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Review of the methodologies used in the assessment of root canal transportation

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Abstract

Background: The aim of this review is to identify, evaluate, and analyze the methodologies used for the quantitative assessment of root canal transportation. Numerous research papers have examined various transportation methods employed across different instrumentation approaches. A range of experimental models, utilizing simulated canals or extracted teeth provide valuable illustrations of the significance of root canal transportation. However, studies have utilized several approaches for quantitatively evaluating root canal movement, which poses challenges in comparing the results. In this study, a comprehensive literature review was conducted by searching databases such as PubMed, Google Scholar, and Scopus, as well as examining the reference lists of relevant papers. The search was carried out up to the year 2023, using relevant keywords to identify various methodologies employed in the evaluation of root canal transportation.

Results: The methods used in the selected papers were gathered, evaluated, and categorized. Scientific studies typically follow a standardized structure that encompasses three fundamental stages: image capture, measurement of images, and computation of parameters.

Conclusion:It is concluded that in future research concerning root canal transportation, a full evaluation of the root canal's length be performed using a 3D imaging technique is recommended. This method would necessitate measuring the distance from the center point for each segment, despite its inherent drawbacks of being laborious and expensive.

Keywords: images superimposition**;** CBCT; Micro-CT; Image Acquisition; Transportation.

1. Introduction

Root canal instrumentation primarily aims to enlarge the root canal to facilitate cleaning and to employ irrigation agents to prevent reinfection. It also simplifies the insertion of root canal obturating material, ensuring adequate apical closure (Loizides A *et al*., 2006).

Due many root canals are curved, the possibility of procedural mishaps is significant. The original root canal geometry and apical foramen placement must be preserved during endodontic treatment. The safety of the whole procedure is at risk during root canal transportation since there are still areas that need to be cleaned (Lopes HP *et al*., 1997).

Researchers have previously employed a diverse range of criteria to evaluate the efficacy of instruments regarding root canal transportation, centering capability, minimal dentine thickness, tapering and root canal inner wall, smoothness, angular changes in curvature, canal aberrations, and loss of the working length were also considered." However, the most prominent examples include transportation and centering ratios (Short JA *et al*., 1997).

Various studies have reported on the methods used to evaluate root canal preparation, and these reports may be found in the literature. However, the actual assessment capacities of such approaches are often constrained (López, F.U. *et al*., 2009).

The employment of simulated roots is one example of such a technique using resin block-built canals (Merrett SJ *et al*., 2006; Weine FS *et al*., 1975), histological sections (Glosson CR *et al*., 1975), scanning electron microscopy (SEM) (Hülsmann M *et al*., 2005), serial root sections (Berutti E *et al*., 1993), silicon molds (Abou-Rass M *et al*., 1992), computed tomography (Nielsen RB *et al*., 1995), and computer-assisted techniques (Haller RH *et al*., 1995), in addition to photographic (Hülsmann M *et al*., 2005) and radiographic comparisons (Schäfer E *et al*., 2003).

An academic paper from a previous period emphasized the importance of conducting a systematic and critical assessment of root canal preparation studies. It underscored the necessity of carefully considering the advantages and drawbacks of the research while also noting a recurring pattern of introducing novel evaluation criteria in each subsequent study (Hülsmann

M. *et al*., 2013).

The objective of this research is to identify and appraise current approaches used for evaluation root canal transportation. So, specific inquiries include: What are the procedures utilized for quantitative assessment of canal transportation? and When evaluating root canal transportation, what are the positive and negative effects of employing different methods and metrics?

2. Review the research strategy

We conducted an organized literature search from 1960 to 2023 using electronic databases (PubMed, Google Scholar, and Scopus). Transportation, assessment, micro-CT, CBCT, image superimposition, and a simulated canal were among the target keywords used. This study focused on endodontic journals and other dental literature. These articles were restricted to those written in English. The inclusion and exclusion criteria were used to assess whether the remaining articles fulfilled the requirements, based on an initial screening of their titles and abstracts. For this study to be considered, it had to either describe or use some kind of quantitative canal transportation assessment approach. When the requirements for inclusion were not satisfied, the articles were declared irrelevant and removed. After the exclusion of irrelevant research, the full-text publications were retrieved and carefully evaluated.

