RESEARCH

Assessment of using digital manipulation tools for diagnosing mandibular radiolucent lesions

R Raitz¹, JNR Assunção Junior², M Fenyó-Pereira³, L Correa^{*,3} and LP de Lima⁴

¹São Leopoldo Mandic, Dental Research Institute, Campinas, São Paulo, Brazil; ²Stomatology Department, School of Dentistry, Metropolina de Santos University, Santos, São Paulo, Brazil; ³Department of Stomatology, School of Dentistry, University of São Paulo, Brazil; ⁴Logx Financial and Statistical Consulting, Sao Paulo, Brazil

Objective: The purpose of this study was to analyse the use of digital tools for image enhancement of mandibular radiolucent lesions and the effects of this manipulation on the percentage of correct radiographic diagnoses.

Methods: 24 panoramic radiographs exhibiting radiolucent lesions were selected, digitized and evaluated by non-experts (undergraduate and newly graduated practitioners) and by professional experts in oral diagnosis. The percentages of correct and incorrect diagnoses, according to the use of brightness/contrast, sharpness, inversion, highlight and zoom tools, were compared. All dental professionals made their evaluations without (T_1) and with (T_2) a list of radiographic diagnostic parameters.

Results: Digital tools were used with low frequency mainly in T_2 . The most preferred tool was sharpness (45.2%). In the expert group, the percentage of correct diagnoses did not change when any of the digital tools were used. For the non-expert group, there was an increase in the frequency of correct diagnoses when brightness/contrast was used in T_2 ($p = 0.008$) and when brightness/contrast and sharpness were not used in T_1 ($p = 0.027$). The use or non-use of brightness/contrast, zoom and sharpness showed moderate agreement in the group of experts [kappa agreement coefficient (κ) = 0.514, 0.425 and 0.335, respectively]. For the non-expert group there was slight agreement for all the tools used ($\kappa \leq 0.237$).

Conclusions: Consulting the list of radiographic parameters before image manipulation reduced the frequency of tool use in both groups of examiners. Consulting the radiographic parameters with the use of some digital tools was important for improving correct diagnosis only in the group of non-expert examiners.

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Introduction

The interest in digital image processing methods has arisen from the recent possibility of improving the quality of visual information for human interpretation and the ease of communication and consultation by means of the internet. Particularly in oral pathology, this improvement in image quality is essential for a better diagnosis, especially if the original source of the

digital image is a conventional radiograph. Sometimes these digital images need a particular type of processing in order to correct some non-optimal exposures that may negatively interfere with the image of the lesion.¹

The tools most often used in digital manipulation are brightness, contrast, density and zoom, and their use can improve image quality.² In oral pathology, digital manipulation has some influence on radiographic diagnosis, such as contrast adjustments,^{3,4} sharpness, smoothness and embossing for caries diagnosis,⁵ use of noise filters for detection of vertical root fractures⁶ and use of the inversion tool for bone loss measurements in periodontal disease.^{7,8} However, digital image manipulation can

*Correspondence to: Prof Dr Luciana Corrêa, University of São Paulo, School of Dentistry, Av. Prof. Lineu Prestes, 2227, Cidade Universitária, 05508-900 São Paulo – SP, Brazil. E-mail: lcorrea@usp.br
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increase the time taken to interpret the image and this processing may not contribute to an increase in the percentage of correct diagnoses.² The great challenge is to know which tools are useful and applicable to each diagnostic task in order to discard superfluous signs and stress useful signs in the images.⁹

There is no study focused on the influence of digital manipulation in the radiographic diagnosis of jaw cysts and tumours. The ameloblastoma (Amel), keratocystic odontogenic tumour (KOT), dentigerous cyst (DC) and idiopathic bony cavity (IBC) frequently have similar radiographic features, and improvement of image quality may have a positive influence on the differential diagnosis of these lesions.

