# RETROSPECTIVE EVALUATION OF DENTO-ALVEOLAR MORPHOLOGY AFTER FIXED ORTHODONTIC TREATMENT AT HUSM: LASER SCANNING 3D MODEL

**MOUSTAFA MAHMOUD HASSABALLA MASSOUD**

**UNIVERSITI SAINS MALAYSIA**

**2017**

# RETROSPECTIVE EVALUATION OF DENTO-ALVEOLAR MORPHOLOGY AFTER FIXED ORTHODONTIC TREATMENT AT HUSM: LASER SCANNING 3D MODEL

**By**

**MOUSTAFA MAHMOUD HASSABALLA MASSOUD**

**Thesis submitted in fulfillment of the requirements for the degree of Master of Science**

**FEBRUARY 2017**

# ACKNOWLEDGEMENTS

## ALLAHU AKBAR

He who succeeds in any course of action or study is like an army who goes to the battle field and wins the battle successfully. He therefore, needs to thanks **Allahu ta'ala** who spares this life, hence thanks to **Allah SWT** for his shower of blessings without which it would not have been possible for this success.

I am grateful and wholeheartedly express my profound gratitute to renowned supervisor, teacher and guide **Dr. Mohammad Khursheed Alam** as my main supervisor for his guidance, source of inspiration, constructive criticism and encouragement during and after contact hours patiently set aside for the challenges and contribution towards the success of this study. I will always be obliged to him for his wholehearted support and kindness extended to me during my entire period of study. I am indeed overwhelmed and extremely thankful to **Dr. Norma Abd Rahman** for her helping attitude and moral support.

I wish to say a very big thank you to my school dean, whole lecturers in the school of Dental science, Universiti Sains Malaysia (USM) due to their precious and wonderful knowledge that I gained much from them. I also thank my fellow in the school of Dental science Universiti Sains Malaysia like, Cik. Suzana Yahya for her valuable time during the programme and all of my course-mates for the time we shared which will forever remain in my memories and, many thanks to my special fellow colleague Dr. Fazal Shaheed for his weighty kindness.

My special gratitude goes to my family and friends in Malaysia and Egypt for what we went through when I left and specially my parents **Mr. Mahmoud Hassaballa** and **Mrs.M.Mostafa,** my wife **Hala Ahmed**, my son **Youssef Moustafa,** my daughter **Reemas Moustafa** and Co. for their words of encouragement. I thank you all from the bottom of my heart.

We thank all the staff and students of Dental School for their enthusiastic and supportive role in the study. I salute especially staff Klinik Pakar Pergigian for this attention and time towards the success of this study. I will forever remain loyal and respectful to you. However, I have nothing to repay you but to pray that my Allah SWT repay you in manifolds.

Lastly, I met what I expected in Malaysia especially all the benefits I thought in USM, the facilities, qualified and professionals' tutors. Even if we leave still we will pave the way for others to come. I am really grateful my USM.

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| HUSM | Hospital Universiti Sains Malaysis |
| BC | Before Birth of the Christ |
| 3D | Three dimensional |
| C | Inter-canine distance |
| 1-PM | Inter-first premolar distance |
| 2-PM | Inter-second premolar distance |
| IMD | Inter-molar distance |
| MCF | Distance between fossae of first molar |
| A/L | Arch length |
| A/P | Arch perimeter |
| LII | Little Irregularity Index |
| OJ | Overjet |
| OB | Overbite |
| DC | digital caliper |
| 2D | Two-dimensional |
| CT | Computed tomography |
| CBCT | Cone beam computed tomography |
| MRI | Magnetic resonance image |
| CAD | Computed aided design |
| CAM | Computed aided manufacturing |
| VRML | Virtual Reality Modelling Language |
| STL | Stereolithographic |
| HD | Highly dimensional |
| DVD | Digital versatile disc or digital vedio disc |
| ICC | intra-class correlation coefficients |
| USA | United states of America |
| RP | Rapid prototyping |
| MSCT | Multi-slice computed tomography |
| KPP | Klinik Pakar Pergigian |
| AC | Armored cable |
| UID | User interface design |
| CPU | Central processing unit |
| RAM | Random-access memory |
| GHz | Giga Hertz |
| PS | Power and sample size calculation |
| N | number |
| SD | Standard deviation |
| USB | Universal Serial Bus |
| DXF | Drawing Exchange Format |
| ANCOVA | Analysis of co-variables |

| | |
|---|---|
| LCD | Liquid Crystal Display |
| PC | Personal Computer |
| lbs | Pound |
| MB | Mega Bit |
| A/W | Arch Width |
| ICP | Interactive Closed Point |
| ME | Measurement Error |

# LIST OF SYMBOLS

| | |
|---|---|
| N | number of samples |
| Z | 1.96 (constant) |
| σ =SD | standard deviation |
| Δ | precision unit |
| $\bar{x}$ =M | mean of a series |
| d = $x_1$ - $\bar{x}$ | deviation of item from mean |
| ∑ | Epsilon |
| ∑d2 | square of deviation |

