RELIABILITY OF CEPHALOMETRIC MEASUREMENTS
: A COMPARISON OF DIGITAL IMAGE INPUT TECHNIQUES
(SCANNER VS DIGITAL CAMERA)

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ABSTRACT

Digital cameras have been used widely for intraoral photography. Advances in computer sciences have led to their wide application of digital radiologic imaging techniques to cephalometric assessment of the craniofacial skeleton. Recently, computer-aided cephalometric analysis is performed by digitization of a tracing, digitization of the radiograph or on-screen digitization of scanned radiographic image. No previous study has reported the use of digital cameras to capture a radiographic image. Therefore, the purpose of this study was to explore the reliability of cephalometric measurements by comparing 4 computerized methods (3 utilizing direct on-screen digitization of the radiographic image captured by 3 digital cameras and 1 utilizing direct on-screen digitization of the radiograph image captured by a scanner) with the traditional manual method of tracing. Forty lateral skull radiographs were photographed by 3 digital cameras, scanned by a scanner and traced by hand. Thirty-four cephalometric measurements (Mahidol Analysis) were conducted by a computerized cephalometric analysis program (Ceph Smile plus version 2.0.1) and manual method. No statistically significant difference ($p<0.05$) was found in means of all 34 cephalometric measurements among the 5 methods. When comparing the manual method with the other 4 methods. Most of the mean differences were less than 0.25 mm and 0.25 degrees. Pearson’s correlation also revealed a very high correlation ($r>0.8$) between manual and 4 computerized methods. It can be concluded that the computerized method (digital camera and scanner) compared favorably with the traditional manual method. The results demonstrate that either a digital camera or a scanner is sufficiently accurate to produce digital images for clinical cephalometric analysis.

KEY WORDS: CEPHALOMETRIC/ SCANNER/ DIGITAL CAMERA

144 P.

ความน่าเชื่อถือในการวัดค่าภาพรังสีกะโหลกศีรษะด้านข้าง: การเปรียบเทียบเทคนิคในการนำภาพเข้าเครื่องคอมพิวเตอร์ (การใช้เครื่องสแกนเนอร์ และการใช้กล้องถ่ายภาพรังสี) (RELIABILITY OF CEPHALOMETRIC MEASUREMENTS: A COMPARISON OF DIGITAL IMAGE INPUT TECHNIQUES (SCANNER VS DIGITAL CAMERA)

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บทคัดย่อ

กล้องดิจิตอลได้ถูกนำมาใช้ในการถ่ายภาพในช่องปากทางทันตกรรมจัดฟันอย่างแพร่หลาย ความก้าวหน้าทางวิทยาศาสตร์คอมพิวเตอร์ ทำให้เกิดการนำภาพรังสีดิจิตอลมาใช้ประโยชน์ในการวิเคราะห์โครงสร้างกะโหลกศีรษะและใบหน้า ปัจจุบันมีการใช้คอมพิวเตอร์ในการวิเคราะห์ภาพถ่ายรังสีกะโหลกศีรษะด้านข้างซึ่งทำได้โดย การดิจิไทซ์ภาพวาดลายเส้นของภาพถ่ายรังสี หรือ ดิจิไทซ์บนภาพถ่ายรังสีโดยตรง หรือ สแกนภาพถ่ายรังสีให้เป็นภาพดิจิตอลส่งเข้าเครื่องคอมพิวเตอร์และดิจิไทซ์บนหน้าจอคอมพิวเตอร์โดยตรง อย่างไรก็ตามยังไม่มีรายงานปรากฏว่ามีการนำกล้องดิจิตอลมาถ่ายรังสีกะโหลกศีรษะและส่งภาพเข้าเครื่องคอมพิวเตอร์ เพื่อวิเคราะห์โครงสร้างกะโหลกศีรษะและใบหน้า ดังนั้นวัตถุประสงค์ของการวิจัยนี้เพื่อประเมินความน่าเชื่อถือของการวัดค่ากะโหลกศีรษะและใบหน้าโดยการเปรียบเทียบวิธีการวัดค่าด้วยคอมพิวเตอร์ 4 วิธี (3วิธีแรกเป็นการดิจิไทซ์ภาพรังสีดิจิตอลซึ่งเกิดจากการถ่ายภาพถ่ายรังสีด้วยกล้องดิจิตอล 3 ชนิด และวิธีที่ 4 เป็นการดิจิไทซ์ภาพรังสีที่เกิดจากการสแกนภาพรังสีเถ่ายข้าเครื่องคอมพิวเตอร์) และเปรียบเทียบกับการวัดค่าภาพถ่ายรังสีด้วยมือ

ภาพรังสีกะโหลกศีรษะด้านข้างทั้งหมด 40 ภาพ จะถูกถ่ายโดยกล้องดิจิตอล 3ชนิด ถูกสแกนด้วยเครื่องสแกนเนอร์ และถูกวาดภาพลายเส้นด้วยมือ ภาพรังสีดิจิตอลที่เกิดจากกล้องถ่ายภาพและเครื่องสแกนเนอร์ จะถูกนำเข้าเครื่องคอมพิวเตอร์ และวิเคราะห์วัดค่าโดยโปรแกรมคอมพิวเตอร์สำเร็จรูปที่ใช้วิเคราะห์ค่าโครงสร้างกะโหลกศีรษะและใบหน้า (โปรแกรมเซฟล์สไมล์พลัสเวอร์ชั่น 2.0.1) ภาพวาดลายเส้นจะถูกวัดด้วยมือโดยใช้ไม้โปรแทรกเตอร์และดิจิตอลคาลิเปอร์ ค่าที่ใช้ในการวิเคราะห์กะโหลกศีรษะและใบหน้ามีทั้งหมด 34 ค่า (ค่าวิเคราะห์ของมหิดล)

ผลการศึกษาพบว่าไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติ (ที่ระดับนัยสำคัญ0.05) ในค่าเฉลี่ยของค่าที่ใช้วัดทั้งหมด 34 ค่าของวิธีทั้ง 5 วิธี เมื่อทำการเปรียบเทียบค่าเฉลี่ยของวิธีที่วัดโดยคอมพิวเตอร์แต่ละวิธีเทียบกับการวัดค่าด้วยมือ พบว่าความแตกต่างของค่าเฉลี่ยส่วนใหญ่มีค่าน้อยกว่า 0.25 มิลลิเมตร และ 0.25 องศา พบว่าค่าสัมประสิทธิ์ของเพียร์สันมีค่าสูง ($r > 0.8$) เมื่อเปรียบเทียบระหว่างการวัดค่าด้วยมือและการวัดค่าด้วยคอมพิวเตอร์แต่ละวิธีทั้ง 4 วิธี

จึงสามารถสรุปได้ว่า วิธีการวัดค่ากะโหลกศีรษะและใบหน้าด้วยโปรแกรมคอมพิวเตอร์(โดยการสร้างภาพรังสีดิจิตอลด้วยกล้องดิจิตอลและเครื่องสแกนเนอร์) มีประสิทธิภาพดีเมื่อเปรียบเทียบกับการวัดค่าด้วยมือ ผลการศึกษาแสดงให้เห็นว่ากล้องดิจิตอลและเครื่องสแกนเนอร์มีความน่าเชื่อถือในการสร้างภาพรังสีดิจิตอลสำหรับใช้ในการวิเคราะห์ภาพถ่ายรังสีกะโหลกศีรษะและใบหน้าในคลินิก

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CHAPTER 1

INTRODUCTION

Since the introduction of cephalometry by Broadbent in 1931, the technique has been an important tool to orthodontists and oral surgeons in studying dental malocclusion and underlying skeletal discrepancies. The application of cephalometric analysis includes case diagnosis, treatment planning, evaluation of treatment results, and prediction of growth.

Traditional cephalometric analysis is preformed by tracing radiographic landmarks on acetate overlays and using these landmarks to measure the desired linear and angular values. This traditional hand-tracing process can be time consuming, and the linear and angular cephalometric measurements obtained manually with a ruler and protractor may be prone to error.

Rapid advances in computer science have led to the wide application of computers in cephalometry. When using computer-assisted software programs for cephalometric analysis, the landmarks are usually digitized first. The software program can then generate the values of cephalometric measurement instantaneously, when the locations of all the required landmarks are entered. The digital cephalometric images can be integrated with patients' records to establish a computer-based filing system and to take advantage of image processing, storage, and transmission. Many commercially available or customized programs have been developed to perform cephalometric analysis directly on the screen-displayed digital image (1, 2). Such applications can substantially reduce potential errors in the use of digitizing pads and eliminate totally the need for hard copies of cephalometric images in traditional analysis. The performance of a computer-assisted digital cephalometric analysis system from monitor-displayed digital images has been reported (3). The computer assisted system may reduce the time needed for traditional cephalometric analysis, especially for taking measurements.

With the development of computer technology, it has become possible to 'capture' a radiographic image and display this on a computer monitor. Various methods have been reported, such as mounting the image on a viewing box, and 'capturing' it using a television/video camera or digital camera (4-6). In addition to converting conventional film to electronic format using a digitizing pad or using a camera or a flatbed scanner, there are two additional types of technology used in current digital imaging. One method utilizes a photo-stimulable phosphor plates sensors, and the other utilizes charged couple device (CCD).

Digital acquisition has been achieved using a photo-stimulatable storage phosphor plate sandwiched into a standard cassette. The captured radiographic image is displayed on a computer monitor as an array of small points (pixels), each with a particular shade of grey: the contrast and density of this image can be altered in the same way as a television picture. The digital image is concurrently held in the computer’s memory as a corresponding array of numbers (each representing a value on the grey scale) and as such can be manipulated mathematically, offering the possibility of image processing to alter its visual appearance on the monitor. For example, it is possible to alter the x-ray image from negative to positive, manipulate contrast and brightness and filter the image. The perceived advantage of these techniques is that they can greatly facilitate landmark identification and, therefore, overall accuracy. As a further development, a screen cursor can be guided over the image on the monitor, using either a keyboard or mouse, and with appropriate software anatomical landmarks can be recorded. Additional software then calculates the cephalometric values.

The digital conversion of an existing cephalometric radiograph is known as “indirect acquisition” or “digitization.” This kind of conversion can be accomplished by laser scanners, flat-bed scanners with a transparency adaptor or digital cameras/video-cameras. Scanners use CCDs (charge-coupled devices) to detect light transmitted through a radiograph with subsequent conversion to digital signals in proportion to the light intensity detected. The digital signals will be transformed to shades of gray as discussed earlier. Most of the digital cameras/video-cameras currently available use a CCD (charge-coupled device) sensor as well. The CCD in a similar way as with scanners detects the light transmitted through a radiograph when placed on a view box and, in sequenced, this is converted to digital signals and gray shades dependent on the light intensity detected. Digitization simply turns an analog image into a digital form that can be further analyzed and manipulated by various computer tools. Although, in theory, the information obtained could be, at best, the same as in the analog image, some concerns have been expressed about possible distortions from the lens system in digital cameras as well as contrast resolution with scanners.

When an x-ray film is digitized with a flat-bed scanner, possible information loss should be kept in mind and diagnostic conclusions should be considered carefully in this context. Regardless of the image acquisition process, as soon as a digital image is captured it can be displayed on a computer monitor or printed. The type of monitor used are the cathode-ray tube (CRT) and the liquid crystal displays (LCDs), which are becoming very popular due to the reduced space they occupy. Monitors vary greatly in quality and demonstrate limitations; one of them is that they cannot display the spatial and gray scale resolution that the contemporary digital systems are able to capture. However, in a study comparing performance of a CRT monitor, a laptop display, and film for caries detection, no statistically significant differences were found among the different displays (7). It is remarkable, though that the raters in this study stated that they were less comfortable diagnosing caries on laptop screens compared with the other displays. The possible effects of monitor performance on the cephalometric image quality and diagnostic efficacy are not clear and need further investigation.

Digital imaging, in conjunction with computer technology, allows orthodontists to achieve paperless practices and serves as a powerful communication tool. Digital images captured by first-generation digital cameras, based on charged couple device (CCD) technology, were acceptable for producing printed images for ABO case presentations. These cameras as well as their successors, however, have not been evaluated at other image sizes printed or displayed on a computer screen, such as those used in patient presentation. Additionally, no previous studies have reported the reliability of cephalometric analysis from digitally capture lateral cephalometric radiographs obtained by digital camera.

CHAPTER 2
OBJECTIVES

This study describes one of several methods of digital image input technique for cephalometric measurement in which conventional lateral skull radiographs were photographed into a computer by using a various type of digital cameras and saved as JPEG image files. The recorded X-ray image was subsequently digitized directly on-screen using a mouse pointer linked to appropriate software. This system has several potential advantages: the need for a digitizing tablet is eliminated and instead a camera is used, a stage in the analysis of X-rays is eliminated and the stored image can be manipulated to assist in point identification.

Prior to the study the apparatus was checked for its accuracy by repeat recording of an image of known exact dimensions. Consistent and accurate measurements of known distances were obtained.

The method of direct on-screen digitization of the camera-obtained cephalometric images was compared with two currently used methods of cephalometric landmark registration. In the first of these, points were identified and marked directly onto tracing paper, which was in term manual measurement, and in the second method direct on screen digitization of the scanner-obtained cephalometric images was undertaken.

Objectives

To evaluate and compare the reliability of cephalometric measurements obtained between hand measurements and

1. Direct on-screen digitization of the photographed cephalometric images
2. Direct on-screen digitization of the scanned cephalometric images

The null hypothesis assumed there was no difference in cephalometric measurement between methods.

Expected Benefits

1. This study will be a guideline to utilize the digital camera as one of the image capture techniques.

2. If the photographed imaged are sufficiently reliable, digital camera can be used as an alternative mean for image capture in digital cephalometry.

CHAPTER 3
LITERATURE REVIEW

Cephalometric radiographs have been used for many years as part of the records to assist with orthodontic diagnosis and treatment planning. The wealth of information on the radiograph has gradually been directed to a number of commonly accepted landmarks and planes which make up a cephalometric analysis. The analysis has traditionally been carried out on a tracing of the radiograph which is then measured using a ruler and protractor.

Cephalometry is an important tool in orthodontic diagnosis, treatment planning, evaluated of treatment results and prediction of growth. The major sources of error in cephalometric analysis include radiographic film magnification, tracing, measuring, recording, and landmark identification. Previous studies revealed that inconsistency in landmark identification is an important source of error in conventional cephalometry (8-10). This error is specific to each landmark an affected by experience and training of the observers (11).

Rapid advances in computer science have led to its wide application in cephalometry. Computer-aided cephalometric analysis is faster in data acquisition and analysis than conventional methods. Many cephalometric programs have been developed to perform computer-aided cephalometric analysis by digitizing the landmarks. However, digitizing may introduce errors such as head film movement and improper sequencing of digitized points. To take advantage of image processing and computer-based filing systems that can integrate patients' records and images, the original cephalometric radiographic films may be transformed into a digital format by a scanner or video camera. A radiographic system for taking direct-digital lateral cephalograms at reduced radiation dose is presently available (12, 13). Consequently, many commercially available or customized programs have been developed to conduct cephalometric analyses directly on the screen-displayed digital image (14-16) for analysis directly on the screen-displayed digital image. Computer-aided cephalometric analysis on digitized cephalogram could substantially reduce the potential errors in the use of digitizing pads and eliminate the production of hardcopies of digitally born images for conventional cephalometric analysis (16). Digital cephalometry also has the benefits of image storage, transmission and processing (17).

The errors in cephalometric analysis are composed of systematic errors and random errors (10); the latter involves tracing, landmark identification, and measurements. Computer- aided cephalometric analysis can totally eliminate the mechanical errors in drawing lines between landmarks and in measurements with a protractor. Earlier studies reveal that computer-aided cephalometric analysis does not introduce more measurement error than hand tracing, as long as landmarks are identified manually (18, 19). However, the inconsistency in landmark identification is still an important source of random error in computer-aided digital cephalometry. For digital cephalometry to be a better tool in clinical orthodontics, the cephalometric analysis, represented by widely used linear and angular measurements, must be as comparable and reliable as it is on conventional radiographic film. In the previous study, it was demonstrated that the differences in landmark identification between original cephalometric radiographs and their digitized counterparts were statistically significant (20). This difference may be the major source of differences in the determination of linear as well as angular measurements on original radiographs and their digitized counterparts. Chen et al, 2004 (21) explored the effect of the differences in landmark identification on the values of cephalometric measurements on digitized cephalograms in comparison with those obtained from original radiographs. They found that measurement differences between the original cephalograms and the digitized images are statistically significant but clinically acceptable.

Errors in cephalometric analysis

The errors in cephalometric analysis are composed of systematic errors and random errors.

Systematic error

Systematic error implies a bias in the recording and measuring system to produce apparent measurements predictably different from the true ones.

Systematic error includes such factor as

1. Geometric magnification of the radiographic image
2. Distortion due to differential magnification between different planes (22)

Random error

Sources of random error included:

1. Translation in space at the focal spot (8)
2. Alteration/ translation/ rotation of the cephalostat
3. Alteration/ translation/ rotation of the head position of the patient (Fig. 1)

In terms of random errors of cephalometric measurements, the effect of projection errors caused by incorrect patient positioning should be considered. The effect of incorrect patient positioning on linear and angular measurements was reported by Ahlqvist et al. (23, 24). When the misalignment of the patient’s head was less than $\pm 5^{o}$ errors were generally less than 1% in length measurement and less than ± 1% in angle distortion and if rotation increase more than $\pm 5^{o}$ increase the error and become significant. A misalignment of the patient’s head of more than 5^{o} is easily detected and should be corrected immediately. This information means that the percent error of cephalometric measurements from error in landmark identification might be greater than that from projection error.

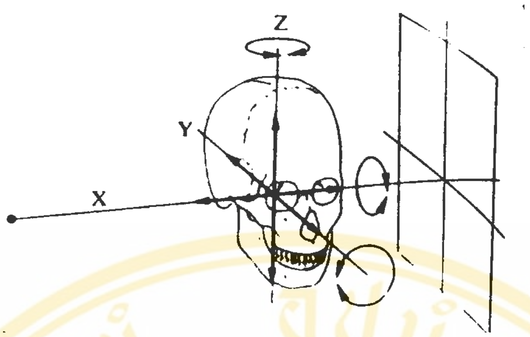

Fig.1 Directions of possible misalignments of the patient

4. Alteration/translation of the film

Directed digitizing on the film may introduce errors such as head film movement and improper sequencing of digitized points. To take advantage of image processing and computer-based filing systems that can integrate patients' records and images, the original cephalometric radiographic films may be transformed into a digital format by a scanner or video camera. Consequently, many commercially available or customized programs have been developed to conduct cephalometric analyses directly on the screen-displayed digital image. Such applications could substantially reduce the potential errors in the use of digitizing pads and totally eliminate the need of hardcopies of digitally born images for conventional cephalometric analysis.

5. Focus to film distances

Ahlqvist et al. (23) suggest that the short focus to object distances results in greater projection error than long focus to object distance. Application of long focus to objective distance has been suggested to minimize projection errors.

6. Landmark identification (8, 10, 25-31)

Identification errors are associated with landmark recognition. Research carried out on conventional cephalometrics proved landmark identification to be the main source of error (8, 10, 30, 31).

Arises through uncertainty in the visual identification of radiographic landmarks, many previous studies have shown that it is impossible to estimate the positions of landmarks without error. However, we should make efforts to minimize the effect of error in landmark identification on the cephalometric measurements, especially the items with inherited lower reliability in digitized cephalometry. The impact of the error in landmark identification on the cephalometric measurements can be considered in different aspects. The first is the magnitude of the error inherited in the identification procedure for the specific landmark, which was investigated in the work of Chen et al. (20). The average value of measurements by all observers was used as the gold standard for a specific landmark to quantify the actual error. The second is the distance between two landmarks, which are connected to construct a reference plane or calculate a given linear measurement. In the case of linear measurement, the shorter the line segment measured, the greater the percentage of error produced by a given measurement error. This topographic problem is also true for angular measurements. The closer the points in the construction of an angle, the greater will be the impact of measurement error on the angular measurement calculated.

7. Landmark registration, measurement procedure : technique, mechanical errors (32, 33), tracing errors (See Table1)

Table 1: Source of error and how to eliminate error

	Source of error	Error can be eliminated by
Major cause	1. Uncertainly in landmark identification (On film) 2. Unsharpness of film 3. Poorly defined structure	Error arise from original x-ray film eliminated by retaken. If arise from digital image should recapture the image or enhance quality of image
Minor cause	1. Arc of viewbox surface 2. Thickness of pencil marker 3. Translucent of tracing paper	Eriksen and Solow (22); suggested flat platform or do not digitized on emboss surface. Broch et al. (27); suggest diameter of pencil = 0.003 inch and matta acetate paper. Ricket (34); suggest the pencil sharp 6H and using "Dome" Protractor

8. Quality of image (35, 36), quality of film x-ray

The quality of the image/ image of radiograph has been demonstrated to be of the utmost importance (37).The quality can affect the level of accuracy of landmark identification (37, 38). High quality of image provides the best condition for accurate landmark identification and reliability of cephalometric measurement is significantly affected. Wenzel et al. (39) reported that if improve enhancement of sharpness has likewise been reported beneficial for radiographic caries detection.

The reliability of landmark identification is expected to be affected by the image quality. There are several ways of acquiring a digitized cephalometric image, and the image quality would depend on how the image was acquired. In the study of Chen et al. (21), the digitized images were secondarily captured by a film scanner from the images on conventional films. Inevitably, image signal deterioration would occur in the digitization process of scanning and transformation into digital format. In this case, the quality of the digitized images would be less than that of the original images on film. However, the result of his study implied that the parameter setting for their digitized cephalogram was almost adequate in terms of performance of cephalometric analysis, which was demonstrated by the low level of measurement differences and the generally comparable interobserver errors between original and digitized cephalograms. The rapid technological advances in equipment in digital dental radiology have led to the increased popularity of direct digital cephalometric images, which are either captured by computed radiography or by digital radiography. How directly acquired digital cephalometric measurements vary from traditional ones should be further studied.

9. Image capture (camera/ scanner setting)

Method of decrease distortion image suggested by Sarver (40). (Figure 2)

1.Surface of lens should be paralled to the surface of object
2. Surface of lens should be flat (curve surface of lens sources of distortion)
3. Increase camera –subject distance should be the maximum possible
4. Increase focal length of the lens (Telophoto)
5. Lens perpendicular to surface object

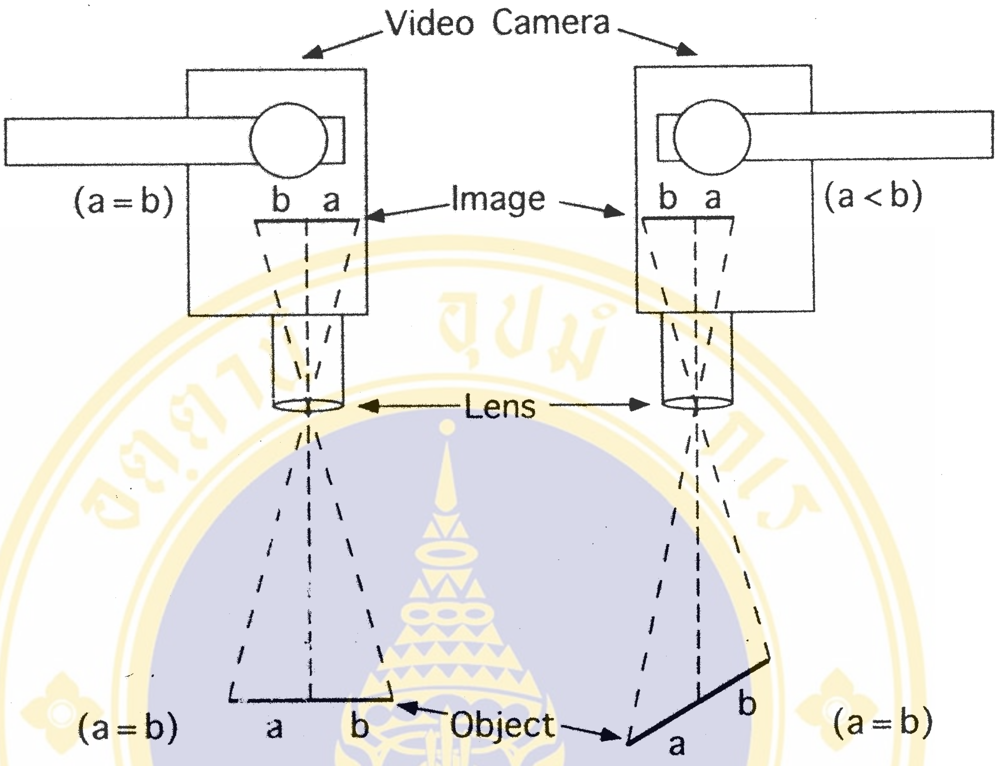

Fig.2 Show perfect camera setting (left) and imperfect camera setting (right)

Turner and Weerakone (41) suggested that flatbed scanner with optical resolution 300 x 600 dpi (or more than) and scan density = 1 – 4800 dpi is sufficiently accurate to use in a clinical setting but is not yet sufficiently exact for use in research projects owing to hardware limitations.

Ongkosuwito et al. (42) reported scanning of cephalometric radiographs at a resolution of 300 DPI is sufficient for clinical purposes and comparable to analogue cephalometrics. The 300 and 600 DPI resolutions were found to be comparable. However; all methods were found to be poor in assessing skeletal jaw relationships longitudinally.

10. Screen monitor (40, 43, 44)

Seventeen-inch to nineteen-inch monitors will provide better viewing and organizing space than will smaller units. Twenty-one-inch monitors are very nice to have but are costly space hogs. LCD flat monitors are space saving but are currently pricey. The smaller the dot size (ie, 0.25 vs 0.27) and the higher the maximum resolution, the higher the price of a monitor

Sarver (40); reported that the curve screen monitor displays distortion and curve screen monitor highest accuracy was found at the center of the monitor and the magnification increases toward the periphery of the monitor. Therefore, error can be eliminated by the use of flat screen monitor or LCD monitor with anti-reflection/ anti-static screen but they are more costly.

12. Experience of observant or Prior experience of the investigator (45)
13. Individual radiographic anatomy knowledge (45)
14. Intra & inter-observer validity (32, 46-48)
15. Repeated identification of the same landmark on the same cephalometric image (8, 49)
16. Software

Inaccuracies in the software measurement process tend to be inaccurate in cephalometric analysis. Therefore, one should eliminate this by determining the accuracy and reproducibility of measurement before used.

In summary, the analysis of cephalometric lateral skull X-rays is critically dependent on the accurate location of carefully defined anatomical and constructed landmarks. Errors in landmark identification, both systematic and random, are a significant source of error (8-10, 26, 30, 48, 50), so that the methodology used to identify and record landmarks must be meticulous.

Currently, there are four techniques commonly used to identify and record landmarks in cephalometric studies

1. Overlay tracing of the lateral skull radiograph on an X-ray viewer, followed by direct measurement of cephalometric lines and angles on the tracing paper using a ruler and protractor
2. Overlay tracing of the radiograph to identify anatomical and constructed points followed by transfer of the tracing to a digitizer linked to a computer
3. Direct digitization of the lateral skull X-ray using a digitizer linked to a computer
4. Direct digitization of x-ray image from the computer monitor

Several studies have examined the accuracy and reproducibility of landmark identification using these different methods. Direct digitization of radiographs is reported to be the most reproducible and therefore the most accurate method (51, 52), although the difference between methods is small and statistically significant in only a few instances.

Compared to other methods, direct digitization of X-rays involves fewer stages to record landmarks, and because the angles and distances are automatically calculated using computer software there is less margin for error (50, 53). However, as Richardson (51) pointed out, this highly accurate measurement technique is not necessarily going to reduce overall landmark error when the points being digitized are poorly defined. Furthermore, the design of a digitizer's cursor can obscure structures peripheral to the landmark of interest and the cross-hairs of the cursor can be difficult to distinguish against a dark background (53). This problem does not occur when digitizing a tracing.

Landmark identification using tracing paper and hand instruments compares favorably with the results of digitized X-rays and the results of studies using this method can be considered perfectly valid (51, 52). Tracing alone was found to produce more reproducible results in certain circumstances: for example, the points articulare and gonion can be constructed on a tracing, but only estimated using the digitizer (52). Other points were easier to visualize and locate when the outline of the structure could be traced first, such as the apex of the upper incisor root (53).

Conversely, taking hand measurements from tracings is by far the most time consuming and tedious method, and carries the possibility of errors caused by misreading the measuring instruments and transcribing the data to computer (52).

In a study by Davis and Mackay (54), the time taken to trace the cephalometric radiographs manually was compared with the time taken to trace the corresponding digital images. No significant difference was found; however, the time required to actually capture the digital image was not considered.

Bergin et al. (55) reported that computer calculated method is about 20 minutes faster compared to an ordinary manual radiographic analysis.

Table 2: Show the method of cephalometric analysis and its advantage and disadvantage

Methods	Advantage	Disadvantage
Manual tracing	1. Accuracy 2. No high cost equipment 3. Every where & every time when you need 4. Easy & save	1. Time consuming 2. Coarse Measurement (eg: angular measurment) 3.Need space storage 4.Required film maintenance 5.Limited in research
Direct digitized on tracing	1. Accuracy 2. Reliability 3. Reproducible:for example, the points articulare and gonion can be constructed on a tracing, but only estimated using the digitizer (52). Other points were easier to visualize and locate when the outline of the structure could be traced first, such as the apex of the upper incisor root 4. Research	1.Time consuming 2.Tedious method 3.Require special equipment such as digitized plat form and digitizer 4.Required computer, digitizer, software
Directed digitized on film x-ray	1. Most reproducible 2. Most accurate method 3. Fewer stages to record landmark 4. Less margin for error 5. Reliability 6. Research	1. The cross-hairs of the cursor can be difficult to distinguish against a dark background 2. Required special equipment such as digitized plat form and digitizer 3. Dim environment 4. Required computer, digitizer, software

Table 2: Show the method of cephalometric analysis and its advantage and disadvantage (Cont.)

Methods	Advantage	Disadvantage
Directed digitized on screen monitor	1. No need to buy expensive (and sometimes bulky) digitizing tablets with associated hardware 2. Can adjust the brightness, contrast and saturation to make identification of hard and soft tissue easier 3. With some packages (e.g. Screenceph, American Orthodontics, Compuceph, Ceph-smile) possible to review the placement of cephalometric points 4. Edge enlargement image and also permits enlargement without loss of image quality 5. Automatically outline the contour lines of the soft & hard tissue 6. Automatically recognizing measuring & analysis the landmark of hard and soft tissue 7. VTO & Orthodontic Treatment Simulation which patient can see	1. Require image capture (eg. Sacnner ,camera) 2. Change of screen monitor may be effect to measurement 3. Experience of investigator 4. Increase step may produce error 5. To be carried out by a manual 6. To be fatigued

Table 2: Show the method of cephalometric analysis and its advantage and disadvantage (Cont.)

Methods	Advantage	Disadvantage
Directed digitized on screen monitor	8. Time saving compared with a manual method 9. Favourable cost if incorporated as part as a large radiography department	

Computerized Analysis of Cephalometric Lateral Skull Radiographs

With the development of computer technology it has become possible to ‘capture’ a radiographic image and display this on a computer monitor. Various methods have been reported, such as mounting the image on a viewing box, and ‘capturing’ it using a television or video camera. More recently, digital acquisition has been achieved using a photo-stimulatable storage phosphor plate sandwiched into a standard cassette (5, 6, 56). The captured radiographic image is displayed on a computer monitor as an array of small points (pixels), each with a particular shade of grey: the contrast and density of this image can be altered in the same way as a television picture. The digital image is concurrently held in the computer’s memory as a corresponding array of numbers (each representing a value on the grey scale) and as such can be manipulated mathematically, offering the possibility of image processing to alter its visual appearance on the monitor (57). For example, it is possible to alter the X-ray image from negative to positive, manipulate contrast and brightness and filter the image. The perceived advantage of these techniques is that they can greatly facilitate landmark identification and, therefore, overall accuracy. As a further development a screen cursor can be guided over the image on the monitor, using either a keyboard or mouse, and using appropriate software can record anatomical landmarks. Additional software then calculates the cephalometric values. Cohen et al. (50) developed a cellular logic image processing system (CLIP4) to automatically identify the cephalometric landmarks menton and sella. Using image enhancement following video capture of the image, Jackson et al. (57) found comparable results with manual tracing. Cohen and Linney (9) captured the X-ray image using a TV camera linked to a personal computer. They measured sella turcica and menton, and compared their results to those obtained using a reflex metrograph, finding comparable accuracy. Geelan et al. (56) compared images captured by a storage phosphor technique, video capture, and normal tracing. They found no large differences between groups. Lowey (58) compared methods of digitization to measuring images captured using a video camera and found small but statistically significant results between the different measurement techniques, which he felt could be ignored clinically but may be of relevance for research purposes. He concluded that an increase in resolution of his system of capture would improve the results.

