

Three-dimensional Semi-Automated Volumetric Assessment of the Pulp Space of Teeth with Regenerative Dental Procedures

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Abstract

Volumetric change of the pulp space over time is a critical measure to determine the outcome of regenerative endodontic procedures (REP). There is a paucity in the literature on the accuracy of domain specialized medical imaging tools for three dimensional (3D) volumetric assessment. Thus, the aim of this study was to compare two different medical image computing platforms (OsiriX MD and 3D Slicer) to estimate the volume of pulp space post REP. Pre and post CBCT Scans of 35 immature permanent teeth ($n = 35$) with necrotic pulp and periradicular pathosis treated with a cell-homing concept-based REP were processed using two biomedical DICOM software programs: OsiriX MD (commercially available, FDA approved) 2) and 3D Slicer (open source). Volumetric changes in the pulp space were assessed using semi-automated techniques in both the programmes. The data were statistically analyzed using t-test and paired t-test ($P = 0.05$). The pulp space volume measured with both the programmes showed a statistically significant decrease in pulp space volume post REP ($P < 0.05$), with no significant difference between the two programmes ($P > 0.05$). The mean decrease in pulp space volume with OsiriX MD and 3D Slicer were $25.06\% \pm 19.45\%$ and $26.10\% \pm 18.90\%$ respectively. The open-source software (3D Slicer) was as accurate as the commercially available software for the volumetric assessment of the pulp space post REP. This study demonstrates the step-by-step application of 3D Slicer, a user-friendly, easily accessible, open-source multiplatform software for the segmentation and volume estimation of the pulp-space of teeth treated with REP.

1 Introduction

The progress of medical imaging techniques has increased the number of structures that can be assessed and correlated to morphological alterations associated with disease or treatment. Image segmentation and their associated tools are commonly used for producing anatomical measurements of lesions or structures. Though manual assessment of anatomical boundaries by experts is considered as a benchmark, it is extremely difficult due to its labor-intensive and time-consuming nature. Furthermore, as the number of regions of interest (ROI) increase, manually segmented datasets usually contain several small, inaccurately labelled, or detached regions which becomes difficult to recognize in a two-dimensional display [1]. The semi-automated technique with the use of label-specific correction tools, allows for rapid identification, navigation, and modification of the small, disconnected erroneous labels within a dataset while providing valid segmentation results [2].

Regenerative endodontic procedures (REP) are strategies that are aimed at achieving organized restoration of the dental pulp and its surrounding structures [3]. There is an ever-increasing body of research that suggests the ability of REPs to promote root maturation in immature teeth with pulpal necrosis [4–6]. However, the standard image interpretation system based on two-dimensional (2D) radiographs makes it challenging to detect subtle volumetric changes post REP [7, 8]. In these radiographs, any compromise in the geometric configuration results in errors and thereby inaccurate readings, and interpretation of outcomes [9].

Three-dimensional (3D) semi-automated image segmentation using label-specific correction tools has been previously demonstrated to be a useful instrument in the evaluation of REP [10]. Though volumetric quantifications from CBCT datasets have been utilized for REP evaluation, there is a clear shortage of well-designed studies with a standardized quantitative method utilising image processing software platforms for evaluating the outcome of REP. Furthermore, both from the clinical and educational context, not all clinicians or institutions may have access to paid software, thereby raising the need to validate open-source platforms. In view of this, the purpose of this research was to quantify and compare the change in pulp space volume post REP by a semi-automated approach utilizing two different 3D software platforms (i.e., OsiriX MD and 3D Slicer).

2 Methodology

Informed consent was obtained from patients or their parents/guardians. The study protocol was approved by the institutional ethics committee at A.B. Shetty Memorial Institute of dental sciences, Deralkatte, Mangalore. The research was carried out in accordance with guidelines and regulations set down in the declaration of Helsinki. Pre- and post-operative CBCT scans of 35 teeth in 28 patients aged 8–38 years with one or more immature permanent teeth were included in the study. These patients had undergone a cell-homing concept-based REP based on the clinical guidelines proposed by the American Association of Endodontists, and the European Society of Endodontology position statements [11, 12]. Two limited FOV CBCT scans (CS 9000; Carestream Dental, LLC Atlanta, USA) was obtained one immediately after the procedure and a second after a follow-up interval once the teeth were deemed clinically successful with significant evidence of radiographic changes [13].

Volume measurements The CBCT datasets were processed to quantify changes in the pulp space volume post REP using two biomedical DICOM software programs i.e., 1) OsiriX MD (commercially available, FDA Approved), and 2) 3D Slicer (open source).

