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Review Article

Concept and Scope of Dental Digitization - Teleorthodontics

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Abstract: Teleorthodontics refers to the use of Information Technology and Telecommunications to facilitate Orthodontic Consultation about the care to be rendered, the Practitioner, the Patient and Public Education as well as promoting Public Awareness. Despite skepticism, there are several advantages of including Teleorthodontics in the clinical Orthodontic Practice. In the present review, the new communication healthcare system and its applications in the field of Orthodontics that is destined to change the future of our clinical practice will be discussed. For this purpose, the point to point concept and the scope of Teleorthodontics has been provided. The information discussed in the present article is obtained from the most relevant studies evaluating the performance of Teleorthodontics and remote monitoring systems in clinical practice.

Keywords: Teledentistry, Teleorthodontics, Digital technology**.**

INTRODUCTION

One of the major concerns throughout the world today is to make high quality health care available to all. Traditionally, part of the difficulty in achieving equitable access to health care has been that the provider and recipient must be physically present in the same place. Recent advances in information and communication technologies have increased the number of ways health care can be delivered to reduce these difficulties. The advent of telecommunications in the 20th Century was soon followed by the development of telemedicine, whereby advice and care were provided to patients distant to the clinician [1]. Like other health professionals, dentists have seen a lot of change over the years from extractions and dentures to digital technology that is taking dentistry to other level creating practice possibilities hardly imaginable even 10 years ago. In the 1990's, concept of teledentistry was introduced. Cook (1997) [2] defined this as "the practice of using videoconferencing technologies to diagnose and advice about treatment over a distance". In terms of quantitative research, Mandall *et al.*, (2005) [3] compared the perceived appropriateness of orthodontic referrals when using digital information supplied via 'store and forward' tele-orthodontics and clinical examinations of the same patients. The results showed that triaging referrals using tele-orthodontics was acceptable.

Tele-orthodontics is a broad term that encompasses remote provision of orthodontic care, advice, or treatment through the medium of information technology, rather than direct personal contact. A simple and relevant example is an orthodontist seeking advice from colleagues by sharing digital records and communicating over the Internet. Less commonly, tele-orthodontic consults and treatments have been reported in conjunction with general dentists in order to facilitate orthodontic treatment [4]. In the early to mid-2000s, promising results were achieved by orthodontists supervising general dental practitioners in real time to provide orthodontic services to patients with limited access to orthodontic care [5]. Simple remote monitoring of patients during the retention period has also been performed with patients sending picture instead of travelling for in-office visits.

The application of the "tele-orthodontics" concept however has been limited due to lack of technological facilities for networking and communication in developing countries [6]. In orthodontics, in addition to clinical examinations, hard-copy records are taken to undertake treatment planning for a case when the patient is not present. These records most commonly consist of a referral letter; plaster study models of the teeth, intra-oral and facial photographs and appropriate radiographs. The advent of digital technology holds many advantages compared to these physical records. These include ease of storage, ease of records transfer and a reduction in risk of damage and

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loss. Digital radiographs are now commonplace and referrals, along with photographs, are being increasingly communicated via email. Technology is available to produce digital study models and 3D facial scans using stereophotogrammetry. Therefore, all orthodontic records can be produced digitally, but question arises on can they be used to plan treatment appropriately. Whetten *et al.*, (2006) [7] found that orthodontic treatment planning decisions were not significantly affected if digital study models were used instead of plaster models. Therefore, prior to the advent of fully electronic referrals, it is appropriate to determine the reproducibility of treatment plans using differing diagnostic information formats, including digital records [8].

With the advent of tele-orthodontics, and more specifically remote monitoring, the scheduling of in-office visits can be personalized per patient, creating a supposedly more efficient work flow. This not only maximises profitability by reducing chair time, but also improves patient convenience. There are many "applications" (app) that facilitates this technology, which allows patients to accurately capture their occlusion using smart phones. Since people are increasingly using smart phones and "apps" on them, orthodontic applications on these platforms have also increased correspondingly. Scans made by patient using smart phones are analysed and viewed by orthodontist who is then able to provide real- time monitoring of the patient's treatment remotely. This could be especially important in areas with limited access to orthodontic care and for those who travel frequently and have busy schedules. Other perceived advantages include earlier diagnosis, closer management through remote monitoring, saving time, transportation cost, increased convenience for patients [9]. Implementation of a telehealth system i.e. tele-orthodontics can improve primary oral health-care services; hence widen the reach of specialty care as well as can expand the chances for utilization of medical education and training by health-care professionals and community. Utilization of these services in India can set up a pivotal role in expanding and improving the oral health and other related ill habits such as smoking and tobacco chewing, deleterious oral habits leading to malocclusion etc., in large extent [10]. This article has as its objectives to draw inferences of scope, ethics, progress and shortcomings from research studies in tele-orthodontics till date: to arrive at a new paradigm in oral health services in India at a very low cost.

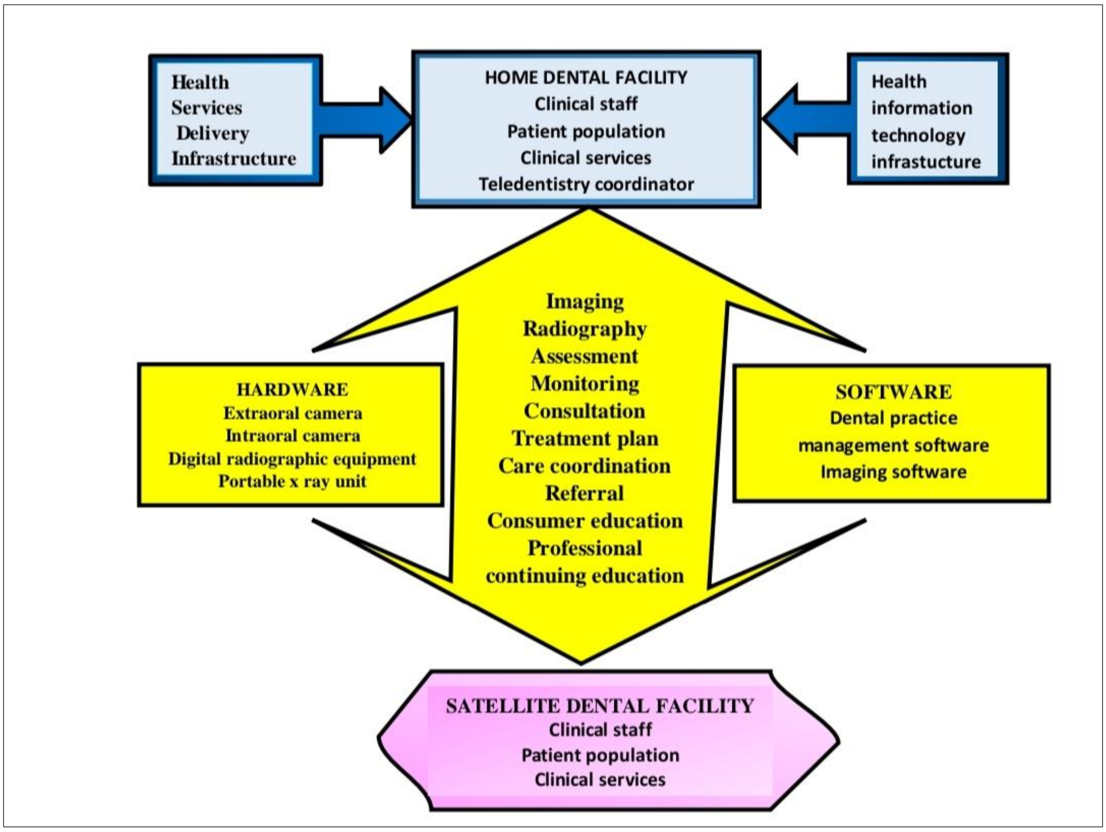

Figure 1: Framework of Tele-Dentistry

TELEORTHODONTICS

Evolving technology and integration of digital solutions in orthodontic practice have transformed diagnosis and treatment planning for tele-orthodontics from a traditional two-dimensional (2D) approach into an advanced three- dimensional (3D) technique. The use of digital technology meets the demand of multiple-doctor practices, multiple practice locations, patient volume growth, and allows efficient and convenient storage, retrieval, and sharing of information which are the important aspect of teleorthodontics. Recent developments and introduction of intraoral and facial scanners, digital radiology, cone-beam computed tomography (CBCT), and additive manufacturing improved the efficiency, accuracy, consistency, and predictability of the treatment outcomes. Computer-aided design and computer- aided manufacturing (CAD/CAM) systems were first used in the dental field in the mid-1980s. CAD/CAM consists of three key components: 1) data acquisition and digitizing; 2) data processing and design; and 3) manufacturing [11]. As computer software and dental materials evolved over time, the CAD/CAM technology became increasingly popular resulting in chairside design and milling of high-quality complete crowns and multiple-unit ceramic restorations. The advent of digital intraoral impression devices allowed high-resolution 3D virtual models to be captured. Intraoral mapping based on different non-contact optical principles and technologies is now possible without the negative aspects of dental impressions such as discomfort for the patient, imprecision, and lab work. The digital models give the flexible options for design and manufacture of a large range of dental restorations, implants, study models, and orthodontic appliances such as customized indirect brackets, arch wires, expanders, aligners, retainers, etc. The highly-accurate open file formats are incorporated in the patient electronic health record which can be remotely stored, accessed, and managed through a secure, cloud- based digital hub from basically anywhere. Most digital intraoral scanners work in conjunction with cloud-based technology where raw images once scanned can be securely transmitted to the cloud storage facility and further processed/refined for diagnostic purposes.

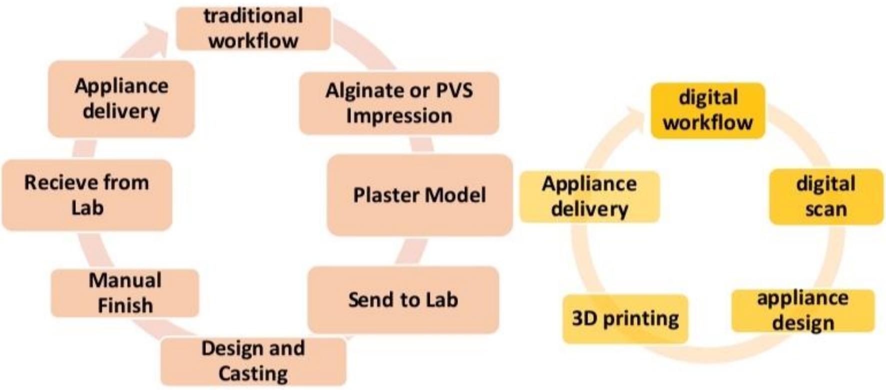

Figure 2: Traditional and Digital Workflow in Orthodontic Practice

Cloud computing has significantly influenced the healthcare industry in the past years. The concept provides massive amounts of storage and computing power without requiring end-user special knowledge about the physical location and the configuration of the system [12]. The information technology enables convenient, on-demand access at a greater speed in less time to a shared pool of computer resources (network, server, database, software, storage, and applications). This also improves the management and administration efficiency at a reduced cost. Such cloud based system is specifically developed to address the requirements for highest level of availability, security, and privacy protection in healthcare. Through it, orthodontic records and image archiving services can be synchronized and shared between healthcare organizations, dental professionals, clinics, and patients in real time on a daily basis. The file systems and employed structures are easily adaptable to since they are open, industry standard formats instead of proprietary, closed formats.