3. An Overview of Studies

In 1975, the resin-simulated canal (RSC) was introduced to simulate the anatomy of a natural tooth's canals to address the problem of uneven canal shapes among teeth that had to be extracted before preparation. There have been several instrumentation investigations on resin simulations (Weine F *et al*., 1975). The shape, curvature, and size of resin-simulated canals can be standardized, and infection control is not a concern. If the canal is molded in transparent resin, the instruments can be seen clearly. Because of these benefits, resin-simulated canals are commonly utilized in teaching and as models in many scientific studies (Wu C *et al*., 2015; Kamha S *et al*., 2016; Di Nardo D *et al*., 2020; Conceição I *et al*., 2020; Kataria EM *et al*., 2021; Kadir Sk *et al*., 2022).

Despite their supposed benefits, plastic building blocks can't compare to human dentin when it comes to toughness and temperature resistance. Notably, it has been observed that certain resins may be melted by the frictional heat produced by rotary devices, indicating that this approach may not always be practical (Shen Y *et al*., 2013).

The studies reported that the prepared canal's cross-sectional shape differed between RSC and extracted teeth . It was thought that this was because RSC had nearly round cross-sections, whereas the roots that were extracted were often elongated or less circular. After instrumentation, the extracted roots became more round in cross-section, while the RSC became less round. However, no instrument made a round canal at any level of the natural root canals, or RSCs (Shen Y *et al*., 2013).

In terms of the distance and route of transportation, Coleman and Svec discovered that the form of the canal longitudinally was quite comparable for both substrates. This has increased the likelihood that RSC may be employed in canal instrumentation investigations, where the extent of canal transportation and variations in canal curvature are crucial (Coleman CL, Svec TA, *et al*., 1997).

Bramante et al. suggested a cross-sectional study of artificial teeth where the artificial tooth is set in resin with reference holes. The plaster box that holds the tooth-resin block can be opened to take it out. The tooth is split horizontally, and a picture is taken of the post-canal shape. After putting it back together in the muffle, it can be prepared with instruments. In cross-section, the shape of the canal post-operatively is compared to the pre-operative shape of the canal (Bramante *et al*., 1987). The variations of this original technology have used stainless steel (Campos and Rio, 1990). Teflon (Hülsmann *et al*., 1999), or rubber-based molds (Short *et al*., 1997). This "muffle system" evaluates the size, shape, form, and centering ratios of root canal cross-sections (Short *et al*., 1997; Kosa *et al*., 1999). The same canal may be used as a reference for comparison, as its preoperative and postoperative shapes are documented.

The geometry of a canal after instrumentation can also be evaluated using periapical radiographs, which have been employed in several research studies to evaluate tooth anatomy and study root canal transportation. However, as periapical radiographs are only two-dimensional, they cannot adequately depict the root canal shape (Tarim Ertas E *et al*., 2013; Nabavizadeh M *et al*., 2014).

Cone-beam computed tomography (CBCT) is a practical, non-destructive 3D imaging method. The root canal system's volume, surface area, cross-sectional shape, and taper can all be evaluated using this method. By using rendering, it is possible to reproduce the tooth in three dimensions and cross-sectional (cut plane), enabling a better pre- and postoperative assessment of the root canal morphology (Mamede-Neto I *et al*., 2017). When compared to micro CT, CBCT has less radiation and poorer resolution, which may present issues when enhancing data during imaging and for study (Dhingra A. *et al*., 2015).

micro-CT enables a comprehensive, non-destructive, three-dimensional study of root canals and assessment of the shaping characteristics of various instruments at certain levels, both pre- and post-instrumentation; The micro-CT is widely used for root canal assessment. Various characteristics, including changes in root canal volume, area, perimeter, and diameter in various sections before and after instrumentation, can be assessed. (Pasqualini D *et al*., 2015; Zuolo ML *et al*., 2018; Pinheiro SR *et al*., 2018; Česaitienė G *et al*., 2019). For these reasons, the current generation of micro-CT devices is regarded as a better approach for assessing the quality of root canal preparation procedures (Stavileci M. *et al*., 2013).