The pulp space volume using the OsiriX MD software was performed by an endodontist who was well versed with the working of the OsiriX MD software. The “closed polygon selection” tool under the ROI tool button was used to trace the boundary of the pulp space on alternate slices (axial images, slice thickness: 0.3mm) from a fixed coronal reference point (end of the coronal seal) to the apex of the root. After outlining only half of the slices between the two reference points, the missing ROI can be generated using the “generate missing ROIs” tool under the “ROI” dropdown menu. The “Grow Region (2D/3D Segmentation)” algorithm facilitates this automated process based on the differences in Hounsfield units between the pulp space as well the surrounding hard tissues. The automated outlines are manually adjusted with the “closed polygon selection” tool and “repulsor tool” to refine the ROI (Fig. 1A). After collecting all the ROI within one series, “ROI volume” tool automatically calculates the volume by multiplying surface and slice thickness and then adds up the individual slice volumes to reconstruct a 3D model (Fig. 1B). The operating system used was Macintosh Operating System (Mac OS; Intel Core i5, 1.8 GHz, 4 GB RAM).

The volume measurements with the 3D Slicer software were performed by an experienced endodontist with prior experience of the software and their plug ins. The use of GrowCut technique accompanied by morphological operations such as erosion, dilation, and island removal were used for effective segmentation of the pulp space.

Briefly the following workflow was performed for pulp space segmentation: a) CBCT dataset was loaded into 3D Slicer b) identification of a region inside the pulp space preceded by a stroke with a brush size of around 0.5 cm beyond the pulp space. (Fig. 2A). c) automatic competing region- growing using GrowCut. (Fig. 2B) d) usage of editing tools and manual refinement after visual inspection of results (qualitative assessment). e) use of segment statistics module to extract the pulps pace volume. (Fig. 3) The operating system used was Windows 10 (Microsoft corporation; AMD Ryzen 5, 2.0 GHz, 8 GB RAM).

Both the evaluators conducted the measurements separately and were blinded by the results of each other. Since the intra observer reliability was high for both the evaluators, the measurements were performed only once. The results were generated in millimeter and centimeter cube units and the data presented in percentage. **(Table.1, Supplementary material)**.

Data analysis Statistical analysis of the data was performed using SPSS (v 21.0, IBM). Normality of numerical data was assessed using the Shapiro-Wilk test and parametric tests were used for comparisons. Intergroup comparisons were made using the t-test. The intragroup comparison was made using paired t-test. A P-value < 0.05 was considered as significant, keeping α error at 5% and β error at 20%, thus giving power to the study as 80%.

3 Results

The pulp space volume measured by two different image processing dicom software programs (OsiriX MD & 3D Slicer) showed a statistically significant decrease in post REP pulp space volume (Fig. 4). The mean decrease in pulp space volume with OsiriX MD was $25.06\% \pm 19.45\%$, and 3D Slicer was $26.10\% \pm 18.90\%$. However, no significant difference was found between OsiriX MD & 3D Slicer values ($p > 0.05$). The time taken for volumetric analyses in a patient was approximately 12 to 19 minutes with the OsiriX MD and 8–13 minutes with 3D Slicer.

4 Discussion

Advancements in 3D imaging tools that minimize human effort have yielded images with greater sensitivity in relation to pathological changes and improved anatomical resolution which facilitate clinical research and clinical practice. Furthermore, the development of 3D medical imaging software programmes allows the analysis and quantitative interpretation of the obtained data, facilitating the identification of small previously undetectable quantitative variations which improves our precision to diagnose and evaluate the individual responses to a given treatment. It is established that when 3D anatomical structures are assessed using their 2D equivalents, it may lead to errors [14]. To overcome

this disparity, it is recommended to use concepts of geometric correction and 3D Multiplanar reconstructions (MPR) [14, 15].

Once imaging data is acquired, the next step is image segmentation, which refers to the delineation of the desired anatomy, or ROI. Discrimination of the anatomy of interest from surrounding tissues often requires expertise and time, and knowledge of specialized software is needed to perform the segmentation. Time taken for segmentation may vary significantly depending upon the ROI. Some software programmes offer algorithms and protocols that are tailored for more efficiently defining certain anatomical regions. No standardized approach to image segmentation currently exists, and the segmentation process can be automated or manual, but many workflows promote a semi-automated approach similar to ours, since fully automated segmentation often fails to match human assessment leading to procedural errors, thereby reflecting on the final measurements, especially with regards to the low contrast images produced by CBCT [16].

One of the desired outcomes of REP is root maturation with reduction in pulp space volume. The change in the volume of the pulp space can be considered as an indicator to determine the success post REP [17, 18]. Moreover, the precision of the segmentation regulates the accuracy of the 3D engineered scaffolds and is envisaged to play a significant role in cell - based regenerative endodontic strategies [19].