Comparing Methods of Landmark Identification

It has been questioned wheather these differenes of entering the cephalometric information into the hardware unit affect the accuracy of the outcome compared with each other and conventional tracing and measuring method. Baumrind and Frantz (1, (30)) produced a visual assessment which they called the envelope of error for hand tracing, and a similar distribution was found for electronic digitization of landmarks. Richardson (51) compared direct digitization of the radiograph and conventional hand tracing in the location of 14 landmarks on 50 lateral cephalometric radiographs. The standard deviations of the difference were less when the digitizer was used, for the majority of landmarks. The author felt that digitization seemed to have an advantage for reliably location cephalometric landmarks. Houston (53) conducted a study on 25 consecutive cephalometric radiographs to compare the reproducibility between the direct digitization of a radiograph and its tracing. He found that there were no statistically significant differences between the two methods for any measurement. The average error from repeated digitization of the radiograph (1 week apart) were slightly greater than those of hand tracing. In contrast, direct digitization of the radiograph was found to produce the lowest error compare with both digitization of its tracing and the manual method, in a study of 25 radiographs by Sandler (52). He has examined three different methods of measurement of cephalometric radiographs. He compared conventional tracing and measurement by hand with digitization of the tracing and with direct digitization of the radiograph. Twenty-five radiographs were traced twice for hand measurement, twice for digitization of the tracing and directly digitized twice. Using Dahlberg's method for error estimation he found errors above 1 mm for linear distances for all methods for Nasion- A point, Menton-Gonion, and Articulare-Pogonion. Error greater than 2 mm were found for the upper incisor to maxillary plane angle, upper incisor to SN plane angle and interincisal angle, for all methods. Taken overall, direct digitization of the radiograph produced the lowest errors. The value of any cephalometric analysis is affected by precision of identification of the landmarks involved. Many authors have examined this problem. However, the use of the tracing was advantageous for linear measurements involving constructed point, such as gonion and articulare. In another study, Oliver (15) compared measurement methods: (1) manual method; (2) digitization of radiograph; (3) digitization of the tracing with the radiograph; (4) digitization of enhanced digital image of radiograph; and (5) digitization of the enhanced digital image of a tracing with radiograph. For digitization of the tracing with the radiographs were traced without pre-identification of landmarks prior to the digitization process. Using a sample of five cephalometric radiographs, Oliver measured six common cephalometric angles. The author concluded that the digitization of a radiograph was less précised than both the manual method and digitization of the tracing with radiograph. This was true for both digitization methods (direct and indirect). The enhancement of the digital radiographic image did not produce any statistically significant improvement in the precision of identification of the cephalometric variables under study. A comparison between the direct and indirect digitization method showed that the direct method (using external digitizing equipment) had a slightly higher reproducibility; the different in the standard deviation of the measurements was less than 0.7 degree for every variable tested for both the tracing and radiograph.

The use of electronic digitizing apparatus has allowed mathematical calculation of angles and distances using Cartersian [x and y] co-ordinates from the digitization of landmarks. These may be obtained either directly from the radiograph, or from a tracing of the radiograph. Stabrun and Danielsen, Graveley and Benzies (46, 47) examined the errors on single tracings and found the 95 per cent confidence interval estimate for the precision of any angular measurement to be no better than ± 1 degree, and almost ± 5 degrees for the inter- incisal angle. They suggested that the quality of film will affect the level of accuracy of landmark identification. Many techniques to enhance the quality of film have been suggested. Xeroradiography has been examined as a possible alternative to conventional radiographs, the edge enhancement effect production sharper images than radiographs. This has been reported to be of some benefit in reducing errors (59, 60); but requires special equipment for then preparation and processing of the plate and also delivers a higher radiation dosage (61). The use of video imaging techniques in which a cephalometric radiograph is captured using a video camera, the image being stored digitally, has been reported by Jackson et al. (57).This technique allow processing of the captured image to enhance are of interest. An initial assessment of errors using the image enhancement apparatus compared with conventional manual methods of tracing showed no improvement in precision using the new system, although the authors suggested that this may be due, in part, to a lack of familiarity with the system, and also to the relatively low resolution of the image (An initial decision had been taken to use a resolution of 512 x 426 pixels as this was subjectively considered no worse than the higher resolution of 1025 x 852 pixels. At the lower resolution, one pixel is equivalent to o.5 mm). The hardware for this system was assembled by IBM and appropriate software to run a cephalometric analysis package developed in conjunction with IBM. Another system of digital storage and manipulation of captured video image has recently become available as part of an orthodontic and orthognathic analysis and planning package. The system [ISI] comprises a video camera with a resolution of 579 x 583 pixels mounted in a light box, a frame store with a resolution of 512 x 512 pixels, printer, plotter, high resolution image monitor, and computer. One of the claimed advantages of the ISI system is the opportunity to enhance the video image of the radiograph prior to tracing or landmark identification. This report is concerned with precision of landmark identification and the subsequent calculation of cephalometric valued using this new ISI system, compared with both traditional manual tracing methods and with direct digitization of the radiograph using a computer set up , called Cardiff Cephalometrics [CC]. This comprises the following Hewlett-Packard hardware: 9836C computer linked to a 9874A digitizer. Hard copy is produced on a 2602A printer and/or 7550A graphics plotter. This software was developed in the author's hospital department.

The results of the investigations mentioned above are not directly comparable owing to the way in which repeat tracings of lateral skull x-rays have been examined and the different approaches used in the statistical analysis of the results.

Where the method of point identification is being compared between successive recordings of the same radiograph, it is appropriate to construct Cartesian axes around the radiograph in order to measure the horizontal and vertical distance of each point from the ordinate and abscissa, respectively. These distances can then be compared between recordings and between methods. This approach is more revealing than comparing the values of cephalometric lines and angles of successive tracings where errors in the vertical or horizontal plane (the envelope of error) can be hidden by the cephalometric analysis (51).

For example, B point is more difficult to identify in the vertical plane than in the horizontal (8, 30) and the angle SNB would fail to identify differences in the vertical position of B point between tracings. Conversely, using Cartesian axes, comparison of the vertical and horizontal distances of a point and between successive readings would show any differences. Having said this, in any study comparing methods of point identification, it is useful to include the differences between common cephalometric lines and angles in order to quantify the practical significance of the technique on cephalometric error.

When the position of landmarks are compared between successive recordings any difference noted (in the horizontal or vertical plane) can range from zero upwards. Negative differences are meaningless, as the researcher will never know the true position of a landmark (53). Plotting the differences on a graph for a series of X-rays would reveal a skewed curve, rather than a normal curve. In his study comparing methods, Sandler (52) found one-third of the data to be skewed and all kurtosed at the 5 per cent level: nearly two-thirds were significantly kurtosed at the 1 per cent level. The application of parametric statistics to skewed data may not be appropriate and non-parametric techniques should be used (53).

Automated cephalometric analysis

The problem of automation of cephalometric analysis on conventional radiographs was considered by Baumrind and Miller (62). With the introduction of digital imaging, automated and semi-automated landmark identification directly from the digital image has also been investigated. This would avoid the need for manual tracing of cephalometric radiographs and remove operator subjectivity. With regard to cephalometric analysis, several systems have shown varying degrees of success in identifying different landmarks (63, 64). The system developed by Parthasarathy et al. (64) demonstrated a success rate of 83% in identifying nine cephalometric landmarks on five cephalometric images. Success was defined as lying within a three-pixel radius (approximately 1 mm) of the corresponding landmark identified by two orthodontists.

In a more recent study (65), analyses from automated systems were compared with those from six clinicians working on 10 images. The nine landmarks used were the same as those used by Parathasarathy et al. (64). A success rate of 71% was obtained, success again being defined as lying within 1 mm of average clinician estimation of the landmark. An example of the automated system used to identify landmarks is shown in Figure 3. The system has provided a reasonable estimate of the landmarks menton, gonion, sella, and glabella, but there are obvious errors in the identification of other landmarks, such as anterior nasal spine and the maxillary incisor apex.

The automated systems reviewed above are at present unable to match human operators in the accuracy of landmark identification. When assessing the results of the automated systems, it is important to consider the validity in addition to the reproducibility of landmark identification.

Fig. 3 Automatic Landmark Identification

Cephalometric analysis

Landmark identification

When carrying out landmark identification on a digital image of a cephalometric radiograph, identified landmarks can be shown on the displayed image. Corresponding angular and linear measurements can also be displayed and then stored with the image. This enables the operator to edit landmarks that may have been incorrectly placed. It also permits the operator to review identified landmarks their position again at a later date.

Reliability of landmark identification

The diagnostic value of cephalometric analysis depends on the accurate and reproducible identification of clearly defined landmarks on cephalometric radiographs (46, 66, 67). The difficulty in identifying these landmarks is compounded by the variability of the patient's hard and soft tissues, the radiographic quality, and the experience of the clinician. This is why landmark identification constitutes the main source of cephalometric analysis error (27, 68, 69). Manual analysis of a cephalometric radiograph is time-consuming, and measuring with a ruler and a protractor can increase significantly the total error of the method. The introduction of computerized cephalometric analysis gave the possibility of direct digitization of radiographs. This process involves fewer steps, decreases the measurement error because the linear and angular cephalometric variables are automatically calculated, and facilitates the transmission of information between practitioners (41, 51, 54). However, in the clinical environment, time pressures can contribute to decreased reliability when the clinician is asked to subjectively define and digitize the position of a series of cephalometric landmarks (70).

The process of cephalometry involves the identification of numerous anatomical landmarks for clinical or research purposes. The errors of identification of conventional cephalograph have been well investigated (8, 10, 26, 30, 52, 71, 72). Baumrind and Frantz (8) reported large variation in the magnitude and configuration of the envelope of error for the 16 anatomical landmarks studied. They recommended replication of landmark estimate to reduce these errors. Stirrups (72) found that the use of rare-earth screen/film combination did not significantly affect the reproducibility of selected landmark identification. The radiation requirement was 20 percent less compared to conventional barium–strontium sulphate screen/film combination.

Houston (53) showed that computerized cephalometry is more reliable than manual tracing on acetate paper. Macri and Wenzel (73) compared the reliability of landmark identification in indirectly captured digital image, of varying quality, on computer display with those on radiographic films. They found that the low resolution of the computer image resulted in greater identification error. Digital processing of the computer image improves the reproducibility of the better quality radiographs but not those of the poor quality ones. Similar findings were reported by Cohen and Linney (9) and Jackson et al. (57).

In an attempt to quantify and analyse the effect of identification error on the reliability of identification and measurement of landmarks, several statistical analyses have been devised (29, 31, 74). Battagel (75) compared several statistical analyses on cephalometric error. The author recommended that all reported results should be interpreted in relation to the measurement error.

Advances and affordability in digital radiographic imaging have recently been a demand for medical professions to automate analysis and diagnosis that were once performed manually. Many studies have attempted to improve computer aided landmark identification in the past. In general, their aim was to reduce the intra- and interexaminer variability and save valuable clinical time. Automatic landmark identification was first described by Cohen and Linney (50) who applied a computer algorithm to retrieve the landmarks Menton and Sella. Although limited in the number of variables supported, this automatic process was an innovative departure from conventional analysis that relied on subjective decisions. Other studies followed with the same goal to enable the practitioner to scan a radiograph and run software that within seconds could retrieve accurate landmarks. Implementation of different algorithms, among others, ‘‘knowledge-based system,’’ (63)‘‘pyramid method,’’ (64) ‘‘grey-scale mathematical morphology,’’ (76) ‘‘heuristic image processing,’’ (20) or ‘‘active models shape,’’ (77) attempted to locate more landmarks, but with limited success. Other models such as ‘‘spatial spectroscopy’’ (78) and ‘‘pulse coupled neural networks and genetic programming’’ (79) showed somewhat better results. Recently, a new version of a cephalometric program was introduced (Viewbox 3.1.1, dHAL Orthodontic Software, Athens, Greece), which offers an innovative feature that can help landmark identification by detecting the edges of anatomical structures. In contrast to previous attempts, which aimed at a completely automatic landmark identification, the objective of this new feature is perhaps less ambitious but it could prove to be a more realistic and clinically useful alternative to conventional manual landmark digitization.

Cephalometric analysis and other analyses

For cephalometric analysis, it seems that orthodontists in the future will continue to rely on radiography (80). For a number of years, many have used a digitizing pad connected to a computer for landmark identification in conventional cephalometric film radiographs. A computer program facilitated subsequent cephalometric analysis. Although it may not have increased accuracy, the digitizing procedure offered clinicians a means to automatically check on the more problematic landmarks and the ability to perform the analyses within seconds. Conventional films can be converted to digital images with a scanner or, as in the past, a video camera. Early studies revealed that digital cephalograms captured from film by a video camera had lower resolution than the film, resulting in greater errors in landmark identification (81, 82). Now, scanners can provide adequate spatial resolution, and many clinics scan their radiographic films to benefit from computer-based image analysis and filing systems that integrate the patients'records and digital images.

Several programs have been developed that facilitate analysis of digital lateral and frontal cephalograms and digital clinical images for traditional orthodontic analyses. One program, PorDiosW (Institute of Orthodontic Computer Science, Middelfart, Denmark) (83), facilitates cephalometric analysis as well as analysis in surgical patients with developmental cranial anomalies (84). The following cephalometric analyses are available in that program: Björk, Down, frontal, Jarabak, occlusogram, Ricketts, and Tweed, and the orthodontist can define his or her own analyses. During landmark sampling, the soft tissue can be drawn freehand or with the "soft tissue detection" feature, which generates the soft tissue based on the gray-level information in the image.

A number of studies have evaluated the effectiveness of cephalometric programs for digital images. One study compared the reproducibility of cephalometric landmark recording in conventional films with that in images acquired by SP digital radiography in hard-copy and monitor-displayed versions (4) and found no unequivocal evidence that one modality was better than the other. Images obtained with the Orthophos Ceph digital unit showed no significant differences in reproducibility of cephalometric landmark recording of bony tissues between original high-resolution images and those with much lower resolutions (85).

In recent years, great efforts have been made to develop systems for computer-assisted identification of cephalometric landmarks (1, 78, 86). These systems offer limited accuracy and are extremely time-consuming to use. Ongkosuwito et al. (42) compared the reproducibility of longitudinal cephalometric measurements between analogue and digital methods using two different resolutions (Scan 300 dpi and 600 dpi). They found that the inter-observer agreement was good. The 300 DPI was comparable to the analogue method. The reproducibility for the variables was comparable, but mandibular incisor increments tended to show better results with the 300 DPI method, whereas skeletal jaw relationship increments were not reliable with either method. Maxillary incisor increments, however, were reliable with both methods. The 300 and 600 DPI resolutions were found to be comparable. Scanning of cephalometric radiographs at a resolution of 300 DPI is sufficient for clinical purposes and comparable to analogue cephalometrics. However, all methods were found to be poor in assessing skeletal jaw relationships longitudinally.

Table 3: Summary of methods of Landmark Identification and Cephalometric analysis and findings

Author	Methods	Findings
Baumrind and Frantz**,** 1971 (8, 30)	1. Conventional hand tracing 2. Digitization of the radiograph	They found the envelope of error for hand tracing, and a similar distribution was found for electronic digitization of landmarks (1) machine porion (2) sella (3) nasion (4) orbitale (5) upper incisor apex (6) point A (7) lower incisor edge (8) upper incisor edge (9) point B (10) lower incisor apex (11) pogonion (12) menton (13) upper first molar apex (14) upper first molar cusp (15) lower molar cusp (16) lower molar apex (17) "upper" gonion (18) "lower" gonion (19) condyle (20) anterior nasal spine (21) posterior nasal spine

Table 3: Summary of methods of landmark identification and cephalometric analysis and findings (Cont.)

Author	Methods	Findings
Gravely and Benzies, 1974 (37) Stabrun and Danielsen, 1982 (66)	1. Conventional hand tracing	They examined the errors on single tracings and found the 95 per cent confidence interval estimate for the precision of any angular measurement to be no better than ± 1 degree, and almost ± 5 degrees for the inter- incisal angle. They suggested that the quality of film will affect the level of accuracy of landmark identification.
Hurst et al, 1979 (60) Coupley, 1979 (61) Chate, 1980 (59)	1. Conventional hand tracing 2. Xeroradiography	The edge enhancement effect produced sharper images than radiographs on ***Basion's y-axis and Gonion y-axis.*** This has been reported to be of some benefit in reducing errors (59, 60); but requires special equipment for preparation and processing of the plate and also delivers a higher radiation dosage (61) and 8 / 32 variables show neither technique provided a significant reduction in interobserver differences. Nasion's Y axis, Menton's Y axis Portion's X and Y axes Basion's X axis Bolton point's X axis Anterior nasal spine's X axis Tip of the nose's X axis

Table 3: Summary of methods of landmark identification and cephalometric analysis and findings (Cont.)

Author	Methods	Findings
Richardson, 1981 (51)	1. Conventional hand tracing 2. Digitization of the radiograph	The standard deviations of the difference were less when the digitizer was used, for the majority of landmarks. Two advantages of the digitizer were that for points on a curved outline having such terms as the ***'most anterior', 'most posterior', 'highest' or 'lowest' as part of*** their definition the digitizer can be used to ***find*** the point in addition to digitizing it. The digitizer also offers advantages in terms of speed and of preparation of data for computer analysis. The author felt that digitization seemed to have an advantage for reliably location cephalometric landmarks.
Houston, 1982 (53)	1. Direct digitization of a radiograph 2. Direct digitization of its tracing.	He found that there were no statistically significant differenced between the two methods for any measurement. The average error from repeated digitization of the radiograph (1 week apart) were slightly greater than those of hand tracing.

Table 3: Summary of methods of landmark identification and cephalometric analysis and findings (Cont.)

<table>
<tr><th>Author</th><th>Methods</th><th>Findings</th></tr>
<tr><td>Cohen, 1984 (48)</td><td>1. Direct digitization of a radiograph
2. Direct digitization of its tracing.</td><td>He demonstrated the reverse results with those of Houston.</td></tr>
<tr><td>Jackson et al, 1985 (57)</td><td>1. Manual tracing
2. Video capture of the image</td><td>He found the results from the image processing system were comparable with manual tracing (see Table below)
<table>
<tr><th></th><th>Image</th><th></th><th>Manual</th><th></th></tr>
<tr><th></th><th>Mean</th><th>SD</th><th>Mean</th><th>SD</th></tr>
<tr><td>SNA</td><td>0.7</td><td>0.88</td><td>0.7</td><td>0.68</td></tr>
<tr><td>SNB</td><td>0.5</td><td>0.67</td><td>0.5</td><td>0.38</td></tr>
<tr><td>ANB</td><td>0.5</td><td>0.46</td><td>0.5</td><td>0.49</td></tr>
<tr><td>MMP</td><td>1.2</td><td>0.93</td><td>1.2</td><td>0.82</td></tr>
<tr><td>U1/PP</td><td>1.4</td><td>1.41</td><td>1.4</td><td>1.08</td></tr>
<tr><td>L1/MP</td><td>2.0</td><td>1.77</td><td>1.9</td><td>1.52</td></tr>
</table>
He suggested that 1024 x 1024 resolution, grey level gave better definition of structures peripheral to a landmark especially in area of low contrast.</td></tr>
<tr><td>Cohen and Linney, 1986 (9)</td><td>1. Manual tracing
2. Captured the X-ray image using a TV camera linked to a personal computer.</td><td>They measured <i>sella turcica and menton,</i> and compared their results to those obtained using a reflex metrograph, finding comparable accuracy.</td></tr>
</table>

Table 3: Summary of methods of landmark identification and cephalometric analysis and findings (Cont.)

<table>
<tr><th>Author</th><th>Methods</th><th>Findings</th></tr>
<tr>
<td>Sandler, 1988 (52)</td>
<td>1. Manual tracing
2. Direct digitization of a radiograph
3. Direct digitization of its tracing</td>
<td>He found that direct digitization of the radiograph was found to produce the lowest error compare with both digitization of its tracing and the manual method.
He found error above 1 mm for linear distances and greater than 2 degrees for angles for all methods (see table below)
<table>
<tr><th>Error above 1 mm for linear distances</th><th>Error greater than 2 degrees for angles</th></tr>
<tr><td>Na-A point
Me-Go
Ar-Go</td><td>Upper incisor to maxillary plane angle Upper incisor to SN
Interincisal angle</td></tr>
</table>
However, the use of the tracing was advantageous for linear measurements involving constructed points, such as Gonion and Articulare.</td>
</tr>
</table>

Table 3: Summary of methods of landmark identification and cephalometric analysis and findings (Cont.)

Author	Methods	Findings
Oliver, 1991 (15)	1. Manual method 2. Digitization of radiograph 3. Digitization of the tracing with the radiograph 4. Digitization of enhanced digital image of radiograph 5. Digitization of the enhanced digital image of a tracing with radiograph	The author concluded that the digitization of a radiograph was less precised than both the manual method and digitization of the tracing with radiograph. This was true for both digitization methods (direct and indirect). Upper* & lower incisors * are the least reproducible, because of the difficulty of locating root apices. (*$p<0.05$) SNA***, ANB* ** have error in identification of A point. (***$p<0.001$) SNB* has error in under-estimation of maximum concavity of point B (*$p<0.05$) The enhancement of the digital radiographic image did not produce any statistically significant improvement in the precision of identification of the cephalometric variables under study. A comparison between the direct and indirect digitization method show that the directed method (Using external digitizing equipment) had a slightly

Table 3: Summary of methods of landmark identification and cephalometric analysis and findings (Cont.)

<table>
<tr><th>Author</th><th>Methods</th><th>Findings</th></tr>
<tr><td>Oliver, 1991 (15) (Cont.)</td><td>1. Manual method
2. Digitization of radiograph
3. Digitization of the tracing with the radiograph
4. Digitization of enhanced digital image of radiograph
5. Digitization of the enhanced digital image of a tracing with radiograph</td><td>higher reproducibility; the different in the standard deviation of the measurements was less than 0.7 degree for every variable tested for both the tracing and radiograph.(see Table below)
<table>
<tr><th></th><th colspan="2">SD diff</th></tr>
<tr><th></th><th>Directed Tracing</th><th>Indirect Film</th></tr>
<tr><td>SNA</td><td>0.30</td><td>0.19</td></tr>
<tr><td>SNB</td><td>0.19</td><td>0.08</td></tr>
<tr><td>ANB</td><td>0.22</td><td>0.21</td></tr>
<tr><td>PP/MP</td><td>0.25</td><td>0.12</td></tr>
<tr><td>U1/PP</td><td>0.63</td><td>0.41</td></tr>
<tr><td>L1/MP</td><td>0.10</td><td>0.70</td></tr>
</table></td></tr>
<tr><td>Macri and Wenzel, 1993 (81)</td><td>1. Manual method
2. Captured digital image, of varying quality, on computer display with those on radiographic films.</td><td>They found that the low resolution of the computer image resulted in greater identification error.
Digital processing of the computer image improves the reproducibility of the better quality radiographs but not those of the poor quality ones. Similar findings were reported by Cohen and Linney (9) and Jackson et al. (57)</td></tr>
</table>

Table 3: Summary of methods of landmark identification and cephalometric analysis and findings (Cont.)

<table>
<tr><th>Author</th><th>Methods</th><th>Findings</th></tr>
<tr><td>Lowey, 1993 (58)</td><td>1. Manual method
2. Digitization to measuring images captured using a video camera</td><td>He found small but statistically significant results between the different measurement techniques, which he felt could be ignored clinically but may be of relevance for research purposes.
He concluded that an increase in resolution of his system of capture would improve the results.</td></tr>
<tr><td>Geelan et al, 1998 (4)</td><td>1. Manual tracing method
2. Digitization to measuring images captured using a video camera
3. Captured by a storage phosphor technique</td><td>They found no large differences between groups. The images had a lower precision than film (P < 0.005) and hard-copy (P < 0.02).
There was no significant difference between film and hardcopy.
The lower reproducibility seen for the monitor-displayed images is most probably of little clinical significance.
Average deviation from the mean (all modalities) (see Table below)
<table>
<tr><th>mm</th><th><0.75</th><th>0.75–1.5</th><th>>2.00</th></tr>
<tr><td>S</td><td>x</td><td></td><td></td></tr>
<tr><td>N</td><td>x</td><td></td><td></td></tr>
<tr><td>Sp</td><td></td><td>x</td><td></td></tr>
<tr><td>Snp</td><td></td><td>x</td><td></td></tr>
<tr><td>Ss</td><td></td><td>x</td><td></td></tr>
<tr><td>Pr</td><td>x</td><td></td><td></td></tr>
<tr><td>Is</td><td>x</td><td></td><td></td></tr>
<tr><td>As</td><td></td><td>x</td><td></td></tr>
</table>
</td></tr>
</table>

Table 3: Summary of methods of landmark identification and cephalometric analysis and findings (Cont.)

<table>
<tr><th>Author</th><th>Methods</th><th>Findings</th></tr>
<tr>
<td>Geelan et al, 1998 (4) (Cont.)</td>
<td>1. Manual tracing method
2. Digitization to measuring images captured using a video camera
3. Captured by a storage phosphor technique</td>
<td>Average deviation from the mean (all modalities) (see Table below)
<table>
<tr><th>mm</th><th><0.75</th><th>0.75–1.5</th><th>>2.00</th></tr>
<tr><td>Ms</td><td></td><td>x</td><td></td></tr>
<tr><td>Ii</td><td>x</td><td></td><td></td></tr>
<tr><td>Ai</td><td></td><td>x</td><td></td></tr>
<tr><td>Gn</td><td></td><td>x</td><td></td></tr>
<tr><td>Mp</td><td></td><td>x</td><td></td></tr>
<tr><td>Mi</td><td></td><td>x</td><td></td></tr>
<tr><td>Id</td><td>x</td><td></td><td></td></tr>
<tr><td>Sm</td><td></td><td>x</td><td></td></tr>
<tr><td>Pg</td><td>x</td><td></td><td></td></tr>
<tr><td>Ar</td><td>x</td><td></td><td></td></tr>
<tr><td>Ba</td><td></td><td>x</td><td></td></tr>
<tr><td>Or</td><td></td><td></td><td>x</td></tr>
<tr><td>Po</td><td></td><td></td><td>x</td></tr>
</table>
</td>
</tr>
<tr>
<td>Chen et al, 2000 (3)</td>
<td>1. Manual tracing method
2. Digitization to measuring images captured using a scanner 150 dpi, 64 grey level, 512 x 512 pixel matrix, 0.17 mm pixel size</td>
<td>The differences of landmark identification between original radiographs and their digital counterparts were statistically significant. (see Table below)
<table>
<tr><th>*p<0.05</th><th>Horizontal</th><th>Vertival</th></tr>
<tr><td>< 1 mm</td><td>Gn*
ANS*</td><td>Po*
Gn*</td></tr>
<tr><td>> 1mm</td><td>Or*,Me*
PNS*
LIA*</td><td>Or*</td></tr>
</table>
The inter-observer error for each landmark in digital images was generally larger than that in the original radiographs. However, statistically significant differences of</td>
</tr>
</table>

Table 3: Summary of methods of landmark identification and cephalometric analysis and findings (Cont.)

<table>
<tr><th>Author</th><th>Methods</th><th>Findings</th></tr>
<tr><td>Chen et al, 2000 (3) (Cont.)</td><td>1. Manual tracing method
2. Digitization to measuring images captured using a scanner 150 dpi, 64 grey level, 512 x 512 pixel matrix, 0.17 mm pixel size</td><td>inter-observer errors between 2 modalities were only found for 4 of the 19 landmarks. These 4 landmarks, Po, Ar, ANS, and UM, should be scrutinized more carefully during potential applications of digital cephalometry .(See Table below)
<table>
<tr><th colspan="4">Landmark ; *p<0.05</th></tr>
<tr><td>Po*</td><td>N</td><td>Gn</td><td>UIA</td></tr>
<tr><td>Ar*</td><td>S</td><td>Pog</td><td>UIE</td></tr>
<tr><td>ANS*</td><td>Or</td><td>B</td><td>LIA</td></tr>
<tr><td>UM*</td><td>Go</td><td>A</td><td>LIE</td></tr>
<tr><td></td><td>Me</td><td>ANS</td><td>LM</td></tr>
</table>
</td></tr>
<tr><td>Turner and Weerakone, 2001 (41)</td><td>1. On-screen digitization of the scanned bitmap image (Screenceph method)
2. Tracing followed by digitization of the identified points and
3. Direct digitization</td><td>For the 8 angular & 4 linear cephalometric measurements examined the Screenceph method compared favourably with the two conventional methods.
The median difference between methods was 0·5 degrees and 0·2 mm. Using constructed Cartesian axes to examine the x, y discrepancy between repeat measurements and comparing Screenceph to tracing followed by digitization, there were significant differences in 3 instances at the 5% level and 2 instances at the</td></tr>
</table>

Table 3: Summary of methods of landmark identification and cephalometric analysis and findings (Cont.)

Author	Methods	Findings
Turner and Weerakone (41) (Cont.)	1. On-screen digitization of the scanned bitmap image (Screenceph method) 2. Tracing followed by digitization of the identified points and 3. Direct digitization	1% level. These differences represented median scores of 0.14 to 0.32 mm greater for Screenceph. Comparing Screenceph to direct digitization 15 significant differences out of the 28 measurements were noted: six at the 5% level and 9 at the 1% level. The actual difference in median scores ranged from 0·2 mm to 0·53 mm. Screenceph is sufficiently accurate to use in a clinical setting but is not yet sufficiently exact for use in research
Ongkosuwito et al, 2002 (42)	1. Manual tracing method 2. Digitization to measuring images captured using a scanner 300 dpi 3. Digitization to measuring images captured using a scanner 600 dpi	Scanning of cephalometric radiographs at a resolution of 300 DPI is sufficient for clinical purposes and comparable to analogue cephalometrics. However, all methods are poor in measuring skeletal jaw relationships longitudinally.

Table 3: Summary of methods of landmark identification and cephalometric analysis and findings (Cont.)

<table>
<tr><th>Author</th><th>Methods</th><th>Findings</th></tr>
<tr>
<td>Chen et al, 2004 (21)</td>
<td>1. Manual tracing
2. Digitized image captured using a scanner 150 dpi, 64 grey level, 512 x 512 pixel matrix, 0.17 mm pixel size</td>
<td>They found that measurement differences between the original cephalograms and the digitized images are statistically significant but clinically acceptable.
The distribution of cephalometric items according to the level of measurement difference (md) between traditional and digitized cephalograms. (See Table below)
<table>
<tr><th>Md <1.0</th><th>1.0 <md < 1.5</th><th>1.5 <md < 2.0</th><th>2.0 < md</th></tr>
<tr><td>ANB</td><td>SNA</td><td>A-Nv</td><td>Pog-Nv</td></tr>
<tr><td>UI-NPog</td><td>SNB</td><td>NAPog</td><td>UI-SN</td></tr>
<tr><td>AArGn</td><td>UFH/LFH</td><td>SN-FH</td><td>UI-LI</td></tr>
<tr><td>bl</td><td>Ar-A</td><td>SN-OP</td><td>LI-OP</td></tr>
<tr><td></td><td>Ar-Gn</td><td>SN-MP</td><td>LI-MP</td></tr>
<tr><td></td><td>Ar-A/Ar-Gn</td><td>Wit's</td><td></td></tr>
<tr><td></td><td>ArAGn</td><td>AGn</td><td></td></tr>
<tr><td></td><td>AGnAr</td><td></td><td></td></tr>
<tr><td></td><td>au</td><td></td><td></td></tr>
<tr><td></td><td>ul</td><td></td><td></td></tr>
<tr><td></td><td>ab</td><td></td><td></td></tr>
</table>
Linear measurement in millimeters, angular measurements in degrees
bl =Distance between the projections of point B and lower incisal edge onto FH plane
au =Distance between the projections of point A and upper incisal edge onto FH plane
ul =Distance between the projections of upper and lower incisal edges onto FH plane
ab =Distance between the projections of point A and B onto FH plane</td>
</tr>
</table>

Table 3: Summary of methods of landmark identification and cephalometric analysis and findings (Cont.)