In contrast, examining a single tooth with a microCT requires an average of three hours. Additionally, the investment required for frequent clinical utilization renders the technology unsuitable. Radiation doses are too excessive for in vivo investigations, whereas microCT is optimal for in vitro investigations (Tachibana H *et al*., 1990; Rhodes JS *et al*., 1999).

Despite the considerable variation in the aforementioned procedure, all the included techniques share the same three steps: Image acquisition (scanning and imaging), image superimposition, and image measuring these phases were outlined, contrasted, further classified, and debated.

Root Canal Image Acquisition (Scanning and imaging):

Two-dimensional (2D) and three-dimensional (3D) image acquisition techniques were used to capture pictures of the root canal (Fidler A *et al.*, 2021).

periapical radiographs (Burroughs JR *et al*, 2012; Talati A *et al.*, 2013), digital cameras (Saber SE *et al.*, 2014; Wu H *et al.*, 2015), cameras connected to stereomicroscopes (Hiran-Us S *et al.*, 2015), stereoscopic magnifiers (Aguiar CM *et al.*, 2009), and standardized digital radiographs (Nabavizadeh M *et al.*, 2014; Ferrara G *et al.*, 2015) are examples of 2D image acquisition methods.

Different kinds of computed tomography (CT) (Hashem AA *et al*., 2012), CBCT (Elsherief SM *et al*., 2013), spiral CT (Maitin N *et al*., 2013), and microCT (Pasqualini D *et al*., 2015; Zuolo ML *et al*., 2018; Pinheiro SR *et al*., 2018; Česaitienė G *et al*., 2019) are examples of acquiring 3D image methods.

Three-dimensional methods are capable of generating 2D root canal images (either longitudinal or cross-sectional images) from a 3D image of the canal. In contrast, two-dimensional acquisition methods are limited to producing 2D root canal images (either longitudinal or cross-sectional images). When illustrating a longitudinal section, root canals are denoted by a range of widths along a straight or curved line. Beyond the projection plane, any curvature that is not accessible for examination is disregarded, thus enabling an evaluation of the complete length of the root canal. In cross-sectional imaging, variously sized round, elliptic, or asymmetrical geometric features represent root canals. The CSI approach, in contrast to a LI, permits transportation evaluation in either orientation but only at a single canal level. The number of potential CSIs acquired using two-dimensional techniques is limited, especially if physical sectioning is performed, in contrast to a LI, which permits analysis at any point along the canal. Additionally, physical sectioning in cross-sectional imaging is complicated and difficult in the last 3 mm of the canal, where there is maximum transportation in this area. By creating a CSI using three-dimensional imaging techniques obtained by microCT, these limitations may be overcome. The number of potential CSIs acquired using two-dimensional techniques is limited, especially if physical sectioning is performed, in contrast to a LI, which permits analysis at any point along the canal. Additionally, physical sectioning in cross-sectional imaging is complicated and difficult in the last 3 mm of the canal, where there is maximum transportation in this area. By creating a CSI using three-dimensional imaging techniques obtained by microCT, these limitations may be overcome (Fidler A. *et al*., 2021).