Dental software is user-friendly software, easy to operate and configure, which fully utilizes all the features of modern Windows operating systems. It follows the natural flow of work practices and provides an opportunity to fully devote professional work, and tedious administrative tasks carried out easily and efficiently to the maximum extent possible. It contains a comprehensive graphical record of the patient that is essential for superior treatment in Orthodontics. All patient information is clearly shown (by tables and graphics) on one screen and all relevant information can be reached in one or two mouse clicks. Technically it is capable of storing and displaying multimedia content–X-ray images, digital photographs, video recordings; intraoral camera scanned documents as well as direct integration with other specialized programs. It has planners showing appointments in a time interval of interest and date which are set, regardless of the number of jobs and number of employees to allow the dynamism and flexibility in the work of doctors and assistants. The system communicates with patients in several ways: by e-mail messages, SMS messages or by sending written scanned notices. Despite the many benefits and promises of these systems, they help to improve clinical practice and its impact on disease outcome. Therefore, their use in medicine, particularly in orthodontics, is slow and limited with little impact on clinical practice.

Electronic Medical Record in Dentistry

Dental record, in paper or electronic format, integrates all data related to dental care for one patient. Among other dental record provides a graphic description of the condition of patient's mouth, including dental caries (or damage to the teeth), dental disturbances in tooth growth, disturbances in the root of the tooth, periodontal disease and other diseases and anomalies of the teeth. Medis. Net. Dental [13] is a complete software solution for both dental clinics and private dental practice. It allows its users to work with data about the current state of the teeth of their patients, a historical overview of the patient's teeth, keeping records of treatments administered, the materials used, invoicing for delivered services, distribute work hours of medical staff, patient scheduling check-ups, etc. However, the central part of this software module occupies a dental record with graphical status of the teeth. Electronic dental record within Medis.Net. Dental module is implemented so it can functionally and visually to have small deviations from the traditional, printed dental records. This aims to enable medical personnel the simpler transition from current mode to the use of electronic dental records, with minimal changes to existing work processes. Thus, the graphical user interface implemented on the pattern of printed dental board. It consists of two tabs (tab control). The first tab, visible immediately upon opening the record, contains personal data of the patient, warning signs, the number of health card, personal number of the insured person, information about health insurance and employment details. This tab corresponds to the first page of printed record. The second tab contains the patient's medical record, and it corresponds to the inside pages of printed record. The largest part of this tab cover two controls for graphical representation of the state of teeth and surrounding tissues. Two controls allow the display of the primary and permanent at the same time. Depending on the age of the patient can be present only the primary dentition, both dentitions or permanent dentition only. Each tooth in the view is represented by 5 area of the crown that exists in the printed record and using a suitable number of roots (13). The teeth were grouped into 4 quadrants (upper right, upper left, bottom left, and bottom right) with the 8 teeth each. Each tooth is numbered in a standard double-digit format where the first digit represents the number of the quadrant, and the second represents the number of the tooth within the quadrant. Moving the mouse cursor over the teeth leads to a magnified view of the teeth in order to facilitate staff to work with him, and the situation (diagnosis or therapy) of the teeth or any part thereof to be printed as text next to the tooth (tooltip). In the era of paper (which is still present), patient information is stored in its medical record. In the lower right part of the tab with health data is the control for the selection state of the teeth (outlook bar) that contains the most commonly used diagnosis, therapy, prosthetic compensation, a state of health of teeth and the possibility of placing the number of roots of a tooth that deviates from the standard. Selected state is applied to the tooth or the tooth by left mouse click on the selected area. Any errors are easily corrected by re clicking on the same surface. The choice of diagnosis and treatment that exist in the database facilities by list view control in the lower right part of the form. It is important to note that the database contains a catalogue of diagnosis with respect to a particular speciality. The same control is used for placing and invoicing of services provided. In the lower left corner of the form are two buttons to open a historical review of the situation of the teeth. One button opens an overview of all the teeth on the selected date. The second button opens an overview of all states of selected teeth from the time when teeth starts to grow to the current situation. This review was not readily available by using printed dental records, and it can significantly assist the dentist in making decisions so that it currently provides an insight into the development, disease and therapy applied to the tooth to the dentist then analysed [13].

Importance of implementation of electronic health records in teleorthodontics

During the treatment the doctor has access to all relevant patient records, personal information (general data), medical history, documentation and a complete graphical and tabular presentation of the status of the teeth and carried out interventions to date. Thus, all patient data can be found in one place and clearly presented, with the possibility of coping. Also, doctors and teams from different practice can achieve superior communications in order to exchange experiences and opinions with respect to rights of privacy of the patient. This significantly reduces the possibility of setting incorrect diagnosis, it is possible to operate more efficiently and improve the quality of healthcare services. Use of electronic dental records enables patients that all its documents and data are stored in one place, which prevents the occurrence of errors. The software is technologically capable of storing and direct display of multimedia content such as X-ray images, digital photographs, intraoral pictures, videos, and the patient can relax whether dentist has taken all the necessary documentation. It also prevents the possibility of them losing patients due to negligence. There are frequent cases where the patient undergoing orthodontic treatment happens to get transferred in another city or country, then there is also the possibility of sending documentation from the original doctor to the doctor available nearby to the patient. In addition to communication between dentists the system itself communicates with patients in several ways: by e-mail messages, SMS messages or by sending written notices which are considered to be one of the benefits. Using new technology in dentistry, including the electronic medical records in practice, therefore, increase patient comfort and allows safe and effective treatment.

Advantage of using electronic dental records

The advantages of using electronic dental records in relation to work with the printed one, especially for larger dental clinics including improved control over the record, easier storage and data access. The possibility of processing large amounts of data in order to conduct scientific research and improve care for patients, better access to information relevant to the management of the clinic/dentist office, etc. Historical overview of all the teeth or the individual teeth by using electronic dental records is readily available from the moment you open the record or the moment of eruption of teeth to the current moment. This functionality can to some extent facilitate dental decision-making regarding further treatment. Electronic exchange of data between remote dental clinics/offices, which are allowed to use electronic dental records, can significantly contribute to the overall increase in knowledge in this field thereby aiding in easiness for tele-orthodontics. Electronic data exchange between the distant offices which by organization belonging to the same health institution should make easier and speeds up the daily work of these clinics.

The concept of the virtual waiting room

The concept of the virtual waiting room provides the dynamism and flexibility in the work of dentists and assistants. Planners offer a high degree of setup options, it displays appointments in the date and time range for which the planners adjust for dentists in which planner is the patient. This mode allows you to schedule treatment for their patients schedule follow-up examinations at three or six months. The software offers the possibility of direct communication with patients in several ways: a) by e-mail messages; b) by SMS messages and c) by sending written notice to patients in envelopes. Dentists and teams from different practice can achieve outstanding communication in the interest of improved treatment of the patient and easier to exchange experiences and opinions.

Software for orthodontic diagnosis

Diagnosis in orthodontics is primarily done by radiographs and photography. But with help of digitalisation in orthodontics various 3D techniques are being used as diagnostic aids. This helps it to get it stored along with patient record in cloud system and can also help in sending it to any other dental professional helping in the tele-orthodontic system.

Digitisers:

Computer-aided cephalometric software has been widely available since the introduction of personal computers. Early implementations relied on a digitiser to get the coordinates of the points directly from the radiograph or from its tracing, and only relatively recently have scanners or digital radiographs been introduced. Digitisers are electromagnetic devices that detect the position of a cross hair pointer on a tablet by means of electromagnetic fields. For this reason, a certain amount of interference from external fields or metal objects is expected. Accuracy is reported to be approximately 0.1 mm, although values differ between various models and manufacturers. Studies assessing digitiser accuracy have found both systematic and random errors, but the total errors are not large, at least when compared to more serious error sources, such as the error of landmark identification [14]. Digitisers can be used either directly on the radiograph or indirectly on a tracing of the radiograph. Direct use requires a digitiser with a translucent surface, so that the radiograph can be lit from underneath. This is the recommended procedure, as it is considered to exhibit smaller errors, because there is no need for the intermediate step of creating a tracing. The major benefit of using digitisers is that the radiograph is inspected directly by the human eye, thus taking advantage of the capabilities of this organ. A very important capability, when viewing a radiograph for landmark identification, is the power to discriminate between different shades of grey. The human eye has a rather limited power in this respect, being able to discern approximately 30 grey levels. However, this is coupled with an extraordinary ability to accommodate to a very wide range of light intensities (of the order of 10 10) by adaptation mechanisms, such as the opening and closing of the iris and the different sensitivities of the photoreceptors. At each adaptation level, there are limited intensities that can be discerned, but as the observer scans the radiograph, the eye changes its accommodation level, in effect extending the total range of grey levels detected.

Scanners:

Scanners digitise an image by shining light on it and reading the reflected or transmitted light, using a light-sensitive element (usually a charge-coupled device, CCD). In the case of radiographs, the light source is typically placed on a cover above the radiograph (the light transparency unit), and the CCD scans the radiograph from underneath. The intensity of the transmitted light is converted to a digitised signal that constitutes the image of the radiograph. Scanners have certain characteristics that determine the quality of the image. These are resolution, colour depth and optical density. Ensuring a good image is paramount to precise measurements.

Resolution:

Resolution refers to the number of pixels of the resulting image. It is usually measured in dots per inch (dpi) and can extend above 1,200 dpi. It is important to differentiate between the optical resolution of the scanner and the total resolution. The optical resolution is determined by the number of elements of the CCD and the step size of the motor that moves the CCD. These factors commonly allow resolutions of 600–1,200 dpi. Software interpolation can then be applied to increase the resolution to much higher values.

