RESEARCH ARTICLE

Assessment of three methods of geometric image reconstruction for digital subtraction radiography

¹Polyane M Queiroz, ¹Matheus L Oliveira, ²Jefferson L O Tanaka, ²Milton G Soares,
¹Francisco Haiter-Neto and ³Evelise Ono

¹Department of Oral Diagnosis, Area of Oral Radiology, Piracicaba Dental School, University of Campinas, Piracicaba, Sao Paulo, Brazil; ²Department of Dental Radiology and Imaging, Brazilian Dental Association, Ponta Grossa, Parana, Brazil; ³Department of Oral Medicine, State University of Londrina, Londrina, Parana, Brazil

Objectives: To evaluate three methods of geometric image reconstruction for digital subtraction radiography (DSR).

Methods: Digital periapical radiographs were acquired of 24 teeth with the X-ray tube at 6 different geometric configurations of vertical (V) and horizontal (H) angles: V0°H0°, V0°H10°, V10°H0°, V10°H10°, V20°H0° and V20°H10°. All 144 images were registered in pairs (Group V0°H0° + 1 of the 6 groups) 3 times by using the Emago® (Oral Diagnostic Systems, Amsterdam, Netherlands) with manual selection and Regeemy with manual and automatic selections. After geometric reconstruction on the two software applications under different modes of selection, all images were subtracted and the standard deviation of grey values was obtained as a measure of image noise. All measurements were repeated after 15 days to evaluate the method error. Values of image noise were statistically analyzed by one-way ANOVA for differences between methods and between projection angles, followed by Tukey's test at a level of significance of 5%.

Results: Significant differences were found between most of the projection angles for the three reconstruction methods. Image subtraction after manual selection-based reconstruction on Regeemy presented the lowest values of image noise, except on group V0°H0°. The groups V10°H0° and V20°H0° were not significantly different between the manual selection-based reconstruction in Regeemy and automatic selection-based reconstruction in Regeemy methods.

Conclusions: The Regeemy software on manual mode revealed better quality of geometric image reconstruction for DSR than the Regeemy on automatic mode and the Emago on manual mode, when the radiographic images were obtained at V and H angles used in the present investigation.

Dentomaxillofacial Radiology (2016) 45, 20160120. doi: 10.1259/dmfr.20160120

Cite this article as: Queiroz PM, Oliveira ML, Tanaka JLO, Soares MG, Haiter-Neto F, Ono E. Assessment of three methods of geometric image reconstruction for digital subtraction radiography. *Dentomaxillofac Radiol* 2016; 45: 20160120.

Keywords: digital dental radiography; radiographic image enhancement; computer-assisted image processing

Introduction

Digital subtraction radiography (DSR) is a useful technique to detect subtle changes in the mineral

composition of structures such as the tooth and bone.¹ The accuracy of this method depends on differences in geometric projection that are inversely proportional to image quality. Greater geometric discrepancy leads to lower quality of digital subtraction.² Differences in density and contrast between the initial (reference) and

Correspondence to: Ms Polyane Mazucatto Queiroz. E-mail: polyanequeiroz@hotmail.com

Received 26 March 2016; revised 29 June 2016; accepted 30 June 2016

secondary images also affect DSR.³ Thus, it is advisable that both radiographic images are obtained under similar conditions of projection and processing.⁴

In the early 1980s, new software applications for DSR were introduced with reconstruction algorithms to derive a plain image with approximate geometric projection of a reference image obtained at a different geometric configuration. Geometric image reconstruction in DSR is based on the principle developed by Dunn *et al*,⁵ who applied mathematical equations to find coordinates of corresponding points of a reference image in a secondary image. This results in a stable alignment between pairs of points and improves the performance of DSR.^{6,7} The correspondence of points can be accomplished manually or automatically. In manual mode, the results may depend on the experience and ability of the observer to manipulate the computer mouse, which is time consuming and demands patience.^{8,9} In automatic mode, the software automatically reconstructs the image, leading to more objective and reproducible results.^{9–11} In addition, since automatic selection of points makes use of multiple points of reference, more reliable outcomes are expected.⁹ Software applications should be of practical use to dentists, irrespective of the geometric reconstruction method.¹²

Software applications have been designed to establish geometric standardization and achieve better performance in DSR. The software Emago is one of them and has been widely used since 1992.¹³ In 2005, the software Regeemy was developed and among its advantages, there is the availability for download at no cost and the possibility of manual or automatic selection of multiple points of reference.¹⁴ Since then, successful results have been obtained for DSR, as shown by Ono *et al*¹⁵ and Sunku *et al*¹⁶ in the diagnosis of apical root resorption, and Giannastacio *et al*¹⁷ in the follow-up of apical surgery.