Author	Methods	Findings
Shinawatra et al, 2005 (87)	1.Original radiographs 2. Scanned lateral cephalograms 3.Directed digitized on film	The results demonstrated that Ceph-smile is sufficiently accurate to use in a clinical setting but is not yet sufficiently exact for use in research projects owing to hardware limitation.
Kazandjian et al, 2006 (88)	1. Manual method 2. An edge-based algorithm	The computer-assisted method did not agree with manual digitization in 7 of 13 landmarks and 5 of 10 variables. With a tolerance of 0.5 mm or degrees, the two methods did not agree in cephalometric variables. Intraoperator reliability was improved for B point (x-axis), and Menton (x- and y-axis). It got worse for point A (y-axis). Interoperator reliability was improved for B point (x- and y-axis), Soft Labrale Inferior (x- and y-axis), Soft Pogonion (x-axis), and Menton (y-axis). It decreased for point A (y-axis). Intra and interoperator reliability got better for only one cephalometric variable under study (SNB). The edge-locking feature seems to be a promising tool for increasing the reliability of on-screen cephalometric analysis.

Table 3: Summary of methods of landmark identification and cephalometric analysis and findings (Cont.)

<table>
<tr><th>Author</th><th>Methods</th><th>Findings</th></tr>
<tr><td>Kazandjian et al, 2006 (88) (Cont.)</td><td>1. Manual method
2. An edge-based algorithm</td><td>There seem to be difficulties in locating the appropriate edges when artifacts or soft tissue edges are located near the targeted landmark.
The existence of very small, but systematic differences between the two digitization methods manifests the need for further improvement.</td></tr>
<tr><td>Lance et al, 2006 (89)</td><td>1. Original radiographs
2. Scanned lateral cephalograms
3. Hardcopy</td><td>The Differences were statistically significant.
<table>
<tr><th colspan="2">Distortion between the</th></tr>
<tr><td>original & scanned image</td><td>original & Printed</td></tr>
<tr><td>0.8* mm vertical enlargement</td><td>1.1* mm vertical enlargement</td></tr>
<tr><td>0.4* mm horizontal reduction</td><td>0.4 * mm horizontal enlargement.</td></tr>
</table>
Cephalometric comparisons between original and digital images showed statistical differences in
<table>
<tr><td>FH-OP*</td><td>y-axis*</td></tr>
<tr><td>Max.central incisor-FH*</td><td>FMA* (*p<0.05)</td></tr>
<tr><td>facial plane*</td><td>FH-NA*</td></tr>
</table>
</td></tr>
</table>

Table 3: Summary of methods of landmark identification and cephalometric analysis and findings (Cont.)

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<tr><th>Author</th><th>Methods</th><th>Findings</th></tr>
<tr><td>Lance et al, 2006 (89) (Cont.)</td><td>1.Original radiographs
2.Scanned lateral cephalograms
3.Hardcopy</td><td>Cephalometric comparisons between the digital and the hard-copy images showed statistical differences in
<table>
<tr><td>facial plane*</td><td>FMA*</td></tr>
<tr><td>y-axis*</td><td>FH-NA*</td></tr>
</table>
All measurements with differences contained the landmarks porion and orbitale.
No differences were found between the original and the hard-copy images.</td></tr>
<tr><td>Santoro et al, 2006 (90)</td><td>1.Conventional film
2.Digital image</td><td>An overall greater variability in the digital cephalometric measurements was found.

Differences between the 2 methods for landmark in table below.
<table>
<tr><td>SNA*</td><td>U1/L1**</td><td>S-Go: N-Me**</td></tr>
<tr><td>ANB*</td><td>L1-GoGn*</td><td>N-ANS : ANS-Me*</td></tr>
</table>
(P < .05*), (P < .0001**).

The 2 tracing methods provide similar clinical results; therefore, efficient digital cephalometric software can be reliably chosen as a routine diagnostic tool.</td></tr>
</table>

An introduction to digital radiography in dentistry (91)

Digital radiography has been used widely in medicine, but it was only in the 1980s that the first intra-oral sensors were developed for use in dentistry. Unfortunately, the early systems could not capture panoramic and cephalometric images, and this made it impossible for surgeries to abandon film processing and adopt digital technology. Recently, the development of cost effective intra- and extra-oral digital technology coupled with an increase in computerization of practices has made digital imaging a superior alternative in many respects to conventional film imaging. Advantages of this type of system for the orthodontist and the patient include the ability to gain cephalometric analysis and superimposition quickly on the chairside computer, manipulation of images to aid diagnosis, dose reductions, and the ease of storage.The basic principles behind digital radiography and also to discuss some problems, such as set-up costs and cross-infection control issues that can affect the systems currently available

Principles

Conventional imaging

Conventional intra-oral radiographic film consists of silver halide grains in a gelatine matrix. When this film is exposed to X-ray photons, the silver halide crystals are sensitized and are reduced to black during the developing process. The film acts as both the radiation detector and the image display. With extra-oral films indirect action receptors are used to help record the image. This type of film is sensitive to light photons which are emitted by adjacent intensifying screens. Although the film is constructed of silver halide crystals these are primarily sensitive to light rather than X-rays. The use of intensifying screens reduces the dose and can be used where fine detail is not required.

Digital radiography imaging

In digital radiography, instead of the silver halide grain the image is constructed using pixels or small light sensitive elements. These pixels can be a range of shades of grey depending on the exposure, and are arranged in grids and rows on the sensor, unlike the random distribution of the crystals in standard film. However, unlike film the sensors are only the radiation detector and the image is displayed on a monitor. The signal that is produced by the sensor is an analogue signal, i.e. a voltage that varies as a function of time. The sensor is connected to the computer and the signal is sampled at regular intervals. The output of each pixel is quantified and converted to numbers by a frame grabber within the computer. The range of numbers is normally from 0 to 256 with 0 representing black, 256 representing white and all others are shades of grey. The number of grey levels relates to contrast resolution and the size of the pixels is related to spatial resolution. Together, these determine the overall resolution (i.e. the ability to distinguish between small objects close together) of the image. Resolution can also be expressed in line pairs per millimetre. Most conventional E speed films have a resolution of 20 LP/mm whereas with digital images the resolution ranges from 7–10 LP/mm. The reduced resolution should not interfere with clinical diagnosis.

Image acquisition

There are two ways to acquire a digital image

1.) Indirect acquisition (91)

A digital image can be produced by scanning conventional radiographs using a flatbed scanner and a transparency adaptor, or by using a charged coupled device camera instead of the flatbed scanner. This image can then be manipulated using software packages or be passed on to a second party via a modem.

Scanners (92)*:* Adequate quality flat bed scanners for clinical use have come down in price to under $100 (year 2000), and the accompanying software has improved amazingly. For about the same cost as a reflective scanner, one can purchase an add-on transparency adapter that will allow him/her to scan cephalometric radiographs. Some units come with a transparency adapter, but make sure it is the type that can handle an 8X10-in transparency. Other manufacturers of flat bed scanners include 35-mm slide transparency adapters or offer them as accessories. Dedicated slide (negative) film scanners have greatly improved, and their prices have come down considerably. Any of the mid-priced film scanners available will serve an orthodontist well. Dedicated slide film scanners are much to be preferred over their flat bed attachment counterparts. They are very compact, they function with much greater ease, and the software is designed specifically for handling slides. Caution: The selection of a film scanner brand should not be made before trying out the software interface. Software can make a big difference in ease of use. The ideal scanner setup would include both a flat bed and a dedicated film scanner.

This peripheral device allows you to reading, photos, documents, slides, etc, into computer. Scanned copies of documents are not legal copies.

When one are ready to purchase a scanner, do not accept anything less than 300 × 600 dpi resolution and 24 bit color. These are the minimum requirements for scanning photographic images. Be aware, however, that higher resolution is not always desirable because it requires so much more memory. Higher resolution always costs more memory but does not always produce greater detail. If you want to scan a document and print it later, scan it at 150 to 200 dpi. Similarly for photos, you should scan at 200 or 300 dpi. If one want to enlarge him/her images, or one require high-quality images and have tons of memory, scan at 600 dpi. Before scanning, one should ask this question: How much resolution do I really need?

In conclusion, the findings in this study suggest that the settings of resolution and grayscale or color that one selects on a scanner to digitize a cephalometric film do not matter significantly when standard scanner settings are used. However, a lower resolution without color may be the best combination of settings. Moreover, a subjective opinion of the image quality can predict how precise an orthodontist will be in landmark identification, but only if the resolution is relatively high. Cephalometric digitization: A determination of the minimum scanner settings necessary for precise landmark identification.

Camera

Camera types

1) Single lens reflex.(SLR) Fig.4
2) Compact digital camera. Fig.6

The characteristics and functions commonly found on most cameras are discussed. No single camera can meet the requirements of every photographic assignment. There are a number of cameras to choose from in the fleet. These cameras produce negatives that range in size from 35mm to 8x10 inches.

The number and types of cameras available at an imaging facility depend primarily on the mission of the facility. All cameras have common features. There are three general categories of cameras: small format, medium format, and large format. This is reflected to a viewing screen for focusing and composition. This allows one to see what the lens sees regardless of the lens focal length or the lens-to-subject distance. The reflex system is simple and reliable. It has three main elements: a hinged mirror, a matte focusing screen, and a five-sided glass prism called a pentaprism. The mirror, in the viewing position, is below the viewing screen and behind the lens. It is at a 45-degree angle and projects the image formed by the lens up to the focusing or viewing screen. The pentaprism reflects the image from the focusing screen, so one can see it in the camera eyepiece. Figure.4 shows the design of a typical SLR camera.

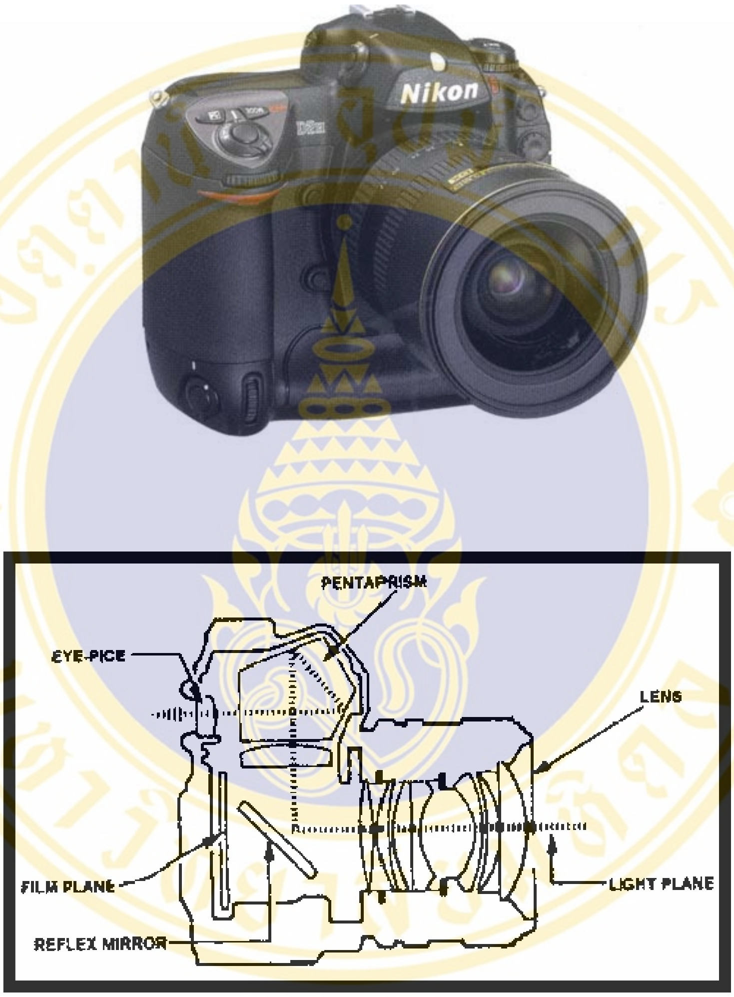


Fig.4 Show the design of a typical SLR camera and design of a typical SLR camera

Single-Lens Reflex (93)

Single-lens reflex (SLR) cameras have a focusing and viewing system that shows the image formed by the picture-taking lens. SLR cameras are designed so the distance between the focusing screen and the lens is exactly the same as the distance between the lens and the film; therefore, whatever appears in focus on the focusing screen will also be recorded in focus on the film. With an SLR camera, there is no parallax error. Sometimes two small prisms or a split screen is included in the central area of an SLR camera viewing screen. When the image is out of focus, it appears split in this area (Fig. 5). Some screens have a central grid of minute prisms that produce a shimmering effect when the image is out of focus. An SLR camera is focused by rotating the focusing ring on the lens until the image seen through the viewfinder is in sharp focus. SLR cameras are the most commonly used camera in Navy imaging today

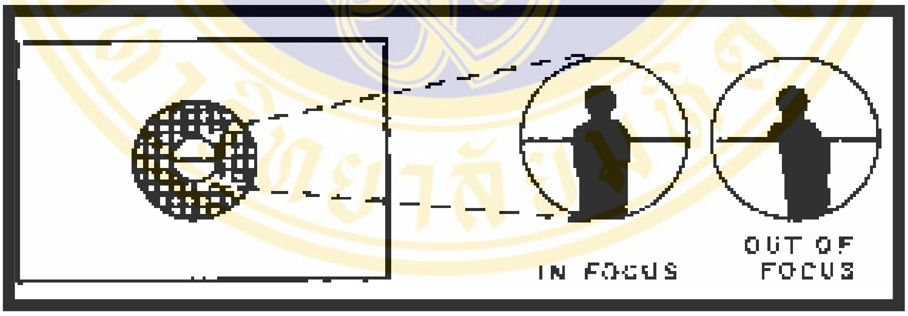


Fig. 5 Split-image focusing

Image Sharpness

The outer edges of a lens are least likely to produce a well-defined or aberration-free image; therefore, proper use of the diaphragm, aperture, or f/stop can improve image sharpness by blocking off light rays that would otherwise pass through the outside edges of a lens. There is a limit to how far the aperture can be stopped down and still increase image sharpness. When the aperture is very small, it causes diffraction of light rays striking the edge of the diaphragm. Diffraction results in a loss of image sharpness. This loss of image sharpness is especially noticeable in copy work. Physical limitations in the design of lenses make it impossible to manufacture a lens of uniform quality from the center to the edges; therefore, to obtain the best quality with most lenses, you can eliminate the edges of the lens from being used by closing down the aperture about two f/stops from wide open This recommended adjustment is called the **optimum** or **critical aperture.** The optimum aperture for a particular lens refers to the f/stop that renders the best image definition. When a lens is stopped down below the optimum aperture, there is an actual decrease in overall image sharpness due to diffraction. Although the depth of field increases when a lens is stopped down below the optimum aperture, image sharpness decreases; therefore, increased depth of field should not be confused with image sharpness. For example, the image formed by a pinhole camera has extraordinary depth of field but lacks image sharpness. When the lens aperture is closed down to the size of a pinhole, it behaves like one. This is an important factor for subjects in a flat plane (such as copying) where depth of field is not needed.

Advantages

Many of the advantages of SLR cameras derive from viewing the scene through the taking lens. Most other types of camera do not have this function; subjects are seen through a viewfinder that is near the lens, making the photographer's view different from the lens' view. SLR cameras provide photographers with precision and confidence; they are seeing an image that will be exposed onto the negative exactly as it is seen through the lens. There is no parallax error, and exact focus can be confirmed by eye—otherwise hard for macro photography and when using telephoto lenses. The true depth of field may be seen by stopping down to the taking aperture, possible on all but the cheapest cameras. Because of the SLR's versatility, most manufacturers have a vast range of lenses and accessories available.

Compared to most fixed-lens compact cameras, the most commonly used and cheapest SLR lenses offer a wider aperture range and larger maximum aperture (typically f/1.4 to f/1.8 for a 50 mm lens). This allows photographs to be taken in lower light conditions without flash, and allows a narrower depth of field, which is useful for blurring the background behind the subject, making the subject more prominent. This is commonly used in portrait photography.

The variety of lenses also allows for the camera to be used in multiple situations. This gives the photographer considerably more control over how the picture is framed than a simple view camera. In addition, SLR lenses can also be found with extremely long focal points, letting a photographer be far away from the subject. This is particuarly useful if the subject is dangerous (i.e., wildlife), or the subject would prefer the photographer to stay away (i.e., a celebrity).

Disadvantages

Single-lens reflex cameras cannot be made as small or light as other camera designs such as rangefinder cameras, autofocus compact cameras and digital cameras with electronic viewfinders (EVF) due to the mirror box and pentaprism/pentamirror. The mirror box also prevents lenses from having rear elements closer to the film or sensor; this means that simple designs for wide angle lenses cannot be used. Instead, poorer-performing, larger and more complex retrofocus designs are required.

The SLR mirror blacks out the viewfinder when the picture is taken. In addition, moving the mirror takes time, limiting the maximum shooting speed; the mirror also causes noise and vibration. Some SLRs have used partially-reflective fixed mirrors to avoid these problems, including the Canon Pellix, but these reduce the light getting to the film or sensor. To avoid the noise and vibration, many professional cameras offer a mirror lock-up feature, but thisblacks out the viewfinder totally when in use.

Most digital SLRs in general cannot display a live view on their rear LCD displays, unlike Compact or Bridge cameras, and must be held to the eye to compose the picture (with the exception of the Olympus E-330 and related Panasonic DMC-L1). Movie modes are also unavailable [2]. Electronic viewfinders have the potential to give the advantage of a digital SLR (through-the-lens viewing) without many of the disadvantages, but as of 2006 sensor and display technology is insufficient for wide acceptance among the advanced amateur or professional markets that buy digital SLRs.

The price of SLRs in general also tends to be much higher than that of other types of cameras, due to the internal complexity of the device. This is only aggravated by the fact that additional components, such as a flash attachment or various types of lenses, can be extremely expensive as well. Typically the initial investment in equipment is prohibitive enough to keep the casual photographer away from SLRs.

There is also the obvious problem of a higher rate of breaking down due to more moving components. Because many SLRs have interchangeable lenses, there is a tendency for dust, sand and dirt to get into the main body of the camera, dirtying or even jamming the mirror's movement. In addition, these particles can also jam or otherwise hinder the focusing feature of a lens. This problem has been somewhat reduced in DSLRs as some cameras have a built-in sensor cleaning unit.

Compact Digital Camera (Fig.6) (92)

Last year’s crop of everyday digital cameras sported 1 million-pixel CCDs (charge coupled devices). This year, 3 million-pixel CCDs are common, with 6 million-pixel CCDs available on high-end cameras for a considerably higher cost. It is logical to expect to see 3 to 6 millionpixel CCD cameras with interchangeable lenses appear on the market at affordable prices in the near future. Clinical nirvana is approaching. A through-the-lens viewing digital camera with an auxiliary LCD (liquid crystal display) screen used with a quality macro lens would be an ideal tool. One macro lens of the proper focal length would do it all with ease, and the LCD screen would allow the clinician to correct mistakes on the spot. One million-pixel CCDs produced great screen images but very limited photo-quality print sizes. The newer 3 million-pixel CCD cameras can produce an 8X10-in photo-quality print. Each clinician must make a number of decisions in selecting not only the digital camera to be used, but also how large a file is necessary for his or her needs. The larger the file captured, the fewer the number of images that can be stored on your hard drive or on a single storage disk.

Cameras and capture devices (94)**:** Judging an imaging system starts with establishing ones own goals and parameters in terms of the quality of the results that will be acceptable. Because cost is a factor, the clinician must make decisions that involve compromising the quality of the final digital image. The best digital cameras are very costly, as are the best printing devices. A $20,000 budget may purchase the basic top of the line digital equipment. The cost of making prints can also be a major concern when prints can cost several dollars each. The best digital cameras still cannot come anywhere near the photographic quality of a 35 mm slide produced by a good clinical camera. Many operators are taking regular film photographs as before and using digital images only for computerized manipulation. Certainly as time passes, digital camera prices will come down and the quality of images produced will go up and up. For the present, film still produces the best quality images at a most reasonable cost. Polaroid prints and prints made from film can be scanned into a computer by using a variety of print scanning devices, which are showing up on the market. Digital images can be reproduced in 3×5 inch or 4×6 inch sizes with miniature dye sublimation printers that are coming on the market at affordable prices, dye sublimation prints do not, however, have archival quality. This is yet another cause for concern when orthodontic records must be stored for many years after the completion of therapy.

There are many different brands and models on the market.When one are looking for a digital camera, one must be aware not only of image resolution, but also of image compression methods, warranties, technical support, software, etc. What is image resolution? In simple terms, it tells how many colored dots (pixels) are used to form the image. When talking about digital cameras, most vendors would probably say that 1024 × 840 pixel resolution is adequate. You may think that larger numbers correspond to better quality, and you would be generally correct. However, other factors do influence image quality, such as lens quality. Do not assume that all 1.5×10^6 pixel cameras are better than all 1.3×10^6 pixel cameras. If possible, take actual photographs with various cameras and compare. One may find that paying an extra $1,000 for that new camera is not worth it in the final analysis.

Digital cameras can be divided into two categories, professional cameras (about $10,000 or more) and nonprofessional cameras (with prices starting at $300 or so). If one do not make a living as a photographer, then you should definitely exclude professional cameras from consideration. There are many cameras at affordable prices ($800 or less) that produce great results.

Fig.6 Compact Digital Cameras

Lens: Big advances have been made in the construction of lenses for digital imaging. The difference in physical size of compact digital camera lens and its 35 mm. equivalent is obvious. Lenses are measure in ‘focal lengths’, a zoom lens has two numbers being of more interest to us in terms of ‘working distance’ Table 4 is a guide to 35 mm. zoom equivalents for digital cameras. Owing to the varying physical size of the sensor, zoom, equivalents vary from camera to camera. A zoom lens of 8 mm to 30 mm would be suitable, although there are no hard and fast rules to calculate this figure. A factor of importance when taking clinical photography is the ‘macro’ capability of the lens. ’Macro’ is the ability to produce an image at 1:1 magnification or greater and, though many cameras will be designated as having ‘macro’, not all will achieve 1:1 magnification. Cameras such the Nikon Coolpix range have good macro capacibility; in practice you will rarely need true ‘macro’. The best way of checking the macro facility on a camera is to try it.

The user must be careful that the camera is not using ‘digital zoom’ to achieve close-up. Digital zoom is when the camera zooms in electronically on the image. These images can be pixilated (individual pixels can detected in the image), however. If the user is using a high picture quality setting this effect is minimized. Because the camera is enlarging the centre of the image, just like enlarging a 35 mm picture, the user will get a ‘grainy’ result. Image can be cropped on the computer to achieve the same effect and in most cases this would be the preferred option.

Table 4: 35 mm equivalents compared to digital camera focal lengths.

Image sensor	Make/Model	Zoom	35 mm eqivalent
1 / 2 inch	Nikon Coolpix 950	7mm.-21mm.	38mm-115mm.
1 /1.8 inch	Nikon Coolpix 995	8mm.-32mm.	38mm-152mm.
	Nikon DX 4900		35mm-70mm.
	Nikon Coolpix4500	7.85mm.-32mm.	28mm-155mm.
2/3 inch	Nikon Coolpix5700	8mm.-72mm.	35mm-280mm.
	Minolta 7i / 7 Hi	7.2mm.-50.8mm	28mm-200mm.
	Sony DSC-F717	9.7mm-48.5mm	38mm-190mm.

Focal length

One of the most important characteristics of any lens is its focal length. It's the focal length that determines a lens' angle of view-wide angle, normal, or telephoto.

Lens focal lengths are indicated in millimeters (mm). On a more familiar 35mm camera, a lens with a focal length of less than 35 mm is considered a "short" or wide angle lens and one over 65mm is considered a "long" or telephoto lens. Lenses between 35mm and 65mm are considered normal and the 50mm lens is the most common normal lens.

Choice of lens depends in part on what one plan to do with the camera. Wide-angle lenses are best for photographing buildings, landscapes, interiors, and street photography. Telephoto lenses are best for portraits and many nature scenes. Normal lenses are a compromise (See Table 5).

Table 5: Choice of lens depends in part on what one plan to do with the camera.

Film format	Film diagonal (mm)	Normal Lens
35mm	43mm	50mm
2 1/4 x 2 1/4 inch	90mm	80mm
4 x 5 inch	163mm	150mm

Since 35-millimeter film has an image area measuring 24-by-36mm, its diagonal is 43 mm-not quite 50 mm. The 50mm lens has become the normal lens because there is some latitude in characterizing a lens as normal and it's more a range than an exact number.

Digital cameras use the same relationships as other cameras to determine wide-angle, normal, and telephoto lenses. However, the focal lengths are much shorter because solid-state image sensors are much smaller than the smallest film. For example, while 35mm has an area of 36 x 24 mm, a 2/3-inch image sensor is only 8.8 by 6.6 mm and many sensors are even smaller. (Fig.7)

Fig. 7 The sizes of 1/3-inch, 1/2-inch, and 2/3-inch image sensors would look against the background of a frame of 35mm film

The table below shows the diagonal measurements of typical image sensors and 35 mm film. These measurements roughly specify what the normal focal length for each would be.

Table 6: Show the diagonal measurements of typical image sensors and 35 mm film

Image sensor	Width (in mm)	Height (in mm)	Diagonal (in mm)
35mm Film	36	24	43
2/3-inch sensor	8.8	6.6	11
1/2-inch sensor	6.4	4.8	8
1/3-inch sensor	4.8	3.6	6

To make digital camera focal lengths more comprehensible to photographers familiar with 35mm cameras, you'll often see references to lens focal lengths such as: 7 mm equivalent to a 50 mm lens on a 35 mm camera.

White balance: Conventional 35 mm photography of x-rays invariably caused of problems in past. Because of the differing ‘colour temperature ’of fluorescent light tubes in x-ray, the results were often a disappointing green or blue cast image. Digital cameras come equipped with many functions to overcome this and the ‘auto white balance’ function on digital cameras will compensate for most types of light source. In addition to the ‘auto white balance’, the user has the option of using pre-set ‘white balance’ settings such as daylight, speedlight (flash), tungsten and fluorescent. The user can also set the camera to produce greyscale (B/W) images directly. This guarantees a B/W image and will also give a much smaller file size.

Technique: When copying x-rays without a tripod, 'shutter priority' (the user determines the shutter speed and the camera automatically selects the correct aperture) is the setting of choice. This is selected using the mode button and thumbwheel on the Nikon Coolpix 4500.

Intra-oral imaging required as much 'depth' of focus as possible. Hence, it requires a small (large number) aperture and, as a powerful light source is being used(e.g. electronic flash), the shutter speed is always going to be fast. X-ray imaging, however, need little 'depth' as an x-ray is flat, but if the users are 'hand holding' the camera the shutter speed 'camera shake'. The minimum shutter speed which the author would recommend for hand held images is one-sixtieth of second. Even this can cause some shake of a second. Even this can cause some shake, for example, if the user is leaning over a light box, one-sixtieth will often not eliminate 'shake'. The user should get into a comfortable position, preferably resting on something solid, to take the image.

Use of tripod, or having something to rest the camera on, would be the ideal set-up. Autofocus will work in mast cases; focus zones do not need to be used here as the subject is flat. If using a tripod or some other form of rest, then much slower shutter speed can be used. Metering should again be set to 'matrix' as this gives an 'average' reading of the whole x-ray.

Barrel and Pincushion Distortion

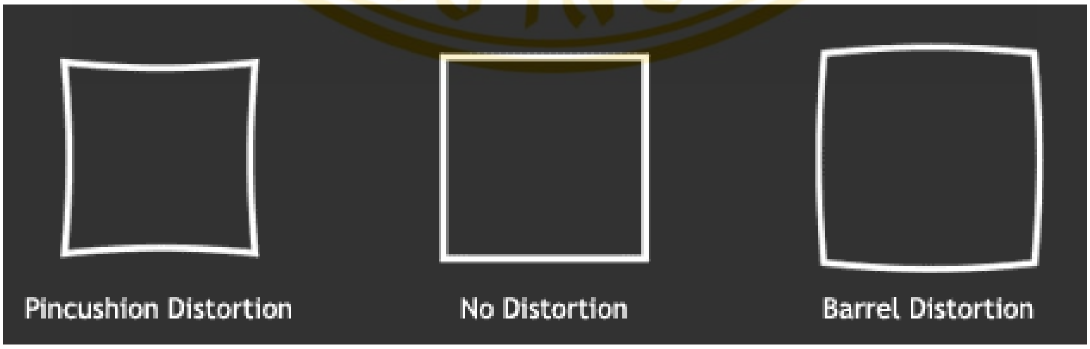


Fig 8.Show Pincushion distortion and Barrel distortion

Typically, wide angle lenses tend to suffer from barrel distortion and telelenses from pincushion distortion. (Fig.8)Both effects tend to be stronger at the extreme ends of zoom lenses, especially on compact cameras.

2.) Direct digital imaging (91)

There are two systems available, one produces the image immediately on the monitor post-exposure and is therefore called Direct Imaging. The second has an intermediate phase, whereby the image is produced on the monitor following scanning by laser. This is known as semi-direct imaging.

2.1) Semi-direct image plate systems

The image plate method involves the use of a phosphor storage plate (PSP). This plate stores energy after exposure to radiation and emits light when scanned by a laser. The scanner stimulates the phosphor plate and stores a record of the number of light photons detected.

Loading of the scanners generally only requires subdued lighting as the plates are slightly sensitive to visible light. However, some products are more light sensitive than others. The lasers used are centred around the 600-nm band and are usually of the helium-neon variety. Scanners, the size of a breadmaker, can accommodate multiple image plates at any one time. The exact numbers varies between manufacturers. There is a delay while the image is ‘developed’ before it appears on the monitor. Up to eight bitewing radiographs take about 90 seconds and a panoramic image can take approximately 3 minutes to be scanned. Again, the scan times do vary between manufacturers. Although the plate can store energy for a number of days, information starts to be lost within minutes after exposure and it is advised to scan the plates quite quickly to optimize the image recovered. To fully remove the latent image the plate should be exposed to high intensity light (as found on viewing boxes).

Image plates are available in exactly the same sizes as conventional film and come with disposable plastic barriers. They have no wires attached and are reusable for thousands of exposures, but do need careful handling to avoid surface damage. Current systems have a spatial resolution of 6–8 LP/mm.

2.2) Direct sensor systems.

The sensor for the radiation image is usually a Charge Coupled Device (CCD). It consists of silicon crystals arranged in a lattice and converts light energy into an electronic signal. This technology is widely used in video cameras. The sensor cannot store information and must be connected via fibre optic wires to the monitor, which can make the sensor bulky and awkward to use.

The greatest advantage of the direct sensor system is the gain in time. The image is directly projected onto the computer screen. Originally, the active areas of the sensors were smaller than conventional film, which increased the incidence of 'coning off' and required repeat exposures to capture all the desired information. Recent innovations have produced sensors approaching or equal to standard film sizes.

Extra-oral digital imaging

Extra-oral digital imaging is available using both systems. However, the larger CCD sensors are extremely expensive and usually requires the purchase of new X-ray generators, although a 'retro-fit' system has been developed in the USA. These constrictions effectively mean that the PSP method is the one most commonly used.

Panoramic radiography

The PSP method of panoramic digital imaging is very similar to conventional film. The film and intensifying screen are replaced by a storage phosphor plate. The plate is scanned after exposure, which can take up to 3 minutes or longer depending on the product used. The resolution of these systems is greater than 4 LP/mm.

Cephalometric radiography

Naslund et al. (12). investigated the effect of dose reduction obtained with PSP on the identification of cephalometric landmarks and concluded that dose reductions of up to 75 per cent did not effect the localization of cephalometric landmarks. It is also worth noting that 68 Current Products and Practice with CCD sensors the image is acquired over 15 seconds as the sensor and narrow X-ray beam move up the facial bones and could lead to an increase in the incidence of movement artifact.

Advantages of digital imaging over the conventional film

Dose reduction

Dose reductions of up to 90 per cent compared to E-speed film have been reported by some authors in the diagnosis of caries (95). Although some researchers do claim dose reductions compared with conventional extra-oral film, in practice the background noise rises to unacceptable levels. It is now accepted that there is no appreciable reduction compared with films used in conjunction with rare earth intensifying screens.

Image manipulation

This is perhaps the greatest advantage of digital imaging over conventional film. It involves selecting the information of greatest diagnostic value and suppressing the rest. Manufacturers provide software programmes with many different processing tools, however some are more useful than others and these include:

Contrast enhancement

This can effectively compensate for over or under exposure of the digital image. It has been shown that contrast enhancement of CCD devices were more accurate than E-speed film for detecting simulated caries under orthodontic bands (96).

Measurements

Digital callipers, rulers and protractors are some of the many tools available for image analysis. Many authors have reported on their application in cephalometric analysis (97, 98). The images can also be superimposed onto each other and onto digital photographs.