Colour Depth:

Colour depth corresponds to the number of bits dedicated to each colour of the image. Computer colour images are composed of three primary colours (red, green and blue). These colours are mixed in different proportions (intensities) to produce all the different colours of the image. The computer usually assigns one byte (8 bits) to represent each primary colour, so most computer images are 24-bit images. Higher-level machines and scanners can use more bits per colour (12 or 16 bits) to describe more shades of grey (4,096 or 65,536). High-bit images (12 or 16 bits) seldom offer substantial benefits for orthodontic research purposes because of the inability of conventional monitors to display high colour depth and the inability of the human eye to detect very fine gradations in light intensity. It should be pointed out that 12- or 16-bit greyscale images are used effectively in computed tomography (CT) images. In such images, either the greyscale range can be compressed to 8 bits for display of the whole dataset or only a part of the extended range can be selected. By choosing to view the high intensity pixels, the bony tissues are made visible, whereas the soft tissues can be displayed by selecting the lower range. This procedure is commonly known as windowing.

Optical Density:

Optical density refers to the range of light intensities that a scanner can acquire. It determines the quality of a scanned radiographic image. This depends on the capabilities of the CCD and the electronics of the scanner. It is expressed in a logarithmic scale and typically ranges from 2.4 to 4.2 for consumer scanners on the market. On scanning of radiograph light of a particular intensity falls on the radiograph, and part of this is transmitted through it and reaches the CCD. The ratio of transmitted light to incident light at a particular location of the radiograph is the transmittance. The inverse of this ratio is the opacity. The logarithm of opacity is the optical density of the radiograph:

Noise:

Noise is another factor that degrades scanned images. Noise appears as random variations in image intensity at the pixel level and is most evident in the dark areas of the image. It can be reduced substantially by multiple scanning. This technique scans the radiograph more than once and averages the results. Due to the random nature of noise, the average of multiple scans will tend to cancel out noise and retain the true value. High-end scanners are capable of acquiring multiple values for each pixel and take the average during a single pass.

Digital Radiography

Digital radiographic machines register the intensity of the radiation transmitted though the patient’s head by an electronic sensor and convert it directly to a digitised signal, thus eliminating the intermediate steps of developing a film and digitising it with a scanner. The sensor is a charge-coupled device (CCD). Most sensors have small dimensions and it is not possible to cover the whole area of interest. To solve this problem, the manufacturers use an array of sensors, arranged side by side.

The array extends along the required width and is moved vertically during the exposure, in tandem with the x-ray source, to scan the whole head (horizontal scanning is also available). This method presents certain differences in comparison to the conventional approach including longer exposure, reduced radiation exposure, increased duration of stillness of patient, different magnification pattern. The conventional (non-digital) systems use a beam that diverges from a single point towards all directions, to produce a cone-shaped geometry. This results in symmetrical magnification of the exposed structures around the central beam. In contrast, some digital systems use a fan-shaped beam that scans the patient vertically (or horizontally) in a parallel fashion. Therefore, magnification is present only along the horizontal (or the vertical) axis. This problem has been overcome in newer machines that incorporate rotational movement of the x-ray source, or movement of a slit diaphragm, thus producing comparable magnification to conventional systems. Other digital systems use a hybrid method to acquire the image. A special phosphor storage plate (PSP), like a conventional film, is used to obtain the image, by means of conventional x-ray equipment. The plate is then inserted into a special scanner, and the captured image is converted to a digital file.

Advantages and Capabilities of Computer-Aided Cephalometrics

The advantages of using a computer for performing cephalometric measurements are so significant that probably no research is being conducted by manual methods anymore. The obvious speed factor is especially important when a large number of diagnostic records need to be processed. Ease of use is also important, because it relieves the operator of fatigue. Error control, a major problem in any investigation, is where computer-aided cephalometrics should focus.

Error Control: A common conclusion that error of point identification is the most significant source. Computers may help in reducing this error by the following methods:

Image Enhancement: Various image manipulations can be applied such as Contrast, brightness and gamma can be adjusted, and histogram techniques can be applied over the whole image or at specific areas.

Multiple Digitisation: Multiple digitisation has been recommended as a method to reduce point identification error. Baumrind and Miller reported that in order to reduce this error by half, each point should be digitised four times, and the average of the four attempts should be used as the location of the point. Cephalometric software allows multiple digitisation on screen (without showing the previous attempts, so as not to bias the user) and calculate the average position.

Magnification of the Image and Precision Limitations: The scanned image can be magnified on-screen to almost any detail in order to facilitate point placement. The limiting factor here is the resolution at which the radiograph was scanned. A resolution of 150 dpi will produce approximately 6 pixels per mm, which far exceeds the usual requirements of cephalometrics. The precision with which points are located on-screen depends on a number of factors, such as scanning resolution, the zoom setting when digitising and the internal design of the software, movement of mouse. However, two other factors come into play at this magnification. One is the resolution used during scanning. If this was relatively low, then the image pixels will be apparent, setting a limit to the effective precision; although we can place the mouse and digitise at sub-pixel positions of the image, there is no way to ensure that the digitised location is correct. The final limiting factor is the internal design of the software program, which may not allow unlimited precision.

Automatic Point Location

One of the reasons that the error of point identification is high for points such as Gonion and Gnathion is that these points are located on curved osseous boundaries. The investigator has the task of locating the most extreme point along this boundary (e.g most inferior and posterior point, in the case of Gonion), not an easy task given the absence of anatomical markers. An alternative is to delegate the task to the computer. Software already exists that can assist in this respect. The user need only draw the outline of the boundary, and then the software automatically locates the points on this boundary following simple geometrical rules of point definition. The anteroposterior direction is defined by the Frankfort horizontal plane, which has been digitised previously, thus circumventing errors caused by improper head orientation.

Magnification Adjustment: A common problem with orthodontic research studies is that the cephalometric radiographs acquired by different x-ray machines possess a different magnification factor. Although angular measurements are not affected, linear measurements need to be rescaled to a common magnification for proper comparison. Correction to natural size is recommended, in order to avoid confusion and obtain valid results. Differences of magnification present larger problems in superimposing. If the original and final cephalometric radiographs of a patient have been taken on machines with different magnification, it is not possible to superimpose them manually, unless one resorts to such creative measures as enlargement or reduction of the tracings by photocopying.

Structural Superimposition: Superimposition of radiographs on internal osseous structures is recommended for assessing treatment or growth changes. This is not easy to accomplish manually because a lot of structures need to be traced and precision may be compromised. Computers allow direct superimposing of radiographic images using different colours for each. When two structures align, the colours are blended together to produce a different colour. This facilitates the procedure significantly. Automated methods that aim to superimpose anatomical structures so that the optimum alignment is achieved are currently in the experimental stage.

Morphometrics

The field of morphometrics is relatively new in biology and has only recently been applied to orthodontics. Morphometrics aims to overcome some of the fundamental problems of conventional cephalometrics, such as the problem of separating size from shape selecting an appropriate superimposition scheme and interpretingthe results of the measurements.

Warping of Images: Computer graphics have advanced to the point that it is now easy to modify images by deforming them and blending them in a controlled manner to create realistic pictures of objects that do not exist. Two terms are coined for such procedure, but they are sometimes used interchangeably in the literature: “Warping” refers to the deformation of a single image, and “morphing” refers to the deformation of two images and the creation of a new image by blending the two warped images together, most often used for the creation of animated sequences. In orthodontics, such movies are used to show simulations of treatment, by depicting a smooth transition from the initial photograph of a case to the final result. But the diagnostic value is debatable, due to the following reasons: 1. The warped image is based on the cephalometric prediction of the facial outline. Thus, the final result is no more accurate than the cephalometric tracing. 2. The warped image is based on the initial pre-treatment photograph. The photograph is warped so that the facial outline changes shape and becomes the same shape as the tracing prediction. In this process, the remainder of the face is also deformed, not according to any biological model, but based on mathematical algorithms. This deformation will not reflect the true changes that are produced by treatment, even if the final facial outline has been accurately predicted.

Three-Dimensional Records: Three-dimensional records are utilised in increasing frequency, driven by advances in computer hardware and software and by the recognition that two-dimensional records are inherently limited in their ability to document the 3D craniofacial structures and the dentition. Since the beginning of orthodontics, the only 3D orthodontic records have been the study casts. The ideal goal in orthodontic diagnosis would be to replace all two-dimensional records (cephalometric and panoramic radiographs, facial and intraoral photographs) with three-dimensional ones. The diagnostic procedure and treatment planning (measurements and treatment prediction) would take place directly on the 3D records, thus circumventing many of the current limitations [15].

Intraoral scanners: Three-dimensional digital impressions were first introduced in 1987 by CEREC1 (Siemens, Munich, Germany) using infrared camera and optical powder on the teeth to create a virtual model. Over the years, computer hardware and software developments have dramatically improved the technologies completely replacing traditional alginate and polyvinyl siloxane (PVS) impressions in a large number of dental and orthodontic offices. New intraoral scanners for acquisition of digital impressions are continuously entering the clinical practice all over the world [16]. The optical scanners can be used to capture both in vivo images of the dentition and in vitro images of the physical models to create a 3D digital representation. Intraoral scanner devices offer numerous applications in orthodontics such as digital storage of study models and advanced software for cast analysis, landmark identification, arch width and length measurements, tooth segmentation, and evaluation of the occlusion [14]. The platforms allow clinicians to obtain a digital diagnostic set-up, perform indirect bonding, and export the digital scans into open source file formats. The electronic files are shared with third-party providers and imported into a variety of digital workflows for advanced treatment planning of surgical cases, implants, and superimposition with CBCT data. Digital impressions streamline and expedite the traditional workflow, reduce the number of patients' visits, and maximize the efficiency and cost savings in the orthodontic office. Besides the better control and improved accuracy of the directly obtained digital models, scanners add the plug-and-play capability of an automatic exchange of patient information within the office or outside laboratories. Lost or broken appliances could easily be refabricated using the digital files from a database in the Cloud.