Considering the great importance of the reconstruction process in producing subtracted images of high quality for adequate interpretation, the aim of this study was to evaluate three methods of geometric image reconstruction for DSR.

Methods and materials

144 digital periapical radiographs of 24 teeth in dry dentate mandibles were obtained from a previous study (Ono *et al*,¹⁵ 2011). The radiographs were acquired using the Visualix image receptor (Dentsply-Gendex, Milano, Italy) and the Gendex 765DC X-ray unit (Gendex Dental Systems, Dentsply International, IL) operating at 65 kVp and 7 mA for 0.064 s. The exposure time was determined in a pilot study as the shortest time that produced an acceptable image in terms of brightness and contrast (as low as reasonably achievable principle).

Each tooth was X-rayed with the X-ray tube at six different geometric configurations of vertical (V) and

horizontal (H) angles, as presented by Heo *et al*:¹³ V0°H0°, V0°H10°, V10°H0°, V10°H10°, V20°H0° and V20°H10°. The radiographs obtained at V0°H0° were considered as the reference images and the remaining as secondary images. An acrylic apparatus allowed proper and standardized angular positioning of the X-ray tube and image receptor.

Two software applications registered all images: Regeemy—Image Registration and Mosaicking—0.2.43 (DPI-INPE Sao Jose dos Campos, Brazil and Vision Lab Electrical and Computer Engineering Department, University of California, Santa Barbara, CA) and Emago[®]—Advanced 3:50 (Oral Diagnostic Systems, Amsterdam, Netherlands). All 144 radiographic images were registered in pairs (reference and secondary images) three times by using the Emago with manual selection and Regeemy with manual and automatic selections. In both software applications, the manual reconstruction was based on the selection of four reference points in areas of highly contrasted contours such as the cemento-enamel junction and the cusp tips. In Regeemy software, manual selection of points was first performed, followed by image registration and digital subtraction. Subsequently, geometric reconstruction was performed with automatic selection of multiple points. Considering the sample of images used in this study, approximately 60 points were automatically detected in areas of high contrast on the reference images and served as coordinates for the software algorithms to reconstruct secondary images. In Emago software, automatic gamma correction was performed before manual selection of points to optimize radiographic density and contrast. In Regeemy software, density and contrast adjustments were performed automatically after manual or automatic selection of reference points. After geometric reconstruction on different software applications and modes of selection, all images were saved as tagged image file format) and subtracted (Figure 1).

A standardized region of interest (ROI) was selected (Figure 2) encompassing the entire tooth in all groups of subtracted images by using guides and X and Y coordinates in Adobe Photoshop[®] v. 7.0 software (Adobe Systems Inc., San Jose, CA). The ROIs eliminated the black and/or white peripheries of subtracted images owing to the translational movement of the secondary image to realign with the reference image. Then, the standard deviation (SD) of grey values, which represents image noise and is inversely related to image quality, was obtained from subtracted images to assess the geometric reconstruction process of the three groups: manual selection-based reconstruction in Emago (MRE), manual selection-based reconstruction in Regeemy (MRR) and automatic selection-based reconstruction in Regeemy (ARR). Four and multiple points were selected on manual and automatic selection-based reconstructions, respectively.

All measurements were repeated after 15 days to evaluate the error of the method. Thus, SDs of grey

Figure 1 Digital radiographs of different groups and subtracted images under different reconstruction methods. ARR, automatic selection-based reconstruction in Regeemy; MRE, manual selection-based reconstruction in Emago; MRR, manual selection-based reconstruction in Regeemy.

values from the ROIs obtained in the two phases were subjected to regression analysis that produced a linear regression model with a regression of the type $Y = aX + b$, where X and Y represent the steps performed in the first and second phases, respectively, and “ a ” and “ b ” are regression coefficients. To verify the absence of systematic and random errors, the coefficient “ a ” should be equal to 1 and the coefficient “ b ” should be equal to 0, so that $Y = X$. The verification of this condition was performed by Student’s t -test. Because no statistical difference was found between both phases of measurements, SDs of grey values were averaged for statistical analysis. The SDs of grey values were

statistically analyzed between methods and between projection angles within each method by one-way ANOVA followed by Tukey’s test, with a level of significance of 5% ($\alpha = 0.05$).