**PENILAIAN RETROSPEKTIF MORFOLOGI DENTO-ALVEOLAR SELEPAS RAWATAN PENDAKAP GIGI DI HUSM: IMBASAN LASER MODEL 3D**

## ABSTRAK


Tujuan kajian ini adalah untuk menentukan kesahihan dan kebolehpercayaan ukuran ortodontik pada model imbasan laser 3D yang dihasilkan oleh pengimbas laser NextEngine dan perisian ScanStudio HD dan untuk menilai perubahan dimensi arkus pada subjek yang dirawat secara cabutan dan tanpa cabutan selepas rawatan ortodontik konvensional. Model kajian 104 pesakit (416 model) dipilih secara rawak daripada arkib di Pusat Pengajian Sains Pergigian, Universiti Sains Malaysia. Sejumlah 100 model pergigian diukur menggunakan digital kaliper (DC) dan perisian ScanStudio HD untuk mencapai objektif pertama dan 416 model pergigian digunakan untuk objekif kedua. Perbandingan statistik digunakan adalah ujian t, ujian t berpasangan dan analysis kovarians bagi suatan berulang (ANCOVA). Kesahihan (ketepatan) pengukuran-pengukuran digital menunjukkan tiada perbezaan statistik dalam sebarang bentuk pengukuran yang dijalankan. Nilai pekali kebolehpercayaan antara model-model imbasan laser 3D dan pengukuran menggunakan DC mempunyai korelasi yang kuat Keputusan tersebut menunjukkan ukuran linear pada model pergigian mengunakan model-model imbasan laser 3D adalah sah dan boleh diguna pakai serta boleh digunakan untuk pelbagai prosedur klinikal ortodontik.

Perbezaan yang ketara ditunjukkan dalam kumpulan sebelum rawatan untuk 1-PMD dan LII bagi arkus maksila. Manakala terdapat perubahan ketara pada semua parameter

kecuali pada ICD, 1-PMD, LII dan OB selepas rawatan. Perbezaan yang ketara dapat diperhatikan pada semua parameter kecuali pada ICD dan 1-PMD untuk kumpulan cabutan. Bagi kumpulan tanpa cabutan, perubahan ketara dapat diperhatikan dalam semua parameter kecuali dalam IMD, MCF dan OJ.

Terdapat perbezaan yang ketara pada semua parameter bagi arkus mandibular kecuali pada ICD, 1-PMD dan A/L dalam kumpulan sebelum rawatan. Manakala terdapat perubahan yang ketara pada semua pembolehubah kecuali A/P dalam kumpulan tanpa cabutan dan semua parameter kecuali 2-PMD, IMD dan MCF bagi kumpulan cabutan untuk sebelum dan selepas rawatan.

Keputusan kajian ini menunjukkan rawatan ortodontik konvensional secara cabutan dan tanpa cabutan berpotensi menghasilkan perubahan ketara diantara arkus. Dengan itu, hasil kajian ini akan memberi manfaat pada pesakit ortodontik di Hospital Universiti Sains Malaysia dimana rekod 3D akan dapat digunakan semasa diagnosis dan pelan rawatan ortodontik.

**RETROSPECTIVE EVALUATION OF DENTO-ALVEOLAR MORPHOLOGY AFTER FIXED ORTHODONTIC TREATMENT AT HUSM: LASER SCANNING 3D MODEL**

## ABSTRACT

The purpose of this study was to evaluate the validity and reliability of orthodontic measurements made on laser scanned 3D models created with NextEngine laser scanner and ScanStudioHD software and to evaluate arch dimensional changes in subjects treated with extraction and non-extraction after conventional orthodontic treatment using laser scanned 3D models. Dental models of 104 patients (416 dental models) were randomly selected from the archives of School of Dental Sciences, Universiti Sains Malaysia. Scanning, imaging and measuring were completed to achieve objectives. A total of 100 set were measured by Mitutoyo digital caliper (DC) and ScanStudio HD software to achieve first objective and 416 dental models were used to achieve the second objective. Statistical comparisons were performed using paired t-test, independent t-test and RM ANCOVA. The validity (accuracy) of the digital measurements showed no statistical differences in any of the measurements performed. The reliability coefficient values were comparable between laser scanned 3D models and measurements using DC and the values of coefficient were in the range of strong correlation. The results showed that linear measurements of dental models using laser scanned 3D models are valid and reliable and can be used for various clinical orthodontic procedures.

Significant differences were found in pre-treatment groups for 1-PMD and LII in maxillary arch whereas there were significant changes in all parameters except for ICD, 1-PMD, LII and OB in post-treatment group. Significant differences were observed in all parameters except for ICD and 1-PMD in XLA group. In non-extraction group, significant changes were observed in all parameters except in IMD, MCF and OJ.

There were significant changes in all parameters of mandibular arch except for ICD, 1-PMD and A/L in pretreatment group whereas there were significant changes in all parameters except for ICD, 1-PMD and LII in post-treatment group. For pre and post-treatment differences, the changes of mandibular dental arch were significant in all variables except A/P in non-extraction group whereas all parameters except for 2-PMD, IMD and MCF were changed significantly in extraction group.

The results of the present study showed conventional orthodontic treatment with extraction and non-extraction pattern potentially producing statistically significant changes of the dental arches. Thus, this finding would be beneficial for orthodontic patients at Hospital Universiti Sains Malaysia (HUSM) as 3D record for comprehensive diagnosis and consequently successful orthodontic treatment planning.

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of the study

Orthodontics is a scientific term for orthodontia that originates from Greek language, *Orthos* meaning proper, straight or perfect, and *Odous* meaning tooth. Orthodontics is the first specialty of dental sciences that is interested in the study and treatment of malocclusions, which may be due to inadequate jaw relationships, dental irregularities or both. Orthodontics can deal only with dental displacement, or can focus on the control and alteration of alveolo-facial growth or can be carried out for only aesthetic reasons with regards to improving the general appearance of patients' face or teeth (Lowe, 2013). Tooth movement in orthodontics depends mainly on remodeling of the periodontal ligament and alveolar bone by mechanical means. Orthodontics works not only on teeth movement but also on reconstructing the entire jaws or face. So, it is better to define orthodontics as dento-facial orthopaedics or dento-alveolar orthopaedics (Meikle, 2007). Irregular, protruding and crowded teeth have been a psychological trauma for some people since antiquities and attempts to correct these abnormal developments would be reverted back to 1000 Before Birth of the Christ (BC) because a number of devices were developed by various researchers for regulation of teeth and distinctly used in that era (Proffit *et al.*, 2014b).