Optical Scanning Technologies:

Several scanning technologies using different optical components and structured light sources are currently employed in orthodontics:

1. **Confocal Laser Scanner Microscopy (CLSM):** The basic principle of confocal microscopy was pioneered by Marvin Minsky in 1957. Images are projected point-by-point, line-by-line, or multiple points at once and three dimensionally reconstructed with a computer, rather than obtained through an eyepiece [17]. The key feature is its ability to produce optical slices of the objects at various depths with high resolution and contrast in the x, y, and z coordinates. Spatial filtering is employed to eliminate out-of-focus glare or light of background information. Change of display magnification and image spatial resolution, termed the zoom factor, is enabled by altering the scanning sampling period. Modern confocal microscopy systems integrate various components such as beam scanning mechanisms and wavelength selection devices which are often referred to as a video or digital imaging system.
2. **Optical triangulation:** Optical triangulation measures distance to objects without touching them with accuracy from a few millimetres to a few microns. Triangulation sensors are particularly useful in acquiring high-speed data in inspecting delicate, soft, or wet materials where contacts are undesirable. The system uses a lens, a laser light source, and a linear light sensitive sensor. The laser irradiates a point on a specimen forming a light spot image on the sensor surface. The distance from the sensor to the surface is then calculated by determining the position of the imaged spot and the baseline angles and length involved [18].
3. **Optical Coherence Tomography (OCT):** Optical coherence tomography (OCT) is an interferometric technique that performs cross-sectional high-resolution imaging of the internal morphology of biological materials and tissues. Micron-scale measurements of distance and microstructure are obtained from backscattered or back reflected light waves in real time and in vivo. The relatively long wavelength light is able to penetrate into the scattering medium up to 2-3 mm deep in most tissues. It and can be successfully applied where standard excisional biopsy is not possible or hazardous [19].
4. **Accordion Fringe Interferometry (AFI):** Accordion fringe interferometry (AFI) employs a revolutionary linear interferometry technology that traditionally projects to three dimensions. AFI delivers the most precise laser fringe projection available which quickly digitizes the shapes of 3D objects with the highest accuracy of point cloud data. AFI employs laser beams from two-point sources to illumine the objects and uses a charge-coupled device (CCD) camera to capture the curvature of the borders. AFI is suitable for a wide range of applications that require high speed, portability, and infinite projector depth of field from a 3D digital system [20].
5. **Active Wavefront Sampling (AWS):** Active wavefront sampling (AWS) uses a 3D surface imaging technique, which requires only one optical path of an AWS module and a single camera to acquire depth information. The optical wavefront traversing a lens is sampled at two or more off-axis locations and a single image is recorded and measured at each position. Target feature image rotation can be used to calculate the feature's distance to the camera. AWS reduces system cost by eliminating the need for expensive laser-based

target illuminators and multiple cameras to acquire 3D images [21].

Scanning Systems:

1. **iTero®, Align Technology:** The iTero® digital impression scanner was developed by Cadent Ltd. in 2006, and acquired by Align Technology, Inc. (San Jose, CA) in 2011 [15]. iTero® employs confocal laser scanner microscopy technique. The device projects 100,000 parallel beams of red laser light which pass through a probing face and a focusing optics to reach the teeth. The reflected light is then transformed into digital data through the use of analog-to-digital converters. The system scanning capability does not require coating the teeth in powder thereby allowing the wand rest directly on the teeth during scanning. One disadvantage is that the iTero® camera needs a colour wheel attached to the acquisition unit, which results in a larger and bulky scanner head in comparison to other systems. 153iTero® comes as a mobile cart containing a central processing unit, large working surface with a touch screen display, a wireless mouse, a wireless foot pedal, a built-in keyboard, and a scanning wand [14].
2. **True Definition, 3M ESPE:** The 3M True Definition scanner was officially launched in 2013 as an updated version of the Lava™ chair side oral scanner which has been widely used in general and restorative dentistry since 2006. The True Definition scanner captures 3D images using active wave front sampling on the principle of structured light projection. 3M ESPE named this scanning technique "3D-in-motion video technology". The system employs a rotating aperture element placed off-axis in the optical apparatus either in the imaging or the illumination path which measures the defocus blur diameter. The user should first dry and lightly dust with powder the entire arch so the scanner can locate the reference points. The True Definition features an ergonomic scanning wand and a rolling card with a HP® high performance CPU computer unit with 22" touch screen monitor [22].
3. **Lythos™, Ormco Corporation:** The Lythos™ Digital Impression System was introduced by Ormco Corporation (Orange, CA) in 2013. The intraoral scanner uses accordion fringe interferometry technology to capture and stitch together a 3D data in real time, acquiring high-definition details at all angulations of the tooth surface. Lythos™ provides 3D video imagery of 2.5 million points per second. The Lythos™ scanner is portable, weighs around 13 kg, and can be positioned directly on the ground or on a chairside table [23].
4. **CS 3500, Carestream:** Carestream Dental (Atlanta, GA) launched the portable digital impression system, CS 3500, at the end of 2013. The scanner employs confocal laser scanner microscopy technique which allows capture of true-colour 2D and high- angulation 3D scans of up to 45º with a depth of field of -2 to 13 mm. The image resolution is 1024 x 728 pixels and the accuracy measure up to 30 microns. The system is trolley-free and uses a wand with a single, forked USB cable that can be plugged in any computer, eliminating the need for a dedicated workstation. Two scanning tip sizes are included to accommodate children and adults. CS 3500 features a light system which guides the user during the data capture and the image acquisition process. It is compatible with open source software or it can work as part of the integrated Carestream CAD/CAM dental restorations system. 3Shape (Copenhagen, Denmark) announced the TRIOS® intraoral scanning solution in December 2010. The system operates by the principle of confocal microscopy, with a fast-scan rate. CS 3500 is compatible with open source software or it can work as part of the integrated Carestream CAD/CAM dental restorations system [24].
5. **TRIOS®, 3Shape:** 3Shape (Copenhagen, Denmark) announced the TRIOS® intraoral scanning solution in December 2010. The system operates by the principle of confocal microscopy, with a fast-scan rate. The high-definition camera features teeth shade measurement and provides scans in enhanced natural colours or in a standard noncolor pattern. The scanning wand does not requires the use of powder, has an autoclavable tip and an anti-fog heater [25].
6. **FastScan®, IOS Technologies:** Glidewell Laboratories' IOS FastScan® intraoral camera and modelling system was commercialized in July 2010. The digital impression system uses the principle of active triangulation with sheet of light projection. Ego-motion technology is used to optimize image stabilization by having the camera moving automatically on a track within the housing wand. That built-in motion detection software eliminates hand-movement distortion, capturing high-resolution surface detail. The camera scans 40 mm per second throughout a depth of field that is greater than 15 mm. An application of titanium dioxide powder is required [21].
7. **3D progress, MHT Optic research:** The 3D Progress digital impression system is supplied by Medical Height Technology (MHT) company (Verona, Italy) and MHT Optic research (Zurich, Switzerland). The technology beyond the product is a confocal scanning microscopy with a Moiré pattern detector. A Smart pixel sensor supports precise and quick capture of up to 28 scans per second which are stitched in a single 3D image in less than one tenth of a second. 3D Progress allows a wide focus of acquisition, ranging between 0 to 18 mm depth of field [26].
8. **Planmeca PlanScan®, E4D Technologies:** Formerly known as the E4D NEVO scan and

design system, the Planmeca PlanScan®, driven by E4D Technologies (Richardson, TX), is an intraoral scanner widely utilized in restorative dentistry. PlanScan® uses optical coherent tomography with blue laser technology. Point and stitch image reconstruction occurs at video-rate scanning speed. The single smaller wavelength of 450 nm is more reflective, capturing sharper images of various hard and soft tissue translucencies, and dental restorations [27].

Desktop Scanners

Various extraoral 3D scanners have been designed to capture 3D images of both impressions and physical casts for the acquisition of digital study models. The scanning technology employs a non-destructive laser beam and several digital cameras to reproduce high resolution images of the target's surfaces. Impressions, models, or bite registrations are positioned inside a chamber platform which is automatically rotated and inclined during scanning, ensuring complete multiple angle coverage of the model's geometry. The laser light is projected onto the object, and the cameras acquire its mirror image from the surface. Upon scanning completion, a rendered stereolithographic model is created, and plaster models, impressions, and bite registration can be discarded, eliminating the need for storage.

1. **Ortho Insight 3D™:** (Motion View Software, LLC, Chattanooga TN) was introduced in 2012, offering a high-resolution, robotic scan with an accuracy of 40-200 microns. The automated laser scanner is designed to capture full arch impressions, plaster models, and bite registrations, and create 3D digital models. The software also allows measurements and automated functions such as landmark identification, arch length analysis, tooth segmentation, and evaluation of the occlusion. The optional software modules include indirect bonding and cephalometrics. 3Shape company (Copenhagen, Denmark) offers three desktop 3D scanners with the capability to digitize both plaster models and impressions with different resolutions and speeds. The R500 and R700 series use red light laser technology with two 1.3-megapixel digital cameras which ensure 20 microns accuracy. The advertised R700 series scanning time is 1 minute and 30 seconds for a plaster model and 7 minutes for an impression which makes the scanner suitable for medium-sized orthodontic offices and labs. The 3Shape R900 series scanner uses blue LED laser technology and employs four 5-megapixel cameras which ensure 15 microns scanning accuracy with colour texture. The advertised R900 scanning time is 1 minute and 20 seconds for a plaster model and 2 minutes and 10 seconds for an impression which makes the scanner suitable for large high-volume, productive-orientated labs. Ortho Analyzer™ is the 3Shape imaging and digital model software package which features sculpt and rebase applications with collision control, tooth movement simulation, superimposition of study models with photographs or DICOM data originating from CBCT scanners, and digital manufacture of appliances or dental restorations [28].
2. **Maestro 3D:** (AGE Solutions, Piza, Italy) is another desktop scanning device which allows digital conversion and storage of physical models and impressions. The scanner37 system has a LED projector with two digital cameras which capture scans with 0.07 mm resolution and 10 microns accuracy. The Maestro 3D extraoral scanner comes with several modules: Easy Dental Scan software for inspection and editing; Ortho Studio software for tooth, arch, overjet, and overbite measurements, cross sectioning, and occlusion inspection; Virtual Setup module for tooth movement, distance and collision evaluation, attachment management, modelling, and export for 3D printing [29].

Documentation of Dentition

Plaster casts have a long and proven history as a routine dental record and have been the gold standard for dentition analysis for years. Nevertheless, plaster models have several disadvantages including labor-intensive work, demand on physical storage space, fragility, degradation, and problems of potential loss during transfer. Digital study models offer a reliable alternative to traditional plaster models. Their advantages in orthodontic diagnosis and treatment planning include easy and fast electronic transfer of data, immediate access, and reduced storage requirement. Digital models can be integrated into various patient management systems, digital records, along with the digital photographs, radiographs, and clinical notes.

