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Analysis of Compound Enhancement Algorithms (CEA) based on Adaptive Histogram Equalization (AHE) on Intra-oral Dental Radiographs Images

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ABSTRACT

Abnormalities are the main interest of dentists in examining the radiographs for determining any diseases that may appear at the apices of the teeth. However poor quality radiograph produces weak visual signal that may produce misleading interpretations. Hence the quality of radiograph influence dentists' decision that reflects the success or failure of any suggested treatments. Therefore this work intend to analyze the abnormality found in intra-oral dental radiographs by comparing the original images with images that had been enhanced using compound enhancement algorithms (CEM) namely Sharp Adaptive Histogram Equalization (SAHE) and Sharp Contrast adaptive histogram equalization (SCLAHE). Results show that SCLAHE enhanced images provide slight improvement, compared to the original images, in detecting widen periodontal ligament space abnormality.

Keywords: *Image processing; Intra-oral dental radiograph; periapical lesion; AHE; CLAHE*

1 INTRODUCTION

Radiographic diagnosis influence treatment planning and overall cost of dental health care (Steetman,1995). Radiograph images are often noisy and low in contrast and sometimes make it difficult to interpret (Baksi, 2010). High contrast in radiograph images is expensive in term of examination time and x-ray dose to patients (Yousuf, 2011). Besides, radiation also harms human body and bone (Kanwal, 2011). Hence, image processing techniques are an acceptable technique that can be used to assist dentists in improving the diagnosis (Mehdizadeh, 2009; Alves, 2006; Sund, 2006). Contrast enhancement is one of the techniques that are actively being researched to improve the dental radiographs. Even though contrast enhancements are usually built in the software accompanying the x-ray machines, the interactive trial and error adjustment of contrast and brightness is a time-consuming procedure (Sund, 2006). Thus a more automated and universal contrast enhancement is needed to overcome this problem. This work compares the performance of sharpening function combined with adaptive histogram equalization (SAHE) and sharpening combined with contrast limited adaptive histogram equalization (SCLAHE) with the original image. The tests are limited to assessing the abnormality detection of dedicated pathologies. Comparison and correlation are made between the dentists' perceptions and statistical values such as contrast improvement index (CII), signal to noise ratio (SNR) and root mean square error (RMSE).

2 RESEARCH BACKGOUND

Contrast enhancement algorithm has proven to have some impact in improving dental radiographs (Baksi, 2010; Yousuf, 2011;Kanwal, 2011; Mehdizadeh, 2009; Alves, 2006; Sund, 2006). Contrast is the visual differences between the various black, white and grey shadows exist in an image (Regezi, 1999). Contrast enhancement algorithms are functions that manipulate the brightness intensity of the image by stretching brightness values between dark and bright area (Parks, 2011). This operation will generate clearer image to the eyes or assist feature extraction processing in computer vision system (Zhou, 2005).

Approach that manipulates contrast is termed histogram equalization (HE). This technique enhanced the original image through brightness intensity distribution applied to the whole image (Ahmad, 2010; Jen 2005) which make the image become over-enhanced and look unnatural (Yoon, 2009). Due to this effect, the use of adaptive histogram equalization (AHE) is introduced image (Ahmad, 2010; Jen 2005; Yoon, 2009).This approach overcomes the drawback of HE but produces wash out effect (Zhiming, 2006) and introduces artifacts (Jen 2005). Thus, the creation of Contrast Limit Histogram Equalization (CLAHE) limits local contrast-gain by restricting the height of local histogram (Pisano, 1998). However CLAHE problem is related to high contrast in both foreground and background increasing the visibility of the main mass at the cost of simultaneously creating small yet misleading intensity in homogeneities in the background (Rahmati, 2010).

All these drawbacks encourage the combination of HE, AHE and CLAHE with other algorithms (Yoon, 2009; Jagatheeswari, 2009; Mahmoud, 2008; Kimmel, 2000; Kitasaka, 2002, Thangavel, 2009). Sharpening filter is often combined with classic contrast enhancement methods (Mahmoud, 2008; Kimmel, 2000; Kitasaka, 2002) to enhance medical images Zhiming, 2006; Mahmoud, 2008; Kimmel, 2000; Kitasaka, 2002).