Successful dento-alveolar changes in orthodontic treatment is based essentially on proper diagnosis, clinical examination and good treatment planning (Proffit and

Ackerman, 2007a). In orthodontics, study model analysis is a time-consuming procedure but it is empirically important for comprehensive diagnosis and subsequently good treatment planning (Sheridan, 2000). Plaster models have a long and proven history in dentistry especially in orthodontics. Plaster models have been called the ‘‘gold standard’’ in orthodontics (Rheude *et al.*, 2005). Initially, treatment changes in orthodontic have been recorded with plaster or gypsum-based models, which are too bulky in size and bulkiness in size is likely to be damaged or create storage problems, and can be difficult for measurements (Hunter and Priest, 1960; Santoro *et al.*, 2003).

Alternatives such as photocopies, photography and holograms have been suggested for digitization of points from the plaster study model (Rheude *et al.*, 2005). Various methods have been used up to date to measure and to analyze plaster models. Dividers, calipers, and Boley gauges have provided the regular tools of measurement against which newer methods and techniques have been evaluated (Champagne, 1992; Hunter and Priest, 1960; Schirmer and Wiltshire, 1997). Digital radiographs and digital photography are becoming the norm in orthodontic records for economy and convenience reasons. Recently, medical and dental histories, digital photographs, digital radiographs and all treatment notes are in digital format, thus the ability to obtain digital study models or electronic study models has become most appealing (Rheude *et al.*, 2005).

Several efforts have been made to replace study model by using two dimensional (2D) images obtained with standardized cameras (Normando *et al.*, 2011) but image deficiencies have been noted related to inaccuracy (Luppanapornlarp and Johnston Jr, 1993; Schirmer and Wiltshire, 1997). As a result of advances in computer technology and digital techniques, various methods of three dimensional (3D) study model imaging have been developed as an alternative for easy measuring of occlusal relationship, electronic storage of records, ease of access, ease of record, ease of transfer and high accuracy (Fleming *et al.*, 2011; Luppanapornlarp and Johnston Jr, 1993). In 3D system, data is collected using imaging equipment, processed by computer and then displayed on standard 2D screen to give the illusion of depth. Depth view causes the image to appear in 3D (Seeram, 1996; Smith *et al.*, 2009). Three dimensional (3D) imaging is an advanced system in the medical field that shortly has found a considerable number of applications in the field of dentistry (Papadopoulos *et al.*, 2002b). Fleming and researchers surveyed dental practitioners in 2001 and found that the application of 3D models in orthodontic practices has increased steadily with an alarming percentage of almost 18% of in the United States of America (USA) (Fleming *et al.*, 2011). 3D model as an alternative to standard model will make dental practice more efficient, convenient and accessible and will appeal to patients as up-to-date dental care. Electronic data also has the advantage of rapid access to data, easy transfer of digital information, versatility, financial and time savings (Fleming *et al.*, 2011; Straga, 2009).

The development of 3D computer imaging has many applications in Orthodontics, includes analysis of study models, examination and identification of bite mark, to achieve the 'virtual orthodontic patient' by facial scanning, facial soft tissue growth studying, studying of functional facial muscle movements, changes of arch form, and development of head shape (Al-Khatib *et al.*, 2012; Baik *etal.*, 2006; Kusnoto and Evans, 2002; Martin-de las Heras *et al.*, 2005). 3D image can be created by designing 3D Computer-Aided System (3D-CAD), Surface laser scanner, Optical scanner, 3D cephalometer, 3D-magnetic resonance image system (3D-MRI), 3D ultrasound (ultrasonic holography) system, CT scanner, 3D multi-camera scanner, 3D holographic sensor, Stereophotogrammetry, CBCT system and Automated Infrared Photogrammetry.

Recent technologic innovations have generated a variety of techniques for medical imaging. One of these had initially developed technique for industry which was laser surface scanning (Da Silveira *et al.*, 2003). Nowadays, surface laser scanning is widely used in industry, medicine and Orthodontics as a noninvasive alternative technique for generating a 3D computerized image by capturing large amounts of data in a computer within a short period of time and measuring distances on reconstructed surfaces (Commer *et al.*, 2000; Kuroda *et al.*, 1996). 3D laser scanners are inexpensive, simple to operate, and completely non-destructive to hard or soft tissue. Despite the ability of 3D laser scanner to scan only visible surfaces, its advantages in ease of use, self-calibration, and auto image distortion correction make generating 3D computerized images very convenient (Commer *et al.*, 2000). Surface laser scanning has common applications in orthodontics as a noninvasive alternative for generating an accurate 3D computerized image. Laser scanning has been used to assess changes of facial soft-tissue following functional treatment (Morris *et al.*, 1998), following extraction (XLA) and non-extraction (NXLA) orthodontic treatment (Ismail *et al.*, 2002), following orthognathic surgery (Moss *et al.*, 1994), and in cleft lip and cleft palate patients (McCance *et al.*, 1997).

Laser scanner can be used for scanning of soft tissue, and has the advantage to create 3D images. Images have been created to establish database for normative populations (Yamada *et al.*, 2002), and cross sectional development changes (Ayoub *et al.*, 1998), and also to evaluate clinical outcomes in surgical (Ayoub *et al.*, 1998;

Ayoub *et al.*, 1995; Ji *et al.*, 2002; McCance *et al.*, 1997), and non-surgical treatments (Ismail *et al.*, 2002; McDonagh *et al.*, 2001; Moss *et al.*, 2003) in the head and neck region. There was some difficulties regarding intra-oral laser scanning may be because of the possibility of uncontrolled movement of patients during scanning, besides laser safety issues (Mah and Bumann, 2001).