In the present study, the aim was to evaluate the influence of digital tools on the process of radiographic diagnosis of Amel, KOT, DC and IBC. Firstly, we established which digital tools expert and non-expert examiners frequently chose during this radiographic interpretation. Secondly, we determined whether the concomitant use of these digital tools with objective diagnostic guidelines or their non-use increased the frequency of correct diagnoses.

Materials and methods

Approval of this study was obtained from the Ethics Committee of the School of Dentistry, University of São Paulo.

Selection of conventional radiographs

3 radiologists selected 24 conventional panoramic radiographs presenting unilocular radiolucent lesions with histological diagnosis of Amel, KOT, DC and IBC (6 radiographs of each). These radiologists were not included in the group of examiners. When necessary, a CT exam confirmed the unilocular aspect of the lesion. These radiologists chose radiographs with representative radiographic aspects of each lesion group, and six images was sufficient to categorize the majority of clinical outcomes of these diseases. Panoramic radiographs with good contrast, correct alignment in the film and image of the lesion without any interference were selected.

Digitization process

The radiographs were digitized by means of a table scanner provided with a cover for transparency reading and an adapter for slides and negatives, with an optical resolution of 9600 × 4800 dpi (Scan Maker i800; Microtek, Santa Fe Springs, CA). The scanning process was standardized with 600 dpi resolution, TIFF image format and greyscale type at the same percentage size each time. After digitization, an operator manipulated the radiographs using Adobe Photoshop 6.0 software (Adobe Systems, San Jose, CA) for colour optimization, equalization and brightness/contrast standardization.

This process was always performed by the same operator with the same hardware (Laptop HP, Pavilion ze2000, processor Intel Celeron M, 1.3 GHz, 480 MB RAM, 80 GB HD, 15" screen, 1024 × 768 dpi; HP, Palo Alto, CA). This equipment was used afterwards for all the analyses in a room with the same light intensity. Figure 1 shows an example of each digitized lesion. To characterize the size of the lesions, one operator manually contoured the lesion margins using a draw tool. Area, perimeter and shape factor (shape factor = $4\pi A/p^2$ where area = A and perimeter = p) of this contour were established through morphometric software.

Analysis of digital images by examiners

Two groups of examiners analysed the digitized radiographs: a group of non-experts (six third-year dental students, undergraduates enrolled in private institutions after conclusion of the radiology discipline and eight newly graduated general dental practitioners) and a group of experts (three oral surgeons, three stomatologists, three oral radiologists and three oral pathologists).

Images were evaluated using Trophy 2000® software (Trophy, Vincennes, France). Previously, all examiners received training about the use of image processing tools (brightness, contrast, inversion, sharpness, highlight and zoom). They were able to work with the interface when homogeneous repetition in the sequence of clicking on the tool icons was detected. After this training, the examiners randomly observed all the digital images using the same display under default settings (Sony®, LCD 15 inch, 0.297 pixel pitch, 1024 × 768 dpi resolution and constant luminance of 250 cd m⁻²; Tokyo, Japan). During this observation, whether to choose a digital tool or not was a personal decision. At the end of the observation/manipulation, the examiners selected one of the four diagnostic possibilities (Amel, KOT, DC, IBC). The proportion of each lesion in the sample was not revealed.

The examiners analysed the images at two distinct time intervals: first without consulting a list of parameters containing objective radiographic criteria for the diagnosis of each lesion (T_1) and then with consultation of this list (T_2). The radiographic parameters were established in a previous study.¹⁰ These parameters describe the characteristics of such lesions with regard to the patient's age, size and delimitation of the lesion, presence of a radio-opaque halo, dental and cortical involvement, presence of alterations in the jaw base, degree of radiolucency, growth pattern and margins of the lesion. All the images were analysed on the same day for both time intervals. The interval between T_1 and T_2 was 60 days.

During the analysis, a researcher recorded the frequency of use of digital tools. At the end of each analysis, the examiner selected the tool he considered the most important for the particular interpretation.