Digital models may be virtually manipulated to section and analyse specific teeth, arch form, amount of crowding or spacing, and type of malocclusion. Measurements such as overjet, overbite, tooth size, arch length, transverse distances, and Bolton discrepancy are achievable. The user can obtain a digital diagnostic setup, simulate a proposed treatment plan, perform bracket placement, and indirect bonding. CBCT and digital models can be merged to facilitate treatment planning of orthognathic cases, creation of surgical guides, placement of temporary anchorage devices (TADs), exposure of impacted teeth, or preparation for dental prostheses. Moreover, if a physical model of the dentition is required for the manufacture of an orthodontic appliance, digital models can be 3D printed with a rapid prototyping technology. The software is an aid in the CAD/CAM process, able to repair errors in the mesh prior to 3D printing, edit the models, and design appliances [30]. Digital models were commercially introduced in 1999 by OrthoCAD™ (Cadent, Carlstadt, NJ) [31]. The results from a recent survey conducted by the Journal of Clinical

Orthodontics demonstrated a significant increase in the use of digital models for pre-treatment diagnosis and treatment from 6.6% in 2002 to 18% in 2008. Today, many orthodontists acquire digital models through the use of proprietary services. Traditional impressions, plaster models, or intraoral scans are submitted to the selected company so that they can generate the digital models and made them available for download in proprietary or stereolithography (STL) file format. STL is an open, industry standard file format that is supported by most intraoral scanners and widely used for rapid prototyping, computer-aided manufacturing, and across different 3D modeling interfaces. Another open file format is PLY, polygon file format (also known as Stanford triangle format), which is used when color and/or transparency information is needed. The direct method makes dental impressions redundant by using an intraoral scanner to capture directly in the patient’s mouth. Indirectly, digital models can be produced by scanning alginate impressions and plaster models with a desktop scanner, intraoral scanner, or computed tomography imaging. There are no universal standards for defining model accuracy. However, in orthodontics, it is generally accepted that measurement accuracy up to 0.1mm is adequate for clinical purposes and does not compromise the diagnostic value of a model [32]. Numerous studies have evaluated the reliability of stereolithographic models obtained by indirect methods by assessing the agreement of measurements on plaster and digital models. It has been shown in the literature that digital models have clinically insignificant differences for reproducibility of orthodontic measurements [33]. Tooth size has been found to be similar or slightly smaller in OrthoCAD™ compared to measurements made on plaster models. Overjet measurements were not significantly different in some studies however Quimby *et al.*, (2004) found a significantly smaller overjet measurement when obtained with OrthoCAD™. Space available or arch length to be used in estimating crowding, demonstrated to be significantly different between OrthoCAD™ models and plaster models with differences ranging from 0.4 mm to 2.88 mm [34]. Laser-scanned models are suggested to be highly accurate in comparison to plaster models and CBCT scans and provide clinicians an alternative to physical models and CBCT reconstructions in diagnosis and treatment planning. Both CBCT and intraoral scanning of alginate impressions were concluded to be valid and reliable methods to obtain measurements for orthodontic diagnostic purposes. Furthermore, different digital model conversion techniques have shown no statistically mean differences when using 3D palatal rugae landmarks for comparison. 3D digital models are also proven as an effective tool in evaluating palatal rugae patterns for human verification and identification.

Documentation of Intra Oral Tissues: In recent software programs, such as 3Shape’s Ortho-Analyser, all traditional methods to analyse digital dental models— such as the analysis of tooth dimension, distances between teeth, the Bolton ratio, space requirements, dental arc shapes, and the traditional measuring of the overjet and overbite—will be recorded semi automatically. During this process, it can be helpful to magnify and use clipping procedures to increase the accuracy of the measuring and analysing procedures. After analysing the documentation, a total report of this analysis, including some relevant images, should be made and sent to the referring dentist and other healthcare professionals. Once a case has been analyzed, the process of treatment planning can begin. The segmented dental crowns and, if available, the segmented dentition on the cone beam computer tomography (CBCT) radiographs can now be used to simulate the dental movement needed to correct a malocclusion using virtual repositioning software. A setup of the dentition can then be made [35]. Some orthodontic labs use a file transfer protocol (FTP) to enable the easy and safe uploading of the files. These FTP servers are built on a client server architecture and use separate control and data connections between the client and the server. FTP users may authenticate themselves using a “clear text sign-in” protocol, normally in the form of a username and password, but can connect anonymously if the server is configured to allow it. Secure transmission protects the username and password and encrypts the content. A virtual setup can now be considered a standard procedure for the planning of each orthodontic treatment. For making a digital setup, the dental crowns should be segmented from the digital dental model, using software, for instance the Insignia software, for virtual segmentation. After segmentation, a reference for the dentition based on the original dentition and the alveolar bone should be selected. In some setup software programs, such as Ortho-Analyser, the occlusal plane and the palatal midline are defined as reference planes. Then an automatic suggestion for segmentation will be presented by the software. This segmentation process is done in most software programs in a semi-automatic way [36]. Clipping functions can be used to evaluate relations between the teeth and between the arches (including contact points and occlusal stops). One single tooth or a group of teeth can be moved at the same time during making the setup. Occlusal contacts should be evaluated and corrected in the setup when needed. A colour scale can be used to show the contact points in the setup. The original digital dental model and the setup can be evaluated in a virtual articulator, to evaluate the actual and planned functional contacts and occlusion. During this process of virtually moving teeth, the dentist or technician is able to quantify and visualize the applied tooth movement. Obviously, tooth movement has its biological limitations. Too much expansion or compression of the dental arches may result in unstable results and periodontal recessions. So, the setup should be made based on biological principles and clinical experience. The role of the orthodontist during this setup fabrication is very important, because the technician will not be able to decide about the need for expansion of the dental arches or interdental reduction of tooth material (“stripping”), or whether to extract teeth. If a lab technician makes the setup, a treatment plan should be available and after making the setup the planned virtual treatment should be sent to the orthodontist for evaluation. The original tooth position and changes in dental position introduced in the setup should be recorded and available for further reference [37].

Documentation of Face: Facial scanners provide three-dimensional topography of the facial surface anatomy, automatic facial landmark recognition, and analysis of the symmetry and proportions of the face. Practical applications further include quantitative and qualitative assessment of growth and development, ethnic variations, gender differences, and isolation of specific diagnostic traits in selected populations of patients with craniofacial anomalies. In addition, facial phenotype associated with fetal alcohol syndrome, cleft lip and palate patients, and short- and long-term effects of nasoalveolar moulding have been evaluated using three-dimensional surface imaging. Volumetric results are also valuable clinical tools to assess primary palate reconstruction in infants with cleft lip and palate [38]. The scanner system has a LED projector with two digital cameras which capture scans with 0.07 mm resolution and 10 microns accuracy. The Maestro 3D extraoral scanner comes with several modules: Easy Dental Scan software for inspection and editing; Ortho Studio software for tooth, arch, overjet, and overbite measurements, cross sectioning, and occlusion inspection; Virtual Setup module for tooth movement, distance and collision evaluation, attachment management, modelling, and export for 3D printing. In 2013, Hayashi *et al.,* compared the in vitro reliability of three scanning systems (SureSmile OraScanner, Konica Minolta VIVID910, and 3Shape R700) to the gold standard SLP250 Laser Probe digital models. The authors found that the deviation values for each comparison were small (< 0.048 mm) and each scanning device generated sufficiently accurate digital models for use by clinicians [39]. Recent scanning technology innovations provided valuable methods for precise three dimensional clinical documentation and objective qualitative and quantitative analysis of the human face. Several techniques such as laser scanning, ultrasound, computed tomography, magnetic resonance imaging, and electromagnetic digitization can analyse facial characteristics in three dimensions but stereo photogrammetric systems are becoming the instrument of choice in anthropometric research.

Stereophotogrammetry: Discussed and introduced by Burke and Beard in 1967 is a unique method which utilizes means of triangulation and camera pairs in stereo configuration to recover the 3D distance to features on the facial surface. It is now systematically used for anthropometric assessment instead of the direct sliding and spreading calliper-based measurements. Today, it is predominately used in plastic surgery, medical genetics, and research settings [40].

3D photogrammetry: Acquires a 180° high-resolution color representation of the human face from ear to ear without direct contact or risks to the patients. A major advantage of the surface imaging system is a near instantaneous image capture (on the order of 1.5 milliseconds) which reduces motion artifacts and makes it suitable for children, even babies. Software tools are available to view and manipulate the image, facilitate landmark identification and calculate anthropometric linear, angular, and volumetric measurements [41].

3D surface imaging: Enables assessment of the spatial position of soft-tissue facial landmarks by assigning coordinates to each point. In a reproducibility study of 3D facial landmarks, Hajeer *et al.,* (2002) used C3D facial scans before and after orthognathic surgery of five patients to identify 24 landmarks on each scan. In addition, they defined four new landmarks by utilizing the Farkas’s anthropometric landmarks (1994). Three sessions of landmark digitization were performed within a week interval. Each landmark had x, y, and z coordinates given by the software and the mean differences were calculated from the three identification sessions by identifying the differences between the individual coordinate points. The results showed that 20 of the chosen landmarks had high reproducibility based on accepted 0.5 mm cut off point. The following landmarks whose localization depended on the underlying skeleton had problems of reproducibility: menton, left and right zygion, and left and right gonion (x-coordinate); left and right zygion, left and right gonion, left and right tragion, and glabelle (y-coordinate); menton, left and right otobasion inferius, left and right tragion, and left and right gonion (z-coordinate) [42]. Several types of 3D photogrammetric imaging systems have been described and evaluated in the literature, e.g. 3dMDface System (3dMD, Atlanta, GA, USA), C3D Imaging System (Ferranti, Birmingham, UK), Rainbow 3D Camera (Genex Technologies, Inc., Kensington, MD, USA), 3D Vectra (Canfield Imaging Systems, Fairfield, NJ, USA), and the Facial Insight 3D (Motion View Software, LLC, Chattanooga TN, USA) [43]. Aldridge *et al.,* (2005) [44] evaluated the precision and reproducibility of coordinate data and 190 distances on two sets of measurements made on 30 3dMDface images taken from 15 human subjects and found this system to be highly precise and reliable with a submillimeter average error in landmark placement. Weinberg *et al.,* (2006) [45] published a comparison of measurements of mannequin heads using two 3D surface imaging systems, 3dMDface and Rainbow 3D Camera, and direct anthropometry. These three techniques yielded a high degree of agreement among selected anthropometric variables, and the intra-observer precision was high for each method.

