and computer analysis/Schneider’s angle, formulas (dentine removed, transportation, working time, amount of dentin removed, working length)</td>
</tr>
<tr>
<td>Veltri et al. 2005\textsuperscript{57}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>images and computer analysis (amount of material removal, canal transportation, centering ratio, aberrations) images analysis (angle and radius of the curvature, position of the center of the curvature)</td>
</tr>
<tr>
<td>Mahran &amp; AboEl-Fotouh 2008\textsuperscript{88}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>micro-CT (canal transportation) Radiographs and computer analysis (canal aberration, apical transportation)</td>
</tr>
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<td>Cheung &amp; Cheung 2008\textsuperscript{55}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>CT scans Image analysis (canal transportation, centering ratio) images and computer analysis (working time canal transportation, amount of removal resin)</td>
</tr>
<tr>
<td>Vahid et al. 2009\textsuperscript{68}</td>
<td>ex-vitro</td>
<td>extracted teeth</td>
<td>images and computer analysis (working length, canal transportation)</td>
</tr>
<tr>
<td>Moore et al. 2009\textsuperscript{69}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>images and computer analysis (working length, canal transportation)</td>
</tr>
<tr>
<td>Unal et al. 2009\textsuperscript{70}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>micro-CT (cervical dentin thickness, Canal volume)</td>
</tr>
<tr>
<td>Ersev et al. 2010\textsuperscript{72}</td>
<td>in-vitro</td>
<td>simulated canals</td>
<td>images and computer analysis (amount of material removal, canal transportation, centering ratio, aberrations) images analysis (angle and radius of the curvature, position of the center of the curvature)</td>
</tr>
<tr>
<td>Plotino et al. 2010\textsuperscript{71}</td>
<td>in-vitro</td>
<td>simulated canals</td>
<td>micro-CT (canal transportation) Radiographs and computer analysis (canal aberration, apical transportation)</td>
</tr>
<tr>
<td>Hartmann et al. 2011\textsuperscript{72}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>CT scans Image analysis (canal transportation, centering ratio) images and computer analysis (working time canal transportation, amount of removal resin)</td>
</tr>
<tr>
<td>Alves Vde 2012\textsuperscript{73}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>images and computer analysis (working length, canal transportation)</td>
</tr>
<tr>
<td>Hashem et al. 2012\textsuperscript{74}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>images and computer analysis (working length, canal transportation)</td>
</tr>
<tr>
<td>Ba-Hattab et al. 2013\textsuperscript{75}</td>
<td>in-vitro</td>
<td>simulated canals</td>
<td>micro-CT (canal transportation) Radiographs and computer analysis (canal aberration, apical transportation)</td>
</tr>
<tr>
<td>Celik et al. 2013\textsuperscript{76}</td>
<td>in-vitro</td>
<td>extracted teeth</td>
<td>micro-CT (canal transportation) Radiographs and computer analysis (canal aberration, apical transportation)</td>
</tr>
</tbody>
</table>
Parameters used to evaluate root canal preparation

Parameters used to evaluate root canal preparation

Conclusion

1) Deep understanding of the phase of root canal instrumentation leads to the use of several parameters to assess post-operative shape or changes in root canal morphology.

2) Shaping ability of the root canal instrumentation techniques has captured more researches compared with cleaning ability.

3) More attention must be taken regarding entire angular changes by combining both Schneider and CAA methods and their variabilities.

4) More concern regarding micro-computed tomography technique has been expressed as, this non-destructive technique provides a 3-dimensional picture, and allows pre- and post-instrumentation measuring of several parameters. We, therefore, conclude that, currently, the micro-computed tomography technique is a superior methodology to evaluate the quality of root canal instrumentation techniques.

Authors’ contributions

All authors contributed in collecting and classifying papers. Dr. Adnan Asaad Habib wrote the text of the paper and was the corresponding author. Dr. Mazen Ibrahim Taha designed the figures.

Conflict of interest

The authors have no conflict of interest to declare.

Acknowledgment

The staff of Aleppo University, faculty of dentistry.

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