Research related to application of several techniques such as high pass and contrast enhancement had been applied to dental radiographs (Baksi, 2010; Yousuf, 2011; Kanwal, 2011;Mehdizadeh, 2009; Parks, 2011; Zhou, 2005). Some of these techniques are available in the software provided by the x-ray machine vendor such as Digora for Windows (Baksi, 2010) , Photoshop 8.0 (Mehdizadeh, 2009) and Trophy Windows Alves, 2006). Algorithm such as Sliding window adaptive histogram equalization (SWAHE) (Sund, 2006) and frequency domain algorithms (Yalcinkaya, 2006) also provide successful enhancement. High pass filters that have been used are shadow (Baksi, 2010) and sharpening (Baksi, 2010; Gijbels, 2000). Other contrast enhancement variations are adaptive histogram equalization (AHE) (Mehdizaden, 2009), bright contrast enhancement (Alves, 2006) and pseudo-colored with brightness-contrast adjustment (Alves, 2006). Negative or inversion algorithm have been used in (Baksi, 2010; Alves, 2006) to test the effect of brightness changes in dark region of images.

The dental anatomical structures that had been investigated are the upper and lower jaws (Baksi, 2010; Mehdizadeh, 2009; Alves, 2006; Sund, 2006; Yalcinkaya, 2006; Gijbels, 2000). The focus areas that had been studied are specific area around upper and lower teeth such as around palatal, distal and mesial sites (Baksi, 2010; Mehdizadeh, 2009). Besides that area around the teeth (molar and biscuspid) (Alves, 2006; Sund, 2006), the tooth supporting structures such as periodontal ligament (PDL) (Baksi, 2010; Sund, 2006) and lamina dura (Mehdizadeh, 2009; Alves, 2006) were also the main interest of the investigations. These researches correlates the abnormal pathologies in Ozen (Ozen , 2009) which are periapical radiolucency, widen periodontal ligament space and loss of lamina dura. These pathologies are the symptom for the existence of periapical disease (Ozen , 2009).

Most surveys include three to five dentists (Mehdizadeh, 2009), radiologist (Baksi, 2010; Alves, 2006) and post graduate with experiences in oral and maxillofacial radiology including digital radiography (Sund, 2006). The number of image samples used ranges between 12 - 42 of panoramic radiographs (Baksi, 2010), periapical digital radiographs (Mehdizaden, 2009; Sund, 2006), interproximal radiographs (Alves, 2006) and bitewing (Sund, 2006) images. Overall results of these works support the idea that digitally enhanced images do provide extra information for dentists (Baksi, 2010; Mehdizadeh, 2009). The twin-view reading experiments show that it helps improve quality of periapical diseases examinations (Alves, 2006; Sund, 2006). However these studies compared the overall quality of the non-process images and enhanced images but none had based their assessment on the ability of detecting abnormalities.

Therefore this paper proposes to explore the diagnostic potential between the original and enhanced image by compound enhancement algorithms (CEM), namely SAHE and SCLAHE. The CEM is the combination of sharpening function (type of high pass filter) and contrast enhancement.

3 METHODOLOGY

Material

Thirty intra-oral periapical radiographs were obtained using Planmeca Intra Oral machine from Faculty of Dentistry UiTM

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Shah Alam. The questionnaire is designed by aligning the original image, the image enhanced with SAHE and SCLAHE in a row (termed as twin-view (Mehdizadeh, 2009; Alves, 2006). The images are rated using Riker scale. The subject of the research includes three dentists with experiences ranging between six to fifteen years. This study received ethical approval by University Technology MARA Ethical Committee (reference No: 600-RMI (5/1/6).

Method

The methodology consists of three phases; image processing phase; survey phase and finally statistical measurements phase.

The first phase involved image processing processes. SCLAHE consists of two steps; sharpening filter and CLAHE enhancement. Sharpening algorithm is used to sharpen the outline of the periapical features (Allen, 2005) and enhanced bone structure (Baksi, 2010). Laplacian filter is used to perform image sharpening process. It detects the outlines of the objects by convolving a mask with a matrix centered on a target pixel. The Laplacian detects the edge using a mask as in Fig. 1 (Allen, 2005) .