4D facial dynamics: Production sequential 3D surface imaging systems (4D Facial Dynamics) are commercially available to provide a quantifiable understanding of soft tissue mobility, true anatomical motion, and facial expression. The 4D systems are used to assess facial function in conjunction with natural head movements, functional progress and outcomes for patients undergoing dental treatment and surgical interventions. Human face is capable of making unique microexpressions which can be of very low intensity and last less than 0.04 seconds. Therefore, the dynamic systems continuously track frame by frame the facial surface movements in order to achieve accuracy in understanding the tracking motions. Motion capture systems with automatic facial landmark recognition software have been found practical objective solutions for the soft tissue quantification movements. Assessment of facial animation could be an essential part for orthodontic diagnosis and craniofacial abnormality, virtual surgical planning, and treatment outcomes [46]. Shujaat *et al.,* (2014) [47] evaluated the dynamics of four facial movements (maximum smile, grimace, cheek puff, and lip purse) pre- and post- lip split mandibulotomy, by using six facial landmarks. The similarity of the facial animation pattern before and after the surgery was calculated after eliminating the head motion and aligning the movement curves using the right and left endocanthion and pronasale as stable landmarks unaffected by the surgery. The results showed that the velocity of all landmarks was lower after the surgery; the smile animation difference was the least (-0.1 mm/s), whereas the largest changed was found for the grimace animation (-5.8 mm/s). Mouth width maximum change after the surgery was found to be for lip purse (3.4 mm), whereas grimace showed the least difference after the surgery. Lip purse animation similarity was highest (0.78) while grimace had lowest similarity (0.71). The 4D dynamic devices have also been employed for interlandmark and vector deviations, and shape and gender comparisons. Virtual and sound animations have been incorporated in some of the recent system improvements.

Role of CBCT in digitisation: By superimposition of the digital dental model, the CBCT, and the facial scan of a patient, a “virtual head” of that patient is available for diagnosis, treatment planning and computer-aided design (CAD) and computer aided manufacturing (CAM) procedures. Specific software (such as Anatomage, Dolphin and 3 shape) can be used for diagnosis and treatment planning. This documentation of the face can also be used to plan maxillofacial surgery before or during Orthodontic treatment [48]. The newest CBCT machines can be used with “unlimited” selection possibilities of the FOV (the part of the skull which should receive a radiation dose). This FOV can be adjusted to the specific needs of each patient. The use of a dry run (a rotation of the device without radiation) to test the correct positioning of the patient and a “scout view” (a run with a very limited radiation dose, to evaluate the accuracy of the FOV chosen) will further improve the quality of the image. After exposure, a powerful computer will reconstruct the data captured on the flat panel detector into a 3D image of the skull. Specific software can then be used to review the images of the skull on three planes. Usually, the CBCT can be reviewed with advanced imaging software (or simple DICOM viewers) from any angle, including axial, sagittal, and coronal cross-sectional slices of the skull. The files of the CBCT (DICOM files) can be changed with specific analyzing software to make certain parts of the image more visible by selecting specific Hounsfield values. Some of the well-known CBCT reviewing software programs for patients for orthodontic and maxillofacial surgery are Anatomage and Dolphin. Recent CBCT machines have been introduced that can make 3D radiographs with the same or even a reduced amount of radiation than that needed for making traditional OPT and head plate radiographs, these indications should be adjusted. Careful selection of the FOV, the resolution of the images (voxel size), and the other settings to get the best image needed for diagnosis are still required. When integrated with digital workflows, CBCT scans bring unparalleled insight to diagnostics and treatment procedures [49]. The Planmeca Oy ProMax machine was the first machine to combine three different types of 3D data capturing with one unit. This machine brings together the ability to make a CBCT image, a 3D facial photo and a 3D dental model scan. It is able to track, record, and analyze jaw movement in 3D in real time. The same machine can also be used to make 2D radiographic images, including an OPT, without the need to change sensors. This machine is not indicated for making a 2D head plate of the skull. A disadvantage of this machine is the need to fix the head to prevent movement of the head during imaging After evaluation, the data can be stored in the Cloud and can be sent to colleagues, radiologists, medical specialists, the dental lab, and the patient. A free image viewer is available. For orthodontics, the software can be used for making a dental setup, and the design of some orthodontic appliances. An alternative CBCT machine capable of capturing radiographic 3D images of the skull, facial scans, a traditional OPT, and a traditional lateral head plate has been recently introduced: the **3Shape X1TM**. During scanning, the need for fixing the patient’s head is not needed because of the use of a tracking device on the head which monitors any movement of the head during the capturing procedure, which is then corrected during the reconstruction process. This machine combines CBCT, panoramic, cephalogram, and face scanning in one system. The low dose and rotating shutter technology should improve image quality and reduction of radiation dose. The use of the “dynamic field of view” enables adjustable FOV at the touch of a button. The software is capable of merging CBCT and panoramic scans with digital impressions and face scans to create a digital patient for diagnostics, treatment planning, and appliance fabrication. The integrated outputs for all images of this machine are in the standard DICOM format, so they can be exported to the software of choice. After segmentation of the dentition, it is possible to make a dental setup with the suresmile software. In this planning process the dental roots can be positioned in the alveolar bone. As the dental crowns from an intraoral scan can be merged with the dentition on the CBCT, the need for followup CBCTs using specific software such as suresmile or 3Shape's Ortho-Analyser can be reduced. If an initial CBCT is available, a progress intraoral scan can be used to review the root position of a specific case. The quality of the scanned brackets as seen on CBCT radiographs is not accurate, so the scanned brackets and the image of the brackets on the CBCT can be merged. This process is needed to enable custom wire fabrication after approval of the setup by the orthodontist. Storage of the data in the Cloud and easy communication with the dental lab, dental and medical colleagues, and the patient is a huge step toward the desired direction of a digital workflow. It can be expected that the quality of this "virtual head" for diagnosis, treatment planning, and treatment evaluation will continue to improve. The fourth dimension (movement) should be added to enable evaluation of the occlusion, the TMJ, and other functional movements of the face [50].

Dynamic Motion Capture of the Mandible

Temporomandibular joints (TMJ), together with the occlusion, the masticatory muscles, and the vascular and nervous systems supplying these tissues, constitute the stomatognathic system. The mandibular movement executed by TMJ is a motor functional movement that reflects the command of all these components and is critical not only for oral related function such as mastication and speech but also for the systematic, mental, and physical functions of the body. Jaw recording is thus important for the understanding of the normal function of the stomatognathic system and for the diagnosis and treatment of TMJ disorders and diseases. Various devices have been developed to record and analyze the mandibular movement for more than a century. Two systems of magnetometry, the mandibular kinesiograph, and the sirognathograph, which depend on the changes in the magnetic flux occurring when a small bar magnet moves relative to a sensor, have been used to measure mandibular movements in three dimensions for a long time. These devices are found not to interfere with the mandible movements. Opto-electronic tracking systems obtain mandibular movements by using cameras to tracking the spatial position of lightemitting diodes. They also have an advantage of disturbing the individual's chewing pattern less than normal chewing function. Three-dimensional (3D) TMJ joint morphology has been reconstructed by spiral and helical computed tomography (CT) and magnetic resonance imaging (MRI). Data have been merged with jaw movement recordings by ultrafast MRI, electromagnetic tracking device, or opto-electric measuring systems in a few previous studies. The disadvantage of MRI imaging is that the patient must lie down on the scan bed, which might alter the mandibular movement. At present, there are dynamic systems to understand the TMJ. The SiCAT Function (SiCAT, Bonn, Germany) can directly combine and merge 3D cone beam computed tomography (CBCT) and electronic jaw motion tracking (JMT) data. CBCT, which offers a 3D image of facial and dental structures, has been widely used in the dental field. The SiCAT JMT system is an electronic recording system that is based on 3D ultrasound measurements. The ultrasound-based system converts the propagation times of multiple acoustic signals into spatial information, which therefore could record the lower jaw movements of the patient in all degrees of freedom. At present, the JMT system is a closed one. All data acquired must be obtained through the Sirona or SiCAT Platform. This provides the advantage that the system is seamless and transitions from one stage to the other easily [51]. As a routine treatment record, a CBCT is taken for a patient. As a preparation, silicone impression material is put in both the maxillary and mandibular side of the FusionBite reference tray and the patient is normally asked to bite on the impression material. During CBCT scanning, the patient wears the FusionBite reference tray with the silicone impression in their mouth. There are eight radiopaque markers on the FusionBite tray, which will serve as landmarks for the fusion of CBCT data and JMT data. The acquired CBCT data were transferred from the scanner to a workstation, where 3D images were constructed by GALAXIS 3D software (Sirona Galileos, Bensheim, Germany). The data are saved as DICOM (digital imaging and communication in medicine) format. For Preparation of the jaw tracking system the paraocclusal T-attachment is contoured according to the low jaw dental arch. Autopolymerizing composite is applied to the bent part of the T-attachment, and adapted to the tooth surfaces or to the study model. A short setting time for the material is required. Remove excess material and sharp edges and make sure the upper teeth are not in touch with the attachment in order to guarantee an undisturbed functional movement of the jaw in the occlusion. The upper jaw sensor is positioned stably on the patient's head. The elastic rear headband is tightened comfortably for the patient. Place the SiCAT FusionBite tray (previously adapted with silicone impression) into the mouth and make sure the patient bites into the right position. Once this is done, the SiCAT JMT+ software is employed. The following steps should be performed next: Attach the SiCAT JMT+ lower jaw sensor to the SiCAT FusionBite. Click "record" and the software will guide the program throughout the calibration sequence. Remember to always keep the SiCAT FusionBite in the mouth and attach the lower jaw sensor to the paraocclusal T attachment, and then press "record." Take out the SiCAT FusionBite. The functional jaw movement such as opening, right, and left lateral movement, protrusive, and chewing can be recorded. Data fusion once the above has been completed, load the CBCT data and JMT files in the software SiCAT Function suite. Choose any three radiopaque markers on the FusionBite tray and the tray will be automatically located and the CBCT and JMT data can be merged automatically. Segmentation of the mandible can be performed semiautomatically in the software. When the approximate position of the mandible is indicated by drawing marks on the radiographic sectional slices, the software will calculate the data and present a 3D image of the cropped mandibular segment on the screen. The blue color is used to represent the mandible and the green color for the fossa. Mandibular movements—including opening, right/left lateralization, and protrusive— can be recorded and re-recorded at any time. The ranges of these movements are automatically displayed and correspond well to the patient's movement. Once the mandible DICOM is successfully segmented, merging of CBCT and JMT data can occur [52]. The visualization of patient specific movement of the mandible, including the condyles, is displayed and is now an exact replica of the patient's mandibular movement. In the dynamic mode, the movement path of any selected point of the condyle and the mandible body such as inter-incisal point movement of the lower mandibular teeth is depicted on the face.