Statistical analysis

Frequencies of correct/non-correct diagnosis were crossed with use/non-use of each digital tool and the association

Figure 1 Examples of digitized radiographs of each unilocular lesion. (a) Ameloblastoma; (b) keratocystic odontogenic tumour; (c) dentigerous cyst; (d) idiopathic bony cavity

between these variables was determined by Pearson's χ^2 test. These associations were made for T_1 and T_2 time intervals separately and with consideration of the expert group, non-expert group and the total. For each tool, the frequency of use/non-use of the tool at T_1 and T_2 time intervals was compared using the McNemar test and the agreement of use/non-use at the two time intervals was measured using the kappa coefficient. Calculations were performed using SPSS® software (IBM Corporation, Armonk, NY). Statistical significance was determined when $p < 0.05$.

Results

Table 1 shows the median values of area, perimeter and shape factor for each group of lesions. The greater lesions were Amel and KOT while DC and IBC were of a similar size. The most irregular lesion was KOT (shape factor = 0.67).

Figure 2 shows the percentages of the most preferred digital tools. At T_1 , sharpness was the preferred tool (45.2%) followed by the choice of no tool (26.3%). This

pattern changed at T_2 since the highest percentage was observed for no tool (43.4%) and the second highest for sharpness (31.7%). The preference for brightness and contrast decreased at T_2 and the highlight, zoom and inversion tools showed a discrete increase at this evaluation time interval. Inversion was the tool with the lowest preference at both T_1 and T_2 time intervals.

Table 2 shows the percentages of correct diagnoses when the examiner used or did not use each tool at the two time intervals of the analysis. Irrespective of using or not using the digital tool, the percentages of correct diagnoses were higher at T_2 than at T_1 , for both expert and non-expert groups. When analysing the influence of the use of tools on the diagnoses in the expert group, there were no statistically significant differences between use and non-use of the tool for correct diagnoses. This result was observed for both T_1 and T_2 time intervals. In the non-expert group, significant differences were observed for the brightness/contrast at both T_1 ($p = 0.027$) and T_2 ($p = 0.008$). In this group, at T_1 the highest percentage of correct diagnosis was observed for radiographs in which brightness/contrast were not used; at T_2 , the correct diagnosis was higher

Table 1 Median (minimum/maximum values) of area, perimeter and shape factor of each group of lesions

Group of lesions	Area (mm^2)	Perimeter (mm)	Shape factor ^a
Ameloblastoma	2188.88 (652.37/3358.17)	190.30 (98.90/304.76)	0.78 (0.45/0.86)
Keratocystic odontogenic tumour	1297.5 (328.00/2509.20)	150.88 (77.91/327.33)	0.67 (0.51/0.76)
Dentigerous cyst	1108.68 (509.09/2943.01)	129.78 (96.72/242.16)	0.73 (0.53/0.83)
Idiopathic bony cavity	945.71 (582.65/3552.66)	129.96 (92.87/233.62)	0.76 (0.63/0.84)

^aShape factor = $4\pi A/p^2$. Values near to 1 indicate regular shape, similar to a perfect circle; values near to 0 correspond to an irregular shape.

Figure 2 Percentages of the most preferred digital tools, considering the time intervals T_1 (when there was no consultation of the list of radiographic parameters) and T_2 (when this list was consulted) ($n = 624$ analyses)

among those that used brightness/contrast; however, in this case only nine radiographs were analysed with the use of brightness/contrast. The non-experts also presented significant differences with regards to the use of sharpness, but only at T_1 ($p = 0.028$), with the highest percentage of correct diagnoses for radiographs where this tool was not used.

When analysing the groups as a whole, significant differences were observed for highlight at T_1 and for brightness/contrast at T_2 ; in both cases the correct diagnostic percentage was higher for those radiographs in which the tool was used.