3-D reconstruction

This application can be theoretically used to reconstruct intra- and extra-oral images. The uses range from profiling root canals to visualizing facial fractures in all three dimensions.

Filtration

The addition of filters to the airspace around the face can clarify the soft tissue profile if the original soft tissue image was poor.

Time

Much time is gained especially with the CCD system where the image is displayed at the chairside immediately post exposure. Although a lag time between scanning and the appearance of an image exists with the PSP method it is still substantially faster than conventional developing processes in general use.

Storage

Storage was initially a problem before the development of DVDs and CD ROMs as three peri-apical images would fill a floppy disc. However, now a CD ROM can hold over 30,000 images. This means that images can be stored cheaply and indefinitely.

Teleradiology

The digital image file can be further reduced in size by compression techniques, and sent via a modem and telephone line to colleagues for review. This had the advantages of not losing radiographs in the post and saving time if an urgent appointment is required. The operator at the other end can also manipulate the image if desired.

Environmentally friendly

No processing chemicals are used or disposed of. Both CCD sensors and the PSP plates are capable of being reused for many thousands of exposures. They can, however, become scratched and damaged if not handled carefully.

Disadvantages of digital imaging

The majority of the disadvantages are associated with the CCD system

Cost

Currently, the cost of converting from intra-oral film to digital imaging is approximately 6600 Euros. This initial outlay should be offset against the time saved and the efficiency of storage of the images.

Sensor dimensions

These are still quite bulky for the CCD system and awkward to position due to trailing fibre optic wires. The original problem of small sensor active areas has been rectified and the same amount of information can be captured as conventional film.

Cross-infection control

Each intra-oral sensor and plate must be covered by a plastic bag, and this bag is changed between patients. However, if they become directly contaminated there is no way of sterilizing them and they should be discarded regardless of expense.

Medicolegal

Concerns have been raised in the past about the ability to manipulate the images for fraudulent purposes. Manufacturers of software programmes have installed ‘audit trails’, which can track down and recover the original image. Many insurance companies in the USA are accepting digital images as valid attachments when the claims are electronically claimed.

Digital radiograph for orthodontist

In the late 1980s, the first direct digital system for intraoral radiography was marketed for dentistry(99). This system used a personal computer (PC), which was relatively expensive at the time and had little storage space, and the PC's DOS-based operating system meant special hardware-dependent programming was needed to display the images. These obstacles were eventually overcome by the introduction of Microsoft Windows, an operating system that has loosened the tight relationship between monitor display and software. Today, intraoral systems for dental radiography are in fairly widespread use in the dental community (100).

However, the use of extraoral digital radiography in dental offices is limited, in part because the systems are quite expensive. In a recent survey of Norwegian dentists, 17% of 309 dentists who used digital radiography in their office used a digital technique for panoramic examination, and 6% used a digital technique to examine the face and skull (101).

On-screen digitizing

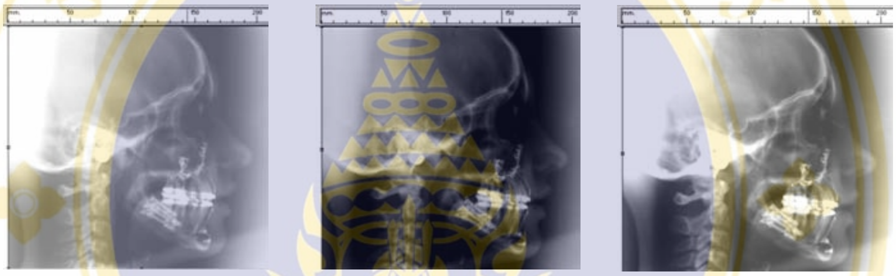
A number of software packages are available for on-screen digitization the images and the reliability of digital images has been investigated by a number of workers.

The advantages of digitizing on screen are:

1) There are not need to buy expansive (and sometimes bulky) digitizing tablets with associated hardware. On–screen digitizing is carried out directly on the computer screen using the mouse, and technology with the clinician should be familiar.
2) The brightness (Fig. 9), contrast (Fig. 10) and saturation (Fig. 11-14) can be altered on the radiograph, which can make identification of hard and soft tissue somewhat easier.
3) With some package (e.g. American Orthodontics, Compuceph, Nemoceph, Cephsmile) it is possible to review the placement of cephalometric points. If the cephalometric points have not been placed in a perfect position they can be move to the correct position and, at the same time, the analysis will be adjusted accordingly, Which can aid junior and ancillary staff in their cephalometric digitization. (Fig.15)

Decrease brightness Original Increase brightness

Fig. 9 Enhance image by adjust brightness



Decrease contrast Original Increase contrast

Fig.10 Enhance image by adjust contrast

Decrease gamma Original Increase gamma

Fig.11 Enhance image by adjust gamma

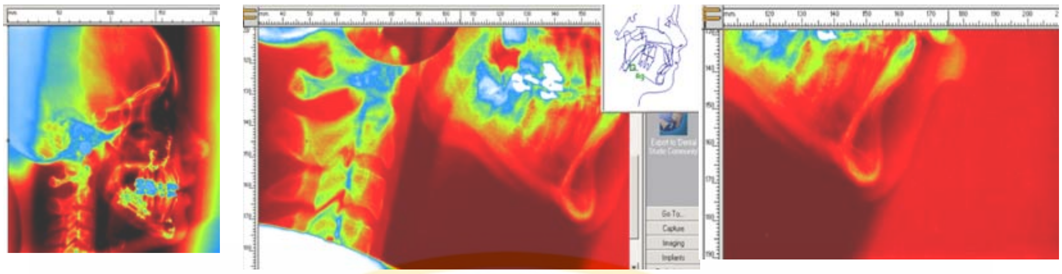


Fig.12 Enhance image by used false colour filter. Easier to see soft tissues and hard tissue

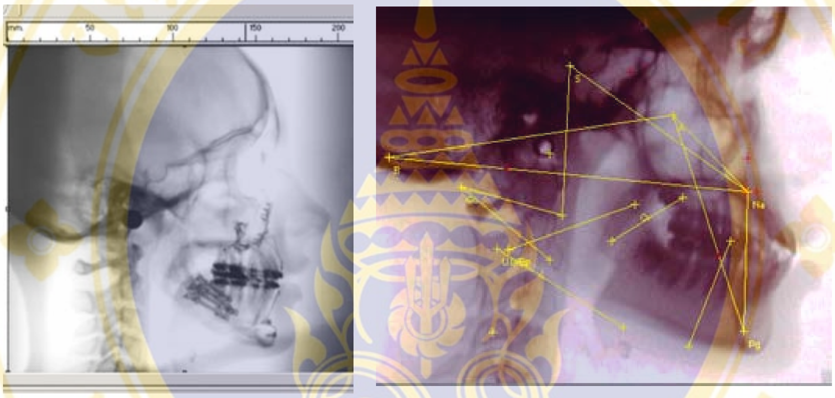


Fig.13 Enhance image by invert image filter

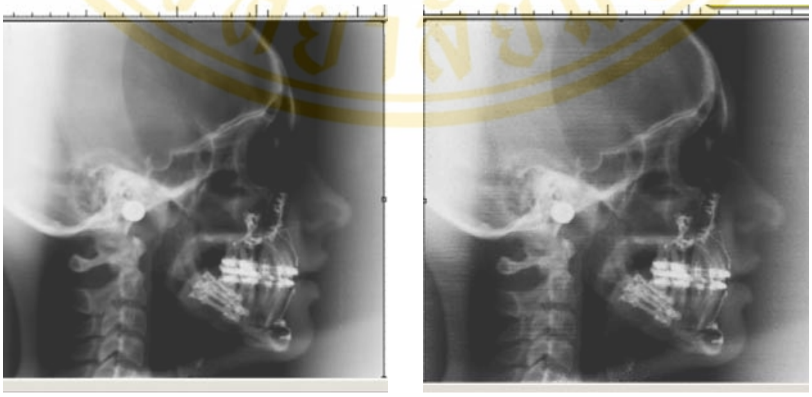


Fig.14 Enhance image by enhancement filter

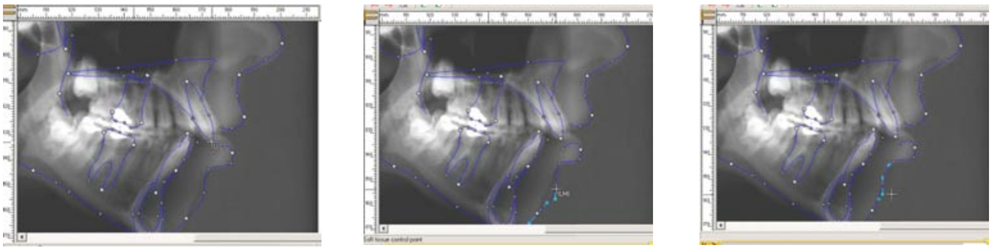


Fig.15 Review the placement of cephalometric points. If the cephalometric points have not been placed in a perfect position they can be moved to the correct.

4) Edge enlargement image and also permits enlargement without loss of image quality to improve landmark clarity and location (Fig.16.)

Fig.16 Edge enlargement image

5) Automatically outline the contour lines of the soft tissue & hard tissue. (Fig.17)

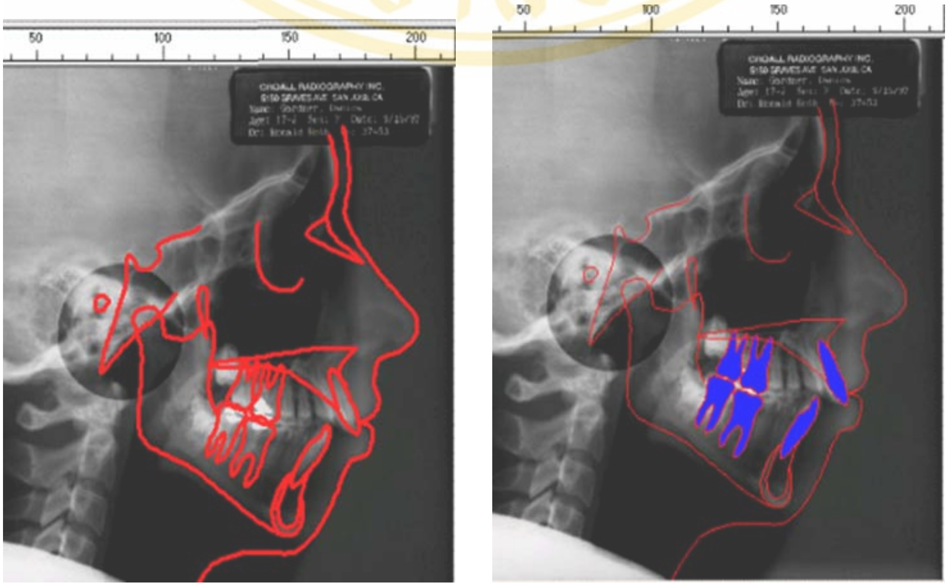
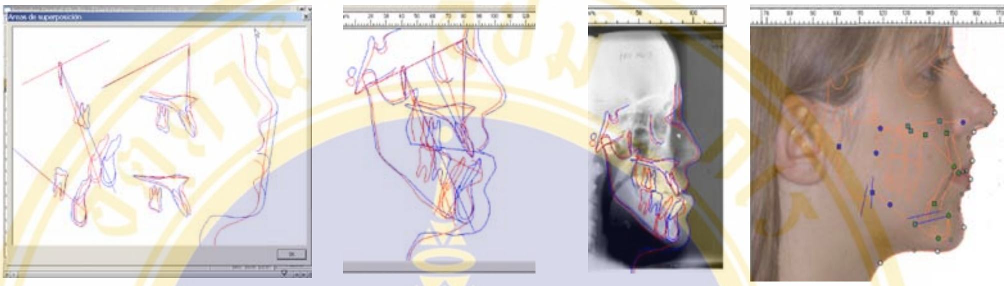


Fig.17 Automatically outline the contour lines of the soft tissue & hard tissue

6) Automatically recognizing measuring & analysis the landmark of hard tissue and soft tissue.
7) Superimposition area (Fig.18a), superimposition tracing (Fig.18b), superimposition a cephalometric tracing over patient image or patient photo or cephalometric radiograph. (Fig. 18c)



(a) **(b)** **(c)**

Fig. 18 Superimposition

8.) VTO, Orthodontic Treatment Simulation and Orthognathic surgery treatment. Possibility of viewing as many treatment plans as one wish
9) Has great benefits as the patient is able to see his/her photos/image radiograph , which makes explaining and understanding treatment much easier. This may increase the patient's acceptance of treatment as understanding is enhanced.
10) Normal values (means &standard deviation) pertaining to the patient's age & sex are readily available for comparision to the general population.
11) Significant faster than manually, thus enabling the orthodontist to assess a large number of cephalometric variables and obtain a more comprehensive diagnostic picture/image.
12) Computer measurement linear & angular & analysis by statistic program , thus simplifying research projects)
13) Computerized cephalometric analysis can potentially increase the accuracy of result . Errors of cephalometric analysis can be attributed to errors related to the point identifacation and error inherent to the measuring procedure and equipment.
14) Reduction patient dose.
15) Favourable cost if incorporated as part as a large radiography department.

Radiographic units

For orthodontists, there are several matters to consider if all extraoral radiography is to be recorded digitally. For CCD-based digital radiography, panoramic units and combination units (in which both panoramic images and cephalograms can be recorded) are available (Table.7). Cross-sectional tomography, which is sometimes suseful in the management of orthodontic patients (102) cannot be performed with the CCD-based digital units. Some companies offer to rebuild a conventional panoramic unit to work with a CCD sensor (103). If this is one, film can no longer be used in the system because the CCD receptor works in a very different manner than the film. Only the DigiPan (Trophy Radiology, Marnela allee, France) unit allows the CCD-based receptor to be exchanged with a conventional film cassette system. The SP imaging plate systems can, in principle, work with any available conventional radiographic equipment because the plates are installed in the same cassette type as film.

Table 7: Digital extraoral radiograph system for dentistry

	Make	Make Type	Company	Address	Web site
1	Denoptix Ceph	SP combi	Gendex Dental Systems	Via Capelli 12 20126 Milano, Italy	www.gendex-dental.com
2	Combi-X	SP combi	Orex	P. O. Box 505, Yokneam 20692, Israel	www.digident.co.il
3	Digora PCT	SP combi	Soredex	Nilsi.nkatu 10-14 P. O. Box 250, 00031 Helsinki, Finland	www.soredex.com
4	OC100 D	CCD combi	Instrumentarium Imaging	Nahkelantie 160 P. O. Box 20 04301 Tuu Finland	www.instrumentarium.imaging
5	Dimax2	CCD combi	lanmeca	Asentajankatu 6 00810 Helsinki, Finland	www.planmeca.com
6	CDRPan	CCD pan	Schick Technologies Inc	31-00 47th Ave Long Island City, NY 11101	www.schicktech.com
7	Orthophos DS Ceph	CCD combi	Sirona Dental Systems GmbH	Fabrikstrasse 31 D-64625 Bensheim, Germany	www.sironadental.com
8	DigiPan	CCD pan	Trophy Radiology S.A.	4, rue F. Pelloutier Croissy-Beaubourg 77437 Marne-la-Vall.e, Cedex 2, France	www.trophy-imaging.
9	DXIS	CCD pan	Signet Radiology	115 Bis, Boulevard du General Giraud, 94100 Saint Maur des Fosses, France	www.dxis-net.com

Image recording and display

When using a digital CCD unit, patients are positioned in the same way they would be in a conventional unit of the same make. After exposure, the image is displayed on the connected PC monitor within 1 or 2 minutes.

The only difference between SP and film radiography is that the SP plate replaces the film and the intensifying screen in the cassette. After exposure, the plate is read into a scanner. The scanner can be anywhere in the clinic, but the plates are somewhat sensitive to room light (light erases the information) and highly sensitive to infrared light. For the Digora system (Soredex, Helsinki, Finland), the plate is tipped into a slot in the rather large scanner, but it is protected by a black plastic envelope until it is safe in the scanner. This takes only a second, so exposure to light is not a problem. The Denoptix (Gendex Dental Systems, Milan, Italy) and the Combi-X (Digident Ltd, Nesher, Israel) systems operate with smaller scanners and therefore take up less space, but the operator must mount the plate in the drumlike scanner. This takes extra time, a critical issue because of the plate’s sensitivity to light. In practice, this means that the light must be dimmed or turned off in the room during this part of the process. Another time-consuming factor for the Denoptix scanner is that the plate is not erased by light after the scanning procedure, as it is for the other 2 SP units; instead, the plate must be transferred to a conventional light box and left in strong light for some minutes before it can be used again. Beyond the inconvenience of an extra working operation, more plates are needed if several images are to be recorded at 1 sitting.

For some systems, there is a limit to the size of the plates compared with the film; the largest possible image size with Denoptix and Digident is 18X 24 cm, while the Digora scanner allows for 24 X 30 cm images (a widely accepted size for lateral cephalometric radiographs in Scandinavia). Moreover, there are differences in scan time between systems and also in how much sound the scanner makes. The Digora system offers the fastest scan time and the most quiete scanner.

CCD receptors are more sensitive to x-rays, so the exposure can be lower than with film (103, 104). Although the maker of 1 medical phosphor plate system has recommended reducing the exposure when the system is used for cephalometric analysis (12, 105) the manufacturers of most SP systems today recommend using the same dose as with film.

Image enhancement

There is potential for improving the diagnostic quality of digital images by enhancing the image of digital image by enhancing the images using various algorithms. Digital images can be enhanced using algorithms the mathematically manipulate the gray-level values of the pixels.

Using enhancement algorithms it may be possible to extract information from radiographs the previously required further additional radiographic exposure to the patients (106). However, image enhancement is actually the suppression of information that the operator deems unnecessary for a particular task, rather than the addition of further information (107).

Images that are of poor quality due to factors such as incorrect exposure or blurring could, in theory, be manipulated and reformatted thereby avoiding further exposure. So it may possible to use a faster film/screen combination, reducing radiation exposure to the patient, then enhance the images without compromising diagnostic quality (39).

Image enhancement can be divided into three main areas: contrast improvement, smoothing, and edge enhancement. Figures 19 and 20 show examples of enhancement algorithms applied to cephalometric radiographs.

Two studies have been carried out to look at the effect of images enhancement techniques applied of image enhancement techniques applied to cephalometry. The first used digital images consisting of 512 x 426 pixels with 256 gray levels (57) Several enhancement techniques were available to the operators and were subjectively selected to aid landmark identification. Analyses of the enhanced digital images were compared with manual tracings of the conventional radiographs. The random error of angular measurements with the enhanced digital images was generally greater than that obtained with manual tracings. Greater spatial resolution and an increase number of gray levels were suggested to improve image quality.

In a separate pilot study (54) that compared manual tracings with corresponding digital images and enhanced digital images, it was found that the most accurate results were obtained from the digital image without enhancement. Whether enhancement techniques improve the diagnostic quality of the digital images seems to depend on the type of radiograph to which they are applied and the method of enhancement used.

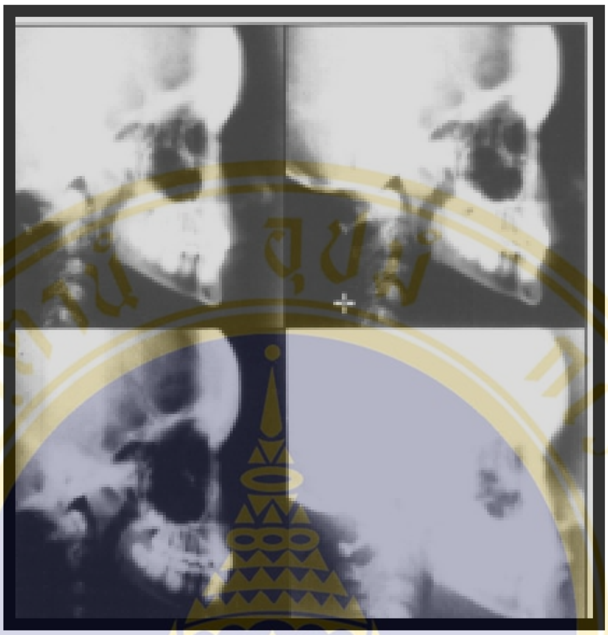


Fig. 19 Contrast Improvement

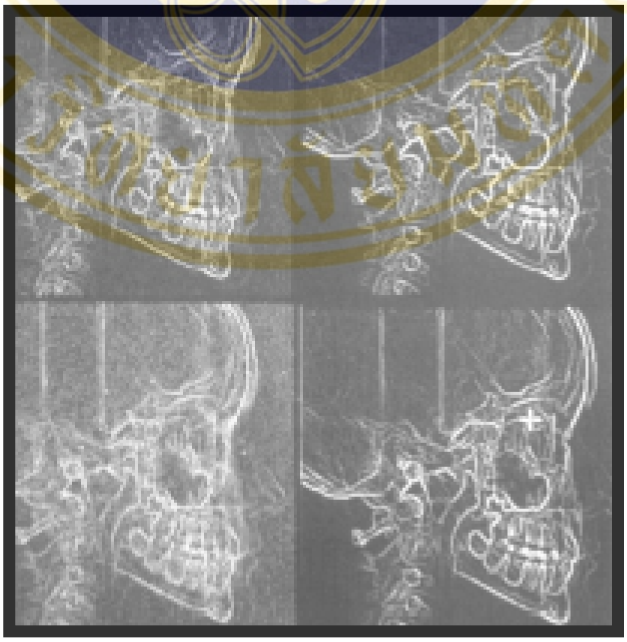


Fig. 20 Edge enlargement

Image resolution

The spatial image resolution varies among the digital systems. The CCD-based digital equipment provides higher spatial resolutions than do the phosphor plates, and this should lead to higher detail conspicuity. However, there is no consensus on the degree of resolution needed for panoramic and cephalometric radiography. One study showed no significant difference in reproducibility of landmark identification between original high-resolution images taken with the CCD-based Orthophos Ceph (Sirona Dental Systems GmbH, Bensheim, Germany) system and the same images in lower resolutions (108). However, the influence on lines and angles used in profile cephalometric analyses was not investigated in this study, which concentrated only on landmark identification. It may be premature to claim that the image resolution of Orthophos Ceph images is unnecessarily high for cephalometric purposes. Imagequality scores and time used for recording the landmarks were almost identical, irrespective of image resolution.

Image quality

Among the SP systems, the Combi-X images have been shown to possess a subjectively lower contrast than the Denoptix and Digora images (109, 110). In a recent study on quality in panoramic images obtained with 5 different digital systems, the investigator (a surgeon who determined whether the quality of the images was adequate to be used for treatment planning before wisdom- tooth removal) reported that 0% of Orthophos, 4% of Digora, 8% of Planmeca, 12% of Combi-X, and 14% of Denoptix images had to be rejected because of graininess or low contrast that could not be enhanced (110). The diagnostic details oral surgeons require, eg, to view the relationship between the roots of the third molar and the mandibular canal, may not be the same as orthodontist need, so the results from the above studies cannot be directly transferred to the orthodontic arena.

Image data compression

Data compression, either lossless or lossy, has been advocated to reduce space demands. Even if lossy compressions do not affect immediate diagnostic accuracy, it may impede the use of the image in programs forfuture automated computer interpretation. Decision support systems are being developed for dentistry (111), and destructive image compression may impair their use. Although compression may no longer be a major issue for image storage, huge files still are a bottleneck in external communication. Without compression, transmission times may be untenable. The effect of various compression techniques depends on the type of image, and more research is needed to determine the limits. In panoramic radiographs, a joint photographic expert's group (JPEG) irreversible compression rate of 1:28 was found to be acceptable without restraining diagnostic performance or image quality (112). In a study of cephalometric landmark recording, reproducibility tended to decrease somewhat more because of high JPEG compression than the lower spatial resolution of lateral skull radiographs, but a compression to 8% of the original storage space was acceptable (108). Irreversible compression, such as with JPEG, should never be the standard for image storage, as it is in some CCD-based extraoral systems; the image destruction with these algorithms can be quite severe (113).

CHAPTER 4
MATERIALS AND METHODS

Materials

This study was conducted at the Department of Orthodontics, Faculty of Dentistry, Mahidol University, Thailand.

Forty lateral skull (19 males and 21 females) radiographs were selected consecutively from the records of patients who had attended for orthodontic assessment at Orthodontic clinic, Mahidol University, Thailand. All the X-rays were taken on 3 X-ray machines (PLANMECA, TROPHY, ASAHI, 68-70 Kvp, 12 mA.) using 8x10 inch Kodak T-MAT G/RA film and a Kodak Lanex Regular rare earth intensifying screen. The X-rays were considered of good quality rather than exceptional quality and as such represented typical lateral cephalometric skull X-rays. The x-ray machines that produced the cephalometric radiographs were set according to the followings: Distance from the x-ray focus tube to the film was 60 inches (5 feet) and distance from mid sagittal plane of head to the film was 15 cm. Each subject's head was fixed in the upright position with the cephalostat during x-ray exposure.

Inclusion criteria were as follows:

1. The sample ages range from 13 to 20 years.
2. The film had good quality to permit identification of the landmarks.
3. There were no unerupted or partially erupted teeth that would have hindered landmark identification.

The other materials included:

1. Acetate tracing paper (3M Unitek® Corporation, Monrovia, USA), size 8x10 inch and paper thickness 0.003 inch.
2. View box (Fig. 21)
3. Masking paper (114).

4. 12” LCD Flat screen monitor (SONY PCG-V50SP) (Fig. 22)
5. Computerized cephalometric program (Ceph Smile Plus version 2.0.1, NECTECH & MU, Thailand) (Fig. 23)
6. Scanner with transparency adapter 8’’x 10’’ (Epson 1680pro, Epson America, USA) (Fig. 24)
7. Stand for holding cameras (KAISER RA3, Germany) (Fig.25)
8. Graph paper sized 21 X 34 cm.(Fig.26)
9. Shape 6H pencil, 0.3 mm
10. Cephalometric protractor estimated to the nearest 0.5 degree (3M Unitek® Corporation, Monrovia, USA)
11. Vernier calipers (Mitutoyo, Mitutoyo Digital, Japan) (Fig. 27).
12. Three cameras which are
    1 Canon EOS300D (SLR) (Canon Kiss Digital Tokyo, Japan) (Fig. 28).
    2 Nikon coolpix S5 (Digital compact camera) (Nikon, Japan) (Fig.29).
    3 Panasonic Lumix DMC-Fx01 (Digital compact camera) (Panasonic Lumix®, Japan) (Fig.30).

Methods

For each method, the radiographs were recorded twice with a 1-month interval between each recording (26). To avoid operator fatigue no more than 10 radiographs were digitized at any one time.

Pilot Study

The purpose of this study was to examine which camera to object distance would yied the best digital images (without distortion; Fig.31). Images were taken of the same graph paper at 10 distances from the subject and at various F stop for each digital camera. The best image for each camera was determined subjectively by the investigator. (Table 8)

Procedure

Three digital cameras (1 SLR camera, Canon EOS300D; 2 digital compact cameras, Nikon coolpix S5 and Panasonic Lumix DMC-Fx 01), were used in this study. All cameras were used to take a photo of the graph paper sized 8 x 10 inch with the mark (X) in the middle of the focus area (Fig.32), at 10 distances (Fig. 33, Table 8) inorder to find out which distance would provide the best image which there was no distortion.

Thesis Study

Using the results from the pilot study, three cameras were set up as shown in Table 9. Before taking photo of the film, the view box was resized to 8x10 inch by covering the unused surrounding area with paper and a red dot was marked at the center of view box area (Fig.34). When the film was photoed, red dot was appeared at center of the film (Fig.35).

To avoid image distortion, the camera was set so that the surface of lens was paralled to the surface of the film and lens was perpendicular to the film surface.

Each digital camera had normal JPEG compression algorithms. The SLR Canon EOS 300D (Canon Kiss Digital, Japan) had maximum resolution of 3072 x 2048 setting. The Nikon coolpix S5 (Nikon, Tokyo, Japan) had maximum resolution of 2816 x 2112 setting and Panasonic Lumix DMC-Fx 01 had maximum resolution of 2816 x 2112 setting which the aspect ratio setting was 4:3. Digital pictures were taken with an auto adjustment mode.

Forty cephalometric images were obtained from 40 selected cephalograms for each type of camera and a scanner. All digital photos were taken by using a stand for camera holding (Fig.37) at a predetermined distance (65 cm). The digital images were carried out in a darkened room using an illuminated viewing screen with a black surround to reduce extraneous light. Each X-ray was firmly secured to the surface of a viewing box. The digital images were then imported into Ceph Smile Plus version 2.0.1 via a PC card reader. Forty cephalograms were also scanned on an Epson 1680pro scanner at 600 dpi and a size of 8 cm X 10 cm. and saved as a JPEG file. Radiographic images were subsequently opened using a Cephalometric analysis program (Ceph Smile Plus version 2.0.1) and digitized on a 12-inch LCD flat screen colour monitor at a screen resolution of 1074 x 728 pixels. The digitizing window is approximately 10 inches wide and 8 inches high on a 12-inch monitor. Each image was digitized according to the program instruction which used 79 landmark points (Fig.37).

Testing of systematic error arising from digital camera and scanner (Fig.38)

One cephalometric radiograph was traced on a 0.003 inch acetate paper with a 0.3 mm black pencil. A clear smooth light viewing box in dim environment was used. A black surround was placed on the radiograph to cut down background illumination (mask film) to facilitate landmark identification. Seventy-nine landmark points (Fig.38) were located by a single fine pencil dot. Once landmark points were completed, the cephalometric radiograph was punched with a pin corresponding to the 79 landmark points.

Then, the punched cephalomeric radiograph was scanned by a scanner (Epson 1680pro) and photoed by three cameras. (One SLR camera; Canon EOS300D, two digital compact cameras; Nikon coolpix S5 and Panasonic Lumix DMC-Fx 01).

For each method, the radiograph was recorded 10 times into a 1.80 GHz-M Mobile Intel Pentium 4 Processor with the use of Windows XP Professional, a 12-inch LCD monitor. Manual measurements were also done 10 times and were set as a gold standard for testing the systematic error arising from digital cameras and scanner.

A comparison of analogue and digital methods (Fig. 39)

Method 1: Analogue measurement (Manual tracing)

Forty cephalometric radiographs were traced and landmark identification was performed on a light box in a dark room by using 0.003-inch matte acetate paper (3M Unitek® Corporation, Monrovia, USA) and the same mechanical pencil with 0.3 mm sharp 6H graphite. Vernier calipers and protractor (3M Unitek®) were used for measuring 34 variables comprising 14 linear measurements and 19 angular measurements (Table 11, Mahidol analysis). Forty cephalometric radiographs were traced and measured manually by one observer.

Twenty radiographs were selected from the sample for re-tracing and re-measurement a minimum of 2 days after the first tracing, their landmarks were identified, and the whole measurement process was repeated.

Method 2: On screen digitization and measurements of digital images captured by scanner and 3 digital cameras.

The cephalometric radiographs used for analogue measurement were converted to digital pictures with scanner and with 3 digital cameras. The average screen resolution was increased to 1600 X 1200 (117 DPI) and an enlargement factor between 2 and 5 was used on screen. For this method the digital pictures previously saved at 600 DPI were used.

For both digital methods the cephalometric analysis was undertaken with Ceph Smile Plus version 2.0.1 (Thailand). The observer was allowed to use various enhancing functions such as changing magnification, brightness, and contrast. Each landmark point was identified by an arrow pointer. After completing the digitizing of a set of landmarks, the program automatically measured the variables.

Twenty radiographic images of each method (scanner and 3 digital cameras), were selected from the sample for re-digitizing a minimum of 2 days after the first digitized, their landmarks were identified, and the whole measurement process was repeated.

Null Hypothesis

The null hypothesis assumed there was no statistically significant differences in cephalometric measurements between 5 methods of cephalometric measurements (manual tracing, scanner and three digital cameras (SLR Cannon EOS300D, Nikon coolpixS5, Panasonic Lumix DMC-Fx 01).

Statistical Analysis

All statistical analyses were performed with the SPSS version 14 (SPSS Science, Chicago, USA). Means and standard deviations in each measurement were calculated.

Systematic error (Validity of instrument) arising from 3 digital camera and scanner was tested by using ANOVA, if the groups were found to be conformed to a normal distribution. But if they were not found to be conformed to a normal distribution, Kruskal-Wallis test would be used.

Statistical comparisons between the five modalities were performed using a two-way analysis of variance (ANOVA) for each cephalometric analysis.