Results

As shown in Table 1, when the SDs of grey values were averaged and compared, significant differences ($p < 0.05$) were detected between projection angles for the ARR method, except between groups V10°H10° and V20°V10° and between groups V0°H10° and V20°H0°.

Figure 2 Selection of the standardized region of interest in the subtracted image.

Also, a significant difference ($p < 0.05$) was observed between projection angles for the MRR method. Similarly to the groups V10°H0° and V10°H10°, groups V20°H0° and V20°H10° were significantly different ($p < 0.05$) from the other groups, but not from each other.

When the MRE method was used, the groups V0°H0° and V20°H10° were significantly different ($p < 0.05$) from each other and from the other groups. The group V0°H10° was not significantly different from

V10°H0°, which is not different from V10°H10°. However, V0°H10° was significantly different ($p < 0.05$) from V10°H10°, which was not different from V20°H0°.

Significant difference ($p < 0.05$) was detected between methods for all projection angles. Images reconstructed by the MRR method presented the lowest values of SD, except on group V0°H0°, in which the lowest values of SD were obtained from images reconstructed by the ARR method. The groups V10°H0° and V20°H0° were not significantly different between the MRR and ARR methods.

Discussion

The SD of grey values expresses the noise (variability of grey values) of the image. Greater SD values represent lower grey value homogeneity and *vice versa*,¹⁸ which may compromise the image quality and diagnostic accuracy.

The three methods of geometric image reconstruction and all projection angles evaluated in this study showed SD of grey values with significant differences. Emago showed significantly higher values. For the three methods, the group V0°H0° was significantly different from the other groups, with the lowest SD of grey values. This is not in agreement with Heo et al,¹³ who obtained images at the same projection angles as in the present study and did not find significant difference between measurements of tooth loss and detection of apical root resorption. Such disagreement may be due to the absence of the trabecular bone in the study of Heo et al,¹³ considering that the teeth were X-rayed in a plaster block. This might have facilitated the selection of control points and reduced anatomic superimposition, leading to better alignment between the reference and secondary images and, consequently, better detection of the lesion.

Guneri et al¹⁹ suggest that Emago tolerates vertical angle differences up to 10° in the subjective evaluation of DSR image quality. In the present study, the groups V0°H0° and V10°H0° were significantly different for the MRE method; however, it is not known whether this is clinically relevant, considering that the images were not evaluated for diagnostic accuracy. The two other methods (MRR and ARR) presented significant difference when the vertical angle ranged in 10° between groups V0°H10° and V10°H0°. The three methods showed the lowest and highest SD of grey values for groups V0°H0 and V20°H10°, respectively. This result supports the study of Rudolph et al,² in which image noise increased with greater variation of projection angle.

Saramabandu et al¹⁰ compared images obtained with an angular difference of 2° and showed that automatic alignment produces equivalent image quality when compared with subtracted images after manual reconstruction. This represents an important step towards full automation of the reconstruction process and can be

Table 1 Mean values of standard deviation (SD) of grey values for different projection angles and reconstruction methods

Projection angles	Mean values of SD of grey values			p-value
	ARR	MRR	MRE	
V0°H0°	5.40 ^{Aa}	7.27 ^{Ab}	14.12 ^{Ac}	<0.001
V0°H10°	16.74 ^{Cb}	9.69 ^{Ba}	28.89 ^{Bc}	<0.001
V10°H0°	11.93 ^{Ba}	11.93 ^{Ca}	30.85 ^{BCb}	<0.001
V10°H10°	19.59 ^{Db}	13.19 ^{Ca}	33.81 ^{CDe}	<0.001
V20°H0°	17.30 ^{Ca}	15.42 ^{Da}	36.33 ^{Db}	<0.001
V20°H10°	21.27 ^{Db}	17.27 ^{Da}	41.32 ^{Ec}	<0.001
p-value	<0.001	<0.001	<0.001	–