	-1	
-1	4	-1
	-1	

Fig 1. Laplacian Edge Detection Mask

CLAHE on the other hand reduces noise that arises from adaptive histogram equalization (AHE). This technique eliminates the random noise introduced during the AHE process by limiting the maximum slope of the grey scale transform function. The slope of the cumulative distribution function is determined by the bin counts. Large bin count will result in more slopes. Thresholding (clipping) the maximum histogram count, can limit the number of slopes (Poulist, 2010).

The second phase involves a survey of dentists' perception ratings on original image and image enhanced with SAHE and SCLAHE. In this phase, the dentist had to classify the presence of periapical radiolucency, the presence of widen periodontal ligament space (widen PDLs) and the presence of loss of lamina dura in the dental images based on the specification in Table 1, Table 2 and Table 3.

Table 1. Rating criteria for detection of the presence of periapical radiolucency.

Class	Description
1	Periapical radiolucency detected
2	No periapical radiolucency detected but other abnormality detected
3	No periapical radiolucency detected and no abnormality detected

Table 2. Rating criteria for detection of the presence of widen periodontal ligamen space.

Class	Description

1	Widen periodontal ligament space detected
2	No widen periodontal ligament space detected but other abnormality detected
3	No widen periodontal ligament space detected and no abnormality detected

Table 3. Rating tcriteria for detection of the presence of loss of lamina dura.

Class	**Description**
1	Loss of lamina dura detected
2	No loss of lamina dura detected but other abnormality detected
3	No loss of lamina dura detected and no abnormality detected

Explanation of each of the class is as follows; Class 1 is for the pathology that is clearly detected. Class 2 refer to no specified pathology appear in the image but other abnormality detected. Finally class 3 refers to none of the particular pathology as well as other pathologies are detected. Class 3 possibly will be a sign that the teeth were either healthy (since no lesion could be observed) or the image quality is not good at all since it cannot show any lesion clearly.

Finally in the last phase the changes in the image appearance are measured statistically. CII, SNR and RMSE are used to measure the quantitative values between SAHE and SCLAHE.

CII is the popular index used by radiologist to check visibility of lesions in radiographs (Yoon, 2002). It is calculated by $C_{processes}/C_{original}$ where both are the contrast values for the region of interest in the enhanced images and original images respectively (Yoon, 2002). *C* is defined as in the following equation;

$$C = (f - b)/(f + b) \tag{1}$$

where *f* is the mean gray-level value of the image and *b* is the mean gray-level value of the background (Bankman, 2008).

SNR is the measurement of the signal out of noise in an image and is calculated by the ratio of the signal standard deviation to the noise standard deviation. The SNR equation is as follows;

$$SNR = 10.\log_{10}\left[\frac{\sum_{0}^{n_x-1}\sum_{0}^{n_y-1}[r(x,y)]^2}{\sum_{0}^{n_x-1}\sum_{0}^{n_y-1}[r(x,y)-t(x,y)]^2}\right] \tag{2}$$

The problem in quantifying and improving the enhancement method is that one must able to separate noise from signal. This show how important is the SNR. It provides measurement for image quality in term of image details and checks the performance of the enhancement methods (Sijbers, 1996).

Finally the average magnitude of error in the enhanced image based on the original image is calculated by RMSE and the lower value is the better (Thangavel, 2009). RMSE equation is as follows;

$$RMSE = \sqrt{\frac{1}{n_x n_y} \cdot \sum_{0}^{n_x - 1} \sum_{0}^{n_y - 1} \left[r(x,y) - t(x,y) \right]^2} \quad (3)$$

4 RESULT

Results are reported as follows; **1)** the characteristics of dentists' score on the abnormalities (Fig. 2 – Fig.7), **2)** Methods score (original images versus enhanced by SAHE and SCLAHE for abnormalities) (Fig. 8-10), **3)** Clearly detected pathologies based on class (Fig.11), **4)** CII, SNR and RMSE relationships analysis between SAHE and SCLAH E (30 images) Fig.12-14) **5)** Table 4 is the values of CII, SNR and RMSE four images that SCLAHE overcome original images for widen PDLs abnormality only and finally **6)** CII, SNR and RMSE values for the four images; Comparison between SAHE and SCLAHE (Fig. 15-17).