Figure 3 shows the percentages of use of each digital tool in the group of experts according to the time intervals of evaluation (T_1 and T_2). For every tool, its percentage of use at T_2 was significantly lower than it was at T_1 ($p < 0.001$), except for the inversion tool for which no difference was observed ($p = 0.885$). There were discordant frequencies of the use of tools in the comparison of the two time intervals, which indicated that the list of parameters promoted less use of digital tools in the expert group. The kappa agreement coefficient (κ) indicated moderate agreement between use/non-use at the two evaluation time intervals for brightness/contrast ($\kappa = 0.514$), zoom ($\kappa = 0.425$) and sharpness ($\kappa = 0.335$), and slight agreement for highlight ($\kappa = 0.105$) and inversion ($\kappa = 0.019$).

Figure 4 presents the percentages of use of tools in the group of non-experts at T_1 and T_2 . Similar to the group of experts, the non-experts also had lower frequency of use of digital tools at T_2 , with the exception of the highlight tool. These differences were statistically significant for brightness/contrast ($p < 0.001$), zoom ($p = 0.018$) and sharpness ($p < 0.001$). This indicated that consultation of the radiographic parameters also modified the

percentage of the use of these digital tools in the group of non-experts. Considering the kappa coefficient for all the tools, the agreement was slight in the comparison of the two time intervals (all coefficients $\kappa \leq 0.237$).

Figure 5 shows the distribution of frequencies for the use of digital tools at T_1 and T_2 for the experts and non-experts as a whole. With the exception of inversion, the other tools had a significantly lower percentage of use at T_2 ($p < 0.001$). Considering the kappa coefficient values, agreement was slight for inversion ($\kappa = 0.068$) and highlight ($\kappa = 0.167$), fair for zoom ($\kappa = 0.296$) and sharpness ($\kappa = 0.267$), and moderate for brightness/contrast ($\kappa = 0.420$).

Discussion

The present study focused on the frequency of the use of digital tools by examiners with distinct experience in the analysis of unilocular mandibular lesions. In this study, we also verified whether the consultation of objective radiographic parameters established for each lesion had any influence on the use of tools. The main findings of this analysis were that this consultation promoted a reduction in the frequency of the use of tools in both the group of experts and the group of non-experts. It was also found that the use of digital tools associated with the consultation of radiographic parameters increased the frequency of correct diagnosis in some cases.

Before discussing this trend in the use of digital tools, some considerations must be taken into account about the selected lesions. Amel, KOT, DC and IBC, which present a similar radiographic pattern,¹¹ are considered lesions that are difficult to diagnose. The radiographs of these lesions were taken with different protocols and

Table 2 Percentages of correct diagnoses according to the use or non-use of each tool by each group of examiners and moment of evaluation (T_1 and T_2)