OsiriX MD is a medical image processing application for Mac running on a 64-bit platform that fully complies with the DICOM standard for image communication and image file formats. OsiriX MD is an FDA approved 510k class II medical device, as per US Food and Drug Regulation CFR21 part 820. OsiriX MD has been previously utilized to analyze the pulp space volume post REP [20]. The advantage with this software is that there is no need to outline the pulp space boundaries in every slice, as it interpolates the ROI for the missed slices and computes the volume. On the other hand, 3D Slicer is an open-source software platform for medical image informatics, image processing, and three-dimensional visualization. The 3D Slicer works across all operating platforms (Linux, Mac OS, Windows). Though this software is not restricted in its use, FDA has still not approved it for clinical use.

Typically, proprietary DICOM imaging software programmes are expensive, and their accessibility to the general clinician is limited. Therefore, the purpose of this study was to evaluate whether an open-source software (3D Slicer) approach would be practical and efficient for the volumetric analyses of the pulp space post REP when compared to that of a proprietary software (OsiriX MD).

The results of this work demonstrated that the mean decrease in volume after REP was 7.62 mm³ with OsiriX MD and 7.685 mm³ with 3D Slicer. Statistically there was no significant difference in the mean change in volumes calculated. This can be attributed to the dedicated tools within these software packages that allows the rapid, automatic outline and measurement of the ROI: the operator is required to only detect the coronal and apical extent (reference point), thereby minimizing observers variations when analyzing 3D images in various planes [21].

Except for a case report and one case series, there are no studies in literature currently which report the volumetric analyses of the teeth after REP [10, 20]. Mostafa EzEldeen *et al.* (2015) conducted a similar study using the two-step livewire, semiautomatic user-guided 3D active contour segmentation technique with the MeVisLab (MeVis Research, Bremen, Germany) software. The mean change in volume after REP was reported to be 27.92 mm³ in the 5-case series [10]. This difference in the outcomes compared to our study may be attributed to the larger no of cases as well as other predisposing factors such as the etiology (trauma) and periapical pathosis in the present study population [13].

The reduction in volume of pulp space post REP was apparently due to the intra canal deposition of cementum or bone like tissues. This assumption is based on various reported histological findings in immature teeth with apical periodontitis treated with REP [20, 22–24]. However, the nature of the tissues formed or the influence of predisposing factors (i.e., trauma, periapical pathosis) has not been discussed nor was it in the scope of this study, which mainly focused on the quantitative efficiency of the two software programs. Though an attempt was made to quantify the hard tissue deposition on the canal walls post REP, we were unsuccessful in delineating its boundaries. This may be due to some of the limitations of CBCT imaging, such as a low contrast, background noise, limited correlation with Hounsfield units, along with a small area of tissue to be assessed ,all of which made it difficult to determine the precise location and quantification of the hard tissue formed post REP [25]. However, in the 3D Slicer the post REP 3D pulp space volume can be overlaid translucently over the pre-operative image and reviewed in a 3D view to assess the hard tissue deposition on the canal walls, which was not reported here as the reproducibility of this technique could not be confirmed or compared with OsiriX MD.

In terms of efficiency, the process with OsiriX MD was time consuming when compared to the grow cut technique in 3D Slicer, as in OsiriX MD multiple points outlining the diameter of the pulp space must be marked manually on the selected slices, until the entire perimeter has been defined.

6 Conclusion

To our knowledge, there has been no study comparing the efficiency of OsiriX MD and 3D Slicer for volumetric analyses of the pulp space post REP. Though a statistically significant difference in volume were recorded post REP, our study demonstrated that both programmes can be used with similar results. Despite the steep learning curve associated with newer medical imaging programs, the open-source software, i.e., 3D Slicer used for volumetric analyses in the present study seems to offer the advantages of being significantly faster and requiring lesser user interaction thereby showing potential for end user application in assessing outcomes of REP.

Declarations

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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Figures