The size of the voxels used in 3DI acquisition techniques is a major factor in determining the accuracy of the assessment of canal transportation. Only micro-CT provides enough resolution, while CBCT imaging should not be employed since the reported canal transportation values are less than the voxel size (Ozer SY et *al.*, 2011). CBCT pictures have a voxel size that ranges from 76 to 400 mm (Nemtoi A *et al*., 2013), which is an order of magnitude bigger than the voxel size of micro-CT images. Micro-CT scans have voxel sizes ranging from 16.7 mm to 39 mm, according to the studies that were looked at (Peters OA *et al*., 2001). The use of CBCT imaging with larger voxel sizes resulted in a partial volume effect, which rendered it difficult to take reliable measurements (Oliveira CA *et al*., 2009).

image superimposition

Several popular programs, including Adobe Photoshop and AutoCAD, have been used in previous studies to superimpose and overlap pre- and post-operative images. The software's layer settings overlap the two photos (before and after preparation) to create an overlay layer with reduced transparency, effectively emphasizing the differences (Lim YJ *et al*., 2013; Saber SE *et al*., 2014; Talati A *et al*., 2013; Garcia M *et al*., 2012; Nabavizadeh M *et al*., 2014; Ferrara G *et al*., 2015; Meireles D *et al*., 2012; Uzunoglu E *et al*., 2015).

image measuring

Gambill's equation was used in the majority of investigations (ANNEX I) (Hashem AA *et al*., 2012; Yamamura B *et al*., 2012; El Batouty KM *et al*., 2011; Junaid A *et al*., 2013; Elsherief SM *et al*., 2013; Capar ID *et al*., 2014; Eliasz W *et al*., 2020; Dhingra A *et al*., 2014; Martin N *et al*., 2013). Calculate the difference in instrumented and uninstrumented pictures between X1, X2, and Y1, X2. A number of 0 indicates no transportation; a value of one indicates proximal or middle movement; and a value of two indicates distal or furcation movement (Elsherief SM *et al*., 2013; Junaid A *et al*., 2013).

The Garip approach (ANNEX I), which involves splitting X1, X2, Y1, and Y2, was utilized by Javidi *et al*. When the ratio is greater than 1, When it is less than 1, the canal has been moved to the outside wall of the root canal curvature, but when it is more than 1, it has been moved towards the inner wall. If the value is one, the canal centering remains unchanged (Javidi M. *et al*., 2012).

Al-Manei further suggests dividing the prepared root canal's dentinal widths by the unprepared root canal's in the furcation and mesial directions to determine the root canal's transportation (Al-Manei KK *et al*., 2014).

Others assessed transportation by calculating the canal's curvature using the “Cunningham and Schneider methods" (Wu H *et al*., 2015).

Zhao *et al*. determined transportation by correlating the differences in micrometers at selected canal locations before and after instrumentation (Zhao D *et al.*, 2014).

The quantity, level, and orientation of measurements for cross-sectional imaging generated by two-dimensional measurement techniques are determined during the image-capturing phase. while the quantity, level, and direction of measurements calculated for longitudinal imaging are acquired during the measurement stage for both the 2D and 3DI acquisition techniques (Fidler A *et al*., 2021).

The reviewed studies had a wide range of measurement levels. Pre and post-instrumentation measurement levels were determined by an arbitrary distance from the apex. Levels were chosen to reflect common levels of aberration (Weine FS et *al.*, 1975; Weine FS et al., 1976). A post-instrumentation-determined level strategy was presented to identify the proper levels with typical aberrations, as aberration levels cannot be established in advance. 2D image acquisition studies had 2–30 levels. The number of slices per tooth is determined by voxel size and measurement levels in 3DI acquisition, ranging from 150 to 900 slices (Moore J. *et al*., 2009). Increased levels enhanced the likelihood of finding maximum transportation levels and transition points (Gilles JA *et al*., 1990). However, increased the assessment workload. To evaluate, merely a few cross-sectional pictures from a three-dimensional image, usually at three, six, or nine millimeters from the working length, if 3D imaging is bought for analysis, it's not wise to only look at a few cross-sections (Fidler A. *et al*., 2021).