The debate over XLA and NXLA treatment in orthodontic treatment has been discussed long ago by researchers and clinicians. The opinions of Angle (Angle, 1900), and Case (Case, 1896) are well known, (Bernstein, 1992) and the change of XLA concepts after the study of Tweed (Tweed, 1944), and Begg (Begg, 1954) showes the influece of XLA and NXLA in clinical orthodontics. Now recent debate, the XLA/ NXLA has approached the impact of the two treatment options on facial esthetics (Bishara *et al.*, 1995b; Boley *et al.*, 1998). Dierkes and colleagues statedthatXLA treatments constrictarch form (Dierkes, 1987), while Gianelly believed that XLA does not constrict arch form (Gianelly, 2003). Recent studies of XLA versus NXLA are mainly focused on effects on profile change, choice of treatment should depend not only on the profile but also may be on some other skeletal and dental parameters (Basciftci and Usumez, 2003).

**1.2. Statement of problem**

Retrospective evaluation of dento-alveolar morphology after fixed orthodontic treatment has been studied around the world. Based on the literature, there is no study done on laser scanning of study models to assess dento-alveolar changes after orthodontic treatment. Dento-alveolar morphology is very important in orthodontic diagnosis and treatment planning. It is also essential for record keeping and forensic application. No previous study has evaluated the maxillary or mandibular arch changes in subjects treated with XLA and NXLA after fixed orthodontic treatment by analysing laser scanned 3D model. It was determined that digital models offer a high degree of validity (accuracy) and measurement differences are likely to be clinically acceptable. The current study therefore, was performed to evaluate the accuracy and reliability of dental arch measurements made on digital models created with NextEngine laser scanner and ScanStudio HD software. The study would be beneficial for orthodontic patients at Hospital Universiti Sains Malaysia (HUSM) as 3D record is essential for comprehensive diagnosis and treatment planning to achieve successful orthodontic treatment. Moreover, efficient and cost effective record keeping and forensic applications are additional benefits that can be derived from this study.

### 1.3 Justification of the study

Comprehensive diagnosis and treatment planning is necessary for successful orthodontic treatment. It is an essential procedure for orthodontist to make the proper diagnosis and consequently treatment planning process. The use of old technique that analyze study model manually is time consuming, hard and inaccurate (Hunter and Priest, 1960; Santoro *et al.*, 2003). Storage of study models is also problematic in terms of cost and space. Several attempts have been made to replace conventional models by using two dimensional (2D) images obtained with standardized cameras (Kahl-Nieke *et al.*, 1996), but deficiencies have been noted relation to their accuracy (Luppanapornlarp and Johnston Jr, 1993; Schirmer and Wiltshire, 1997). The ability to obtain digital study models has become most appealing with advances in computer technology, various methods of three dimensional (3D) study model imaging have been developed (Luppanapornlarp and Johnston Jr, 1993; Schirmer and Wiltshire, 1997). The development of three-dimensional computer imaging has many applications in dentistry, including the analysis of study models (Al-Khatib *et al.*, 2012). A novel feature of the current investigation in dentistry is laser scanning of study model (Da Silveira *et al.*, 2003). Studies involving laser scanning of dental models can be performed easily because computerized 3D wire-frame diagrams allow study models to be cut, superimposed, and measured. Measuring changes in area and length of curvatures gives more insight for many data sets. Combined with 3D cephalometry techniques and software packages, a complete 3D simulation can be obtained to give the orthodontist better control in designing a treatment plan and for assessment after fixed appliances in orthodontic patients. In this study we use NextEngine 3D Scanner to assess its validity and reliability and to measure and compare dento-alveolar changes before and after orthodontic treatment at HUSM.

## 1.4 Objectives

### 1.4.1 General objectives

The overall objective is to retrospectively evaluate dento-alveolar morphology after fixed orthodontic treatment at HUSM by laser scanned 3D model.

### 1.4.2 Specific objectives

i) To evaluate validity (accuracy), and reliability (reproducibility) of orthodontic measurements of laser scanned 3D model using ScanStudio HD software.

ii) To evaluate dento-alveolar changes in extraction and non extraction cases after fixed orthodontic treatment.

## 1.5 Hypothesis

1. Orthodontic measurements made on digital models created with laser scanned 3D dental model are valid and reliable.

2. There is no difference in the dimensional accuracy of 3D digital surface models captured with the NextEngine laser scanning technique and direct measurement with digital caliper on plaster study models.

3. There is a significant difference in dento-alveolar changes such as arch length, arch width and arch perimeter of orthodontic cases.

4. There is a significant difference in dento-alveolar changes of orthodontic cases such as little Irregularity Index, overjet and overbite**.**

## 1.6 Research Questions

1. Are orthodontic measurements made on digital models created with laser scanned 3D dental model valid and reliable?

2. Is there any difference in dento-alveolar changes, such as, arch length, arch width and arch perimeter of orthodontic cases?

3. Is there any difference in dento-alveolar changes of orthodontic cases such as, labial segment, inter-arch relationship?

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Study model

Successful orthodontic treatment is based on proper clinical examination with correct diagnosis and good treatment planning. A few of the basic factors in the diagnosis are the tooth size, spacing condition, arch form and its dimensions, as well as the tooth-arch discrepancies (Proffit and Ackerman, 2007a). Model analysis is a time-consuming process but this analysis should be considered as a primary part in the diagnosis and treatment planning. However, many orthodontists had judged the models subjectively without applying analytical test (Sheridan, 2000).

Regarding, study models had been long proven history by orthodontists and tagged as the ‘‘gold standard’’ in orthodontics. According to them, it has befitting advantages ranging from being a routine dental technique, ease of production, inexpensiveness, and ease in measurement to plaster models being able to be mounted on an articulator for study in three-dimensions. The use of plaster models is an essential part of any dental practice and is required for research. It had earlier emphasized that, storage of study models is problematic in terms of space and cost (Rheude *et al.*, 2005).