ARR, automatic selection-based reconstruction in Regeemy; MRE, manual selection-based reconstruction in Emago; MRR, manual selection-based reconstruction in Regeemy. Mean values followed by different letters (uppercase for vertical and lowercase for horizontal) are significantly different from each other ($p < 0.05$).

applied in a large scale. As in the study of Samarabandu et al,¹⁰ this study showed that the geometric reconstruction quality (SD of grey values) decreased on the MRE method compared with that on the ARR method. However, the lowest SD values were observed at different projection angles for the MRR method. Most of the groups analyzed in this study (66.6%) showed that the MRR is superior to the ARR, with the lowest SD values in the groups V0°H10°, V10°H10°, V20°H0° and V20°H10°. Moreover, Yoon²⁰ showed that images obtained from automatic alignment of a new software present reduced noise when compared with reconstructed images from the MRE method.

In our study, the ARR method had a better performance than the MRE and MRR methods only for images obtained at V0°H0°. At the other projection angles, the MRR method was superior to the MRE and ARR methods. When compared with automatic mode, such a performance may result from the way the reference points were selected. In manual mode, the operator manipulates the image and selects reference points based on density differences visible to the human eye. In automatic mode, the computer selects multiple reference points based on areas of corresponding shades of grey. The density of an area in images at different projection angles may change owing to changes in the location of the trabecular bone, lamina dura and other superimposed structures. Thus,

software applications can be ineffective in detecting reference points with altered density. The inferior performance demonstrated by the MRE method may possibly be related to inherent differences between software applications, since points were manually selected under the same criteria in the MRR and MRE programmes.

The MRE method has demonstrated to be of lower quality when compared with the Sunny software,²¹ Poselt software¹² and an unnamed new software.²² Similarly, the present study revealed that images reconstructed by the MRE method were of lower quality when compared with the MRR and ARR methods, irrespective of the projection angle. This highlights the better performance of Regeemy over Emago, regardless of the projection angle and mode of selecting points (manual or automatic).

In conclusion, the Regeemy software on manual mode revealed better quality of geometric image reconstruction than the Regeemy on automatic mode and the Emago on manual mode, when the radiographic images were obtained at vertical and horizontal angles used in the present investigation. Considering that radiographic interpretation is greatly influenced by image quality, manual selection-based reconstruction in Regeemy is recommended as the method of choice among the three methods assessed in this study for DSR.