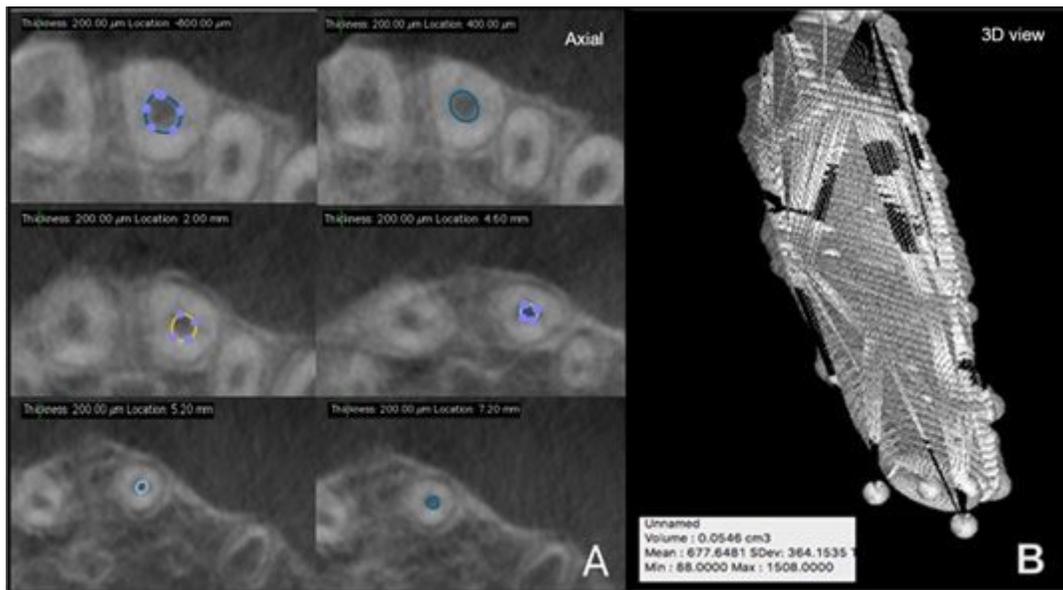


Figure 1

Pulp space volume assessment using OsiriX MD (A) illustrates the ROI in various axial slices and (B) reconstructed 3D model along with the volume statistics.



Figure 2

Grow Cut technique in 3D Slicer (A) initialization of an area inside and outside the ROI using paint effect (blue arrow). (B) automatic competing region-growing using Grow Cut effect (red arrow).

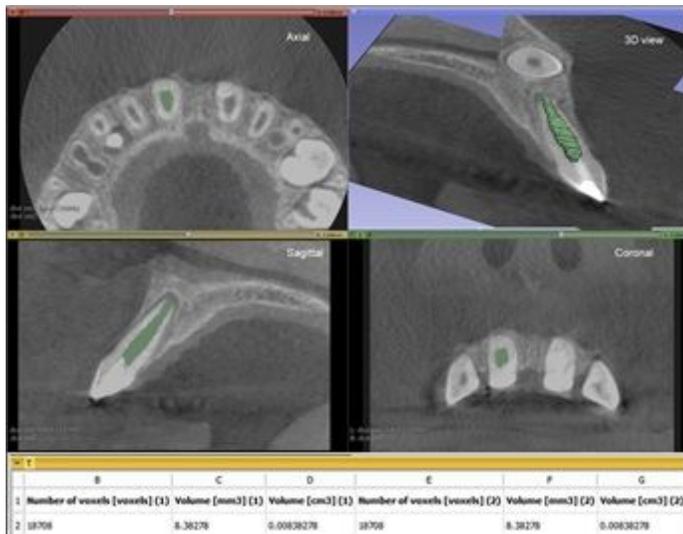


Figure 3

Pulp space volume assessment using 3D Slicer illustrates the ROI in the axial, sagittal and coronal slicing as well as the reconstructed 3D model with the calculated volume.

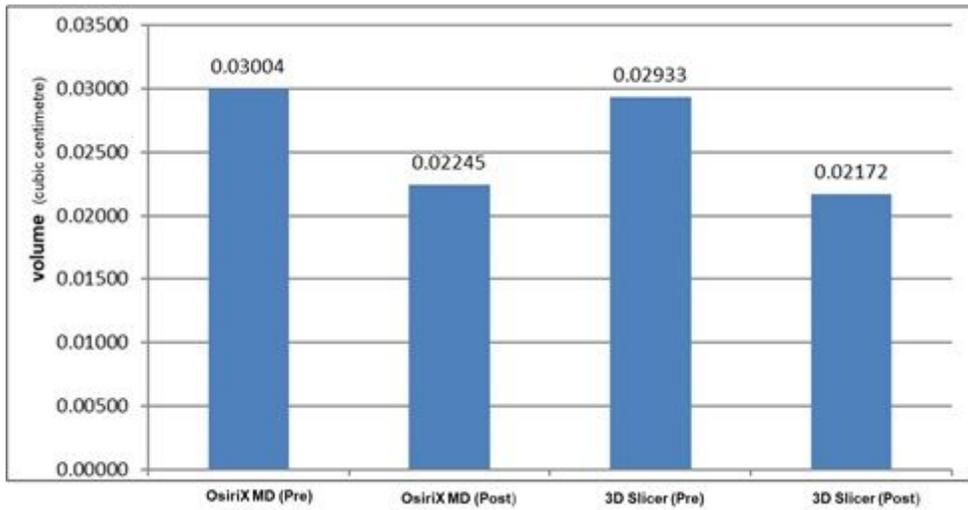


Figure 4

Bar diagram depicting the decrease in volume (mean) calculated with OsiriX MD and 3D Slicer based on the initial (pre) and the final (post) CBCT scans.

Supplementary Files

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