Orthodontic treatment outcome have initially been recorded with plaster or gypsum-based models, which are too bulky and heavenly created in retrieval and storage problems, easy to damage, time consuming while processing and difficult for measurements (Hunter and Priest, 1960; Santoro *et al.*, 2003). In performing analysis of study model, common diagnostic parameterswere measured on dental models, such as overjet, overbite, Little Irregularity Index, arch width, and arch parameter or dimension. The current gold standard for analysis involves plaster models measured with standard calipers or digital caliper however, this measurements has low degree of accuracy (Prentice, 2010).

### 2.2 Standard study model measurement tools

Standard measurement tools referred to dividers and regular sliding caliper with a Vernier scale were used to measure tooth size. Both methods permitted readings to the nearest 0.1 mm but some difficulties and errors were reported (Hunter and Priest, 1960). Dial caliper was used to evaluate changes in dental arch width dimensions after treatment (Kahl-Nieke *et al.*, 1996). Using regular caliper in model measurements is slow and not accurate (Mullen *et al.*, 2007). Traditional photos, photocopies made on photostat machine, photographies, holograms, digital calipers, regular scanner, Vernier gauge and Boley gauges have provided the standard of study model measurements against which advanced methods have been presented (Champagne, 1992; Hunter and Priest, 1960; Rivero *et al.*, 2000; Schirmer and Wiltshire, 1997). Currently, many techniques and methods have been used to measure and analyze plaster models as plaster model remain a recognized tool for orthodontic diagnosis and treatment planning (Rheude *et al.*, 2005).

### 2.3 Digital photography

Presentation of digital image in orthodontics allows the clinicians to use, either a digital camera or standard scanner to digitalize dental models and to measure dimensions of dental arch by a software program established to use these data in 2D. In 2004, Fernández-Boza has presented the first digital photography to replace the traditional photos (Fernández-Boza, 2004). Several attempts that have been made to replace study models by using 2D images obtained with standardized cameras (Kahl-Nieke *et al.*, 1996), but minor deficiencies have been noted related to inaccuracy (Luppanapornlarp and Johnston Jr, 1993; Schirmer and Wiltshire, 1997) and 2D was followed by another attempts to replace digital image. Currently, several digital methods are available for measuring arch dimensions automatically, but more of their accuracy depends on proper calibration. A group of scientists presented a novel, fast, efficient and accurate technique to calibrate the previously introduced 2D computerized system for measuring arch dimensions (Paredes *et al.*, 2005). Digital photography is becoming the norm in orthodontic records for economic reasons and convenience due to advances in computer and software technology. Digital photograph is not beneficial for medico-legal requirements as conventional photo due to lack of negative replica (Fernández-Boza, 2004). Digital photography is slow but a step forward towards digital radiography which assumes an adequate quality and time saving.

## 2.4 Digital radiography

The radiographic image has the advantages of low cost as no film required, no slides and no processing fees, easy to be accessed by patients and professionals, stored automatically, copied electronically, data being transferred immediately and secured very often as no scratch or dust (Christensen, 2005; Sandler *et al.*, 2001). With enhancement of direct digital superimposition techniques and digital point recognition, various methods of 3D study model imaging system have been developed with advances in computer technology (Fleming *et al.*, 2011; Luppanapornlarp and Johnston Jr, 1993). The advantages of digital radiography are time saving, allow immediate diagnosis, adequate quality, easy use by professional, reduction of radiation by 70%, no chemical or films are needed in the saturation, brightness and contrast can be altered and controlled. Software can be used to localize and place cephalometric points in digital radiographic image (Paredes *et al.*, 2006). 3D digital models are valuable alternatives to conventional models for analysis of dental arch and also yield information which could previously be gathered only by cephalometric superimposition (Cha *et al.*, 2007).

In 3D imaging system, imaging equipment collects data, data is processed by software and then displayed on a 2D monitor to give the illusion of depth. Depth perception causes the standard 2D image to appear in 3D (Seeram, 1996; Smith *et al.*, 2009). 3D technology is an advanced imaging system in medical field configured with sophisticated considerable number of applications in the history of dental sciences, including forensic dentistry, orthodontics and oro-maxillofacial surgery (Papadopoulos *et al.*, 2002b). The 3D as an alternative had been developed for easy measuring of occlusal relationship, ease of record, electronic storage, ease of access, ease of transfer and high accuracy (Stevens *et al.*, 2006).

### 2.5 Digital study models

Nowadays, photographs, radiographs, medical and dental histories, and all treatment records are in digital format to control storage problems which is a time consuming procedure, thus the ability to obtain digital study models has become most appealing (Rheude *et al.*, 2005). A computer software program was presented for the first time to support direct analysis of study models as a clinical diagnostic aid using study model photos (Begole *et al.*, 1979). Yen presented a simple computer software using a study model photocopy to assess dimensional changes of dental arch after orthodontic treatment (Yen, 1991). Rivero along some teamwork used a regular scanner to digitalize study model (Lesmes *et al.*, 1998). Gouvianaski and Drescher were one of the first authors to use a digital camera linked to a computer program to photograph and measure study models (Gouvianakis and Drescher, 1987), while Trankmann measured dental models by digitalizing tables (Tränkmann *et al.*, 1990). More than study compared measurements of traditional calipers and digital program and found that the digital system was easier, quicker, more accurate and generally good option for these measurements (Garino and Garino, 2002; Tomassetti *et al.*, 2001; Tran *et al.*, 2003). Digital format is easy to be presented to patients, transmitted to colleague, accessed and measured either at any time or any distance. The disadvantages of digital models was very difficult measurements of poor models, and models of mixed dentition (Paredes *et al.*, 2006). It's however revealed that reliable measurements of the irregularity index and the arch length could be made on digital models. There would be a possibility of high correlations ranging to reasonable percent (98.6-99.9%) for both the irregularity indices and the arch length when compared with measurements on standard models (Goonewardene *et al.*, 2008).