The statistical analysis followed the strategy described below and was applied to evaluate variables at a single point of time (T1 and T2, n = 40). This statistical approach took into account the following criteria:

1. Systematic differences between the two measurement methods were evaluated using the paired t-test.
2. Method error was calculated using Dahlberg’s formula.

$$S(i) = \sqrt{\frac{\sum d^2}{2n}}$$

(d=the difference between the T1 and T2 measurement and the known measures, n=the number of comparisons). The results showed that casual errors of method should not exceed 1° or 1 mm.

Pearson's Correlation Coefficient, representing the quality of the measurements (variables) in its context, correlation between two variables reflected the degree to which the variables were related. The most common measure of correlation is the Pearson Product Moment Correlation (called Pearson's correlation for short). When measured in a population the Pearson Product Moment correlation is designated by the Greek letter rho (ρ). When computed in a sample, it is designated by the letter "r" and is sometimes called "Pearson's r." Pearson's correlation reflects the degree of linear relationship between two variables. It ranges from +1 to -1.

Correlation of +1 means that there is a perfect positive linear relationship between variables

Correlation of -1 means that there is a perfect negative (inverse) linear relationship between variables

Correlation of 0 means there is no linear relationship (no correlation) between the two variables.

Correlations are rarely if ever 0, 1, or -1

The formula for Pearson's correlation takes on many forms. A commonly used formula is shown below.

$$r = \frac{\sum XY - \frac{\sum X \sum Y}{N}}{\sqrt{\left(\sum X^2 - \frac{(\sum X)^2}{N}\right)\left(\sum Y^2 - \frac{(\sum Y)^2}{N}\right)}}$$

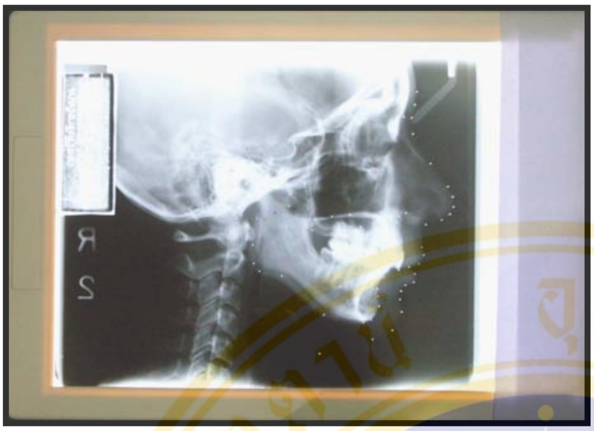
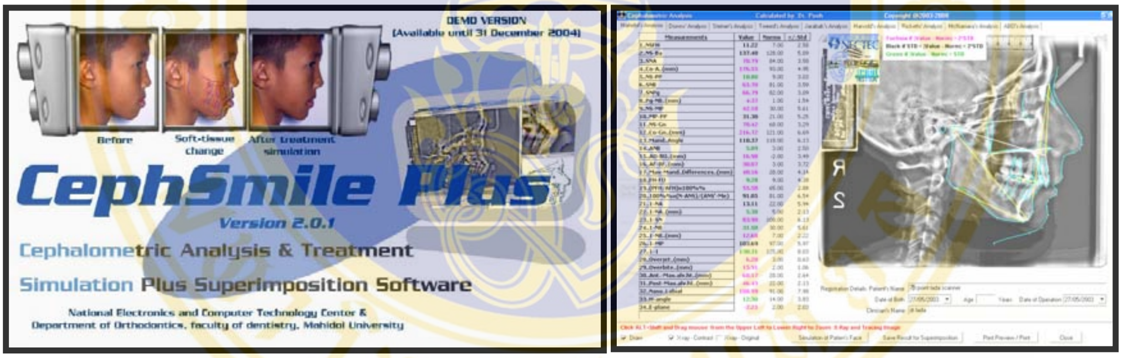


Fig. 21 View box

Fig. 22 12” LCD Flat screen monitor (SONY PCG-V50SP)



DEMO VERSION
(Available until 31 December 2004)

CephSmile Plus
Version 2.0.1
Cephalometric Analysis & Treatment
Simulation Plus Superimposition Software

National Electronics and Computer Technology Center &
Department of Orthodontics, faculty of dentistry, Mahidol University

Fig. 23 Computerized cephalometric program (Ceph Smile Plus version 2.0.1)

Fig. 24 Scanner Epson 1680pro

Fig. 25 Stand for camera holding (KAISER RA3, Germany)

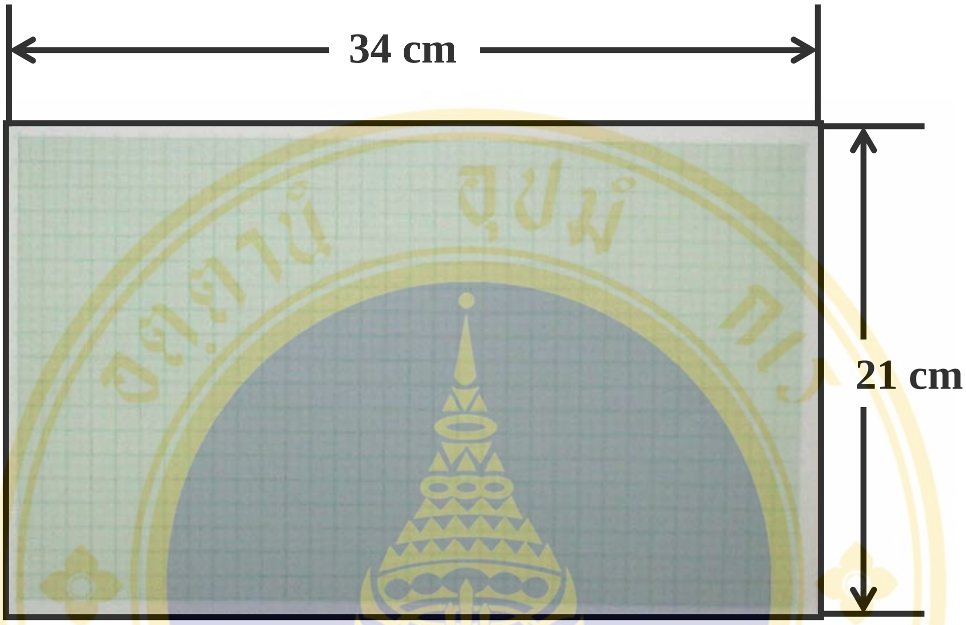


Fig. 26 Graph paper (size 21 x 34 cm)

Fig. 27 Vernier calipers

Fig. 28 Canon EOS300D (SLR)

Fig. 29 Nikon coolpix S5 (Compact digital camera)

Fig. 30 Panasonic Lumix DMC-Fx01 (Compact digital camera)

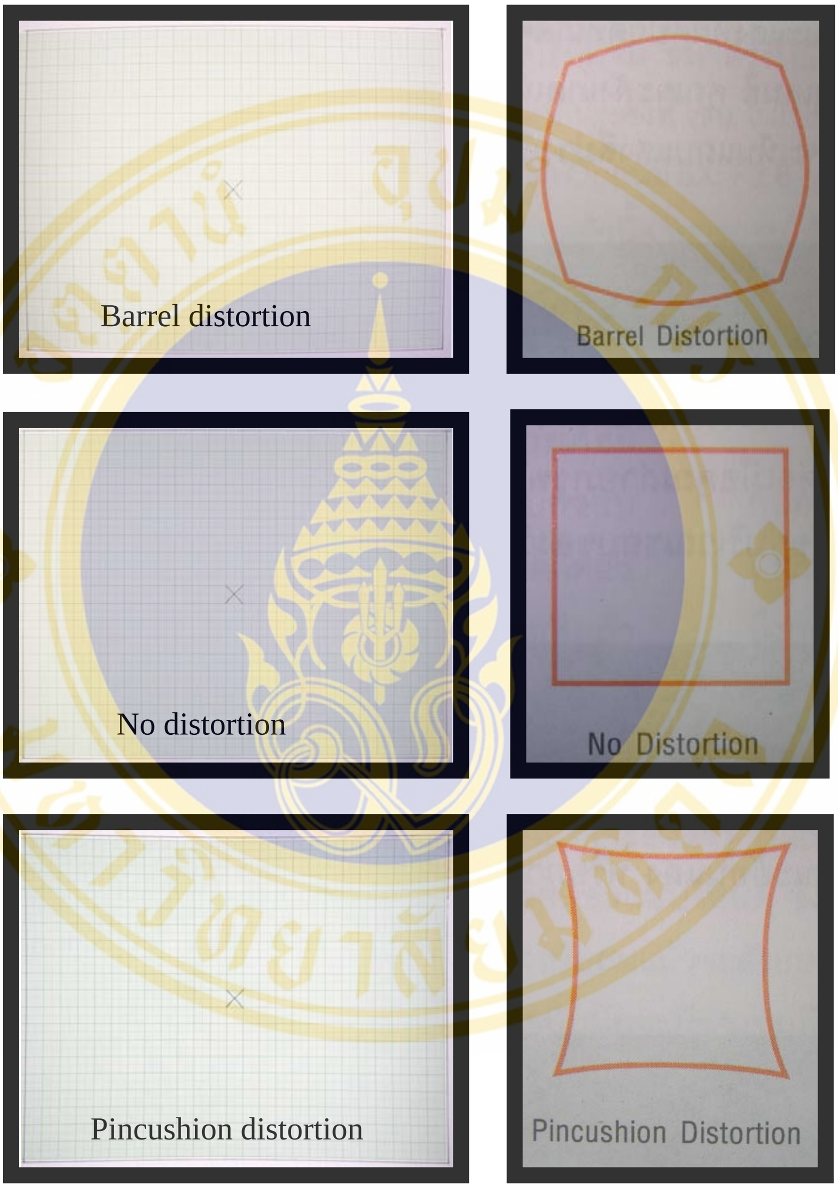


Fig. 31 Show distortion effect arising from digital camera

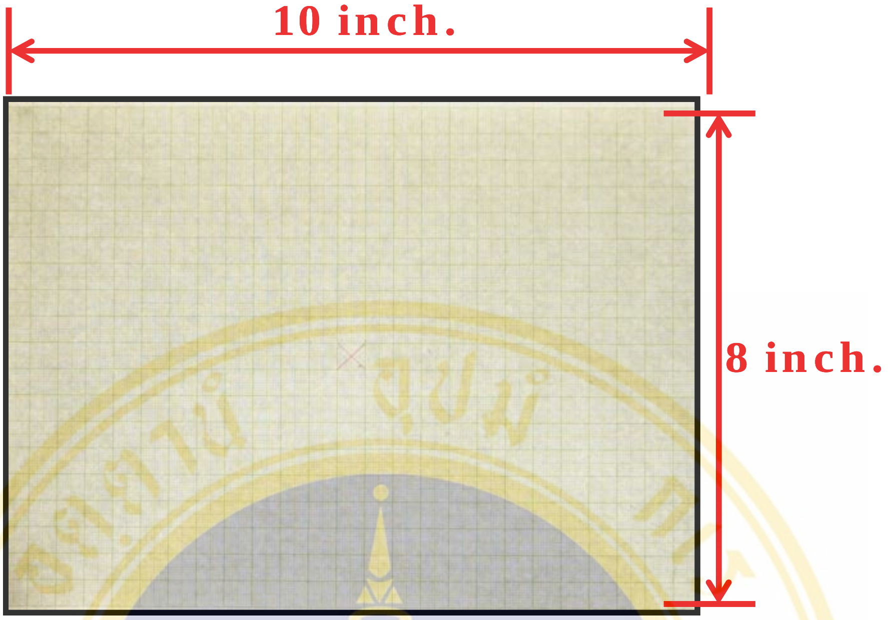
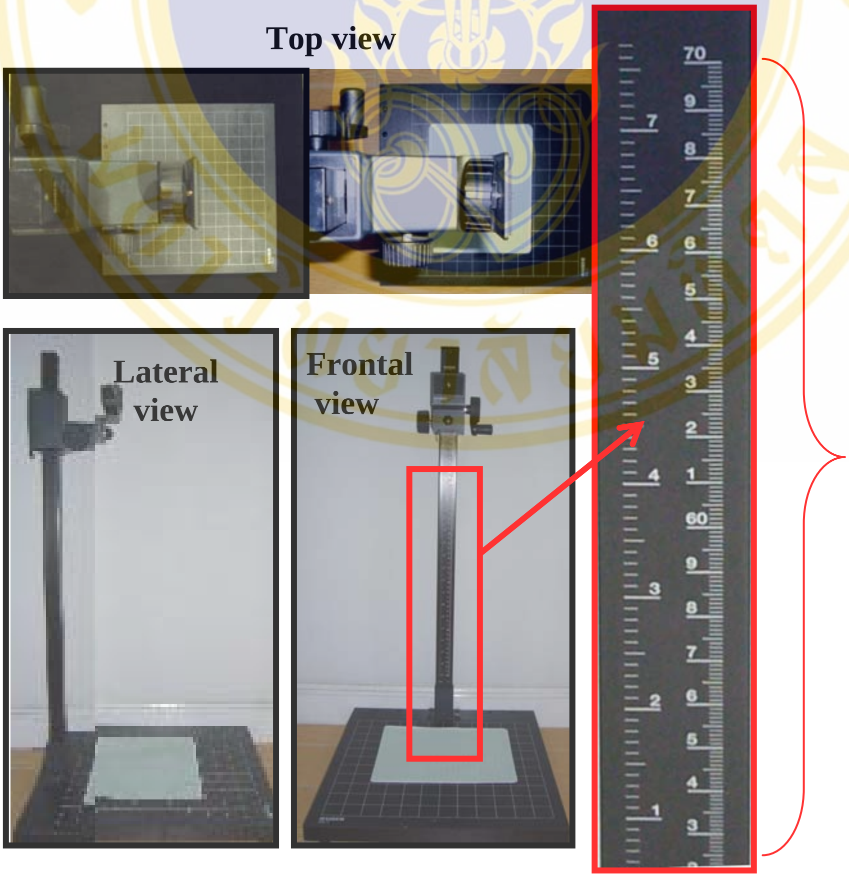


Fig. 32 Graph paper size 8X10 inch with the mark (X) at the center



1. 70 cm
2. 65 cm
3. 60 cm
4. 55 cm
5. 50 cm
6. 45 cm
7. 40 cm
8. 35 cm
9. 30 cm
10. 25 cm

Fig. 33 Ten distances were used to calibrate the best image.

Table 8: Pilot study; Show various camera to object distances. The best image (no distortion) for each camera was determined subjectively by the investigator.

	Model / Distance cm.	SLR Canon EOS 300D	Nikon coolpix S5	Panasonic Lumix DMC-Fx01.
1	70	Pincushion distortion	Pincushion distortion	Pincushion distortion
2	65	No distortion	No distortion	No distortion
3	60	No distortion	No distortion	No distortion
4	55	No distortion	No distortion	No distortion
5	50	Barrel distortion	Barrel distortion	Barrel distortion
6	45	Barrel distortion	Barrel distortion	Barrel distortion
7	40	Barrel distortion	Barrel distortion	Barrel distortion
8	35	Barrel distortion	Barrel distortion	Barrel distortion
9	30	Out of focus	Out of focus	Out of focus
10	25	Out of focus	Out of focus	Out of focus

Table 9: Camera's specification and setting for cephalometric photography

Model	SLR Canon EOS 300D	Nikon coolpix S5	Panasonic Lumix DMC-Fx01
Price(Bath)	36,900(Oct 06)	9,500(Oct 06)	11,900(Oct 06)
Effective pixel	6.3M	6.0M	6.0M
LCD Size	1.8" 118,000 pixels	2.5" 230,000pixels	2.5" 207,000pixels
CCD Size	1/1.8 "	1 / 2.5 "	1 / 2.5 "
ISO setting	100	100	100
Picture size (pixels)	3072x2048	2816x2112	2816x2112
White Balance	Auto	Auto	Auto
Colour saturation	Normal	Normal	Normal
Sensor	6.00Megapixel CMOS	6.00 Megapixel CCD	6.00 Megapixel CCD
Digital zoom	7 autofocus points	3X / 4X	3.6X / 4X
Lens	Interchangeable (EF-S, EF) EF, EF-S 18 - 55 mm F3.5-F5.6 (provided as part of the EOS 300D Kit)	35-105mm. f / 3.0-5.4	28-102mm. f / 2.8-5.6 optical zoom leica 3.6 x 4.6-16.8 mm
Macro	-	4 cm	5 cm
Sized & Weight (Include bat.)	127x94x64mm / 540 g	93x59x20mm /165 g	94x51x24mm/ 155 g
Focus system	TTL	n/a	TTL
Anti-shake	-	-	Anti-shake
Focusing mode	Auto	Auto	Auto
F-number	4.0	4.8	4.1
Focal length (mm)	46.0	14.3	10.3
Exposure time	Auto	Auto	Auto
Camera to objective distance	65 cm	65 cm	65 cm

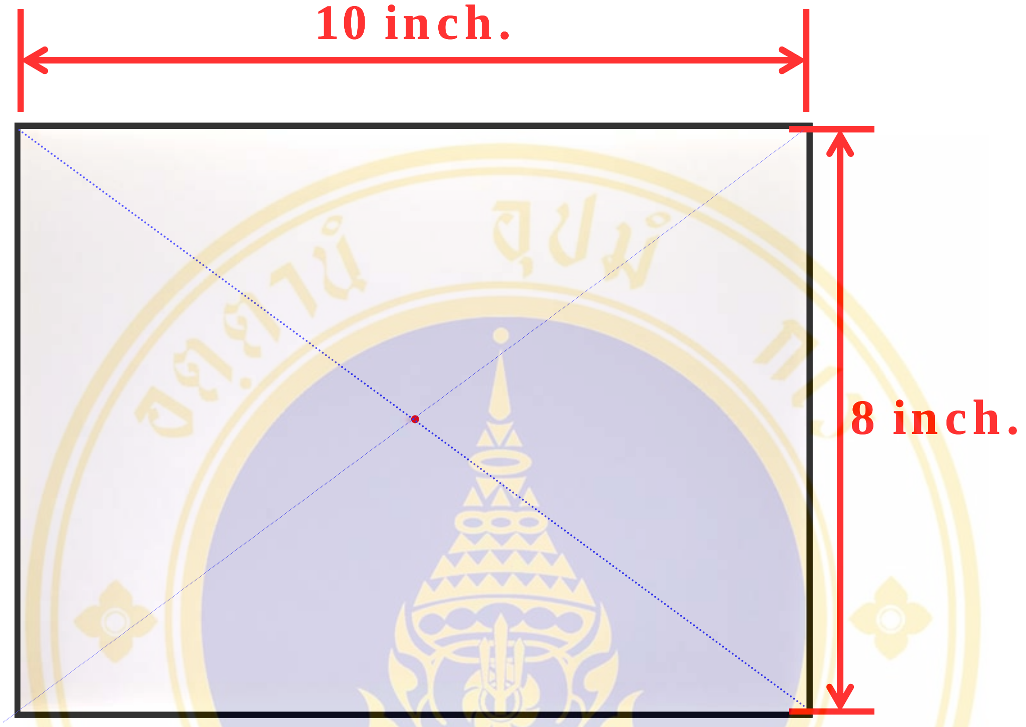


Fig.34 Show the view box was resized to 8x10 inch by covering the unused surrounding area with paper. A red dot was marked at the center.

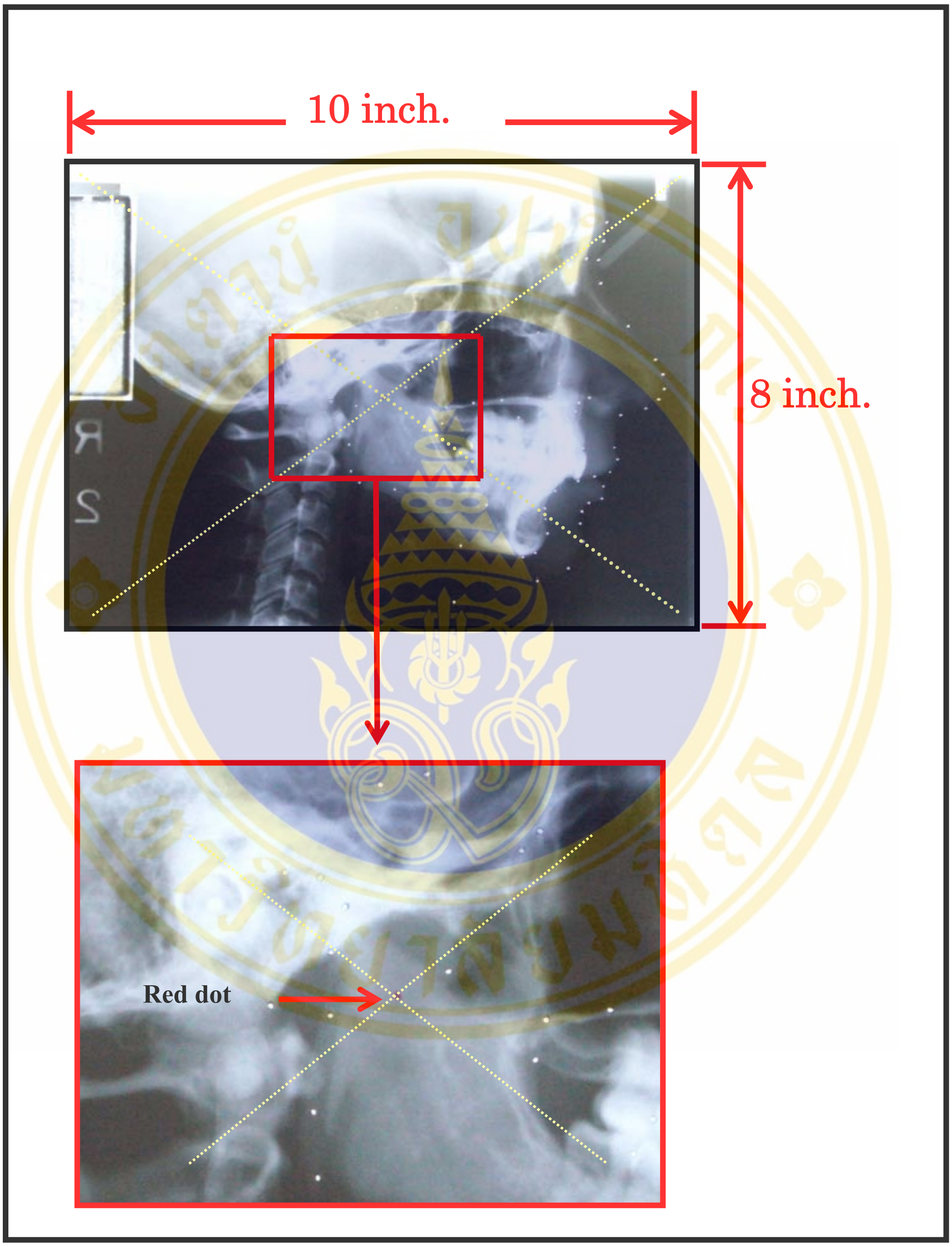


Fig.35 Red dot can be seen at the center of the film

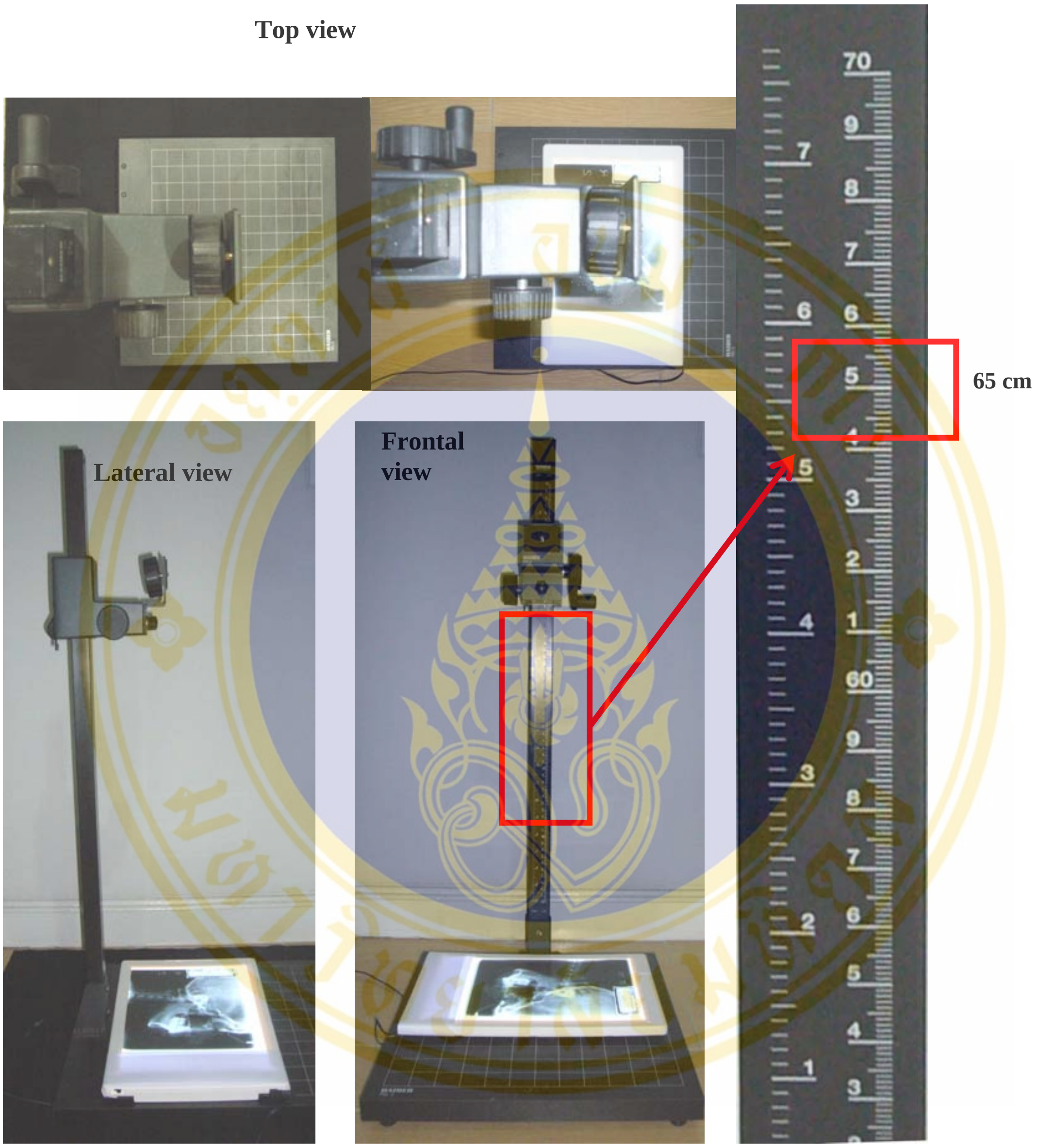


Fig.36 All digital photos were taken by using a stand for camera holding at camera to objective distance of 65 cm

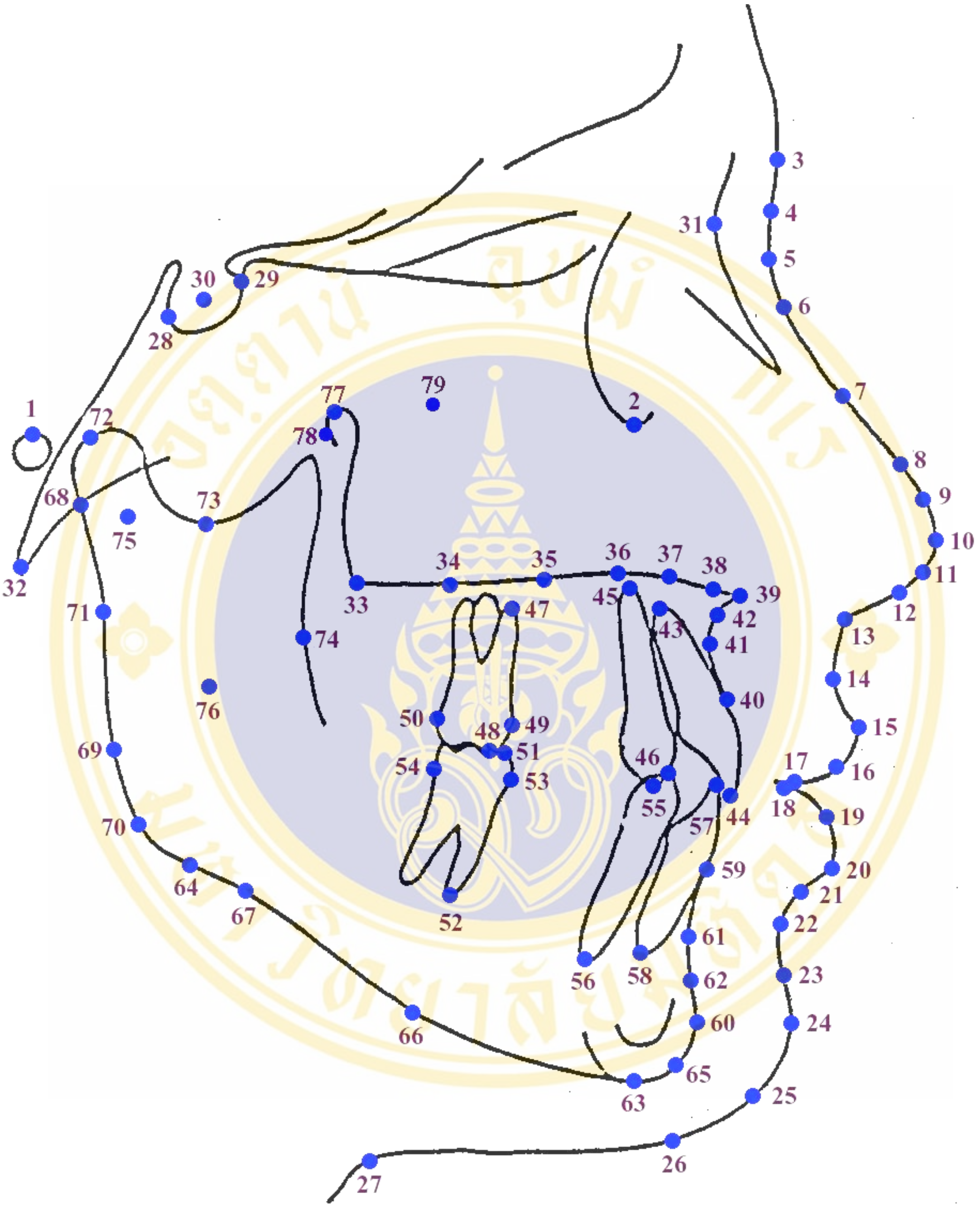


Fig.37 79 Landmark points

Reference Points, Planes, Lines and Measurements

Reference Point Used in Study (Fig.37)

1) Po=The most superior point of the bony external auditory meatus
2) Or =The most inferior point on the infra-orbital margin(Mid-planed)
3) G=Glabella=forehead, The most anterior point on the forehead, in the region of the supra-orbital ridges
4) Middle distance between point G and soft tissue Nasion (Na’).
5) Na’=Soft tissue Nasion =The deepest point in the soft tissue concavity overlying the naso-frontal suture
6) A landmark located at the junction of the inferior limit of the concavity of soft tissue Nasion and dorsum of the nose
7) Nasaldorsum=A landmark located approximately halfway from Nasion to Pronasale
8) A landmark located at the junction of the dorsum and tip of the nose
9) Superior Nasal Tip =A superior point on the nasal tip
10) Pronasale=The most anterior point on the nasal tip
11) Inferior nasal tip=An inferior point on the nasal tip, as the tip becomes confluent with the columella
12) Columella =A landmark on the inferior surface of the nose, representing the anterior delineate of the naso-labial angle
13) Subnasale =The junction of the columella of the nose with the philtrum of the upper lip
14) Superior labial sulcus =The deepest point in the concavity of the upper lip, midway between Subnasale and Labrale Superius
15) Labrale Superius =The muco-cutaneous junction of the upper lip and philtrum
16) A landmark on the upper lip located midway between Labrale Superius and Stomion Superius
17) Stomion Superius =The most inferior point on the vermillion of the upper lip

18) Stomion Inferius =The most superior point on the vermillion of the lower lip

19) A landmark on the lower lip located midway between Stomion Inferius and Labrale Inferius.