To measure and compare canals objectively, all of them should be instrumented all the way to the apical terminus.

moving around various instruments and techniques. The most apical point was typically located 1 mm (Fogarty TJ *et al*., 1991). Short of the working length when using the distance-determined level technique, resulting in an underestimation of transportation and a failure to get the greatest transportation values at the apical third of the canal. The loss of working length and the inability to perform shaping and associated transportation at the canal's apex both result in the creation of the ledge.

The canal that has lost working length cannot be compared to correctly shaped canals since its diameter has decreased across its whole length. Therefore, it should not be subjected to further investigation (Jafarzadeh H *et al*., 2007).

All measures, regardless of the kind of picture, follow the same methodology and fall into two categories: removed material direction and center point distance (Fidler A. *et al*., 2021). Center-point distance measurements are straightforward. It needs no calculation as compared to the removed material distance measurements.

The fact that the CP distance method doesn't require any calculations was especially helpful when only CP evaluation was used for 3DI evaluation. With 3DI, there are a lot of slices, which means that there are a lot of measurements that are hard to show and analyze. To make the presentation easier, the mean values of the measurements in the coronal, middle, and apical thirds of the canal are taken (Peters OA *et al*., 2001).

Even though pooling taking the mean was employed to make it simpler to evaluate and report a large number of data points, it could be deceptive since it obscures how diverse transportation is in various locations. Comparing the entire value of canal thirds to a regional maximum appears incorrect. The effective and full comparison of all transportation information supplied by three-dimensional imaging still presents a difficulty. (Fidler A. *et al*., 2021).

Transportation parameters include removed material measurements. Even so, if the distance from one side of the canal wall is used to measure canal transportation and the other site or direction is disregarded, an incorrect assessment of canal transportation occurs. The Removed Material parameter is not zero for a canal that is centered yet has no transportation. This was resolved by computing the direction of the removed material in the opposing directions as well. Since the (direction of removed material) was calculated and shown in the (longitudinal section) with positive and negative values indicating outer and inner transport, respectively, and vice versa, parameters might still be confused. Cross-section imaging had similar parameter confusion, but for mesial and distal transportation rather than outer and inner (center point cp), measuring the transportation seemed best and easiest to recognize in relation to the center of the pre-and post-instrumentation when compared to the removed material measuring method. It could also be linked to the direction of the removed material (DRM) using an equation that already exists. (CP transportation = 1/2 DRM) (Fidler A *et al.*, 2021).

Measurement in the scientific literature is simplified by a variety of programs, among the most common being “Image Tool Software" (Aguiar CM *et al.*, 2009); magnetic optical disc (Gergi R *et al.*, 2010); DiCom software (Maitin

N *et al.*, 2013); Digimizer Image Analysis Software (GAJOUM, A *et al.*, 2021), (Aminsobhani M *et al.*, 2021), (Al-Gharrawi and Jasim A., 2019).

Conclusion

1- Assessing apical transportation can be difficult because there is no single best approach. Every method employed has limitations.

2- Objective evaluation and comparison of equipment for root canal preparation and transportation calls for a standardized root canal anatomy.

3- While evaluating canal transportation at any depth or angle, 3D image acquisition capture eliminates the primary restrictions of 2D image acquisition.

4- Taking multiple two-dimensional images of the root canal through three-dimensional image collection still doesn't ensure a correct three-dimensional evaluation.

5- Center point (CP) distance and removed material (RM) distance were found to be the two distinct sorts of measurements. When compared to RM methods, CP measurement has two advantages. It entails only a single measurement the difference in canal CP before and after instrumentation and covers transportation in either direction.

6- The large amount of data in three-dimensional evaluation necessitated gathering the measurements by dividing the canals into thirds (coronal, middle, and apical), but this presents a challenge since it hides the substantial local variability in canal transportation.

Suggestions

For future root canal transportation studies, it is proposed to employ three-dimensional image capture to assess the whole root canal length, utilizing (center point) distance for each slice, despite the time-consuming and costly procedure involved.

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The authors declare that they have no conflicts of interest.

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