The pie chart on Fig. 2 and Fig.3 display the pattern of dentists' score for periapical radiolucency abnormality. Referring to Fig.2, it shows that the majority of the scores go to class 1 (57%). Class 3 (23%) shows slightly higher than class 2 (20%).

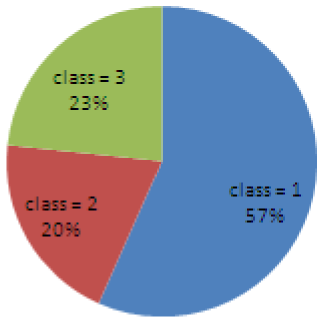

Fig. 2. Dentists' score for periapical radiolucency abnormality

Fig. 3 displays the distribution of scores among the dentists. Original D4, Original D5 and Original D6 refer to the three dentists that evaluate the original images. These notation goes the same to the enhance images by SAHE and SCLAHE. Looking at the pattern of scores among dentists, it shows that the distributions of their scores are almost balance. However it shows clearly that dentists 6 (D6) tend to have more scores (original D6 16%, SAHE D6 11% and SAHE D6 15%) than the other two dentists. However, in general the scores are in similar pattern.

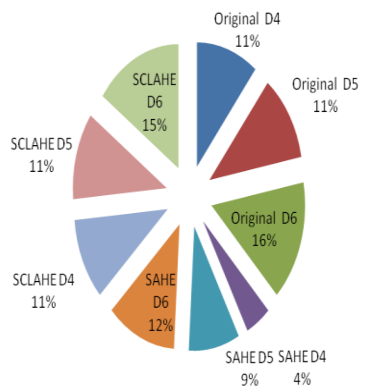

Fig. 3. Scores distribution among dentists for periapical radiolucency abnormality.

The pie charts (Fig. 4 and Fig.5) indicate the pattern of dentists' score for widen PDLs abnormality. It shows that the majority of the scores go to class 1 with 63%, class 2 17% and class 3 20% (Fig.4). As for the pattern of scores among dentists, it shows that the distributions of their scores are almost balance as in Fig.5.

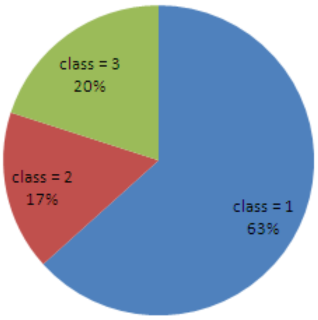

Fig. 4. Dentists' score for Widen PDLs abnormality

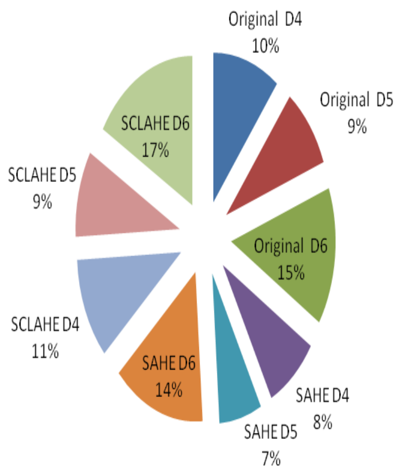

Fig.5. Scores distribution among dentists for widen PDLs abnormality.

Fig. 6 and Fig.7 show the pattern of dentists' score for loss of LD abnormality. The pattern is still the same as previous abnormality where the majority of the scores go to class 1 with 43%, class 2 37% and class 3 20% (Fig.6). As for the pattern of scores among dentists, it shows that the distributions of their scores are almost balance as in Fig.7.