20) Labrale Inferius = Margin of muculo-cutaneous of lower lip

21) A landmark located midway between Labrale Inferius and Labiomental fold

22) Labio-mental fold =The deepest point in the concavity between Labrale Inferius [20] and Soft Tissue chin [24]

23) A landmark located midway between Labiomental fold and Soft tissue Pogonion

24) Soft tissue Popogonion : The most anterior point on the soft tissue chin

25) Soft tissue Gnathion: The most antero-inferior point on the soft tissue chin

26) Soft tissue Menton: The most inferior point on the soft tissue chin ,in the region inferior to Menton

27) Cervical point: The junction of the submental region and the neck

28) The most posterior point on the Sella Turcica

29) The most anterior point on the Sella Turcica

30) Sella Turcica (S): The landmark located the midpoint of the sella region

31) N : Nasofrontal suture =The junction of the Nasal bone and Frontal bone

32) Basion : The most inferior point on the anterior margin of foramen magnum, posterior or inferior point of occipital bone

33) Posterior Nasal Spine: PNS =The posterior limit of the floor of the nose, at the tip of the posterior nasal spine

34) Superior Maxilla 1: A landmark on the superior surface of the maxilla near PNS

35) Superior Maxilla 2: Another landmark on the superior surface of the maxilla

36) Superior Maxilla3: Yet another landmark on the superior-surface of the maxilla, delimiting posterior and anterior maxillary segment in maxillary osteotomy simulation

37) Superior Maxilla 4: Another landmark on the superior surface of the maxilla

38) Superior Maxilla 5: A landmark on the superior surface of the maxilla near ANS,at a point where its supero-inferior thickness is 3 mm

39) Anterior Nasal Spine: The anterior limit of the floor of the nose, at the tip of the anterior nasal spine

40) Prosthion 1: Junction between maxilla anterior alveolar bone crest and cervical of upper anterior teeth

41) A-point =The deepest point in the concavity of the anterior maxilla between the anterior nasalspine and the alveolar crest

42) Sub-ANS = A point located on the anterior surface of the maxilla near ANS, at a point where its supero-inferior thickness is 3 mm

43) Upper Incisor Apex: The root apex of the upper central incisor

44) Upper Incisor Tip: The tip of the crown of the upper central incisor

45) Upper Cuspid Apex: The root apex of the upper Cuspid

46) Upper Cuspid Tip: The tip of the crown of the upper Cuspid

47) Upper Molar Apex: A point located on a perpendicular to the occlusal surface of the upper first molar through the mesial cuspid tip

48) Upper Molar Crown: The tip of the mesial cusp of the upper first molar

49) Upper Molar Mesial: A landmark located at the mesial contact of the upper first molar

50) Upper Molar Distal: A landmark located at the distal contact of the upper first molar

51) Lower Molar Crown: The tip of the mesial cusp of the lower first molar

52) Lower Molar Apex: A point located on a perpendicular to the occusal surface of the lower first molar through the mesial cusp tip

53) Lower Molar Mesial: A landmark located at the mesial contact of the lower first molar

54) Lower Molar Distal: A landmark located at the distal contact of the lower first molar

55) Lower Cuspid Tip: The tip of the crown of the lower cuspid

56) Lower Cuspid Apex: The root apex of the lower cuspid

57) Lower Central incisor Tip: The tip of the crown of the central upper incisor

58) Lower Central incisor Apex: The root apex of the central upper incisor

59) Junction between mandibular anterior alveolar bone crest and cervical of lower anterior teeth

60) Pogonion=The most anterior point on the bony chin

61) B-point: The deepest point in the concavity of the anterior mandible between the alveolar crest and Pogonion (between point 59, 60)

62) Anterior Genioplasty point: A point of the chin between B- point and Pg- point, which represents the anterior limit of the genioplasty osteotomy. This landmark can serve as Protuberance Menti (Rickett's PM point) if digitized on the anterior chin contour as it changes from concave to convex.

63) Menton =The most inferior point on the bony chin

64) Inferior Gonion : A mid-planed point at a tangent to the inferior border of the mandible near Gonion.; menton(Mandibular plane)

65) A Point on Chin contour =The point between the Sella to NPg bisecting to Mandibular plane between Pg and Me (Automatic point)

66) Posterior Genioplasty point: A point between mid-planed of inferior border of mandible, Used to Posterio – Inferior – limit of Genioplasty osteotomy

67) The deepest of concavity of Antegonial notch, which used in Landmark for separated proximal and distal mandibular segments in ramal osteotomy.

68) Articulare: A mid-planed point located at the intersection of the posterior border of ramus

69) Posterior gonion: A mid-planed point on the posterior border of the ramus

70) Gonion=A mid-planed point at the gonial angle of the mandibular located by bisecting the posterior and inferior border of the mandible

71) Posterior Ramus: A mid-planed point on the posterior border of the ramus, approximately halfway between Articulare and Posterior Gonion

72) Condylion: The most postero–superior point of the mid-plane contour of the mandible condyle

73) Sigmoid :A landmark of the depth of the concavity of the mandibular sigmoid notch

74) Anterior Ramus: A landmark located in the depth of the convexity of the concavity of the anterior border of the ramus of the mandible

75) DC: Middle point of the neck of condyle on Ba- N plane.

76) Centre of Ramus or Xi point = Bisecting of two line of the diagonal line (1-4).1 The Posterior aspect of the Ramus [71] and 2 the anterior aspect of the Ramus [74] ,3 Deepest point of Inferior line contact to Sigmoid notch [73] and 4 Line paralled to the line in the Inferior gonion [64]

77) Ptm : Pterygo–Maxillary Fissure A landmark at the 11 O'clock position of the mid-planed contour of the pterygo-mandibular fissure

78) Posterior of Pterygo-maxillary Fissure right angle to the FH or A landmark at the seven o'clock position of the mid-planed contour of the pterygo-mandibular fissure

79) Centre of cranium : Bisecting of BaN and Ptm. Gn

Table 10: Reference Planes and Lines Used in Study

Measurement	
1) NSFH	Angle 30, 31 /1,2
2) NS-Ba	Angle 30, 31 /30, 32
3) SNA	Angle 30, 31 /31, 41
4) Co-A (mm)	Distance 41, 72
5) NS-PP	Angle 30, 31 /33, 39
6) SNB	Angle 31, 30 /31, 61
7) SNPg	Angle 31, 30 /31, 60
8) Pg-NB [mm]	Distance 60 to (31 to 61)
9) NS-MP	Angle 30, 31 /64, 63
10) MP-PP	Angle 64, 63 /33, 39
11) NS-Gn	Angle 30, 31 /30, 65
12) Co-Gn [mm]	Distance 65, 72
13) Mand Angle	Angle 69, 68 /64, 63
14) ANB	SNA [3] – SNB [6]
15) AO-BO [mm]	Distance Pt1, Pt2 (Pt 1 and Pt 2 = bisecting of 41 and 61 right angle to AV1, AV2 (AV1 = Average [48, 51] AV2= Average [46, 55] if Pt1 posterior to Pt2 AO-BO =negative value)
16) AF-BF [mm]	Distance Pt1, Pt2 (Pt1 and Pt2 = bisecting of 41 and 61 right angle to 1, 2 (if Pt1 posterior to Pt2 AF-BF = Negative value)
17) Max-Mand Differences [mm]	Co-Gn [12] – CoA [4]
18) FH-FO	Angle 1, 2 /AV1, AV2 , AV1 = Average [48, 51] AV2 = Average [46, 55]
19) [PFH/AFH] X 100%	[Distance 30, 70] X 100 [Distance 31, 63]
20) 100 % X [N-ANS]/[ANS’-Me]	Dif 1 x 100/ Dif2
21) 1̲-NA	Angle 44, 43 /41, 31
22) 1̲-NA [mm]	Distance 44 right angle to (31 to 41)
23) 1̲-SN	Angle 31, 30/ 43, 44
24) 1̄-NB	Angle 57, 58/ 31, 61

Table 10: Reference Planes and Lines Used in Study (cont.)

Measurement	
25) $\bar{1}$ -NB [mm]	Distance of 57 right angle to(31to61)
26) $\bar{1}$ -MP	Angle 58, 57/ 63, 64
27) $\underline{1}$- $\bar{1}$	Angle 44, 43/ 57, 58
28) Overjet [mm]	Distance Pt1, Pt2
29) Overbite [mm]	Distance of [Dif1 – Dif2]
30) Ant.-Max alv ht [mm]	Distance of 44 right angle to (33 to 39)
31) Post-Max alv ht[mm]	Distance of 48 right angle to (33 to 39)
32) Naso Labial	Angle 13, 12/ 13, 15
33) H-angle	Angle 15, 24/ 31, 61
34) E-plane	The esthetic line or plane extending from the soft-tissue tip of the nose (En,#10) to the soft-tissue chinpoint (DT,#24)

Table 11: Mahidol analysis

	Measurement	
	Linear measurements	
1	Pg-NB	(mm)
2	AO-BO	(mm)
3	Overbite	(mm)
4	Post.max.alv.ht	(mm)
5	$\overline{1}$ -NB (Lower incisor to NB)	(mm)
6	Max-mand diff	(mm)
7	100%(N-ANS)/(ANS'-Me)	(mm)
8	Overjet	(mm)
9	Co-Gn	(mm)
10	Ant.max.alv.h	(mm)
11	PFH/AFH X 100%	(mm)
12	$\underline{1}$-NA (Upper incisor to NA)	(mm)
13	Co-A	(mm)
14	AF-BF	(mm)
15	E-plane	(mm)
	Angular measurements	
16	Mand-angle	(degree)
17	ANB	(degree)
18	FH-SN	(degree)
19	Nasolabial angle	(degree)
20	FH-FO	(degree)
21	NS-MP	(degree)
22	MP-PP	(degree)
23	NSBa	(degree)
24	$\underline{1}$ - $\overline{1}$ (Interincisal angle)	(degree)
25	$\underline{1}$-NA (Upper incisor to NA)	(degree)
26	$\overline{1}$ -NB (Lower incisor to NB)	(degree)
27	NS-PP	(degree)
28	$\overline{1}$ -MP (Lower incisor to MP)	(degree)
29	H-ANGLE	(degree)
30	SNB	(degree)
31	NS-Gn	(degree)
32	SNA	(degree)
33	$\underline{1}$-SN (Upper incisor toSN)	(degree)
34	SNPg	(degree)

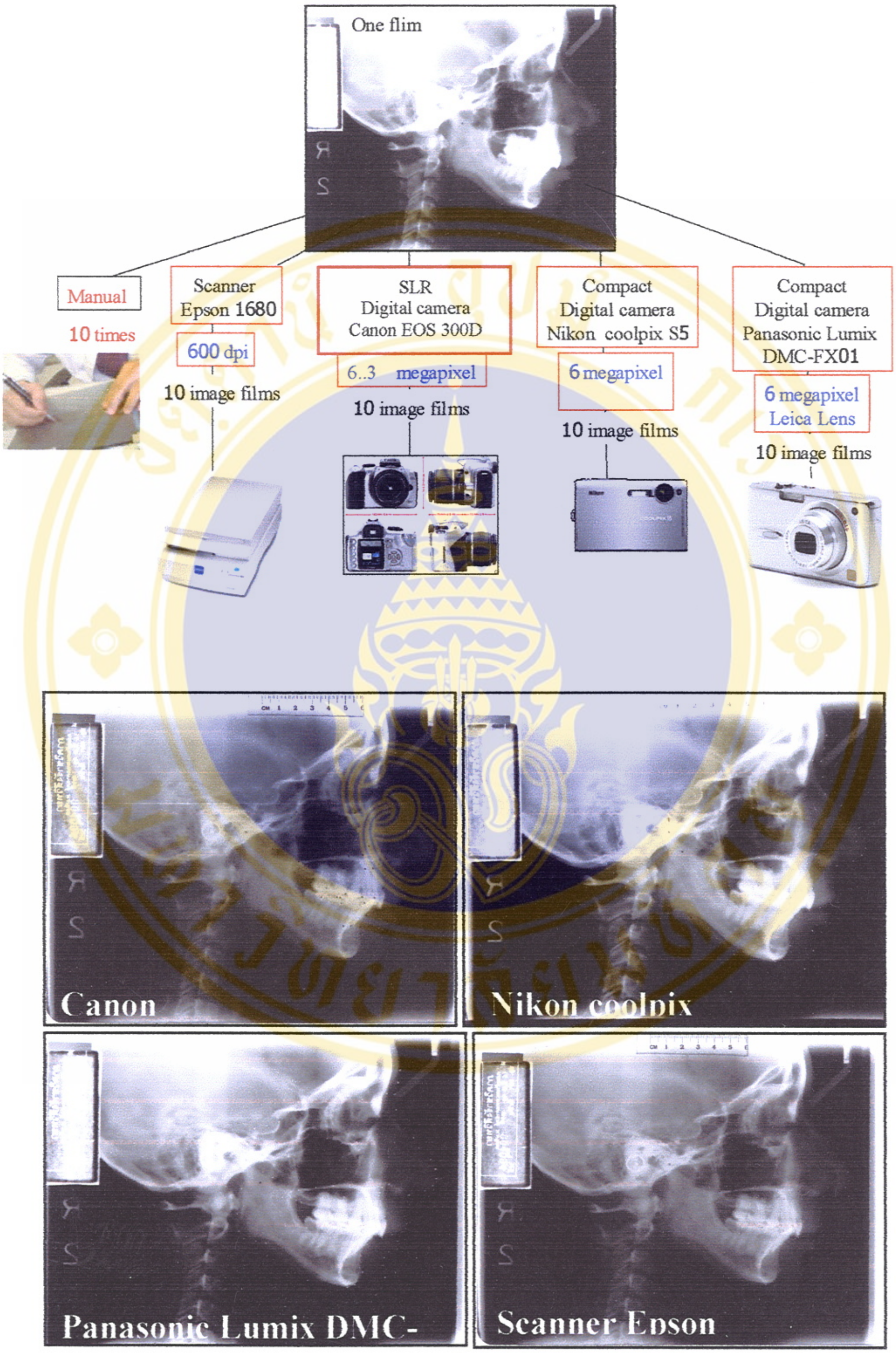


Fig.38 Flowchart to test the systematic error arising from digital cameras and Scanner

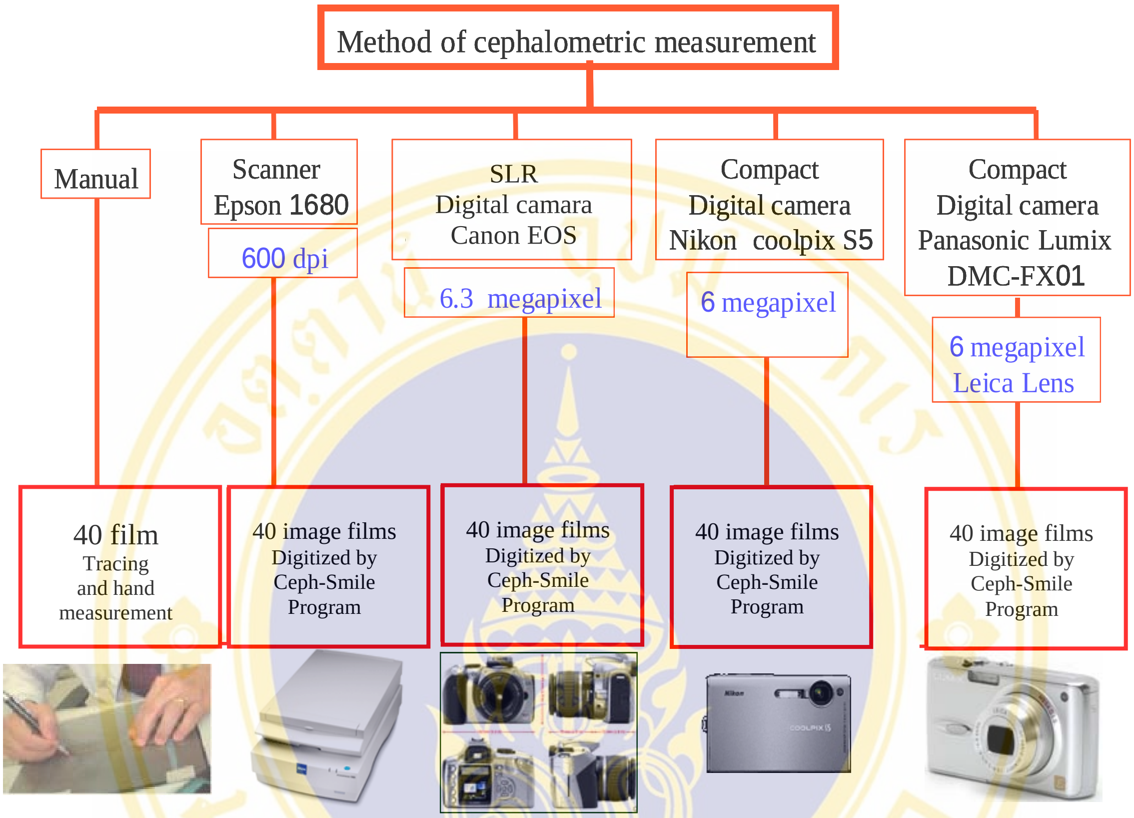


Fig. 39 Flow chart to compare analogue and digital methods

CHAPTER 5

RESULTS

Table12 shows means and standard deviations of 34 cephalometric measurements arising from hand measurement of manually traced film and computer program measurement of digital images obtained from a scanner and 3 digital cameras. There were no statistically significant differences in means of all measurements among five different methods. The result suggested that there was no systematic error arising from either the scanner or 3 digital cameras.

A comparison of mean of 34 cephalometric measurements among five difference methods is show in Table 13. There was no significant difference in means of all measurements among five difference methods.

Table14 describes the deviation of cephalometric measurements from the manual method mean (*$\bar{x}$* and SD) in millimeters and degrees. For 15 linear cephalometric measurements, L1-NB mm (between Manual-Scanner, Manual-Cannon), PFH/AFHX100% (between Manual-Nikon, Manual-Panasonic), Max-mand diff (between Manual-Panasonic) showed *the lowest deviation from the Manual mean. (Manual-Scanner $\bar{x}$ of L1-NB= 0.00±0.06 mm/ Manual-Cannon; $\bar{x}$ of L1-NB= 0.00±0.06 mm/ Manual-Nikon; $\bar{x}$ of PFH/AFHX100%= 0.00±0.03 mm/ Manual-Panasonic; $\bar{x}$ of PFH/AFHX100%= 0.02±0.18 mm/ Manual-Panasonic; $\bar{x}$ of Max-mand. Diff= 0.02±0.18 mm)* while 100% (N-ANS)/ (ANS'-Me) (between Manual-Scanner, Manual-Cannon, Manual-Panasonic), Ant.max.alv.ht (between Manual-Nikon), Max-mand diff (between Manual-Panasonic) showed *the highest deviation from the manual mean. (Manual-Scanner $\bar{x}$ of 100%(N-ANS)/(ANS'-Me) = 0.31±0.74 mm/ Manual-Cannon; $\bar{x}$ of 100%(N-ANS)/(ANS'-Me) = 0.71±0.03 mm/ Manual-Panasonoic; $\bar{x}$ of 100%(N-ANS)/(ANS'-Me) = 0.76±0.29 mm/ Manual-Nikon; $\bar{x}$ of Ant.max.alv.ht= 0.84±0.16 mm)*. In angular measurements, FH-SN (between Manual-Scanner), NS-MP (between Manual-Cannon), NS-MP (between Manual-Cannon), H-angle (between Manual-Nikon), $\bar{1}$ -MP (between Manual-Panasonic) showed *the lowest deviation from the Manual mean. (Manual-Scanner $\bar{x}$ of FH-SN= 0.00±0.09 degree/ Manual-Cannon; $\bar{x}$ of NS-MP= 0.00±0.06 degree/ Manual-Nikon; $\bar{x}$ $\underline{1}$- $\bar{1}$ = 0.00±0.11 degree/ Manual-Nikon; $\bar{x}$ of H-angle=0.01±0.21 degree/ Manual-Panasonic;*

$\bar{x}$ of $\bar{1}$ -MP= 0.00±0.14 degree) while Nasolabial angle (between Manual-Scanner, Manual-Cannon), Mandibular angle (between Manual-Nikon), $\bar{1}$ -$\underline{1}$ (between Manual-Panasonic) showed *the highest deviation from the Manual mean. (Manual-Scanner; $\bar{x}$ of Nasolabial angle = 0.78±0.37 mm/ Manual-Cannon; $\bar{x}$ of Nasolabial angle = 0.95±0.52 mm/ Manual-Panasonoic; $\bar{x}$ of Mandibular angle= 0.43±0.50 mm/ Manual-Nikon; $\bar{x}$ $\underline{1}$- $\bar{1}$ = 0.40±0.25 mm)*. However, there was no significant differences in all cephalometric measurements between manual method and the other four methods.

To have a better overview, the distribution of measurement differences between manual and the other four methods can be seen in Table 15. Scanner-Manual showed measurement differences of less than 0.25 mm. in 13 linear cephalometric measurements. Post.max.alv.ht (mm), Co-Gn (mm) and 100%(N-ANS)/(ANS'-Me) had measurement differences within the limit of 0.25–0.50 mm., whereas no measurement differences were more than 0.50 mm. Canon-Manual showed measurement differencs of less than 0.25 mm. on 11 linear cephalometric measurements. Co-Gn (mm) and Ant.max.alv.ht (mm) had measurement differences within the limit of 0.25–0.50 mm., whereas Max-mand diff and 100%(N-ANS)/(ANS'-Me) showed differences of more than 0.50 mm. Nikon-Manual showed measurement differences of less than 0.25 mm. on 9 linear cephalometric measurements. Only one linear measurement (Overbite) had differences within the limit of 0.25–0.50 mm. whereas 5 measurements had differences more than 0.50 mm. Panasonic-Manual showed measurement differences of less than 0.25 mm. on 12 linear cephalometric measurements. Co-Gn had differences within the limit of 0.25–0.50 mm., whereas 100%(N-ANS)/(ANS'-Me) and Ant.max.alv.ht (mm) had differences of more than 0.50 mm.

In angular cephalometric measurements, Scanner-Manual showed measurement differences of less than 0.25 degree on 15 angular cephalometric measurements. U1-NA, NS-PP, U1-SN had differences within the limit of 0.25–0.50 degree, whereas Naso-labial angle had more than 0.50 degree difference. Canon-Manual showed measurement differences of less than 0.25 degree on 16 angular cephalometric measurements. NS-Ba and H-angle had differences within the limit of 0.25–0.50 degree, whereas Naso-labial angle had more than 0.50 degree difference. Nikon-Manual showed measurement differences of less than 0.25 degree on 14 angular cephalometric measurements. Mand-angle, MP-PP, NS-Ba, NS-Gn had differences within the limit of 0.25–0.50 degree, whereas Upper 1 to NA had more than 0.50 degree difference. Panasonic-Manual showed measurement differences of less than 0.25 degree on 13 angular cephalometric measurements. Six angular measurement had differences were within the limit of 0.25–0.50 degree, whereas no measurement difference more than 0.50 degree.

The systematic and method errors were obtained from the five methods. In all variables, the paired t-test showed no significant difference between the two times of observation. The results show that the systematic difference was small and the method error did not exceed more than 1 degree and 1 mm. This indicated that systematic differences did not play an important role in this study and that the method error was thus a good measure for the measurement error (See Appendix; Tables 17-22).

Table16 presents Pearson's correlation coefficients between 2 methods of measurements. Most values of r were at 0·90 or above. Although some measurements showed r of less than 0.90, however no any measurement was less than 0.80. Manual-Panasonic seemed to show lower correlation comparing to other methods.

Table12: A comparison in linear and angular measurements from manually traced film and digital images from scanner and 3 digital cameras.

			M (n=10)		S (n=10)		C (n=10)		N (n=10)		P 1(n=10)		Sig.	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
1	U1-NA	(mm)	2.75	0.08	2.48	0.29	2.57	0.16	2.77	0.38	2.50	0.39	0.063	NS
2	Ant.max.alv.ht	(mm)	32.45	0.29	32.08	0.86	32.18	0.63	32.55	0.74	32.49	0.40	0.099	NS
3	Overjet	(mm)	2.30	0.16	2.44	0.32	2.44	0.15	2.58	0.51	2.32	0.16	0.129	NS
4	AF-BF	(mm)	14.49	0.20	14.52	0.48	14.42	0.73	14.55	0.29	14.30	0.34	0.155	NS
5	(N-ANS)/(ANS'-Me)100%		90.49	0.20	90.96	0.46	90.45	0.83	90.80	0.57	90.39	0.83	0.155	NS
6	Overbite	(mm)	7.45	0.23	7.31	0.28	7.55	0.32	7.57	0.23	7.32	0.28	0.165	NS
7	Post.max.alv.ht	(mm)	22.73	0.85	22.53	0.42	22.40	0.33	22.49	0.91	22.79	0.69	0.248	NS
8	Max-mand diff	(mm)	19.21	0.49	19.61	0.56	19.22	0.88	19.55	0.94	19.34	0.59	0.292	NS
9	Pg-NB	(mm)	2.42	0.23	2.29	0.46	2.57	0.27	2.46	0.23	2.26	0.44	0.417	NS
10	E-plane	(mm)	-1.14	0.05	-1.10	0.30	-1.18	0.17	-1.18	0.20	-1.09	0.27	0.432	NS
11	Co-A	(mm)	85.80	0.38	85.57	0.40	85.60	0.60	85.86	0.64	85.70	0.46	0.467	NS
12	AO-BO	(mm)	7.28	0.36	7.21	0.83	7.05	0.88	7.31	0.38	7.02	0.56	0.730	NS
13	L1-NB	(mm)	6.02	0.18	6.08	0.36	5.96	0.28	6.07	0.41	6.03	0.30	0.766	NS
14	Co-Gn	(mm)	105.29	0.47	105.48	0.85	105.12	1.01	105.01	0.67	105.21	0.49	0.804	NS
15	PFH/AFH		55.53	1.02	55.43	0.55	55.45	0.29	55.54	0.77	55.71	0.72	0.884	NS
1	U1-NA	(degree)	12.50	0.10	12.22	0.84	12.67	0.46	12.62	0.84	12.41	0.60	0.116	NS
2	NSBa	(degree)	138.50	0.45	138.48	0.57	138.34	0.29	138.33	0.43	138.09	0.31	0.151	NS
3	Mand-angle	(degree)	110.50	0.65	110.96	1.20	110.58	0.50	110.60	0.75	110.46	0.53	0.164	NS
4	ANB	(degree)	5.00	0.10	5.03	0.18	4.89	0.15	4.99	0.36	5.01	0.34	0.177	NS
5	MP-PP	(degree)	30.00	0.05	30.39	0.55	30.08	0.35	30.16	0.55	30.29	0.51	0.183	NS
6	L1-MP	(degree)	103.00	0.65	102.99	0.31	102.56	0.68	102.61	0.84	102.92	0.85	0.199	NS
7	FH-SN	(degree)	11.00	0.35	11.06	0.36	10.95	0.22	10.86	0.29	11.01	0.34	0.242	NS
8	FH-FO	(degree)	10.00	0.45	10.48	0.79	10.09	0.43	10.35	0.45	10.22	0.96	0.343	NS
9	NS-MP	(degree)	42.00	0.20	41.97	0.32	41.77	0.24	41.85	0.39	41.81	0.63	0.404	NS
10	SNPg	(degree)	66.50	0.75	66.87	0.64	66.89	0.17	66.85	0.18	66.84	0.45	0.430	NS
11	SNA	(degree)	70.50	0.10	70.53	0.32	70.43	0.15	70.50	0.33	70.56	0.38	0.435	NS
12	NS-Gn	(degree)	78.00	0.35	77.99	0.41	77.89	0.19	77.82	0.31	77.76	0.30	0.448	NS
13	$1 - \bar{1}$	(degree)	132.00	1.45	132.41	0.81	132.55	0.94	132.53	1.02	132.11	1.31	0.535	NS
14	NS-PP	(degree)	11.50	0.45	11.77	0.41	11.60	0.64	11.69	0.52	11.52	0.33	0.569	NS
15	U1-SN	(degree)	83.00	0.75	82.85	0.81	83.11	0.44	83.11	1.03	82.93	0.61	0.821	NS
16	SNB	(degree)	65.50	0.45	65.49	0.37	65.55	0.11	65.51	0.30	65.48	0.36	0.858	NS
17	Nasolabial	(degree)	110.50	0.85	110.40	1.79	110.79	1.48	110.50	1.49	110.86	1.04	0.902	NS
18	L1-NB	(degree)	30.50	0.75	30.84	0.64	30.49	1.05	30.77	1.34	30.64	0.81	0.914	NS
19	H-Angle	(degree)	12.00	0.50	12.20	0.66	12.21	0.42	12.16	0.71	12.04	0.70	0.990	NS

NS = Non-significant

M=Manual, S=Scanner Epson 1680pro, C=Canon EOS 300D, N=Nikon Coolpix S5, P=Panasonic Lumix Fx-01

Table 13: Statistic comparison of cephalometric measurements among five methods performed by using Randomized block design of ANOVA

	Measurements		M (n=40)		S (n=40)		C (n=40)		N (n=40)		P (n=40)		p-value	
	(n= 200)		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD		
1	L1-NB	(mm)	8.71	2.90	8.71	2.85	8.71	2.84	8.56	2.69	8.86	2.71	**0.058**	NS
2	U1-NA	(mm)	7.21	2.75	7.31	2.96	7.29	3.00	7.17	2.82	7.36	2.72	0.877	NS
3	Post.max.alv.ht	(mm)	22.66	2.36	22.95	2.44	22.89	2.47	22.75	2.41	22.84	2.23	0.318	NS
4	Max-mand diff	(mm)	30.95	6.50	31.00	6.28	30.34	6.19	30.37	6.35	30.93	6.42	**0.057**	NS
5	Overjet	(mm)	4.96	1.80	5.14	1.69	5.07	1.71	5.00	1.66	5.14	1.76	0.188	NS
6	Pg-NB	(mm)	1.41	1.11	1.38	1.05	1.33	1.00	1.27	1.01	1.53	1.45	0.489	NS
7	AO-BO	(mm)	0.16	4.06	0.24	3.94	0.13	3.96	0.14	3.69	0.22	3.90	0.904	NS
8	Co-Gn	(mm)	119.94	8.73	119.96	8.88	120.22	8.91	119.12	8.56	120.20	8.66	0.192	NS
9	PFH/AFH X 100%		63.83	3.87	63.86	3.81	63.90	4.05	63.84	3.84	63.85	3.69	**0.997**	NS
10	100%(N-ANS) /(ANS'-Me)		83.57	7.11	83.26	7.85	82.86	7.14	82.99	6.78	82.81	7.40	0.816	NS
11	Overbite	(mm)	4.54	1.83	4.41	1.82	4.48	1.81	4.27	1.75	4.36	1.73	0.135	NS
12	Ant.max.alv.ht	(mm)	30.61	3.11	30.47	2.78	30.94	3.48	29.77	3.27	31.27	5.45	0.072	NS
13	E-plane	(mm)	4.31	3.11	4.36	3.07	4.44	3.09	4.32	3.08	4.44	3.01	0.241	NS
14	Co-A	(mm)	89.09	7.12	89.22	7.05	89.17	7.00	89.21	6.92	89.15	6.86	0.868	NS
15	AF-BF-mm	(mm)	7.56	4.80	7.62	4.77	7.54	4.83	6.91	4.76	7.41	4.63	0.242	NS
16	Mand-angle	0	121.26	6.13	121.19	6.02	121.25	5.81	121.70	5.64	121.21	5.49	0.481	NS
17	ANB	(°)	4.38	2.30	4.56	1.97	4.49	2.09	4.26	2.26	4.30	2.18	0.271	NS
18	FH-SN	(°)	6.75	2.57	6.75	2.66	6.88	2.63	6.79	2.61	6.93	2.55	0.344	NS
19	Nasolabial angle	(°)	88.18	12.97	88.96	13.34	89.13	13.49	88.37	12.54	87.87	12.83	**0.086**	NS
20	FH-FO	(°)	10.45	3.80	10.42	3.75	10.40	3.73	10.25	3.79	10.09	3.55	0.163	NS
21	NS-MP	(°)	34.51	5.58	34.49	5.54	34.51	5.53	34.46	5.27	34.18	5.08	0.695	NS
22	MP-PP	(°)	26.89	5.35	26.64	5.24	26.85	5.33	26.59	5.25	26.69	4.93	0.67	NS
23	NSBa	(°)	128.17	4.59	128.39	4.58	128.43	4.49	128.50	4.37	128.23	4.44	0.092	NS
24	$\underline{1} - \overline{1}$	(°)	113.15	9.69	113.04	9.62	113.15	9.80	113.00	9.09	112.75	9.44	0.769	NS
25	U1-NA	(°)	28.44	6.41	28.84	6.32	28.60	6.26	28.79	5.97	28.47	6.06	0.541	NS
26	L1-NB	(°)	33.04	6.25	33.16	6.51	33.19	6.34	33.14	6.36	33.21	6.37	0.677	NS
27	NS-PP	(°)	7.54	2.89	7.87	2.74	7.77	2.90	7.72	2.80	7.53	2.81	0.219	NS
28	L1-MP	(°)	99.02	7.49	98.89	7.49	99.15	7.36	99.19	7.41	99.03	7.35	0.381	NS
29	H-ANGLE	(°)	16.40	4.11	16.63	4.43	16.68	4.31	16.41	4.33	16.34	4.30	0.243	NS
30	SNB	(°)	79.31	4.03	79.37	4.08	79.39	4.04	79.53	3.93	79.33	3.83	**0.955**	NS
31	NS-Gn	(°)	69.08	3.97	69.12	3.96	69.00	4.06	68.77	3.89	68.75	3.89	0.427	NS
32	SNA	(°)	83.69	3.55	83.81	3.53	83.72	3.58	83.82	3.48	84.02	3.78	0.37	NS
33	U1-SN	(°)	112.29	7.66	112.56	7.62	112.49	7.49	112.52	7.27	112.20	7.02	0.846	NS
34	SNPg	(°)	79.80	3.85	79.82	3.79	79.81	3.86	79.92	3.74	79.59	3.68	0.754	NS