Presumably, 3D imaging has been developed rapidly in the last two decades and has found applications in oro-maxillofacial surgery, as well as in orthodontics as purported by (Seeram, 1996). Plaster study models could be replaced by the use of 3D images from which tooth size and dental arch dimensions could be obtained for clinical diagnosis and treatment planning which is the first step in orthodontic treatment. In addition, the accuracy of 3D imaging system measurement would enable study model analysis for research purposes.

3D dental models has largely focused on those created with laser scanning while others have investigated holographic scanning, stereophotogammetry, but currently focus on cone-beam computed tomography (CBCT). Recently, 3D virtual study models have made headway into orthodontics and used successfully in our analysis before treatment (Luu *et al.*, 2012). 3D model achieved high degree of accuracy (Mullen *et al.*, 2007).

Program Cécile3 beta was used to digitize dental model to create 3D model. Reproducibility and accuracy of measurements in digital models were compared to plaster models. Two examiners measured three times archwidth, overjet and overbite. They concluded that Cecile3 beta presented a high reliability in obtaining different measurements in dental models (Watanabe-Kanno *et al.*, 2009). Digital models produced by indirect methods were concluded with high degree of validity and differences in measurements are clinically acceptable (Keating *et al.*, 2008). In 2009, Watanabe-Kanno concluded that the validity of the measurements obtained from Cécile3 beta digital models compared to measurements from plaster models were clinically reasonable (Watanabe-Kanno *et al.*, 2009). This study was in good and perfect agreement with study by Stevens and coworkers, because they found that, digital models were clinically acceptable replacement for plaster models for the routine measurements made in most orthodontic practices (Stevens *et al.*, 2006).

With modern advances in software and computer technology, development of direct digital superimposition techniques and digital point recognition, digital photography and radiography of study model have been suggested through the alternative 3D. The alternative 3D can be established by one of the following:

### 2.5.1 3D computer-aided design (3D-CAD)

In 1999, A newly developed 3D computer-aided design (CAD) system for orthodontic diagnosis and treatment planning and clinical applications was presented. The system comprised a measuring unit which obtained 3D information from the study model using laser scanning, and using a personal computer would be more important to generate the 3D graphics. Compared with standard models, the computed diagnostic model had advantages such as speed processing and quantitative evaluation on the amount of 3D movement of the individual tooth relative to the craniofacial plane (Motohashi and Kuroda, 1999). In 2001, Hirogaki developed new theory to reconstruct the whole surface of study model including crowding area, undercuts, irregularities by applying a perceptual grouping algorithm (Hirogaki *et al.*, 2001).

Feasibility of virtual models obtained from OrthoCAD® as an alternative to orthodontic plaster models and corresponding plaster model was assessed and compared to conventional caliper. Inter-examiner error was assessed by measuring tooth size, overjet (OJ), overbite (OB), inter-molar distance (IMD), inter-canine distance (ICD), and midline discrepancy (Zilberman *et al.*, 2003). Mullen compared e-model that was created with e-model software version 6 with that created with traditional method of digital calipers and plaster models, and found that e-model can be as accurate as plaster model and significantly faster. A clinician who has switched to e-model software in diagnosis can be confident and create accurate measurements (Mullen *et al.*, 2007). Persson used CAD technique to evaluate the accuracy of two dental surface digitization devices three-dimensionally (Persson *et al.*, 2006).

Recently, digital model has become available in the form of 3D computerized models as part of the OrthoCAD service. To obtain 3D model with this system, only an impression with Alginate and wax bite are sent to OrthoCAD service centre. The advantage of OrthoCAD software is to create color-coded scheme of bite registration including points of full contact and occlusogram. OrthoCAD is promising when comparing changes before and after treatment. This software also allows the anterior, posterior and transverse adjustment of bite registration (Marcel, 2001). OrthoCad software was used also to compare space analysis measurements made on digital models with those from plaster dental models and the results was accurate (estimated to 0.4mm difference) (Leifert *et al.*, 2009).

### 2.5.2 Computer-aided design (CAD) and computer-aided manufacturing (CAM) system (CAD-CAM system)

Computer-aided design (CAD) and computer-aided manufacturing (CAM) as a new application have become widely used in dentistry over the past 25 years is used in both the dental laboratory and the dental clinics. CAD-CAM is also being used in orthodontic diagnosis and treatment planning. Dentists and dental technicians have different ways in which they can use the new application for example dentists can take digital impression and send to dental laboratory. When dental technicians receive a digital impression, they can create a standard model from the received data and either continue with traditional fabrication or rescan the model for milling the required dental material. Alternatively, the laboratory technician can do all design work directly on computer based on received data (Davidowitz and Kotick, 2011).

A new computer technique and imaging system used SureSmile system for diagnosis and treatment plan. Treatment can be simulated in advance and different treatment strategies can be visualized, this will allow detailed treatment planning. The application of CAD-CAM aims to improve reproducibility, efficiency and quality of orthodontic treatment (Müller-Hartwich *et al.*, 2007).

Dirk Wiechmann and his teamwork designed an arch wire and orthodontic brackets for lingual orthodontic appliances. In case of lingual bracket system, each tooth has its own customized and individual bracket made with CAD-CAM software combined with high-end, rapid prototyping technique. CAD-CAM was used also in bracket fabrication, bracket positioning and customization of archwire (Wiechmann *et al.*, 2003).