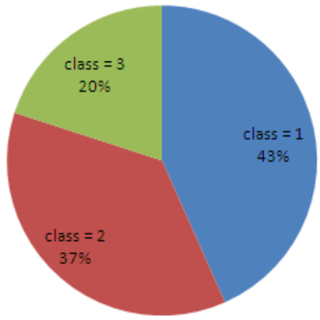

Fig. 6. Dentists' score for loss of lamina dura abnormality

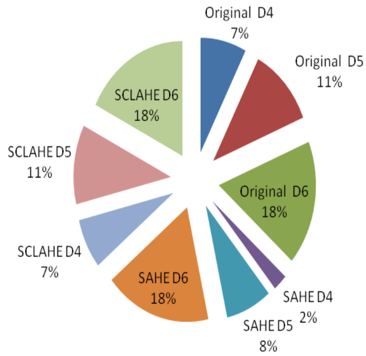

Fig.7. Scores distribution among dentists for loss of lamina dura abnormality

Fig. 8 – 10 shows the pattern for the methods scores (original images versus enhanced image , SAHE and SCLAHE).

Fig. 8 exhibits the class 1 pattern, that original images overcome the enhanced images, but SCLAHE is almost at par with the original. However for class 2 and class 3, SAHE overcome the other two methods.

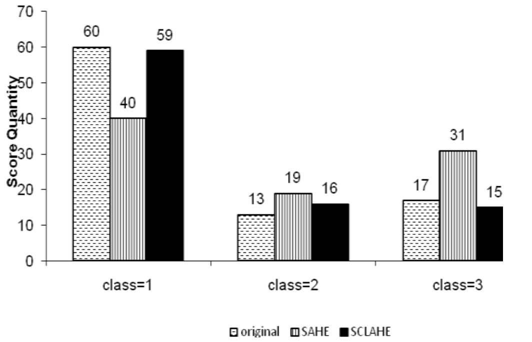

Fig. 8. Method's score (original images Vs Enhanced by SAHE and SCLAHE for Periapical Radiolucency abnormality)

Fig. 9 exhibits the pattern of method scores for widen PDLs abnormality. It displays that images enhanced by SCLAHE overcome the other two for class 1. SCLAHE overcome original by 5 images. As for class 2 both original and SAHE score the same (11) but SCLAHE score 8. Class 3 shows that SAHE overcome the others.

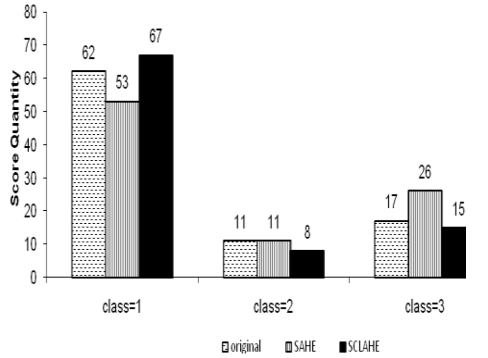

Fig.9. Method's score (original images Vs Enhanced by SAHE and SCLAHE for Widen PDLs abnormality)

Fig. 10 shows the pattern of method scores for Loss of LD abnormality. It displays that images enhanced by original overcome the other two for class 1.But SCLAHE is left behind by 1 only. As for class 2 both all scores are almost the same. Class 3 shows that SAHE overcome the others.

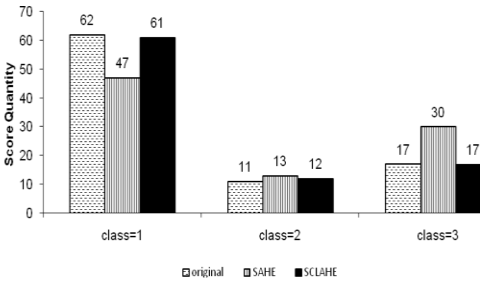

Fig.10. Method's score (original images Vs Enhanced by SAHE and SCLAHE for loss of lamina dura abnormality)

Fig. 11 shows the pattern of the abnormalies scores (periapical radiolucency, widen PDLs and Loss of LD). The graf exhibits that the sample images generally have all the three abnormalities. Other abnormality (class

2) scope also exists , but the amount is lesser. Among the three abnormality, it shows that widen PDLs (53) shows more cases of other abnormality than others. As for class 3 the scores are almost the same as class 1. However, widen PDLs still shows the most cases (67) compares to the other abnormalities.