References

1. Nicopoulou-Karayianni K, Bragger U, Jang NP. Subtraction radiography in oral implantology. *Int J Periodontics Restorative Dent* 1997; **17**: 220–31.
2. Rudolph DJ, White SC, Mankovich NJ. Influence of geometric distortion and exposure parameters on sensitivity of digital subtraction radiography. *Oral Surg Oral Med Oral Pathol* 1987; **64**: 631–7. doi: [http://dx.doi.org/10.1016/0030-4220\(87\)90074-0](http://dx.doi.org/10.1016/0030-4220(87)90074-0)
3. Benn DK. Limitations of the digital image subtraction technique in assessing alveolar bone crest changes due to misalignment errors during image capture. *Dentomaxillofac Radiol* 1990; **19**: 97–104. doi: <http://dx.doi.org/10.1259/dmfr.19.3.2088789>
4. Cury PR, Taba Junior M, Mantesso A, Bonecker M, Araujo NS. Detecção de alterações ósseas utilizando um programa de subtração radiográfica: estudo *in vitro*. *Rev Pós Grad* 2005; **12**: 242–7.
5. Dunn SM, van der Stelt PF, Ponce A, Fenesy K, Shah S. A comparison of two registration techniques for digital subtraction radiography. *Dentomaxillofac Radiol* 1993; **22**: 77–80. doi: <http://dx.doi.org/10.1259/dmfr.22.2.8375559>
6. Mol A, Dunn SM. The performance of projective standardization for digital subtraction radiography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2003; **96**: 373–82. doi: <http://dx.doi.org/10.1016/S1079210403003573>
7. Ruttimann UE, Webber RL, Schmidt E. A robust digital method for film contrast correction in subtraction radiography. *J Periodontol* 1986; **21**: 486–95. doi: <http://dx.doi.org/10.1111/j.1600-0765.1986.tb01484.x>
8. Byrd V, Mayfield-Donahoo T, Reddy MS, Jeffcoat MK. Semi-automated image registration for digital subtraction radiography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1998; **85**: 473–8. doi: [http://dx.doi.org/10.1016/S1079-2104\(98\)90077-4](http://dx.doi.org/10.1016/S1079-2104(98)90077-4)
9. Ettinger GJ, Gordon GG, Goodson JM, Socransky SS, Williams RR. Development of automated registration algorithms for subtraction radiography. *J Clin Periodontol* 1994; **21**: 540–3. doi: <http://dx.doi.org/10.1111/j.1600-051X.1994.tb01170.x>
10. Samarabandu J, Allen KM, Hausmann E, Acharya R. Algorithm for the automated alignment of radiographs for image subtraction. *Oral Surg Oral Med Oral Pathol* 1994; **77**: 75–9. doi: [http://dx.doi.org/10.1016/S0030-4220\(06\)80111-8](http://dx.doi.org/10.1016/S0030-4220(06)80111-8)
11. Lehmann TM, Gröndahl K, Gröndahl HG, Schmitt W, Spitzer K. Observer-independent registration of perspective projection prior to subtraction of *in vivo* radiographs. *Dentomaxillofac Radiol* 1998; **27**: 140–50. doi: <http://dx.doi.org/10.1038/sj.dmfr.4600335>
12. Haiter Neto F, Wenzel A. Noise in subtraction images made from pairs of bitewing radiographs: a comparison between two subtraction programs. *Dentomaxillofac Radiol* 2005; **34**: 357–61.
13. Heo MS, Lee SS, Lee KH, Choi HM, Choi SC, Park TW. Quantitative analysis of apical root resorption by means of digital subtraction radiography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2001; **91**: 369–73. doi: <http://dx.doi.org/10.1067/moe.2001.113592>
14. Dotto GN. Registro de radiografias periapicais para a técnica de subtração [tese]. São José dos Campos: Faculdade de Odontologia de São José dos Campos (SP): Universidade Estadual Paulista-UNESP; 2005.
15. Ono E, Medici-Filho E, Faig Leite H, Tanaka JL, De Moraes ME, De Melo Castilho JC. Evaluation of simulated external root resorptions with registered digital radiography and digital subtraction radiography. *Am J Orthod Dentofacial Orthop* 2011; **139**: 324–33. doi: <http://dx.doi.org/10.1016/j.ajodo.2009.03.046>
16. Sunku R, Roopesh R, Kancherla P, Perumalla KK, Yudhister PV, Reddy VS. Quantitative digital subtraction radiography in the assessment of external apical root resorption induced by orthodontic therapy: a retrospective study. *J Contemp Dent*

- Pract* 2011; **1**: 422–8. doi: <http://dx.doi.org/10.5005/jp-journals-10024-1070>
17. Giannastacio D, Rosa RA, Peres BU, Barreto MS, Doto GN, Kuga MC, et al. Wizard CD plus and pro taper universal: analysis of apical transportation using new software. *J Appl Oral Sci* 2013; **21**: 468–74.
 18. Wenzel A, Sewerin I. Sources of noise in digital radiography. *Oral Surg Oral Med Oral Pathol* 1991; **71**: 503–8. doi: [http://dx.doi.org/10.1016/0030-4220\(91\)90441-E](http://dx.doi.org/10.1016/0030-4220(91)90441-E)
 19. Guneri P, Gougus S, Tugsel Z, Boyacioglu H. Efficacy of a new software in eliminating the angulation errors in digital subtraction radiography. *Dentomaxillofac Radiol* 2007; **36**: 484–9.
 20. Yoon DC. A new method for the automated alignment of dental radiographs for digital subtraction. *Dentomaxillofac Radiol* 2000; **29**: 11–19. doi: <http://dx.doi.org/10.1038/sj.dmfr.4600487>
 21. Lee SS, Huh YJ, Kim KY, Heo MS, Choi SC, Koak JY, et al. Development and evaluation of digital subtraction radiography computer program. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2004; **98**: 471–5. doi: <http://dx.doi.org/10.1016/S1079210404002215>
 22. Güneri P, Gögüs S, Tugsel Z, Ozturk A, Gungor C, Boyacioglu H. Clinical efficacy of a new software developed for dental digital subtraction radiography. *Dentomaxillofac Radiol* 2006; **35**: 417–21. doi: <http://dx.doi.org/10.1259/dmfr/21142030>