NS = Non-significant

M=Manual, S=Scanner Epson 1680pro, C=Canon EOS 300D, N=Nikon Coolpix S5, P=Panasonic Lumix Fx-01

Table 14: Differences of cephalometric measurements between 2 methods in millimeters and degree (Comparison with Manual method)

	Measurements (n= 40)		M-S			M-C			M-N			M-P		
	15 Linear measurements		$\bar{x}$	SD		$\bar{x}$	SD		$\bar{x}$	SD		$\bar{x}$	SD	
1	L1-NB	(mm)	0.00	0.06	NS	0.01	0.06	NS	0.15	0.21	NS	0.15	0.19	NS
2	U1-NA	(mm)	0.10	0.20	NS	0.09	0.25	NS	0.04	0.07	NS	0.16	0.03	NS
3	Post.max.alv.ht	(mm)	0.30	0.08	NS	0.23	0.10	NS	0.09	0.04	NS	0.18	0.13	NS
4	Max-mand diff	(mm)	0.06	0.22	NS	0.61	0.31	NS	0.57	0.15	NS	0.02	0.08	NS
5	Overjet	(mm)	0.18	0.11	NS	0.10	0.09	NS	0.03	0.14	NS	0.18	0.04	NS
6	Pg-NB	(mm)	0.03	0.06	NS	0.08	0.11	NS	0.14	0.10	NS	0.12	0.34	NS
7	AO-BO	(mm)	0.08	0.12	NS	0.02	0.10	NS	0.02	0.37	NS	0.06	0.16	NS
8	Co-Gn	(mm)	0.02	0.15	NS	0.28	0.18	NS	0.82	0.17	NS	0.26	0.08	NS
9	PFH/AFH X 100%		0.03	0.06	NS	0.07	0.18	NS	0.00	0.03	NS	0.02	0.18	NS
10	100%(N-ANS)/(ANS'-Me)		0.31	0.74	NS	0.71	0.03	NS	0.58	0.32	NS	0.76	0.29	NS
11	Overbite	(mm)	0.13	0.01	NS	0.05	0.02	NS	0.26	0.08	NS	0.18	0.11	NS
12	Ant.max.alv.ht	(mm)	0.14	0.33	NS	0.32	0.36	NS	0.84	0.16	NS	0.66	2.33	NS
13	E-plane	(mm)	0.06	0.04	NS	0.13	0.03	NS	0.01	0.03	NS	0.13	0.10	NS
14	Co-A	(mm)	0.13	0.06	NS	0.08	0.12	NS	0.11	0.20	NS	0.06	0.26	NS
15	AF-BF-mm	(mm)	0.05	0.03	NS	0.02	0.03	NS	0.65	0.04	NS	0.15	0.17	NS
	19 Angular measurements													
1	Mand-angle	(degree)	0.07	0.11	NS	0.01	0.33	NS	0.43	0.50	NS	0.05	0.64	NS
2	ANB	(degree)	0.17	0.33	NS	0.11	0.22	NS	0.12	0.04	NS	0.08	0.12	NS
3	FH-SN	(degree)	0.00	0.09	NS	0.13	0.06	NS	0.04	0.04	NS	0.18	0.02	NS
4	Nasolabial angle	(degree)	0.78	0.37	NS	0.95	0.52	NS	0.18	0.43	NS	0.31	0.14	NS
5	FH-FO	(degree)	0.04	0.04	NS	0.05	0.06	NS	0.20	0.01	NS	0.36	0.24	NS
6	NS-MP	(degree)	0.02	0.05	NS	0.00	0.06	NS	0.05	0.31	NS	0.32	0.51	NS
7	MP-PP	(degree)	0.25	0.11	NS	0.04	0.02	NS	0.29	0.1	NS	0.19	0.42	NS
8	NSBa	(degree)	0.23	0.02	NS	0.26	0.11	NS	0.33	0.22	NS	0.07	0.16	NS
9	$\underline{1} - \overline{1}$	(degree)	0.12	0.07	NS	0.00	0.11	NS	0.15	0.6	NS	0.4	0.25	NS
10	U1-NA	(degree)	0.40	0.09	NS	0.16	0.14	NS	0.36	0.43	NS	0.04	0.35	NS
11	L1-NB	(degree)	0.12	0.26	NS	0.16	0.1	NS	0.1	0.12	NS	0.17	0.13	NS
12	NS-PP	(degree)	0.33	0.14	NS	0.23	0.02	NS	0.18	0.09	NS	0.01	0.08	NS
13	L1-MP	(degree)	0.13	0.00	NS	0.13	0.13	NS	0.16	0.08	NS	0.00	0.14	NS
14	H-ANGLE	(degree)	0.23	0.32	NS	0.28	0.20	NS	0.01	0.21	NS	0.06	0.19	NS
15	SNB	(degree)	0.07	0.05	NS	0.08	0.01	NS	0.23	0.10	NS	0.02	0.20	NS
16	NS-Gn	(degree)	0.04	0.01	NS	0.07	0.09	NS	0.31	0.09	NS	0.33	0.08	NS
17	SNA	(degree)	0.13	0.02	NS	0.03	0.02	NS	0.14	0.07	NS	0.34	0.23	NS
18	U1-SN	(degree)	0.28	0.04	NS	0.21	0.17	NS	0.23	0.39	NS	0.09	0.64	NS
19	SNPg	(degree)	0.02	0.05	NS	0.01	0.01	NS	0.12	0.1	NS	0.21	0.16	NS

NS = Non-significant

M=Manual, S=Scanner Epson 1680pro, C=Canon EOS 300D, N=Nikon Coolpix S5, P=Panasonic Lumix Fx-01

Table 15: Show the distribution of measurement differences between manual method and the other four methods

			Deviation from the mean											
			Scanner			Canon			Nikon			Panasonic		
	Parameters (mm)		<0.25	0.25–0.50	>0.50	<0.25	0.25–0.50	>0.50	<0.25	0.25–0.50	>0.50	<0.25	0.25–0.50	>0.50
1	L1-NB	(mm)	X			X			X			X		
2	U1-NA	(mm)	X			X			X			X		
3	Post.max.alv.ht	(mm)		X		X			X			X		
4	Max-mand diff	(mm)	X					X			X	X		
5	Overjet	(mm)	X			X			X			X		
6	Pg-NB	(mm)	X			X			X			X		
7	AO-BO	(mm)	X			X			X			X		
8	Co-Gn	(mm)	X				X				X		X	
9	PFH/AFH X 100%		X			X			X			X		
10	100%(N-ANS) /(ANS'-Me)			X				X			X			X
11	Overbite	(mm)	X			X				X		X		
12	Ant.max.alv.ht	(mm)	X				X				X			X
13	E-plane	(mm)	X			X			X			X		
14	Co-A	(mm)	X			X			X			X		
15	AF-BF-mm	(mm)	X			X					X	X		
			13	2	0	11	2	2	9	1	5	12	1	2

			Scanner			Canon			Nikon			Panasonic		
	Parameters (degrees)		<0.25	0.25–0.50	>0.50	<0.25	0.25–0.50	>0.50	<0.25	0.25–0.50	>0.50	<0.25	0.25–0.50	>0.50
1	Mand-angle	(degree)	X			X				X		X		
2	ANB	(degree)	X			X			X			X		
3	FH-SN	(degree)	X			X			X			X		
4	Nasolabial angle	(degree)			X			X	X				X	
5	FH-FO	(degree)	X			X			X				X	
6	NS-MP	(degree)	X			X			X				X	
7	MP-PP	(degree)	X			X				X		X		
8	NSBa	(degree)	X				X			X		X		
9	$\underline{1}\,\overline{1}$	(degree)	X			X			X				X	
10	U1-NA	(degree)		X		X					X	X		
11	L1-NB	(degree)	X			X			X			X		
12	NS-PP	(degree)		X		X			X			X		
13	L1-MP	(degree)	X			X			X			X		
14	H-ANGLE	(degree)	X				X		X			X		
15	SNB	(degree)	X			X			X			X		
16	NS-Gn	(degree)	X			X				X			X	
17	SNA	(degree)	X			X			X				X	
18	U1-SN	(degree)		X		X			X			X		
19	SNPg	(degree)	X			X			X			X		
			15	3	1	16	2	1	14	4	1	13	6	0

Table16: Pearson’s correlation *(r)* between 2 methods

	(n= 40)		Pearson's Correlation between methods			
			M&S	M&C	M&N	M&P
	15 Linear measurements					
1	L1-NB	(mm)	0.988	0.991	0.980	0.967
2	U1-NA	(mm)	0.931	0.908	0.863	0.920
3	Post.max.alv.ht	(mm)	0.968	0.952	0.974	0.914
4	Max-mand diff	(mm)	0.962	0.950	0.954	0.986
5	Overjet	(mm)	0.959	0.943	0.944	0.960
6	Pg-NB	(mm)	0.973	0.944	0.905	0.942
7	AO-BO	(mm)	0.997	0.985	0.955	0.964
8	Co-Gn	(mm)	0.972	0.991	0.851	0.991
9	PFH/AFH X 100%		0.988	0.972	0.964	0.893
10	100%(N-ANS)/(ANS'-Me)		0.989	0.973	0.965	0.893
11	Overbite	(mm)	0.973	0.977	0.974	0.841
12	Ant.max.alv.ht	(mm)	0.959	0.943	0.944	0.960
13	E-plane	(mm)	0.988	0.991	0.986	0.991
14	Co-A	(mm)	0.994	0.997	0.991	0.996
15	AF-BF-mm	(mm)	0.989	0.987	0.948	0.989
	19 Angular measurements					
1	Mand-angle	(degree)	0.996	0.992	0.928	0.903
2	ANB	(degree)	0.942	0.923	0.940	0.876
3	FH-SN	(degree)	0.993	0.983	0.943	0.937
4	Nasolabial angle	(degree)	0.978	0.970	0.960	0.976
5	FH-FO	(degree)	0.993	0.944	0.956	0.934
6	NS-MP	(degree)	0.996	0.992	0.984	0.898
7	MP-PP	(degree)	0.993	0.991	0.950	0.956
8	NSBa	(degree)	0.994	0.989	0.974	0.976
9	1 -1	(degree)	0.997	0.994	0.975	0.962
10	1-NA	(degree)	0.992	0.993	0.942	0.921
11	L1-NB	(degree)	0.994	0.994	0.995	0.995
12	NS-PP	(degree)	0.961	0.955	0.936	0.852
13	L1-MP	(degree)	0.994	0.987	0.990	0.988
14	H-ANGLE	(degree)	0.947	0.972	0.963	0.963
15	SNB	(degree)	0.995	0.991	0.982	0.996
16	NS-Gn	(degree)	0.995	0.985	0.976	0.801
17	SNA	(degree)	0.994	0.986	0.953	0.889
18	U1-SN	(degree)	0.994	0.997	0.962	0.884
19	SNPg	(degree)	0.995	0.993	0.982	0.803

M=Manual, S=Scanner Epson 1680pro, C=Canon EOS 300D, N=Nikon Coolpix S5 P=Panasonic Lumix Fx-01

CHAPTER 6

DISCUSSION

The results were discussed in two main parts: 1) general considerations, 2) effect of scanner and digital camera on cephalometric measurement

1.) General considerations

1.1 Size of cephalometric measurement parameter

1.2 Error of measurement

1.3 Image quality

1.4 Camera and scanner setting

1.5 LCD Flat screen monitor, Scanner, Digital camera

1.6 Computerized cephalometric program

1.1 Size of cephalometric measurement parameter

In clinical orthodontics, cephalometric analysis has long been used as an important clinical tool in diagnosis, treatment planning, and evaluation of growth or treatment results. Many parameters were proposed to analyze the relationship of teeth to teeth, teeth to jaws, jaws to cranial base, and the inter-jaw relationship. For example, the anterior-posterior jaw relationship could be evaluated by many linear and angular measurements in cephalometrics. Linear measurements may be affected by the inclination of the reference line, and angular measurements cannot indicate correctly the jaw relationship in the case of extreme facial divergency (116). Mahidol analysis which included 34 measurement parameters was used in this study because it not only covers a set of structure relationships but it is also routinely used in orthodontic clinic at Mahidol University. However, the dependence of measurement error should be considered during the interpretation of multiple cephalometric measurements. When a landmark common to a pair of measurements is reused in computing each of those measurements, the significant correlation between measurements may result from the error of measurement, which is contributed to the value for measurements. Houston et al (10) had discussed that the error of identifying a common landmark between linear or angular variables may result in a purely topographic correlation between them, which may exaggerate or attenuate a true biologic correlation. The most practical way to avoid such error is to measure the two variables independently on a separate tracing of each structure.

1.2 Error of measurement

The major errors associated with conventional cephalometry include projection errors and tracing errors. The most important source of tracing errors is uncertainty in landmark identification, and intraobserver error is generally less than interobserver error (47, 48). However, interobserver errors were eliminated from our study because the observer in this study was only one resident who was in the third year of the three-year postgraduate training program and was considered to be competent clinician with average training in cephalometrics. In this study, the systematic and method errors were obtained for the five methods. In all variables, the paired t-test showed no significant difference between the two times of observation. The results show that the systematic difference was small and the method error did not excced more than 1 degree and 1 mm (Table 17-22). This indicated that systematic differences did not play an important role in this study and that the method error was thus a good measure for the measurement error.

When we take advantage of digital cephalometry, it is important to be certain that the digitized image yields the similar performance to conventional radiographic film in terms of cephalometric measurements.Therefore, the major source of error in the determination of linear and angular cephalometric measurements in this study was supposed to be the errors in landmark identification. The extent of the difference for each landmark depended on the radiographic complexities, which were also associated with the reliability of the landmarks. However, in this study, the overall differences of landmark identification among the five methods, conventional radiographs and digitized images input by two techniques (Scanner and 3 camera), were not statistically significant difference.

1.3 Image quality

The potential advantages of digital technology lie in the ability to (1) manipulate the image, (2) reduce patient dose, and (3) improve storage and access of information (117, 118). Several studies have found the main source of error in cephalometry to be the visual identification of the landmarks (10, 25, 26) and thus one of the efforts to improve the precision in landmark identification should be directed towards improvement in the image quality (38, 119), and in this study before digitized landmark, the contrast of all image films were adjusted for improvement of image quality (Table 24). In conventional film radiography, the image quality is already determined during exposure and processing of the image. Once the specific film screen detector has been chosen and the latent image has been obtained, little can be done to improve the quality of the image. In comparison, image processing is an intrinsic part of digital radiography (120). Image post-processing can be repeatedly performed in a single data set to obtain image optimization of the final display version. The representation of head films and observers should be considered as possible sources of error when comparing computer-aided cephalometric analysis based on conventional radiographs and digitized images. The head films used in this study were randomly selected from the patients' files. They were representative of the films that we considered good quality for clinical use.

The source of error in cephalometric analysis associated with the complexity of radiographic images is the difficulty of delineating a landmark on a curved anatomical boundary. One may expect that the powerful tool of digitized image processing could help with landmark identification on poorly defined structures. However, it was reported that the landmark reliability in digitized radiographs of lower quality could not be improved by digital processing (121). Instead, one should make efforts to improve the precision of landmark identification by enhancing the image quality at the beginning. The image revealed on radiographic film is considered an analog, which means that the gray level is continuous. Digital image is composed of many picture elements (pixels), which are represented by discrete pixel values. The quality of a digital image strongly depends on both the number of pixels and the number of gray levels. The reliability of landmark identification on digital images with a pixel size of 0.47 mm was demonstrated to be inferior to that on conventional radiographs (9).However, the reliability on a digitized cephalogram with a pixel size of 0.03 mm was better than that on original radiographs with conventional equipment. The cephalometric radiographs used in this study were randomly selected and represented as good quality for daily routine work and we captured image by using scanner and digital cameras with high resolution (2816x2112 Nikon coolpix S5, 6.0 M; 2816x2112 Panasonic Lumix Fx-o1,6.0 M ; 3072x2048 Canon SLR EOS 300D, 6.3 M) with yielding small pixel size. In our study, pixel sized = 0.176 for Nikon and Panasonic; 0.166 for Canon SLR EOS 300D and 0.04 for Scanner (600 dpi), See Table 23.

The reliability of landmark identification is expected to be affected by the image quality. There are several ways of acquiring a digitized cephalometric image, and the image quality would depend on how the image was acquired. In this study, the digitized images were indirectly captured by a film scanner and photographed by three. Inevitably, image signal deterioration would occur in the digitization process of scanning, photographed and transformation into digital format. In this case, the quality of the digitized images may be less than that of the original images on film. However, the result of this study showed that the parameter setting (Scanner and digital camera) for our digitized cephalogram was almost adequate in terms of performance of cephalometric analysis, which was demonstrated by the low level of measurement differences and the generally comparable systematic errors between original and digitized cephalometric image produced by scanner and cameras.

Many different study designs have been used to test the reproducibility of measurements (4, 20, 43, 51, 54, 56, 70, 121-124). Most of these investigations tested the reproducibility of single landmarks, because the identification of landmarks is the main source of error.

The present study showed that scanning and photography of cephalometric radiographs with a higher resolution has little influence on the measurement error. The findings in the present investigation indicate that digital cephalometrics may be a better method for some measurements. The digital technique also has the following advantages: no need for a dark room for tracing, chemicals, or physical space for storage. It should be borne in mind, however, that digital pictures that originate from poor-quality analogue cephalometric radiographs often give an even poorer image. This is important because poor-quality (digital) cephalometric radiographs influence the identification of landmarks.

The reliability of landmark identification using different digitizing techniques had been investigated in various studies. The phosphor plate technique was found to be slightly better for cephalometrics performed on printed digital pictures compared with digital pictures assessed on screen with 170 DPI, 8 bits, and TIF format (20, 56), When used a flatbed scanner for digitizing, Geelan et al (56) agreed that digital cephalometrics could produce better results using digital pictures of 150 DPI, 8 bits. On the other hand, all authors using a video camera to digitize the cephalometric radiographs (43, 73, 123) found poorer results for their digital technique compared with conventional cephalometric radiographs, using digital pictures with an unknown format and lower quality parameters, 65 DPI, 8 bits and ‘average’ original quality (123), 51 DPI, unknown grey shades (125), or unknown parameters (43). In the present study, pictures in high resolution (600 DPI) with a 24 bit 256 RBG were used. This was necessary because magnification should still be possible without pixelizing when using an average screen resolution of 117 DPI. Grey scale is also important, since identification of landmarks is most often based on evaluation of grey shades. The use of at least a 7-bit grey scale is mandatory because fewer grey shades may lead to unreliable decisions on reproducibility of measurements (126). The compression technique must also be taken into consideration since it could affect the grey scale or number of pixels. In the present study a ‘lossy’ compression technique (JPEG) was used. The JPEG format has been shown to have no effect on diagnostic accuracy in the field of thoracic imaging (127).

It is known that the greatest potential for error lies in the process of landmark identification (8). In general, the current study shows that the differences between the two imaging systems are of small magnitude and are unlikely to be of any clinical significance. This may be attributed to, (1) the rigorous selection criteria of the study, (2) only one observer, (3) good quality images were produced, (4) large sample size.

1.4 Camera and scanner setting

The results in this study demonstrated that there was no systematic error arising from with scanner or 3 digital cameras. The explanation could arise from the good setting of cameras and scanner.

Camera setting

In this study all cameras were set as follows:

1. Surface of lens should be paralled to the surface of film
2. Surface of lens should be flat (curve surface of lens is the source of distortion)
3. Increase camera –film distance should be the maximum as possible (65 cm)
4. Increase focal length of the lens (Telophoto)
5. Lens perpendicular to surface film

Scanner setting

In this study flat bed scanner was used. The scanner was set at 600dpi. The film was scanned at the same predetermined area each time.

1.5 LCD Flat screen monitor, Scanner, Digital camera

Monitor

In this study LCD flat screen monitor was used because flat screen monitor/ LCD Monitor (Anti-Reflection /Anti-Static Screen) eliminated or decreased error but it was more costly, while in curve screen monitor highest accuracy was found at the center of the monitor and the magnification increase toward the periphery of the monitor. In this study the monotor had small dot size 0.25 and maximum resolution

Scanner

The direct digital cephalogram can be conveniently integrated with computer-based filing system of patients’ records by scanning / photograph the traditional radiographic film. Ongkosuwito et al (42) demonstrated that the image quality of a cephalogram scanned at a resolution of 300 dpi is sufficient for clinical purposes and comparable to original analog cephalometrics. It has been suggested that the settings of resolution and grayscale or color when digitizing a cephalometric film by scanner does not significantly affect the precision of landmark identification when standard scanner settings are used. In this study 600 dpi resolution was used in order to be comparable to high resolution of digital cameras.

In this study, the results demonstrated a good subjective image quality without detrimental effect on the determination of the cephalometric analysis.

The results in this study was contrast to Hangiandreou and coworkers (127). They compared four different CCD-based film scanners and addressed the possible loss of information during scanning. The authors concluded that CCD scanners are not able to produce a reliable digital conversion of plain films because of their limitations in density range. However, these errors were eliminated from our study because the scanner and three digital cameras in this study were setting according to the results from the pilot study and the result of this study showed that the parameter setting for our digitized cephalogram was almost adequate in terms of performance of cephalometric analysis, which was demonstrated by the low level of measurement differences and the generally comparable systematic errors between original and digitized cephalometric image produced by scanner and cameras.

The findings of another study by Schulze and coworkers(128) were more or less in the same line, reporting a significant loss of information of scanned radiographs, particularly in the dark zones. They concluded that “whenever an x-ray film is digitized with a flat-bed scanner, possible information loss should be kept in mind and diagnostic conclusions should be considered carefully in this context”(128). Although it is probable that scanned radiographs may lose somewhat information, the results in this study showed adequate information obtained from 600 dpi scanner. Hence, cephalometric analysis of scanned image showed no significant difference when comparing to manual method.

Digital camera

When digital cameras became available, we quickly recognized the advantage of previewing the pictures immediately. This reduced not only the risk of getting bad images, but also the time spent taking them (because duplicates would no longer be necessary).When this advantage was recognized, initially, the image quality of a digital picture was equivalent to slide images from only a higher-end digital camera and scan images from a higher-end scanner, but the price of SLR cameras and scanner made them impractical for a group practice. Like everything in technology, digital cameras became better and less expensive over time (136). It is hard to know when curent technology is standard enough so that your equipment will not become obsolete, unable to be upgraded, and therefore unusable. The first digital camera that the department purchased was Nikon coolpix S4 (Nikon, Tokyo, Japan), which was soon replaced by the Nikon coolpix S5 and S6.

Digital images are captured by a digital camera on an image sensor that contains photosites (137). Photosites are light-sensitive diodes that convert light energy into electrical energy (138). The amount of detail or resolution of a digital camera is determined by the number of photosites present. In general, a pixel, a digital image term, is equivalent to a photosite in the digital camera (139). As the number of photosites in a digital camera and the number of pixels in a digital image increase, the higher the resolution of each, For example: a digital image with a resolution of 1024 X 768 has 1024 pixels in width and 768 pixels in height or a total of 786,432 pixels. A camera that, for example, produces a 2048 X 1536 digital image (2048 X 1536 = 3145,728 total pixels or approximately a 3 megapixel image) has a higher resolution. As the resolution increases, the file size of the digital image increases. For example, a 24-bit (16 million color) image with 3 megapixels has a file size equal to 9 megabytes (file size = total pixels X 3). Thus, the need for storage space on hardware such as hard drives, zip disks, and memory cards increases and can stress the capacity of orthodontic practices. Digital image files can be compressed to decrease the amount of storage space required. The most common type of compression is called JPEG (ISO/IEC JTC1 SC29 Working group 1). JPEG compression involves selectively removing some information from an image and can be done to various degrees. The different degrees of compression are functions of the camera and are labeled various ways by the manufacturer. In general, on the same camera, an image setting labeled fine is compressed less than a normal setting, which is compressed less than a basic setting. When an image is compressed by using a JPEG compression, the quality of the image is degraded, but the storage space requirement is reduced. Thus, more images of lesser quality will use the same amount of storage space.

In this present study, 3 digital cameras (Cannon EOS300D, Nikon coolpix S5, Panasonic Lumix DMC-Fx 01), were set according to a camera’s specification for cephalometric photography (Table 9) and a Epson 1680 flatbed scanner fitted with a transparency hood were used in this study. Each of the digital cameras had normal JPEG compression algorithms. The Canon EOS 300D (Japan: Canon Kiss Digital) had maximun resolutions of 3072 x 2048 setting The Nikon coolpix S5 (Nikon, Tokyo, Japan) had maximum resolutions of 2816 x 2112 setting and Panasonic Lumix DMC-Fx 01 had maximum resolutions of 2816x 2112 setting when the aspect ratio setting is 4:3. Digital pictures were taken with an auto adjustment. The compression technique must also be taken into consideration since it could affect the grey scale or number of pixels. In our study a compression technique (JPEG) was used. A comparison of cephalometric analysis using a Scanner and three digital cameras (SLR Cannon EOS 300D, Nikon coolpix S5 and Panasonic Lumix DMC-FX01) with conventional radiography demonstrated no statistically significant systematic error differences for all measurements.

Panasonic Lumix DMC-Fx 01 had one special property. It had double anti-shake or high sensitivity (Mega O.I.S system (Optical image stabilizer)). This property can help film sharpness when photography and may reduce the use of the camera holding stand needed for film photography.

1.6 Computerized cephalometric program

Table13 demonstrates internal consistency among five methods. The statistical analysis, showed that no statistically significant difference was observed among 5 methods. The results implied that the software program (Ceph Smile plus version 2.0.1) with the special tool to ease locating the landmark has sufficient accuracy in this study. The maximum consistency among methods were ***SNB*** in angular measurement and ***PFH/AFH X100%*** in linear measurement and the minimum consistency among methods were ***Ī-NB, Max-mand diff*** in linear measurements and ***Nasolabial angle*** in angular measurement. The statistical analysis, showed that none of the cephalometric variables attained a statistically significant level (*P*<0·05). The cephalometric measurements of high consistency among methods were composed of several anatomical landmarks such as: ***Sella, Nasion, B point, Gonion, Menton.*** Ceph Smile plus program has a special feature to help locate these landmarks by offering the automatic line or automatic bisecting of the angle. This outstanding features benefit the reproducibility of these landmarks location. Thus, the results showed a high consistency of measurements relating to these anatomical landmarks. The lowest consistency among methods were ***ī-NB, Max-mand diff*** in linear measurements and ***Nasolabial angle*** in angular measurement. These measurements were composed of several anatomical landmarks such as: Lower incisor apex and its edge, Condylar, Point A, Gonion, Pg, Menton. The difficulty of identification is compounded by granularity of the computed image. This is due to increased noise, subsequent to digital enhancement. Due to the radiopacity and definite sharp bend (in contrast to contour or curve) of the dental landmarks, the localization is more consistent. Root tips are more variable, compared to crown tips. As a radiograph is a two dimensional representation of a three-dimensional object, the incisal roots overlap one another, creating a composite image, making the localization more difficult. Similar report by Naslund (12); the articular point, incisor inferior, incisor superior and the apices of the upper and lower incisor are point with a larger degree of superimposition from other structures. Area of Condylion with radio-opaque structure had a greater margin of error in identification than landmarks located on surface of the skull was also reported by Scott et.al (130).

In summary, the lowest consistency among methods may arise from landmark identification of lower incisors and condylion. For the Nasolabial angle, the landmark involved contour or curve, the localization therefore seemed to be less consistent.

Reliability is an important aspect of measurement. If a measure cannot be reproduced consistently, then the value (cost, time, and patient treatment decisions) of the methodology is questionable. In a clinical situation such as orthodontics, a reproducibility that is within 1° or 1 mm will probably not make a difference in treatment. Standard deviation can be used as a parameter to indicate variability in measurement of central tendency. The standard deviations are the same, but the absolute values of the two parameters are distinctly different. The difference for hand tracing and the other modalities (Scanner and digital camera) were equal to or less than 1 mm, 1 degree suggesting a reasonably high level of intra-observer reliability. Similar to other authors (4, 8) who identified the root apices of incisors to be among the least reliable landmarks, we found that a parameter (L1-NB mm) that included the lower incisor root apices had the high mean difference. However, other parameters (eg, L1-NB degree, and $\underline{1}$-$\overline{1}$ degree) that include landmarks using incisor roots had acceptable reproducibility. The overlaping of the roots of multiple incisors make exact identification of the apices difficult. Accuracy is difficult to ascertain in cephalometrics, much less compare among modes of image capture and measurement techniques. If the manually traced conventional cephalogram is used as a reference, then comparison can be made among the groups. Again, a difference less than 1° or 1 mm in means does not appear to cause a clinical difference in classification or treatment decisions in most of the parameters. Thus, there appear to be few differences in the means among the groups.

Other variables that could have influenced landmark identification included the type of registration pointer used in the different software programs. Dolphin uses a crosshair cursor while Ceph Smile program use a conventional pointer that may obscure the landmark. Other authors (52) related the same difficulties with the cursor obscuring landmarks.

Some differences between digital and scanned images could be related to the scanning protocol since the digital images were saved using a gray scale image while the scanned images were saved as RGB color images. However, this did not appear to alter the image quality enough to enhance nor hinder landmark identification. In addition, other research (131) revealed that resolution setting and grayscale versus color when scanning radiographs does not matter significantly when standard settings are used.

As technology progresses, it becomes increasingly difficult to determine if there is adequate evidence to assess the efficacy of the technology before it becomes commercially available. Although a multitude of cephalometric analysis software programs have been on the market for several years, there are few studies (2) comparing their reliability and the similarity of measures across the programs. There are also few studies determining if there are differences between different versions of cephalometric analysis software. It can be difficult for the practitioner to select technology that is reliable and accurate unless appropriate studies are available. This study provides a basis for evaluation of the software programs and digital and conventional cephalometric imaging. Further studies in this area will, no doubt, improve our knowledge about the risks and limitations of digtal technology. But, for now, the orthodontic office can depend on digital technology imaging and analysis with Ceph Smile software.

2.) Effect of scanner and digital camera on cephalometric measurements

Table 15 describes the deviation from the Manual mean ($\bar{x}$ and SD) in millimeters and degree for each method by one observer for each cephalometric measurement which comprised 34 parameters (15 linear and 19 angular measurements). The results showed that most of the parameters had measurement difference that were less than 0.25 mm and 0.25 degrees. Only few parameters showed higher than 0.50 mm and 0.50 degree. Because no significant difference in mean difference was found (Table 14) it can be concluded in this study that digital cephalometry (with scanner, digital cameras and Ceph Smile Plus program) is comparable to analogue cephalometry (Manual tracing and measurement).

Table 16 presents Pearson’s correlation coefficients between 2 methods (manual vs. scanner, manual vs Canon, manual vs. Nikon, manual vs. Panasonic). Most parameters had $r > 0.9$. All parameter had $r > 0.8$. The results confirm that a scanner and 3 digital cameras used in this study were reliable enough comparable to manual technique. However, Panasonic digital camera seemed to be slightly inferior (7 parameters had $r < 0.9$) to others.

Clinical Implication

Several studies reported about the relationship between landmark identification and quality of radiographic image. One of the efforts to improve the precision of landmark identification should be directed toward improvement in the image quality. In addition, investigator should be trained in digital cephalometry in order to reduce the error and improve the reliability in landmark identification. The camera setting in this study with a suitable distance could provide a guidance in choosing the digital camera for capturing cephalometric image.