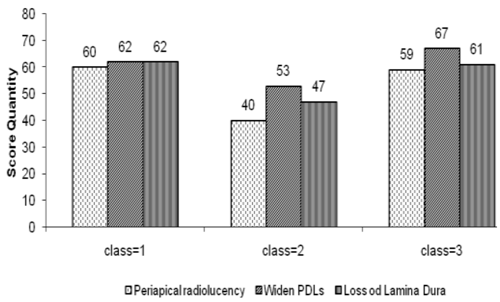

Fig.11. Clearly detected pathologies based on class

Fig.12 – 14 indicate the results of CII, SNR and RMSE values of each of the images. Referring to Fig. 12 below, it shows that CII values for SAHE (sahe_CII) is higher that CII values for SCLAHE (sclahe-CII). But the sahe-CII displays fluctuates pattern as sclahe-CII shows more consistent pattern. ImageID 2 to ImageID 25show consistent values of CII.

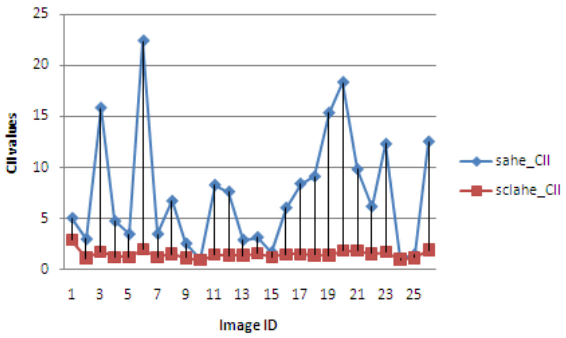

Fig. 12 CII Relationship Analysis between SAHE and SCLAHE

Fig. 13, shows the SNR values for both methods. It shows that SNR values for SCLAHE (sclahe_SNR) is higer than SAHE (sahe_SNR). Furthermore the values of SCLAHE , is more consistent for image ID no 2 to 7 and 23 to 25.

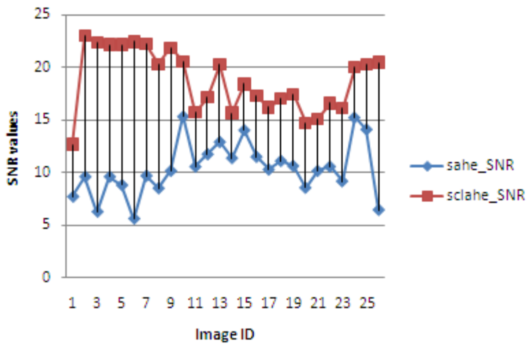

Fig. 13 SNR Relationship Analysis between SAHE and SCLAHE

Fig. 14, shows the RMSE values for the two methods. The graph indicates that SAHE (sahe_RMSE) is higher than SCLAHE (sclahe-RMSE). However SAHE values display fluctuation while SCLAHE values shows consistency manner especially at image ID no 2 to10.

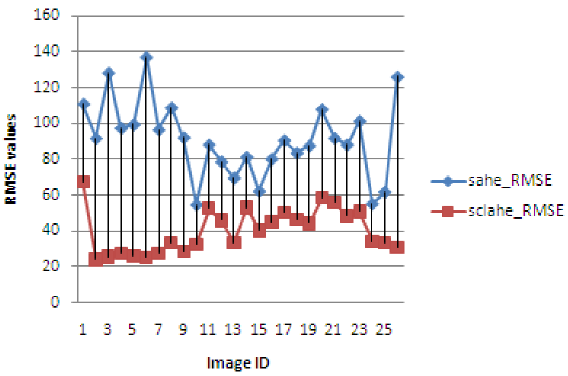

Fig. 14 RMSE Relationship Analysis between SAHE and SCLAHE

Table 4 (please refer at the end of this paper) is the results of CII, SNR and RMSE values for four images that SCLAHE overcome original images for widen PDLs abnormality only. It shows the exact score by the three dentists (D4, D5 and D6) as well as the CII, SNR and RMSE values for the SAHE and SCLAHE. The shaded boxes highlight the different score graded by the dentists between the original, SAHE and SCLAHE.