Digitalising Treatment Planning

Once the patient has accepted a specific treatment plan, orthodontic appliances needed for the planned tooth movement can be selected and designed. For efficient tooth movement a selection of removable, functional, fixed buccal brackets, fixed lingual brackets, or aligners can be used. These days, the use of CAD/CAM procedures in dentistry enables the clinician to customize most of the traditionally used standard orthodontic appliances. Virtual design and the fabrication of custom orthodontic appliances should be used to optimize these appliances for a more effective treatment. A range of dental devices and orthodontic and surgical appliances can now be designed on the virtual patient setup. For the design and fabrication of custom appliances the stereolithographic (STL) files of the digital dental setup representing the accepted treatment plan and dedicated software are used to design dental, orthodontic, and surgical appliances, as needed. Both the initial setup of the dentition and the final setup, which simulates the position of the dentition at the end of orthodontic treatment, can be used for virtual bracket positioning. Dedicated software, such as OrthoCAD, suresmile, OnyxCeph, or OrthoAnalyser, can be used to virtually position scanned orthodontic brackets and tubes from a library of scanned standard fixed appliances onto the dental crowns. If the brackets are positioned on the final setup, which will increase the efficiency of bracket placement, this bracket position has to be transferred by the software to the dentition of the initial digital model. This virtual bracket positioning process should increase bracket bonding accuracy and reduce the need for wire bending and bracket repositioning during orthodontic treatment, which should finally reduce treatment time and improve the outcome of orthodontic treatment [53]. To further increase the efficiency of an orthodontic fixed appliance system, without increasing the costs of the appliances, some software programs, such as OnyxCeph, can be used to virtually position a series of different standard buccal and lingual brackets (depending on the need for increased or reduced torque values) on the digitized dentition. A custom bracket base can then be used to improve the fit of the bracket base of the standard bracket used and the dentition. For lingual systems the combination of standard brackets with individual bases was introduced several decades ago. A combination of a custom bracket base and custom wires was recently introduced by the OraMetrix company: the “Fusion” system The first custom wire system commercially available and now widely used in orthodontics was the suresmile system, made by the OraMetrix company in the US.. After fabrication of the setup, the wires with a dimension, flexibility, and force value as has been selected by the practitioner are bent in three dimensions by a wire bending robot and can be used to finish a case. Depending on the requirements of the case, extra torque can be ordered in specific wires to compensate for the “bracket play” and side effects of the biomechanical system used. Specific CAD/CAM-designed custom orthodontic treatment systems (a combination of custom wires, custom brackets, and a segmented indirect bonding tray), such as Insignia by Ormco for buccal brackets, and custom lingual fixed appliance systems—such as IncognitoTM by 3M, HarmonyTM by American Orthodontics, and eBrace/eLock by the Guangzhou Riton Biomaterial Co for lingual brackets are now also commercially available [54]. For all custom fixed appliance systems, indirect bonding trays or jigs should be designed to transfer the custom appliances to the dentition. The actual implementation of the indirect bonding trays (full arch or a tray divided into pieces can be selected by the practitioner. These systems should be used with a set of custom orthodontic wires as prescribed by the orthodontist.

Digital Design of Orthodontic Retention Appliances

Orthodontic retention appliances—such as removable retainers, tooth positioners, retention wires, surgical splints, and mandibular repositioning appliances for treating sleep apnea and snoring, for orthodontic patients—can now also be designed and printed three-dimensionally with dedicated software. Some printed appliances need to be post-processed, for example to assemble printed parts. If physical dental models are needed, printed dental models can be used. The fabrication and transfer of the custom orthodontic appliances should be accurate and requires an efficient workflow. For the CAD/CAM processes, the (STL) files of the digital dental setup will represent the design of the appliances, and dedicated software can then be used by three-dimensional (3D) printers and wire-bending robots to fabricate the appliances. Three-dimensional printed processes can be used to print physical dental models in acrylic material. These printed models can be used for the traditional fabrication methods of removable and functional orthodontic appliances. These printed models are also needed to assemble the different parts of the appliances after 3D printing in the dental lab with laser sintering of printed and prefabricated parts [53]. For orthodontic appliances, such as rapid expansion devices or Herbst appliances expansion screws or the prefabricated parts of the Herbst Appliances, have to be assembled to the printed parts of the appliance in a dental lab. Although virtual articulators can be used during the designing process (Ortho-Analyser), the use of physical articulators can still be required. Currently, there is a range of 3D printers available for printing physical dental models. The prices of the 3D printers have been reduced and the quality of the printed dental models of most 3D printers is sufficient for orthodontic use.

3D printing:

Additive manufacturing or 3D printing was founded in 1990 by Wilfried Vancraen, CEO and Director of Materialise NV, the first Rapid Prototyping sector company in the Benelux region. 3D printing technology allows the user to create or “print” 3D physical objects, prototypes, and production parts of any shape from a virtual model in a growing range of materials including plastic, cobalt, nickel, steel, aluminum, titanium, etc. Those materials are joined in successive layers one on top of the other through additive processes under automated computer control; The 3D printing process usually begins with a 3D model, virtually designed or obtained through scanning of a physical object. Slicing software automatically transforms the point cloud into a stereolithographic file which is sent to the additive manufacturing machine for building the objects. Today, 3D printing has grown to be competitive with the traditional model of manufacturing in terms of reliability, speed, price, and cost of use. Additive manufacturing is likely to continue rapid growth in conjunction with intraoral scanning technology as a more effective system for orthodontic practices and laboratories for automatic fabrication of high-resolution study models, retainers, metal appliances, aligners, and indirect bonding, accelerating the production time and increasing the capability [56]. Currently, there is a huge selection of available 3D printing technologies suitable for orthodontic use:

1. **Fused Deposition Modelling (FDM)** Fused depositing modelling (FDM) is frequently used for modelling, manufacture applications, and prototyping. The technology was introduced by S. Scott Crump towards the end of 1980s and was popularized by Stratasys, Ltd in 1990. FDM employs the "additive" method of laying down thermoplastic material in layers. Several materials such as acrylonitrile butadiene styrene (ABS) polymer, polyphenylsulfones and waxes, polycaprolactone, polycarbonates, polyamides, lignin, among many others, with diverse strength and thermal properties are available. With an accuracy of just a few micrometers, the bioplotter is able to build body parts with different microstructural patterns including blood vessels, bone, and soft tissue [55].
2. **Selective Laser Melting (SLM) and Selective Laser Sintering (SLS)** Laser based additive manufacturing, such as selective laser melting (SLM) and selective laser sintering (SLS), uses power in the form of a high energy laser beam directed by scanning mirrors to build three-dimensional objects by melting metallic powder and fusing the fine particles together. Compared to other types of 3D printing, SLM/SLS have very high productivity and can build objects from a relatively big selection of commercial powder materials. These include polyamides, polycaprolactone hydroxyapatite, ultra-high molecular weight polyethylene, polyethylene, ceramic, glass, stainless steel, titanium, and Co/Cr alloys. Although most of the initial applications of the laser based technologies were for manufacture of lightweight aerospace parts, the SLM/SLS have found an acceptance for production of orthopedic and dental implants, dental crowns and bridges, partial denture frameworks, and bone analogs [57].
3. **Electron Beam Melting (EBM)** Electron beam melting (EBM) is a type of additive manufacturing for laying down successive layers and creating near-net-shape or highly porous metal parts that are particularly strong, void-free, and fully dense. The EBM technology uses the energy source of an electron beam, as opposed to a laser. Objects are manufactured layer by layer from fully melted metal powder utilizing a computer controlled electron beam in a high vacuum. The technology operates at higher temperatures of up to 1000°C, which could result in differences of the phases formed through solidification. EBM is able to form extremely porous mesh or foam structures in a wide range of alloys including stainless steel, titanium, and copper. The technology is commonly used in orthopedic and oral and maxillofacial surgery for manufacturing customized implants. Their structure permits the ingrowth of bone, provides better fixation, and helps to prevent stress shielding [55].
4. **Stereolithography (SLA):** The term “stereolithography” was first presented by Charles W. Hull in 1986 as a technique for producing solid items by consecutively printing thin layers material that is solidified by a concentrated ultraviolet laser light. SLA is the first so-called “rapid prototyping” process. Most of the SLA immediate use was in the automotive and aerospace industries, but medical and dental applications of this technology gradually emerged. SLA models are currently used for planning cranial, maxillofacial, and neurosurgical procedures and constructing highly accurate replicas of human anatomy, customized implants, cranioplasties, orbital floors, and onlays [58].
5. **Inkjet 3D printing:** The inkjet printing technology employs a nozzle which “prints” a pattern on a thin

layer of powder substrate by propelling a liquid binding agent. The small ink droplets are forced through the orifice by pressure, heat, or vibrations. Phase transformation from liquid to solid occurs immediately after droplets are deposited upon the substrate by UV curing light, drying, chemical reaction, or heat transfer. The polyjet printers allow volumetric color objects to be built in simultaneous incorporation of multiple materials with quite distinct physical properties. In general, the inkjet printing technology is faster than other additive manufacturing processes such as fused depositing modelling. However, depending on the material and process, surface finish, object density, and accuracy may be inferior to stereolithography and selective laser sintering [55].

6. **Digital Light Processing (DLP):** Digital Light Processing (DLP) is a type of nanotechnology that uses a digital micromirror device as a power source projector to cure liquid resin into solid 3D objects. DLP is similar to stereolithography as the method also employs light polymerization. One difference is that DLP creates a single layer as one digital image in tiny volumetric pixels as opposed to SLA’s laser process which must scan the vat with a single point. It can produce objects with a wide variety of properties such as high clarity, springiness, flexibility, water resistance, thermal resistance, and durability. Post-print processing involves washing away the remaining resin and removal of the supports by snapping or cutting [59].
7. **Laminated Object Manufacturing (LOM):** Laminated object manufacturing (LOM) is a process that combines additive and subtractive techniques to build an object. It works by successively layering sheets of material one on top of another and binding them together using adhesive, pressure, and heat application. Once the process is complete, objects are cut to desired dimensions with a knife, a laser, or additionally modified by machine drilling. The most common materials used in LOM are plastics, paper, ceramics, composites, and metals which are widely available and yield comparatively inexpensive 3D printing method. Materials can be mixed in various layers throughout the printing process giving more flexibility in the final outcome of the objects. Surface accuracy is slightly inferior to stereolithography and selective laser sintering. LOM systems are used in sand casting, investment casting, ceramics processing, for concept modelling, and architectural applications [60]. Three dental materials, specially engineered for dentistry, come with the printer in sealed cartridges: VeroDentPlus (MED690), a dark beige, acrylic-based material prints layers as fine as 16 microns with accuracy as thin as 0.1mm used for most appliances; Clear biocompatible (MED610), a transparent material medically approved for temporary intraoral applications and surgical guides; and VeroGlaze (MED620), an acrylicbased material for veneer models or diagnostic wax-ups in A2- shade color match that can be used in the mouth as long as 24 hours [61].

ProJet® 3510 series come with three UV curable acrylic materials: Dentcast, a dark-green, wax-up material, which burns out cleanly for ashfree castings; PearlStone, a while material with a solid stone appearance; and Stoneplast for transparent, clear or stone finish dental models.