Leonardo Ciocca and Roberto Scotti in 2004 described a technique for making ear prostheses using CAD-CAM imaging system, laser scanner and a rapid prototyping machine (Ciocca and Scotti, 2004).

### 2.5.3 Optical scanner

R. Delong *et al.* in 2003 used Comet 100 optical scanner to scan dental impressions and study models. Three-dimensional computerized images from the scanned data were created by custom software (DeLong *et al.*, 2003). The optical surface scanning and 3D computer-assisted comparison is an efficient, accurate and non-destructive technique in analysis of bite mark (Martin-de-las-Heras and Tafur, 2009).

### 2.5.4 3D multi-camera scanning

The multi-camera operating system is based on the laser triangulation method and it was used to evaluate the dental arch three-dimensionally from 3D database from digital models and this is an important tool for analysis of developmental changes of dental arch. Triangulation is a technique that use the known distance between a structured illumination source and a sensing element and the angle of reflection pattern to measure depth of a surface (Xu *et al.*, 1998).

The original multi-camera operating system used two laser modules and four firewire cameras. In 2015, R. Adaškevičiusand A. Vasiliauskas developed 3D multi-camera study model scanning system to create a high accuracy device that could mechanically measure dental arch dimensional changes (Adaškevičius and Vasiliauskas, 2015).

### 2.5.5 Face scanner

Achievement of 'virtual orthodontic patient', where we could see the flesh and hard structures such as bone and dental arch three dimensionally is the ultimate dream of 3D imaging and modeling system. If 'virtual orthodontic patient' can be achieved accurately, it will allow data collection of hard and soft tissue and performance of analyses. Our knowledge and understanding of the masticatory system, tooth movement biomechanics, orthopedic and orthognathic corrections will also be updated. In 1915, Van Loon proposed that a 3D system is required to determine the relationship of the dentition to the face for significant diagnosis and treatment planning (Van Loon, 1915). In 1926, Simon explored the relationship between the study models and the craniofacial complex (Simon, 1926). Subsequently, Aung and colleagues created new laser scanning techniques to facilitate the capture of 3D images which permits their use for rapid surface measurements of face (Aung *et al.*, 1995).

### 2.5.6 Surface laser scanner

Laser scanning was initially developed in industry, biology and medicine as a tool for transforming biological structures into 3D models that contain useful geometric and topological information. Current laser scanning technology makes it relatively straight forward to acquire 3D data for visualization purposes (Sensen and Hallgrimsson, 2008) and also to develop an integrated 3D digital image (Ciocca and Scotti, 2004). Laser scanning devices such as NextEngine are now available at affordable price. Laser scanners are capable of creating 3D images by scanning the external surface of objects such as models & skeleton, with varying degree of resolution that depend on the equipment and the software. NextEngine Laser Scanner meets all the requirements for accurate scanning and imaging of study models (Kuzminsky and Gardiner, 2012).

Commercially available digital models can be produced by direct or indirect method. Indirect methods start with dental impressions. Digital models can then be obtained by laser scanning of plaster models or computed tomography imaging of the impressions or plaster models. The direct method uses an intraoral scanner to scan the patient's mouth directly, making dental impressions redundant (Pani and Hegde, 2008; Santoro *et al.*, 2003). This can be advantageous for patients with a gag reflex or with cleft lip and palate who are at risk of aspiration and respiratory distress while taking dental impressions (Yourtee *etal.*, 2000). Digital models produced by indirect methods were shown to have high grade of accuracy and differences in measurements were clinically acceptable (Keating *et al.*, 2008). Recent study concluded that digital model produced by intra-oral scanner were valid and reproducible (Cuperus *et al.*, 2012). In 2000, a study by Sohmura and associates demonstrated the feasibility of acquisition of data through the use of an ultra-high speed scanner and an originally developed goniometer (Sohmura *et al.*, 2000).

Similarly, an optical set-up for intra-oral data acquisition based on the principle of laser triangulation was presented (Commer *et al.*, 2000). A variety of techniques for medical imaging technology were recently innovated and introduced. Extraction method for laser beam 's trace center-line with sub-pixel accuracy from 2D images was presented and the result was smooth and continued in a region of its trace (Matiukas, 2009).

Laser scanning had the advantages that it is less invasive method of capturing the soft tissues such as face for evaluating or planning outcome of orthodontic treatment. Laser scanned image are used to count surface area or angles, which can be difficult to calculate in original specimen (Da Silveira *et al.*, 2003; Tocheri, 2009). However, laser scanning has several disadvantages which include distortion of the scanned image, time consumption, safety related issues such as exposing the eyes to the laser beam especially in medically compromised patients, pregnant women and growing children, inability to scan the soft tissue which results in difficulties in identification of landmarks that are dependent on surface colour. The disadvantages persist even with the new white-light laser approaches that capture surface texture colour (Hajeer *et al.*, 2004b).

Surface laser scanner can achieve three-dimensional data correctly by using the self-correction mechanism. It also provides great assistance in decreasing distortion, regardless of object-to-scanner distance and the spread of the laser beam over the object makes the scanner work more accurately for smaller objects than for larger objects. In 2002, Kusnoto and Evans found that for scanning dental model, laser scanner produced better images when placed upside down. The best technique is therefore to scan from bottom to top. The novel version of the scanner has the property of laser beam emitting from bottom to top. Shadow, surrounding lights and type of lights were also found to influence the scanner's accuracy and the produced image (Kusnoto and Evans, 2002).