Fig. 15, shows the comparison between the SAHE and SCLAHE of CII values for the four images. It displays the same pattern as previous, where SAHE is higer than SCLAHE but SCLAHE is consistent.

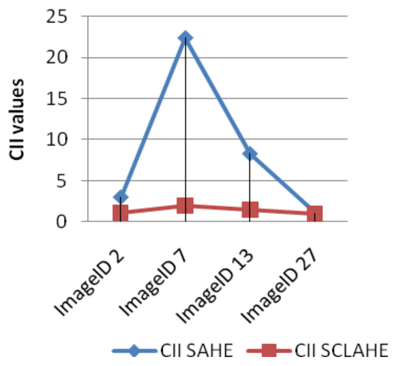

Fig. 15 CII values for the four images; Comparison between SAHE and SCLAHE for widen PDLs abnormality

Fig. 16, shows the comparison between the SAHE and SCLAHE of SNR values for the four images. It displays the same pattern as previous, where SCLAHE is higer than SAHE. The values for SCLAHE is consistent for image ID 2 and 7.

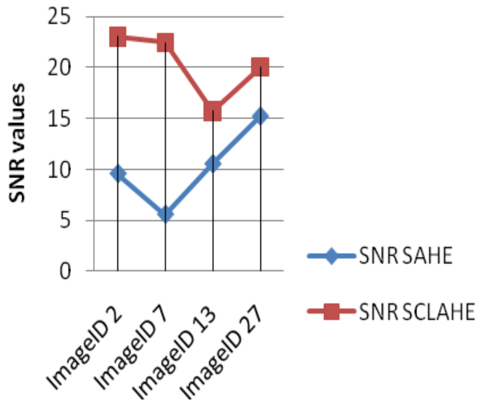

Fig. 16 SNR values for the four images; Comparison between SAHE and SCLAHE for widen PDLs abnormality

Fig. 17, shows the comparison between the SAHE and SCLAHE of RMSE values for the four images. It displays the same pattern as previous, where SAHE is higer than SCLAHE. However the values for SCLAHE is consistent more for image ID 2 and 7.

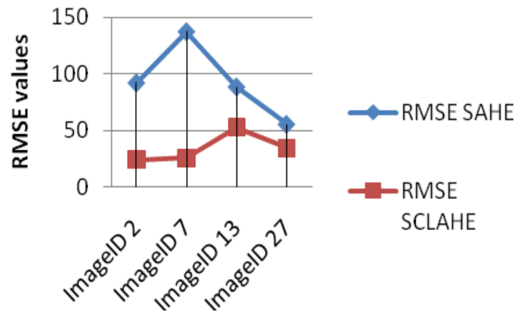

Fig. 17 RMSE values for the four images; Comparison between SAHE and SCLAHE for widen PDLs abnormality

5 DISCUSSION

The present study evaluated the performance of compound enhancement algorithm (CEA) namely SAHE and SCLAHE compared to original intra-oral dental radiographs focusing on six aims; **1)** dentists' subjective visualization evaluation on the existence of pathologies in pre and post processing (Fig. 2 – Fig.11) and **2)** Correlation between dentists' perception and statistical measurement (Fig. 12-17) and Table 4)

Fig 2 -7 are based on the aim of observing the dentists' subjective visualization evaluation on the existence of pathologies between the original and enhanced images. Overall the sample images contain all the three abnormalities of interest. Furthermore the score distribution among dentists shows consistencies (Fig 2 – Fig.7).

Fig. 8- 10 is comparison between methods (original images versus enhanced image by SAHE and SCALHE). It shows that class 1 is the majority of the sample for each abnormality. Original images get the highest score for periapical radiolucency and Loss of LD however SCLAHE only one score behind. As for widen PDLs abnormality, SCLAHE get the highest score (67). Class 2 shows less quantities of score compared to class 3, but the distribution of scores is consistent. Class 3 get higher score than Class 2 and SAHE is the highest compares to original and SCLAHE.