VisiJet® S300 is the fourth material which is a non-toxic white wax material for hands-free melt-away supports. ULTRA® 3SP™ Ortho also comes with specially engineered photosensitive resins for dental and orthodontic applications: Press-E-Cast (WIC300), a wax-filled photopolymer for production of copings with extremely thin margins as well as up to 16 multiple unit bridge; EDenstone (HTM140 Peach), a peach color material able to achieve the look and feel of traditional gypsum models with a high-accuracy detail; and D3 White, a fast-growing, tough material with similar characteristics to ABS plastic and the most common medium for dental model manufacturing for the production of orthodontic appliances [62].

Application of 3D printing:

3D printing solutions are capable to achieve various products with high level of precision. The use of the technology to build dental models, removable appliances, customized brackets and archwires, and occlusal splints has been attempted and reported in the orthodontic literature. Currently, the most common application of the 3D printers is for clear retainers and aligner fabrication. Practitioners can virtually move the teeth to a final ideal position, print a sequence of physical models in the office, and use a thermoplastic material to fabricate aligner trays, working on similar premise to Clear Correct and Invisalign. Skipping the step of 3D printing a physical model, researchers have also used the technology to digitally design a retainer and consequently 3D print it in a fine while polyamide material. Sophisticated software is further available for shaping and trimming the dental model base, for design of bracket pads, hooks angulations, and guiding jigs. Digital titanium Herbst, Andresen, and sleep apnea appliances have been made with smooth surfaces, no sharp edges, and excellent fit on the teeth, palatal and gingival tissues. Additive manufacturing enables features such as hinge production, building threads, and wire insertion to be completed in a single build without assembly. Certain orthodontic appliances with soldered parts might require the use of a stone model since some 3D- printed models would deform or melt from the high temperature. A broader range of materials with greater strength and resistance to moisture and heat should be specifically developed to suit the dental and orthodontic industries. Digitization of the manufacture process and standardization of the material ingredients are important steps for achieving consistent results [63].

Monitoring of Tooth Movement

Once a treatment plan for orthodontics has been made by the orthodontist and agreed by the patient, standard or custom orthodontic appliances are fabricated and positioned on the dentition, tooth movement with removable, fixed buccal, or lingual orthodontic appliances or aligner systems can be started. Effective and optimal tooth movement is needed to achieve the planned change in tooth position. According to published research, the speed of tooth movement will be different for each individual and depends on the orthodontic mechanics used. The orthodontist will use optimal mechanical systems for tooth movement (wires or aligners), and during treatment control visits at certain intervals are scheduled. These control visits should be scheduled according to the need to change (or reactivate) the mechanical system used, to optimize tooth movement. But as tooth movement for an individual patient is not registered, optimal planning of control visits is not possible. Activation of the tooth movement system (changing of the wires or aligners), will not always lead to faster tooth movement, because of the occurrence of hyalinization in the periodontal ligament after activation. So consequent monitoring of tooth movement at planned intervals could be used to optimize the timing of control visits. This monitoring of tooth movement will also help the orthodontist and the patient to visualize whether the actual tooth movement ensures the achievement of the planned treatment goal. Monitoring of tooth movement can be achieved by analysing progress intraoral scans with dedicated software programs, such as Ortho-Analyser. During control visits, a progress scan can be made and superimposed on the initial scan to reveal the differences in tooth position. A disadvantage of this type of monitoring is that the patient has to visit the orthodontic office to make an intraoral scan. Alternatively, an extra oral photograph can be used to correct the “smile line” or a second cone beam computer tomography (CBCT) radiograph can be made to evaluate the tooth position and the jaw position after a surgical correction. Specific software programs can be used to superimpose the CBCT radiographs and facial scans [64].

A “progress setup” can then be made to correct the tooth position according to the progress documentation, and fabrication of a “finishing wire” or “finishing aligners” can then be used to correct the dentition. During treatment, a photo exam is scheduled every two weeks, and during post-treatment monitoring, one photo exam is scheduled every two months the patient will get regular reminders by mail to make the planned series of photographs or a video of the dentition and send them to Dental Monitoring. Every photo exam or video should be uploaded to Dental Monitoring’s server and will be analyzed by dental specialists, including supervision of a qualified orthodontist. The “smartphone” used to make a series of pictures of the dentition. When finishing scan has been made, this scan can be uploaded to DM and this new 3D model can then be used as a reference. Following the recommendations of the orthodontist, the patients will be notified by email that a new set of photos or a video is required. If the frequency of this procedure should be changed, for instance after the start of treatment or at the start of the monitoring of the retention, the patient will receive a message. The Dental Monitoring app is compatible with iPhones 4s or later running iOS 7.0 or higher and smartphones running Android 4.0.3 or higher. The download procedure of the app and the instructions on how to make the required series of photos, and the use of the Dental Monitoring cheek retractor can be best completed in the orthodontist’s office. The patient should teach the person who will take the pictures how to do this. Ideally, that second person comes to the orthodontist’s office for instruction and to practice this procedure. Dental Monitoring has created a Demo Mode to help the patient understand how to use the Dental Monitoring app and how to take acceptable pictures. A short video tutorial which clearly shows the steps needed to take optimal pictures is available on Dental Monitoring’s website. When all the pictures are taken, the patient will be taken back to the website’s home page, where a message will appear indicating that the series of photos are being sent to Dental Monitoring. At the Dental Monitoring lab, analysis of the pictures will be started as soon as possible. The actual position of each tooth will be compared to the initial tooth position and the tooth position registered during earlier digital monitoring of the tooth position with a set of intraoral pictures. Dental Monitoring will provide an analysis of the tooth movement with dedicated computer software and this report will appear four days after the series of photographs are received on the dashboard of the secured Internet site, which is available for each orthodontist. The report of the analysis shows the actual tooth position which has been compared to the initial tooth position on the digital dental model and series of earlier recorded photographs by computers. In this analysis, the movement of the selected tooth can be evaluated in all directions. Three-dimensional matching of images and the initial digital dental model is possible and visualizes the actual movement of the dentition in the selected period of time. The rapport of this analysis of tooth movement in 3D includes a graph, showing the tooth movement velocity of each tooth. The steeper the slope of this graph, the faster the teeth is moving. Initially, one chart for each type of movement was provided, but now that information is provided with two charts. One chart shows movement of translation, and the other shows movements of rotation in degrees. Each chart has three graphs corresponding to one specific type of translation or rotation, and any one of these graphs can be separately evaluated. Each type of movement is clearly defined on the graphs, for more precision in the analysis. This means the orthodontist can now compare the actual pictures with the stored digital dental model and with previous registrations of intraoral photographs.

Dental Monitoring Alerts

If an unexpected situation is detected through the Dental Monitoring algorithm by the company's technicians, the orthodontist will receive an immediate alert on their dashboard, in the "Actions Required" tab. The orthodontist can now easily assess the significance of the alert and review detailed information about the affected teeth and suspect movements reported. Bracket failure, wire failure, and failures of the wire bracket connection are examples of alerts that will be sent to the orthodontist. If the patient agrees, a patient file can be shared with another practitioner, such as the referring dentist or a dental specialist. To share a patient file the Digital Planning and Custom Orthodontic Treatment other practitioner's email address should be filled in on the website. A email will be sent to the practitioner inviting them to share the files (in a read-only version, if selected). The orthodontist can decide to send a registration code to the patient's email address. This allows the patient to review the series of images and the overlay of the initial tooth position and the change in tooth position during treatment [6].

CONCLUSION

With the rapid development and advanced research of diverse technologies and compatible materials, it is possible to obtain single scan digital impressions, virtually design, and 3D print different types of orthodontic appliances. 3D facial imaging further provides comprehensive analysis as an aid in orthodontics, maxillofacial, plastic, and esthetic surgery. Software integration of digital models, 3D facial scans, and CBCT facilitate treatment simulations and establish a meaningful communication with patients. Elimination of traditional impressions and dental-cast production stages enhance practice efficiency, patient and staff satisfaction for a fully integrated digital and streamlined workflow. Patient digital impressions are stored in a more convenient way and can be easily transferred to any lab or an in-office milling machine for a simpler, faster, and more predictable appliance fabrication. New companies, scanner and printer models are emerging daily which result in significant decline of systems cost and enhancement of material qualities. From imaging to product design and manufacture, technologies will offer more affordable and feasible diagnostic and treatment applications beyond the current methods. Katantoula *et al.*, (2017) [65] stated that teleorthodontics is the use of information technology and telecommunications to facilitate orthodontic consultation about the care to be rendered, the practitioner, the patient, and public education, as well as promoting public awareness. The attitudes of orthodontists and general dentists toward teledentistry have been assessed by several authors and support the use of teledentistry in making orthodontic consultations more accessible to dentists and patients. On the other hand, referrals of orthodontic cases via teledentistry are creating new ethical and legal dilemmas. The use of teleorthodontics mandates the need to address certain ethical issues as well as the need to comply with the HIPPA Privacy Rule, which protects all "individually identifiable health information" held or transmitted by a covered entity or its business associate, in any form or media, whether electronic, paper, or oral. It has been suggested that the patient should be informed of the intended use of the photographs and the security measures in place to protect privacy. The patient should provide his or her informed consent for each use of a photograph, whether for diagnostic or educational purposes or other uses. An important dilemma in today's technological climate would be to inform the patient as to who will be analyzing the images and how the images will be transmitted.

FUTURE IMPLICATIONS

With the exponential incorporation of technology, the practice of orthodontics has considerably changed. The goal of tele-orthodontics is to reduce patient's office visits while maintaining regular monitoring, without compromising results. Moreover, tele-orthodontics may be useful for remote consultations, which could be performed across the world without the patient potentially stepping into the office. Comprehensive patient records would still require in-office visits; however, it does open new channels for orthodontic consultations and second opinions. Technological advances come with a dark side as well. Reducing the number of face-to face appointments diminishes the rapport between doctor and patient. This traditional relationship may be reduced or lost, and with that, possibly trust as well. The doctor patient relationship has traditionally been much more than transactional. Dunbar *et al.*, reported in a pilot study that 70% of subjects felt that the face-to-face aspect of the consultation was extremely important, and the majority preferred this over the exclusive use of tele-orthodontic technology. New legal issues will also play a role with patient confidentiality potentially being at risk due to records being communicated over the internet. Patient complaints of malpractice may also increase if patients do not receive an acceptable level of care or if practitioners do not maintain the level of healthcare expected. The key to the future of teleorthodontics would be in balancing the benefits of in-office visits and direct patient-doctor relationships with the convenience and reduced costs of remote monitoring, on an individual patient-to- patient basis, while maintaining an excellent standard of care. mOral health and eDantseva are two portals by Indian Government as an initiative for encouraging teledentistry and national oral health programme.

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