A radiographic film is analogue image in which a continuous gray level represents elements. A digital image is composed of many picture elements (Pixels). The quality of a digital image strongly depends on both the number of pixels and the number of gray levels. Macri and Wenzel (135) reported that the reliability of landmark identification on digital images with pixels size of 0.47 mm was inferior to those on conventional radiographs .However, Cohen and Linnney (9) reported that a digital cephalogram with higher spatial resolution (pixel size = 0.03 mm) can yield greater reliability than the original radiographs with conventional equipment. The cephalometric radiographs used in this study were randomly selected and represented a good quality of daily routine work. The image resolution setting of scanner was 600 dpi with the pixel size of 0.04, maximum resolution on 3 digital cameras also resulted in small pixel sizes (pixel size=0.176 (Nikon), 0.176 (Panasonic), 0.166 (Cannon), See Table 17).

With the aid of Ceph Smile, several construction of lines or planes may be very helpful during locating landmarks. For example, “A-point = The deepest point in the concavity of the anterior maxilla between the anterior nasal-spine and the alveolar crest, B-point = The deepest point in the concavity of the anterior mandible between the alveolar crest and Pogonion, Gn = A Point on Chin contour, the point between the Sella to NPg bisecting to Mandibular plane between Pg and Me”

CHAPTER 7

CONCLUSION

This study compared the results of cephalometric analysis using manual and direct on-screen digitization. The method of direct digitized of the X-rays was undertaken by a scanner and three cameras.

Findings were:

1. There was no significant difference in intraobserver reliability of cephalometric measurements among five methods.
2. Scanning of cephalometric radiographs at a resolution of 600 DPI in this study is sufficient for clinical purposes and comparable to analogue cephalometrics.
3. Digital pictures of cephalometric radiographs at high resolution from either SLR or compact cameras is sufficient for clinical purpose and comparable to analogue cephalometrics
4. The differences between the measurements derived from the landmarks identified on original cephalometric radiographs and those identified on their digitized counterparts were not statistically significant.
5. The results of our study substantiate the benefit of digital cephalometry in terms of the reliability of cephalometric analysis.
6. Orthodontists who are using cameras according to this study are able to capture cephalometric radiographs and import the image into Ceph Smile Plus Version 2.0.1 Program. The cameras setting should be set at maximum resolution with an object to camera distance at 65 cm (The maximum distance of object to camera distance which show without distortion).
7. Orthodontists who are going to purchase any digital camera should calibrate the optimal distance by using a known dimension object before performing image capture in digital cephalometry.

Limitation and Suggestion

Limitation

As technology becomes advance with time, it is difficult to know how long the technology we are using is going to become obsolete. For example, with the 2-year period of this study, Nikon Coolpix S4 was replaced by Nikon Coolpix S5, S6, S8, S9, S10.The results of this study may become obsolete sooner of later due to advancement in technology.

Suggestion

In the future trend, Mahidol University may utilize digital X-ray machines, it would be interesting to test the accuracy of digital cephalometry in combination with Ceph Smile Plus Program.

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APPENDIX

Table 17: Manual method: Systematic difference between first and second measurement

	Linear measurements				T1		T2		T1-T2		
	(n=20)		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
1	1-NB	(mm)	8.75	2.88	9.22	2.16	8.93	2.10	0.29	0.24	NS
2	1-NA	(mm)	7.14	2.75	7.93	2.47	7.58	2.46	0.35	0.10	NS
3	Post.max.alv.ht	(mm)	22.63	2.34	23.28	2.20	23.15	2.37	0.13	0.41	NS
4	Max-mand diff	(mm)	30.86	6.44	30.92	6.20	30.95	6.34	-0.03	0.37	NS
5	Overjet	(mm)	4.77	1.90	5.32	1.43	5.25	1.32	0.07	0.33	NS
6	Pg-NB	(mm)	1.38	1.11	1.77	1.65	1.84	1.59	-0.07	1.57	NS
7	AO-BO	(mm)	0.28	4.09	1.11	3.38	1.00	3.30	0.11	0.28	NS
8	Co-Gn	(mm)	119.80	8.69	116.62	7.59	116.60	7.37	0.02	0.47	NS
9	PFH/AFH X 100%		63.85	3.82	63.07	3.37	63.19	3.77	-0.12	0.63	NS
10	100%(N-ANS) /(ANS'-Me)		83.56	7.02	82.65	6.32	82.74	6.12	-0.09	0.45	NS
11	Overbite	(mm)	4.47	1.86	4.30	1.56	4.28	1.22	0.02	0.58	NS
12	Ant.max.alv.ht	(mm)	30.52	3.13	30.24	2.80	30.27	2.83	-0.03	0.17	NS
13	E-plane	(mm)	4.32	3.07	5.44	2.58	5.40	2.25	0.04	0.57	NS
14	Co-A	(mm)	89.01	7.05	85.62	3.43	85.57	3.21	0.05	0.47	NS
15	AF-BF-mm	(mm)	7.61	4.75	7.87	4.80	7.81	4.78	0.06	0.14	NS
	Angular measurements										
1	Mand-angle	(degree)	121.00	6.10	122.10	6.12	122.13	6.04	-0.03	0.28	NS
2	ANB	(degree)	4.45	2.30	4.91	1.82	4.79	1.96	0.12	0.37	NS
3	FH-SN	(degree)	9.00	2.50	6.93	2.92	6.90	0.35	0.03	0.27	NS
4	Nasolabial angle	(degree)	88.00	13.00	85.89	12.61	85.78	12.69	0.11	0.28	NS
5	FH-FO	(degree)	10.50	3.75	10.27	4.00	10.30	3.85	-0.03	3.81	NS
6	NS-MP	(degree)	35.00	5.50	35.85	5.84	35.83	5.76	0.02	0.28	NS
7	MP-PP	(degree)	27.00	5.30	27.92	5.36	27.91	5.24	0.01	0.35	NS
8	NSBa	(degree)	128.00	4.50	127.75	4.65	126.80	4.65	1.00	0.00	NS
9	1 -1	(degree)	113.00	9.60	110.87	8.12	111.20	8.38	-0.33	0.51	NS
10	1-NA	(degree)	28.00	6.35	29.90	4.84	29.68	4.78	0.22	0.24	NS
11	1-NB	(degree)	33.00	6.25	34.36	5.73	34.34	5.55	0.02	0.42	NS
12	NS-PP	(degree)	8.00	2.85	7.89	2.93	7.92	2.50	-0.03	0.66	NS
13	1-MP	(degree)	99.00	7.40	99.36	7.24	99.24	7.35	0.12	0.33	NS
14	H-ANGLE	(degree)	16.00	4.05	17.43	3.89	17.51	3.71	-0.08	0.42	NS
15	SNB	(degree)	79.00	4.00	78.74	4.32	78.75	4.48	-0.01	0.40	NS
16	NS-Gn	(degree)	69.00	3.95	69.57	4.45	69.58	4.81	-0.01	0.60	NS
17	SNA	(degree)	84.00	3.50	83.93	3.88	83.98	3.91	-0.05	0.17	NS
18	1-SN	(degree)	112.50	7.55	113.10	6.45	113.20	6.23	-0.10	0.47	NS
19	SNPg	(degree)	80.00	3.80	79.16	4.14	79.02	4.31	0.14	0.41	NS

NS = Non-significant, T1= First manual measurement, T2= Second manual measurement, T1-T2=Difference of 1st and 2nd manual measurement

Table18: Scanner method: Systematic difference between first and second measurement

	Linear measurements				T1		T2		T1-T2		
	(n=20)		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
1	1-NB	(mm)	8.77	2.83	9.24	2.36	9.03	2.30	0.21	0.37	NS
2	1-NA	(mm)	7.13	3.12	7.90	2.67	7.68	2.66	0.21	0.39	NS
3	Post.max.alv.ht	(mm)	22.90	2.43	23.38	2.40	23.25	2.36	0.13	0.38	NS
4	Max-mand diff	(mm)	30.93	6.22	30.94	6.51	31.05	6.54	-0.11	0.42	NS
5	Overjet	(mm)	5.16	1.67	5.37	1.42	5.27	1.52	0.09	0.42	NS
6	Pg-NB	(mm)	1.34	1.06	1.87	1.85	1.81	1.79	0.06	0.34	NS
7	AO-BO	(mm)	0.37	3.98	1.16	3.69	1.10	3.61	0.06	0.35	NS
8	Co-Gn	(mm)	119.79	8.83	116.72	7.56	116.65	7.57	0.07	0.43	NS
9	PFH/AFH X 100%		63.88	3.76	63.17	3.57	63.24	3.76	-0.07	0.43	NS
10	100%(N-ANS) /(ANS'-Me)		83.24	7.75	82.70	6.52	82.76	6.43	-0.06	0.43	NS
11	Overbite	(mm)	4.34	1.85	4.27	1.55	4.25	1.53	0.02	0.37	NS
12	Ant.max.alv.ht	(mm)	30.43	2.76	30.34	3.00	30.32	3.03	0.02	0.44	NS
13	E-plane	(mm)	4.39	3.03	5.46	2.58	5.45	2.56	0.01	0.38	NS
14	Co-A	(mm)	89.12	6.99	85.67	3.59	85.67	3.41	-0.01	0.44	NS
15	AF-BF-mm	(mm)	7.70	4.74	7.92	5.11	7.91	5.09	0.01	0.45	NS
	Angular measurements										
1	Mand-angle	(degree)	121.32	6.00	122.20	6.32	122.23	6.24	-0.03	0.28	NS
2	ANB	(degree)	4.62	1.98	4.93	2.13	4.84	2.16	0.08	0.26	NS
3	FH-SN	(degree)	6.79	2.64	7.04	3.23	7.01	3.24	0.04	0.33	NS
4	Nasolabial angle	(degree)	88.65	13.32	85.86	12.92	85.83	13.00	0.03	0.34	NS
5	FH-FO	(degree)	10.34	3.73	10.29	3.99	10.40	4.05	-0.11	0.34	NS
6	NS-MP	(degree)	34.57	5.49	35.90	6.04	35.93	6.07	-0.03	0.38	NS
7	MP-PP	(degree)	26.69	5.18	27.97	5.56	28.01	5.55	-0.04	0.39	NS
8	NSBa	(degree)	128.42	4.53	127.82	4.96	127.84	4.96	-0.02	0.39	NS
9	1 -1	(degree)	112.88	9.55	110.92	8.32	111.17	8.37	-0.26	0.29	NS
10	1-NA	(degree)	28.84	6.24	29.87	5.04	29.78	4.98	0.09	0.40	NS
11	1-NB	(degree)	33.26	6.46	34.38	5.93	34.31	5.75	0.07	0.40	NS
12	NS-PP	(degree)	7.90	2.72	7.99	2.92	7.97	2.81	0.01	0.41	NS
13	1-MP	(degree)	98.98	7.41	99.38	7.44	99.34	7.55	0.04	0.41	NS
14	H-ANGLE	(degree)	16.58	4.38	17.45	4.09	17.61	3.91	-0.16	0.40	NS
15	SNB	(degree)	79.32	4.04	78.79	4.63	78.85	4.68	-0.06	0.43	NS
16	NS-Gn	(degree)	69.21	3.96	69.62	4.65	69.60	4.80	0.02	0.43	NS
17	SNA	(degree)	83.82	3.49	84.05	4.08	84.15	4.11	-0.11	0.42	NS
18	1-SN	(degree)	112.58	7.52	113.15	6.53	113.17	6.43	-0.02	0.46	NS
19	SNPg	(degree)	79.76	3.77	79.21	4.45	79.04	4.62	0.17	0.42	NS

NS = Non-significant, T1 = First measurement, T2 = Second measurement, T1-T2 = Difference of 1st and 2nd measurement

Table19: SLR camera method (Canon EOS 300D): Systematic difference between first and second measurement

	Linear measurements				T1		T2		T1-T2		
	(n=20)		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
1	1-NB	(mm)	8.76	2.82	7.51	2.83	7.58	2.91	-0.07	-0.08	NS
2	1-NA	(mm)	7.23	2.99	7.80	2.67	7.67	2.64	0.13	0.03	NS
3	Post.max.alv.ht	(mm)	22.90	2.45	23.33	2.38	23.25	2.36	0.08	0.02	NS
4	Max-mand diff	(mm)	30.26	6.13	30.94	6.38	30.95	6.46	0.00	-0.08	NS
5	Overjet	(mm)	5.02	1.71	5.37	1.42	5.26	1.55	0.10	-0.13	NS
6	Pg-NB	(mm)	1.30	1.01	1.86	1.85	1.81	1.79	0.05	0.06	NS
7	AO-BO	(mm)	0.26	3.99	1.16	3.69	1.10	3.61	0.06	0.08	NS
8	Co-Gn	(mm)	120.04	8.87	116.75	7.55	116.65	7.57	0.11	-0.03	NS
9	PFH/AFH X 100%		63.92	63.92	4.00	63.17	3.57	63.24	3.76	-0.07	NS
10	100%(N-ANS) /(ANS'-Me)		82.87	7.05	82.70	6.52	82.68	6.45	0.02	0.08	NS
11	Overbite	(mm)	4.41	1.85	4.26	1.58	4.20	1.52	0.06	0.06	NS
12	Ant.max.alv.ht	(mm)	30.83	3.50	30.32	2.97	30.27	2.98	0.05	-0.01	NS
13	E-plane	(mm)	4.45	3.05	5.48	2.55	5.40	2.53	0.08	0.02	NS
14	Co-A	(mm)	89.08	6.94	85.67	3.59	85.67	3.41	-0.01	0.18	NS
15	AF-BF-mm	(mm)	7.60	4.78	7.82	5.02	7.88	5.09	-0.06	-0.07	NS
	Angular measurements										
1	Mand-angle	(degree)	121.38	5.79	122.10	6.31	122.15	6.28	-0.05	0.42	NS
2	ANB	(degree)	4.55	2.10	4.50	2.59	4.45	2.66	0.05	0.59	NS
3	FH-SN	(degree)	6.94	2.62	6.88	3.22	7.00	3.24	-0.13	0.06	NS
4	Nasolabial angle	(degree)	88.81	13.48	85.68	12.85	85.75	12.97	-0.08	0.27	NS
5	FH-FO	(degree)	10.31	3.73	10.13	4.02	10.25	4.07	-0.13	0.05	NS
6	NS-MP	(degree)	34.59	5.48	35.80	6.05	35.78	6.04	0.02	0.79	NS
7	MP-PP	(degree)	26.89	5.27	27.85	5.59	27.95	5.57	-0.10	0.20	NS
8	NSBa	(degree)	128.44	4.43	127.75	4.94	127.76	4.99	0.00	0.94	NS
9	1 -1	(degree)	112.98	9.73	110.75	8.29	110.98	8.43	-0.22	0.05	NS
10	1-NA	(degree)	28.58	6.19	29.73	5.06	29.65	4.98	0.08	0.28	NS
11	1-NB	(degree)	33.33	6.32	34.23	5.83	34.20	5.77	0.02	0.67	NS
12	NS-PP	(degree)	7.81	2.88	7.90	2.90	7.93	2.82	-0.02	0.81	NS
13	1-MP	(degree)	99.26	7.30	99.30	7.43	99.28	7.48	0.02	0.78	NS
14	H-ANGLE	(degree)	16.64	4.27	17.28	4.15	17.45	4.03	-0.18	0.05	NS
15	SNB	(degree)	79.33	4.01	78.73	4.58	78.82	4.72	-0.10	0.25	NS
16	NS-Gn	(degree)	69.10	4.05	69.50	4.64	69.48	4.77	0.03	0.85	NS
17	SNA	(degree)	83.73	3.54	83.93	4.14	83.98	4.16	-0.05	0.58	NS
18	1-SN	(degree)	112.48	7.39	113.09	6.59	113.00	6.47	0.09	0.20	NS
19	SNPg	(degree)	79.75	3.83	79.03	4.50	78.85	4.61	0.18	0.02	NS

NS = Non-significant, T1 = First measurement, T2 = Second measurement, T1-T2 = Difference of 1st and 2nd measurement

Table20: Digital compact camera method (Nikon Coolpix S5): Systematic difference between first and second measurement

	Linear measurements				T1		T2		T1-T2	
	(n=20)		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
1	1-NB	(mm)	8.62	2.69	9.18	2.31	9.09	2.34	0.09	-0.03	NS
2	1-NA	(mm)	7.11	2.81	7.78	2.66	7.67	2.64	0.12	0.02	NS
3	Post.max.alv.ht	(mm)	22.70	2.38	23.33	2.38	23.20	2.41	0.13	-0.03	NS
4	Max-mand diff	(mm)	30.29	6.30	30.94	6.38	30.79	6.36	0.15	0.02	NS
5	Overjet	(mm)	4.91	1.56	5.37	1.42	5.21	1.41	0.15	0.02	NS
6	Pg-NB	(mm)	1.24	1.01	1.80	1.82	1.81	1.79	-0.01	0.03	NS
7	AO-BO	(mm)	0.26	3.73	3.69	1.16	3.76	1.01	-0.07	0.14	NS
8	Co-Gn	(mm)	118.97	8.51	116.75	7.55	116.54	7.61	0.22	-0.06	NS
9	PFH/AFH X 100%		63.86	3.80	63.17	3.57	63.09	3.73	0.07	-0.16	NS
10	100%(N-ANS) /(ANS'-Me)		82.99	6.70	82.70	6.52	82.50	6.55	0.20	-0.02	NS
11	Overbite	(mm)	4.20	1.78	4.26	1.58	4.17	1.54	0.09	0.04	NS
12	Ant.max.alv.ht	(mm)	29.71	3.25	30.32	2.97	30.29	2.94	0.03	0.03	NS
13	E-plane	(mm)	4.34	3.04	5.46	2.54	5.46	2.54	0.00	0.00	NS
14	Co-A	(mm)	89.13	6.85	85.67	3.59	85.67	3.41	-0.01	0.18	NS
15	AF-BF-mm	(mm)	6.99	4.73	7.82	5.02	7.79	5.11	0.03	-0.09	NS
	Angular measurements										
1	Mand-angle	(degree)	121.81	5.61	122.10	6.31	122.01	6.31	0.09	0.00	NS
2	ANB	(degree)	4.33	2.28	4.50	2.59	4.34	2.70	0.16	-0.11	NS
3	FH-SN	(degree)	6.84	2.60	6.89	3.22	7.04	3.22	-0.14	0.01	NS
4	Nasolabial angle	(degree)	88.07	12.53	85.68	12.85	85.70	12.98	-0.03	-0.13	NS
5	FH-FO	(degree)	10.17	3.77	10.13	4.02	10.07	3.94	0.06	0.08	NS
6	NS-MP	(degree)	34.54	5.23	35.80	6.05	35.64	5.97	0.16	0.08	NS
7	MP-PP	(degree)	26.64	5.19	27.85	5.59	27.74	5.69	0.11	-0.09	NS
8	NSBa	(degree)	128.52	4.32	127.75	4.94	127.73	4.97	0.02	-0.03	NS
9	1 -1	(degree)	112.84	9.03	110.75	8.29	110.77	8.35	-0.02	-0.05	NS
10	1-NA	(degree)	28.77	5.90	29.73	5.06	29.56	5.03	0.16	0.03	NS
11	1-NB	(degree)	33.27	6.34	34.23	5.83	34.14	5.74	0.08	0.09	NS
12	NS-PP	(degree)	7.76	2.78	7.90	2.90	7.93	2.82	-0.02	0.08	NS
13	1-MP	(degree)	99.50	7.34	99.30	7.43	99.24	7.47	0.06	-0.04	NS
14	H-ANGLE	(degree)	16.37	4.28	17.28	4.15	17.38	4.00	-0.11	0.15	NS
15	SNB	(degree)	79.48	3.90	78.68	4.59	78.82	4.72	-0.14	-0.13	NS
16	NS-Gn	(degree)	68.87	3.89	69.50	4.64	69.39	4.76	0.11	-0.13	NS
17	SNA	(degree)	83.84	3.44	83.93	4.14	83.98	4.16	-0.04	-0.02	NS
18	1-SN	(degree)	112.51	7.18	113.08	6.56	113.03	6.45	0.05	0.11	NS
19	SNPg	(degree)	79.86	3.72	78.95	4.46	78.85	4.61	0.10	-0.14	NS

NS = Non-significant, T1 = First measurement, T2 = Second measurement, T1-T2 = Difference of 1st and 2nd measurement

Table21: Digital compact camera method (Panasonic Lumix Fx-01): Systematic difference between first and second measurement

	Linear measurements				T1		T2		T1-T2		
	(n=20)		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
1	1-NB	(mm)	8.90	2.69	9.18	2.31	9.07	2.33	0.11	0.49	NS
2	1-NA	(mm)	7.30	2.72	7.78	2.66	7.67	2.64	0.12	0.35	NS
3	Post.max.alv.ht	(mm)	22.80	2.22	63.22	3.58	63.24	3.76	-0.02	-1.31	NS
4	Max-mand diff	(mm)	30.83	6.36	122.13	6.35	122.15	6.28	-0.03	-0.15	NS
5	Overjet	(mm)	5.01	1.86	5.35	1.45	5.26	1.55	0.08	0.16	NS
6	Pg-NB	(mm)	1.49	1.45	1.81	1.85	1.81	1.79	0.00	-0.78	NS
7	AO-BO	(mm)	0.35	3.94	1.16	3.69	1.05	3.74	0.11	0.25	NS
8	Co-Gn	(mm)	120.03	8.61	116.75	7.55	116.65	7.57	0.11	1.30	NS
9	PFH/AFH X 100%		63.87	3.65	63.22	3.58	63.24	3.76	-0.02	0.24	NS
10	100%(N-ANS) /(ANS'-Me)		82.82	7.31	82.70	6.52	82.66	6.44	0.04	0.61	NS
11	Overbite	(mm)	4.29	1.76	4.26	1.58	4.20	1.52	0.06	0.33	NS
12	Ant.max.alv.ht	(mm)	31.16	5.42	30.32	2.97	30.27	2.98	0.05	0.52	NS
13	E-plane	(mm)	4.45	2.97	5.48	2.55	5.40	2.53	0.08	0.52	NS
14	Co-A	(mm)	89.08	6.79	85.67	3.59	85.63	3.48	0.04	3.46	NS
15	AF-BF-mm	(mm)	7.47	4.58	7.82	5.02	7.88	5.09	-0.06	-0.31	NS
	Angular measurements										
1	Mand-angle	(degree)	121.34	5.49	122.13	6.35	122.15	6.28	-0.03	-0.79	NS
2	ANB	(degree)	4.37	2.19	4.51	2.59	4.50	2.58	0.01	-0.39	NS
3	FH-SN	(degree)	6.99	2.54	6.94	3.24	6.95	3.23	-0.01	-0.69	NS
4	Nasolabial angle	(degree)	87.58	12.80	85.68	12.85	85.75	12.97	-0.08	-0.17	NS
5	FH-FO	(degree)	10.01	3.55	10.14	4.01	10.25	4.07	-0.11	-0.52	NS
6	NS-MP	(degree)	34.27	5.05	35.75	6.03	35.83	5.95	-0.08	-0.90	NS
7	MP-PP	(degree)	26.74	4.88	27.85	5.59	27.90	5.62	-0.05	-0.74	NS
8	NSBa	(degree)	128.25	4.39	127.78	4.91	127.68	4.96	0.10	-0.57	NS
9	1 -1	(degree)	112.60	9.37	110.76	8.31	110.98	8.43	-0.21	0.94	NS
10	1-NA	(degree)	28.46	5.98	29.73	5.06	29.65	4.98	0.08	1.00	NS
11	1-NB	(degree)	33.34	6.35	34.23	5.83	34.20	5.77	0.02	0.58	NS
12	NS-PP	(degree)	7.57	2.79	7.85	2.93	7.93	2.82	-0.08	-0.03	NS
13	1-MP	(degree)	99.33	7.40	99.30	7.43	99.25	7.47	0.05	-0.07	NS
14	H-ANGLE	(degree)	16.30	4.26	17.28	4.15	17.45	4.03	-0.18	0.23	NS
15	SNB	(degree)	79.28	3.80	78.73	4.58	78.77	4.70	-0.05	-0.90	NS
16	NS-Gn	(degree)	68.85	3.90	69.50	4.64	69.51	4.64	0.00	-0.74	NS
17	SNA	(degree)	84.03	3.74	83.88	4.12	83.98	4.16	-0.10	-0.42	NS
18	1-SN	(degree)	112.19	6.93	113.08	6.56	113.00	6.47	0.08	0.46	NS
19	SNPg	(degree)	79.53	3.66	79.03	4.50	78.88	4.59	0.15	-0.93	NS

NS = Non-significant, T1 = First measurement, T2 = Second measurement, T1-T2 = Difference of 1st and 2nd measurement

Table22: The method error of the measurement

			Method error: Dahlberg’s formula.				
	Linear measurements (n=20)		Manual	Scanner	SLRCanon	Nikon	Panasonic
1	1-NB	(mm)	0.81	0.50	0.64	0.84	0.87
2	1-NA	(mm)	0.95	0.61	0.57	0.64	0.62
3	Post.max.alv.ht	(mm)	0.86	0.78	0.74	0.68	0.79
4	Max-mand diff	(mm)	0.92	0.87	0.90	0.95	0.88
5	Overjet	(mm)	0.94	0.76	0.77	0.79	0.77
6	Pg-NB	(mm)	0.74	0.52	0.66	0.58	0.53
7	AO-BO	(mm)	0.77	0.66	0.65	0.74	0.67
8	Co-Gn	(mm)	0.91	0.89	0.84	0.74	0.90
9	PFH/AFH X 100%		0.93	0.84	0.42	0.46	0.44
10	100%(N-ANS) /(ANS'-Me)		0.80	0.78	0.66	0.69	0.79
11	Overbite	(mm)	0.84	0.75	0.81	0.71	0.76
12	Ant.max.alv.ht	(mm)	0.91	0.85	0.85	0.84	0.86
13	E-plane	(mm)	0.83	0.74	0.77	0.69	0.75
14	Co-A	(mm)	0.95	0.87	0.94	0.88	0.97
15	AF-BF-mm	(mm)	0.97	0.69	0.84	0.66	0.70
	Angular measurements						
1	Mand-angle	(degree)	0.66	0.65	0.55	0.47	0.87
2	ANB	(degree)	0.65	0.54	0.53	0.61	0.67
3	FH-SN	(degree)	0.91	0.62	0.75	0.94	0.88
4	Nasolabial angle	(degree)	0.84	0.79	0.81	0.88	0.91
5	FH-FO	(degree)	0.80	0.88	0.73	0.61	0.95
6	NS-MP	(degree)	0.84	0.54	0.77	0.65	0.61
7	MP-PP	(degree)	0.85	0.47	0.78	0.66	0.54
8	NSBa	(degree)	0.83	0.64	0.76	0.64	0.71
9	1 -1	(degree)	0.91	0.80	0.84	0.72	0.87
10	1-NA	(degree)	0.83	0.67	0.76	0.64	0.74
11	1-NB	(degree)	0.54	0.56	0.47	0.35	0.63
12	NS-PP	(degree)	0.85	0.55	0.78	0.66	0.62
13	1-MP	(degree)	0.85	0.74	0.78	0.66	0.81
14	H-ANGLE	(degree)	0.80	0.36	0.73	0.61	0.43
15	SNB	(degree)	0.50	0.52	0.51	0.57	0.64
16	NS-Gn	(degree)	0.57	0.70	0.59	0.47	0.81
17	SNA	(degree)	0.58	0.40	0.63	0.51	0.47
18	1-SN	(degree)	0.68	0.33	0.64	0.52	0.40
19	SNPg	(degree)	0.78	0.66	0.62	0.50	0.57

Table 23: Show the comparison study of digital image for cephalometric analysis

Author	Present study, 2006		Ongkosuwito 2002	Held 2001	Chen 2000,04	Forsyth 1996	Macri 1993	Cohen 1986	Gray 1984
Type	Digital image								
	Digital Camera	Scanner	Scanner	Scanner	Scanner	VDO Camera	B/W VDO camera	TV Camera	TV Camera
Grey levels	(24-bit color) 256 color RBG	(24 bit-color) 256 color RBG	(36-bit) 256 gray scale 256 color RBG	(36-bit) 256 gray scale 256 color RBG	(6 bit) 64 gray levels	(6-bit) 64 grey levels	(8-bit) 256 grey levels		(6 bit) 64 gray levels
Pixel size (mm.)	0.176 (N&P) 0.166(C)	0.04 (25/600)	0.08,0.042 (25/300) (25/600)	1.02,0.51, 0.64,0.51	0.17 (25/150)	0.35	0.39	0.03	No larger than 0.1 mm
Pixel matrix	1024X1024	1024X1024	1024X1024	1024X1024	512 x 512	512x512	512 x 512	512x512	Minimum =512 x 512
Monitor resolution	1024x768 Pixel resolution								
Resolution (Scanner/ camera)	2816x2112 6.00 M 2816x2112 6.00 M 3072x2048 6.3 M	600 dpi	300dpi , 600dpi	5,200,400, 600 dpi B&W 75,200,400 dpi color	150 dpi				

Table23: Show the comparison study of digital image for cephalometric analysis (Cont.)

Author	Present study, 2006		Ongkosuwito 2002	Held 2001	Chen 2000,04	Forsyth 1996	Macri 1993	Cohen 1986	Gray 1984
Type	Digital image								
	Digital Camera	Scanner	Scanner	Scanner	Scanner	VDO Camera	B/W VDO camera	TV Camera	TV Camera
Suggest			300dpi sufficient for clinical purposes & comparable to original analog cephalometrics. However, this method was found to be poor in assessing skeletal jaw relationship longtitudinary. It has been suggested that the settings of resolution and grayscale/ color when digitizing a cephalometric film by scanner does not significantly affect the precision of landmark identification when standard scanner settings are used	Precise landmark identification when resolution was relative high	Digital image in pixel size 0.17 substain the benefit of digital ceph. in terms of the reliability of ceph.	Larger than 512x512 pixel & more than 64 gray level	Suggest pixel matrix 1024x1024 accepted result with digital ceph.		Smallest detail (of digital image) with comparable with original conventional radiograph

Table 24: Show the good image qulity can improve precision of land mark identification

Present study 2006	Agreement with	Disagreement with	
Reliability in digital images was comparable to that obtained with conventional equipment for radiographs with good quality.	1978,McWilliams &Welander 1978,Oka & Trussel 1983, Houston 1984,1988,Ishida et al 1989b,Jager et al 1990,1991,Wenzel et al 1991,Eppley BL. 1993Macri & Wenzel. 1985,1998,Jackson et al	1966, Richardson 1971, Baumrind & Frantz 1998, Geelen et al. Reported that the precision of landmark recording was lower for *enhanced monitor-displayed images* than for both *film* and *digitally enhanced hardcopies* in 11 of 21 landmarks.	
		Sig. Difference	Comparable
		1. Sp=ANS*	12. S
		2. Spn=PNS*	13. N
		3. Ss =A-point*	14. Pr
		4. Ar=articular*	15. Is
		5. Ms=molar sup. *	16. Ii
		6. Ai=apex inc. infer. *	17. Id 18. Pg
		7. Gn*Mp=Go*	19. Ar
		8. Mi=molar inf. *	20. Or
		9. Sm=B-point*	21. Po
		10. Ba*	

Table 25: Show similarity and difference in SNB measurement

1999 Kenneth et al DigiGraph	2004 M.D.Gregston et.al	2004 Chen,Chen, Yao,Chang	2006 Present study
Sig. diff		More reliability	
SNB* SNA* Gonial angleๆ	SNB* SNA SN-GoMe FH-GoMe NBa-PTGn U1-NA. mm L1-NB. mm L1-NB. degree	SNB* Wit's	SNB* PFH/AFH X100 %

Table 26: Show similarity and difference in Nasolabial angle measurement

1991 Barry L Eppley et al	2004 Dana,Golsatein, Burch,Hardigan	2006 Present study
More reliability		Less reliability
Hard SNA SNB Soft G-Sn-Pg Sn-Gn-C *Cm-Sn-Ls* *(NLA)* G-Sn/Sn-Me Sn-Stm/Stm-Me	Soft *NLA* Eplane-UL E plane-LL	Soft *NLA*

Table 27: Comparison of material price, time spent for capturing of cephalometric radiograph

Model	Scanner Epson1680	Cannon EOS 300D	Nikon coolpix S5	Panasonic Lumix DMC-Fx01.
Price (Baht) May 2006	90,000	36,900 (May 06)	16,000 (May 06)	16,900 (May 06)
Oct 2006	90,000	35,062baht (Oct 06)	9,500baht (Oct 06)	11,900baht (Oct 06)
AverageTime	3.22 min/1film (600 dpi) 8.07 / 1 film (1200 dpi)	1 min /7 films	1 min /7 .5 films	1 min / 8 films

BIOGRAPHY

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