Focusing on the sample characteristic towards the three abnormalities of interest, it shows that (Fig.11) all the abnormalities are consistently exists in all class 1, 2 and 3.

Based on the discussion above, it shows that dentists prefer original images other than enhanced image for periapical radiolucency and loss of LD. However for widen PDLs abnormality, they prefer SCLAHE. This result is in line with the general conclusion of many studies reporting that image processing techniques do improved diagnostic accuracy and may assist dentists in deciding the most suitable treatment for patients (Baksi, 2010; Mehdizadeh, 2009; Alves, 2006; Sund, 2006; Yalcinkaya, 2006; Gijbels, 2000). Sharpening function that been applied before CLAHE also plays an important role in enhancing the edges and able to enhance bone structures (Baksi, 2010). Enhanced edges are often more pleasing to human visual system than original images (Baksi, 2010; Zhou, 2005). The SCLAHE performance had been reported in (Ahmad, 2010; Ahmad, 2011) as better than original image in clearly detecting widen PDLs (Ahmad, 2010; Ahmad, 2011) and loss of lamina dura (Ahmad, 2010; Ahmad, 2011). However the detection of periapical radiolucency of SCLAHE is at par with original images (Ahmad, 2010; Ahmad, 2011). Still none of the study did any quantitative measurement of the evaluation between the non-processed/original and processes images.

Another issue to be considered regarding this finding is that, the methodology of twin-view might affect the dentists' evaluation since they are used to original images, thus influence their decisions.

Figure 12 – 17 shows the correlation between dentists' perception and statistical measurement of CII, SNR and RMSE. The patterns of relationships between the statistical measurements are; for SCLAHE, CII is low, SNR is high and RMSE is lower compare to SAHE (Fig. 12 – 14). This results in line with the theory that better signal than noise is in SCLAHE than in SAHE (Sijbers, 1996). Looking at RMSE values, the higher values for SAHE shows that the magnitude of errors in this CEM is more than in SCLAHE thus producing lower SNR values (Thangavel, 2009).

Based on results in Fig.12 -14, Table 4 is produced to compare the exact dentists' score with the CII, SNR and RMSE values. We chose widen PDLs abnormality only since SCLAHE performed better than original for this abnormality. The relationship is then viewed using graph (Fig.15-17). Overall the pattern of the four images is the same as the pattern for 30 images where for SCLAHE, CII is low, SNR is high and RMSE is lower compare to SAHE.

Therefore since the overall results show that SCLAHE values of SNR is higher, but the RMSE is lower, and consistence with the dentists' evaluation mode value, it can be concluded that SCLAHE is superior than SAHE in providing better visualization of the intra-oral dental radiograph.

5 CONCLUSION AND FUTURE WORKS

In conclusion this work shows that image processing techniques are able to enhance the image subjective quality and providing better information for dentists. In comparison between the performance of original images and CEM, it shows that dentists still prefer original images in detecting periapical radiolucency and loss of lamina dura. However, since the method used is twin-view, bias might affect dentists' evaluation, since they are applied based on the original images.

However SCLAHE is almost at par with original images in detecting both pathologies. As for detecting widen periodontal ligament space, SCLAHE is able to overcome original images as well as SAHE.

The future work aims to restructure for a new questionnaire that avoid bias as well as getting more respondents for better and more conclusive results.

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Table 4. CII, SNR and RMSE values four images that SCLAHE overcome original images for widen PDLs abnormality

	Original			SAHE			SCLAHE			SAHE			SCLAHE		
ImgID	D4	D5	D6	D4	D5	D6	D4	D5	D6	CII	SNR	RMSE	CII	SNR	RMSE
2	1	1	2	3	1	1	1	1	1	2.89	9.60	91.91	1.12	23.02	24.00
7	2	1	1	3	3	2	1	1	1	22.40	5.58	137.31	1.97	22.44	25.44
13	3	3	1	3	1	1	3	1	1	8.27	10.56	88.36	1.45	15.73	52.67
27	3	3	2	3	3	1	3	3	1	1.03	15.26	55.20	0.97	20.03	34.27

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