Tool	Experts						Non-experts						Total					
	T_1			T_2			T_1			T_2			T_1			T_2		
	%	n	total	%	n	total	%	n	total	%	n	total	%	n	total	%	n	total
Brightness/contrast	Non-use	202	231	$p = 0.839$	70.6	285	$p = 0.027$	48.1	285	$p = 0.008$	56.0	327	$p = 0.637$	54.8	487	$p = 0.028$	62.0	558
	Use	86	57	$p = 0.989$	71.9	51	$p = 0.552$	31.4	51	$p = 0.626$	100.0	9	$p = 0.895$	52.6	137	$p = 0.888$	75.8	66
Zoom	Non-use	194	233	$p = 0.942$	70.8	263	$p = 0.713$	46.4	263	$p = 0.558$	57.7	286	$p = 0.307$	54.5	457	$p = 0.375$	63.6	519
	Use	94	55	$p = 0.603$	70.9	73	$p = 0.028$	42.5	73	$p = 0.776$	54.0	50	$p = 0.145$	53.9	167	$p = 0.934$	62.9	105
Inversion	Non-use	262	260	$p = 0.720$	70.8	320	$p = 0.152$	45.3	320	$p = 0.514$	56.9	327	$p = 0.036$	53.8	582	$p = 0.931$	63.4	475
	Use	26	28	$p = 0.253$	71.4	16	$p = 0.516$	50.0	16	$p = 0.514$	66.7	9	$p = 0.931$	61.9	42	$p = 0.931$	63.8	149
Sharpness	Non-use	98	159	$p = 0.737$	71.7	109	$p = 0.028$	54.1	109	$p = 0.776$	56.4	179	$p = 0.145$	58.5	207	$p = 0.934$	63.6	338
	Use	190	129	$p = 0.253$	69.8	227	$p = 0.152$	41.4	227	$p = 0.514$	58.0	157	$p = 0.036$	52.3	417	$p = 0.931$	63.3	286
Highlight	Non use	182	224	$p = 0.253$	69.2	256	$p = 0.152$	43.4	256	$p = 0.514$	58.2	251	$p = 0.036$	51.6	438	$p = 0.931$	63.4	475
	Use	106	64	$p = 0.253$	76.6	80	$p = 0.152$	52.5	80	$p = 0.514$	54.1	85	$p = 0.036$	60.8	186	$p = 0.931$	63.8	149
Total	64.6	288	288	$p = 0.253$	70.8	336	$p = 0.152$	45.5	336	$p = 0.514$	57.1	336	$p = 0.036$	54.3	624	$p = 0.931$	63.5	624

 T_1 — without consulting a list of radiographic diagnostic parameters established in a previous study.¹⁰ T_2 — with consulting a list of radiographic diagnostic parameters established in a previous study.¹⁰ p — p -Value for the χ^2 test.

variations in the greyscale, density and brightness. Preliminary image processing after digitization standardized these properties and minimized these variations. In addition, in a previous study¹² with similar lesions, we demonstrated that the lesion type does not influence the diagnostic accuracy. Considering the image standardization and the absence of differences in diagnostic accuracy linked to the type of lesion, we can confirm that the lesions had a similar degree of difficulty in radiographic interpretation.

With regard to the trend towards decrease in the frequency of the use of tools after consultation of the radiographic parameters, we believe that the examiners felt less need to modify the images because they were able to visualize details that they had not observed before, irrespective of the degree of expertise. It is also important to consider the fact that image manipulation is not a routine task for these examiners, including the specialists. Probably because of this, we observed a high frequency of non-use of any tool at T_2 . Although the digital radiograph is a common instrument in clinical practice at our institution, the use of tools that manipulate digital information is not incorporated into this context. The examiners were previously trained to use the tools, but we do not exclude the fact that the reduction in the frequency of the use of tools is also associated with a natural trend to conclude the diagnosis without a digital approach, using only the verbal information contained in the list of parameters.

We also observed a different trend in the use of digital tools and diagnostic accuracy when the expert and non-expert groups were compared. None of the tools had any influence on the frequency of correct diagnosis in the group of experts. The frequencies of the use of tools were higher in this group than in the group of non-experts and there was also reasonable agreement among the experienced examiners at T_1 and T_2 . This indicated that consultation of the list of parameters modified the trend towards the use of digital tools by experts but did not influence the diagnostic accuracy. This result is consistent with the results of other studies that demonstrated no effects of image manipulation on the efficiency of diagnosis by experienced readers.² However, for the group of non-experts the use of some digital tools improved the frequency of correct diagnosis, despite the lower frequency of use and low interobserver agreement. This result is in agreement with other studies that reported inconsistency in the use of digital tools by students during image manipulation.^{13–15}

Although the consultation of the list determined a reduction in the frequency of the use of tools, preferences for some digital tools increased at T_2 . The knowledge of objective parameters for observation probably caused better judgements about the effects of the tools on the image. In our study, the most preferred tool was sharpness at T_1 and T_2 , but this tool did not promote high frequency of correct diagnoses in both the group of experts and non-experts. Reasons for the selection of a specific digital tool are still controversial and may be