A commercially available ultra-high speed laser scanning measurement system VIVID 700 and original goniometer with marks for data transfer was used for construction of the entire 3-dimensional shape of study model and reconstruction of the occlusal condition (Sohmura *et al.*, 2000). In 2008, Keating *et al.* used a more advanced commercially available Minolta VIVID 900 non-contact 3D surface laser scanner (Konica Minolta Inc., Tokyo, Japan), a rotary stage and Easy 3D Scan integrating software (TowerGraphics, Lucca, Italy) to capture models to create 3D images to compare between plaster, digital and reconstructed study models. The objectives of the study were to evaluate the accuracy and reproducibility of the Minolta VIVID 900 laser device. They concluded that the Minolta VIVID 900 digitizer was Z a reliable device for capturing the entire surface of plaster models in a 3D digital format (Keating *et al.*, 2008).

3D laser scanner was used for tooth mark analysis in forensic dentistry (Molina and Martin-de-las-Heras, 2015). An optical set-up for intraoral data acquisition based on the principle of laser triangulation was developed. Laser scanning applications in orthodontics were demonstrated by scanning dental models and measuring distances on reconstructed surfaces. The measured distances showed a maximum deviation of about ±0.2 mm compared with the data of the coordinate measurement table, which served as a reference. In addition, reconstruction of three-dimensional tooth movements was performed on the scan data (Commer *et al.*, 2000). Laser scanning and fringe projection are among the possibilities for obtaining CAM files but laser scanning offers higher performance in reconstruction of dental pieces (Munera *et al.*, 2012).

OraMetrix Company in the USA developed OraScanner which is the first 3D hand-held intra-oral scanner. OraScanner depends on the structured light technique. It is equipped with video camera that records the structured light distortions on the dental crowns as it passes over in very short time (about one minute) (Mah and Bumann, 2001). These images can be processed by a computer and combined together to create a complete 3D of dental arch. Naidu has determined that iOC intraoral scanner associated with OrthoCAD software was reliable, valid and reproducible in measuring tooth widths and Bolton ratios (Naidu and Freer, 2013). Difficulty of intra-oral laser scanning may be related to the possibility of patient involuntary movement and laser safety issues (Mah and Bumann, 2001).

Baik evaluated the accuracy of the 3D laser scanner to scan face and soft tissue and concluded that laser scanner is a useful tool for understanding the 3D facial structure and the soft tissue landmarks (Baik *et al.*, 2006).

In another study, Shah *et al.,* used a 3D laser scanner using superimposition of software to assess the accuracy of different impression techniques (Shah *et al.*, 2004). In 2005, Kau *et al.,* conducted a clinical trial to evaluate the reliability of 3D facial scanning technique for the measurement of facial morphology (Kau *et al.*, 2005). The following year, he captured and scanned facial morphology using laser imaging system (Kau *et al.*, 2006b). The same author also described the use of adult facial template in gender-specific facial analysis (Kau *et al.*, 2006a).

Laser scanners are capable of creating images with different shapes and sizes, ranging from something as small as an incisor, to larger objects, such as a skull. Objects can be scanned with lower resolution (less angles of scanning), which saves time but produces scanned images with fewer polygons and less details. Dental models can be scanned at higher resolution to produce detailed images. Increasing angles of scanning creates high resolution image with more detailed and cleared information. A newly presented software called ScanStudio HD also has an option of digitally repairing 3D scans by "filling holes" or mirroring missing sides of the model.

Using software packages (such as Next Engine's ScanStudio HD or Stratovan Checkpoint), the researcher can take screen shots of 3D completed digital model, record points on the specimen, calculate surface area and volume and make accurate measurements (Weber and Bookstein, 2011).

### 2.5.7 3D cephalometer

3D imaging has progressed from the Bolton-Broadbent cephalometer (Dierkes, 1987) and 3D cephalometric computer software (Gianelly, 2003) to the advanced computerized tomography (CT) scan, magnetic resonance imaging (MRI), and ultrasound 3D imaging now available for 3Dreconstruction of anatomy. Technology formerly considered science fiction, such as virtual reality, holographic projections, and stereolithographs now has potential in orthodontists' offices to fully reproduce a patient's anatomical structure three-dimensionally. Although exclusively improved, this technique still time consuming, risk of exposure to radiation, inability to capture soft tissues and bipolar technique inaccuracy (Ayoub *et al.*, 1998; Hajeer *et al.*, 2001).

Attempts to create a 3D reconstruction from lateral and frontal cephalograms have failed because of problems with magnification and distortion. A new method that creates a standard head model for a patient from anatomic measurement points extracted from x-ray images, facial stereo photographs and study models was introduced by Nakasima and colleagues. To obtain precise 3D coordinates from cephalograms, several equations were presented to compensate for radiographic image magnification and distortion. By comparing the constructed model and 3D-CT images, this method proved to be accurate (Nakasima *et al.*, 2005). A method characterized by the use of 3D cephalometric data for 3D simulation of the movement of teeth, jaw and face caused by orthognathic surgery was presented (Bettega *et al.*, 2000; Noguchi *et al.*, 2007).

### 2.5.8 3D-magnetic resonance image (3D-MRI)

The device used for MRI depends on magnetic tomography. The idea of MRI can be summarized as polarization of hydrogen atoms by magnetic field accompanied by the emission of radiation, similar to radio waves. Subsequently, the data from these receivers are processed by computer software to produce magnetic resonance images. Hydrogen concentration in bone is low, thus, the visibilities of bony tissue in this image are limited. Originally, MRI is a technique for 2D imaging system but with the advances in image processing systems it has become one of the most valuable 3D imaging techniques for imaging of body structures (Pavlicek *et al.*, 1983). Software that takes advantage of the high-quality MRI images and transforms them into 3D has been recently developed (Papadopoulos *et al.*, 2002b). The magnetic field does not seem to affect body cells therefore, MRI is a safe technique, it is noninvasive as long as x-ray radiation is not used, and it is suitable for long-term studies on human beings. Magnetic resonance imaging (MRI) technique