Figure 3 Frequency of use of digital tools in the group of experts considering the time intervals T_1 (when there was no consultation of the list of radiographic parameters) and T_2 (when this list was consulted) ($n = 288$ analyses)

arbitrary.¹⁶ The choice of digital tool may be associated with the level of experience, as well as with the natural preferences of the eye.² Expert examiners have a tendency to use digital tools less frequently than non-experts do and this difference in behavior has been attributed to different levels of perceptibility.² At the same time, the human eye contains specialized neural cells devoted to the perception of edges.² The sharpness filter accentuates the margin of the lesion,¹⁷ *i.e.* enhances the edges and removes noise so that the image becomes better suited to visual needs. In addition, in the present study this preference may have been strongly influenced by the nature of the lesion whose diagnosis depends on the clear delimitation of the radiolucency. However, the use of this tool did not have a positive influence on diagnostic accuracy. Other aspects of the image, such as

spatial resolution, may be more essential for the diagnosis of unilocular mandibular lesions.

To the human eye, spatial resolution depends on brightness and contrast in T_1 .^{8,18} In the present study, a significantly high frequency of correct diagnoses was obtained using brightness/contrast, mainly in the non-experts group when objective radiographic parameters were associated. One study demonstrated that decreased brightness and increased contrast causes some improvement in the diagnostic accuracy of periapical lesions, but also had important indexes of no influence on and impairment of the diagnostic process.¹⁹ In the present study, the non-experts achieved successful diagnosis using this tool only after consulting the radiographic parameters, which indicates that this list influenced the adequate use of this tool.

Figure 4 Frequency of use of digital tools in the group of non-experts considering the time intervals T_1 (when there was no consultation of the list of radiographic parameters⁶) and T_2 (when this list was consulted) ($n = 336$ analyses)

Figure 5 Frequency of use of digital tools by experts and non-experts (total of examiners) considering the time intervals T_1 (when there was no consultation of the list of radiographic parameters⁶) and T_2 (when this list was consulted) ($n = 624$ analyses)

Another filter that had an influence on diagnostic accuracy was highlight. This tool controls the regions with high luminosity, a factor that is especially important when considering radiolucent lesions. This tool had high frequency of use by experts and non-experts and was important for correct diagnosis without consulting the list of parameters when experts and non-experts were analysed together. In addition, the use of the highlight tool maintained the same preference level irrespective of consulting the list, which may indicate that the use of this tool promotes a visual effect that was important in the two contexts.

Zoom was used with relatively high frequency in comparison with the other tools, mainly by non-experts. The property of this tool in the magnification of structures could contribute to its high preference in some studies.² Furthermore, the application of this tool is more intuitive, which induces its use by inexperienced readers.¹⁵ However, it did not determine improvement in the frequency of correct diagnoses. Several lesions of this sample had a very large radiolucent image and perhaps the application of zoom negatively influenced the diagnosis, owing to the extreme magnification of the lesion.

Inversion was the tool least useful to the examiners, probably owing to the profound transformation of the

images. These results confirm the study of Raitz *et al*,¹² in which the examiners did not use inversion and the yellow filter. Other studies have demonstrated that the inversion filter did not increase the efficacy in the measurement of bone loss.^{7,8}

In conclusion, expert and non-expert examiners had a low frequency of use of digital tools during radiographic interpretation. The most preferred tool was sharpness, but this did not improve the diagnostic accuracy. In general, the group of experts had a higher frequency of correct diagnoses than the group of non-experts. Consultation of the list of radiographic parameters before image manipulation reduced the frequency of the use of tools in both groups of examiners. The association of consulting radiographic parameters with use of some digital tools was important for improving correct diagnoses in the group of non-expert examiners. Further studies focusing on the perceptibility of digital images must be conducted in order to elucidate various aspects in the interpretation of diagnostic imaging.

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