INTRODUCTION

In the early 1970s, Straight wire appliance was 1st introduced by ***Larry Andrews*** who changed the minds for ideal orthodontic treatment from being an issue of wire bending skills to becoming basically a matter of perfect bracket positioning.[1]

Since successful orthodontic treatment needs to be not only effective but efficient as well, thus the aim of orthodontists is to achieve the most ideal treatment outcome in the shortest treatment time with the least patient discomfort.

Indirect bonding (IDB) technique was 1st introduced in 1972 by ***Silverman et al.*** aiming to make bracket positioning more precise via better visibility, in addition to reducing chair time and improving patient comfort.[2]

In the mid-1980s computer-aided design and computer-aided manufacturing (CAD/CAM) system was first used in the dental field and after then it became increasingly popular.[3,4]

As the innovative digital technology develops and improves, orthodontic diagnosis, treatment planning, bracket positioning and indirect bonding are all shifting to a completely computerized digital format. [5-6]

In 1999 OrthoCAD was the first to commercially introduce digital study models which offered multiple advantages among which are; no storage space, easy transfer and retrieving, simple manipulation sectioning and space analysis, digital diagnostic setup and indirect bracket placement.

Whatever the method for bracket positioning whether direct or indirect on plaster or digital models it's still based on the representation of the clinical crowns without taking into consideration the root orientation. Although one of the requirements for the ABO is the root parallelism as documented via panoramic radiograph.

Root parallelism is the cornerstone of micro-esthetics, proper occlusion, proper occlusal force distribution and post-orthodontic treatment stability.[7–10]

However, recent investigations have shown that the ability of panoramic radiograph to accurately determine root angulation is limited due to magnification and possible distortion due to the large beam deviation resulting from the perpendicular distance between object and film. [11–13]

Recent studies have compared panoramic radiograph to CBCT and concluded that the mesiodistal root angulation was more accurately represented in CBCT.[14,15]

Therefore, the aim of our study was to compare the precision of mesiodistal tooth angulation after the first phase of comprehensive orthodontic treatment (alignment and leveling) via computerized indirect bracket positioning based on the long axis of the clinical crown on 3D digital model only to that guided by the whole tooth on a 3D digital model superimposed via best fit method on digital CBCT.

REVIEW OF LITERATURE

"If you go on a long journey, you don't walk all the way, you fly most of the way, then take a taxi, and then walk the final 100 yards" ***Larry Andrews*.**

The goal of orthodontic treatment is to achieve an exemplary treatment outcome in a reasonable amount of time. A critical component of achieving these goals is an optimal orthodontic bracket placed in the ideal position on each tooth**.**

During the standard edgewise appliance era, wire bending skill was the responsible factor for the best treatment results. The advent of the straight wire appliance in orthodontic practice gave the orthodontists the chance to choose from wide bracket prescription varieties to achieve desirable esthetic and function results with much less time, effort and patient discomfort.

However, the promise of efficient, easy and rapid orthodontic treatment with these bracket systems has not been fully realized in orthodontic practice because of inaccurate bracket placement, which again demanded the need for final detailing with wire bending or even bracket repositioning.[16]

For more precise bracket placement and so better treatment results, Indirect bonding was 1st introduced by ***Silverman et al.*** 1972.[2]

Currently, more attempts were made to position orthodontic brackets more accurately taking root position in consideration but whether this brought about better results or not is yet uncertain!

Topics to be discussed:

I) CBCT.

i- Applications of CBCT in orthodontics.

ii- Accuracy of determining MD root angulation from CBCT.

II) Root parallelism.

i- Importance of precise MD teeth angulation adjustment and root parallelism.

ii- Different techniques used for evaluation of root parallelism.

- Panoramic radiograph.
- CBCT.

III) Orthodontic Digital models.

i- Evolution of digital models in orthodontics.

ii- Different orthodontic digital model fabrication techniques.

- LASER scanning of plaster models and alginate impression.

- CBCT scans and CBCT scanning of alginate impressions or plaster models.
- Direct intraoral scanning of the dentition.

iii- Verification of digital models' accuracy.

IV) Orthodontic bracket positioning.

i- Direct bracket positioning.

ii- Indirect bracket positioning:

- Introduction and evolution of indirect bracket positioning.
- Indirect bonding techniques.
- Added advantages over direct bracket positioning.

V) 3D printing in orthodontics.

i- 3D printing evolution and concept.

ii- Different 3D printing techniques.

iii- Advantages and applications of 3D printing in orthodontics.

I) CBCT

i- Applications of CBCT in orthodontics

Orthodontists were traditionally using two-dimensional radiographs to assess three-dimensional structures. Computed tomography offered the 3D representation advantage yet had some limitations including its high cost, high dose of radiation and low vertical resolution.[17,18]

Cone beam was first introduced in the European market in 1998 and then into the US market in 2001.

It has been used more widely because of its considerably lower radiation dosage (20%), shorter acquisition times and relatively reduced costs[19,20]. Other advantages may include having a smaller system, display modes available exclusive to dentofacial imaging, and the fewer imaging artifacts.[21]

Now, the use of CBCT added many other diagnostic advantages such as: three-dimensional reconstruction, improved image quality, a 1:1 ratio that allows more reliable measurements, more realistic craniofacial visualization, and lower radiation doses in comparison to traditional CT making orthodontic diagnosis and treatment planning much more accurate.[22]

Orthodontic treatment involves the use of various radiographs in its diagnostic protocols, ranging from panoramic radiograph and lateral cephalometry to full mouth radiographs

[23]. Although studies of radiation dosimetry are not directly comparable. ***De Vos et al.*** in 2009, found that the exposure from CBCT is within the same range as traditional dental imaging [22]. CBCT machines vary significantly in their effective dose, ranging from 29 to 477 mSv, some techniques can be applied to help reducing the radiation dose such as: modification of patient positioning (tilting the chin) and use of additional personal protection devices as thyroid collar. Such techniques can reduce the dose by 40% as stated by ***Ludlow et al.,*** 2006.[24]

The effective exposure dose from a CBCT machine for a patient has been registered to range from 45 micro sievert to 650 micro sievert. The stated doses for an equivalent full mouth series and a comparable panoramic radiograph are 150 micro sievert and 54 micro sievert, respectively.[25]

Although the precision of the tooth crown image obtained from cone-beam computed tomographic scans is somewhat low, this could be compensated by integrating it with digital orthodontic model.[26]

Practical Applications of CBCT in Orthodontics includes:

Application in orthodontic diagnosis:

- **3D evaluation of Impacted Teeth.**

One of the most recognized needs for CBCT in orthodontics is the evaluation of impacted canine position[27,28].

CBCT imaging is precise in determining the 3 dimensional position of the impacted tooth, its relationship to neighboring and the exact tooth angulation.[29] CBCT is justified as a supplement to routine panoramic radiographs when canine inclination in the panoramic radiographs exceeds 30 degrees, and/or when adjacent teeth root resorption is suspected, and/or when the canine apex is not clearly apparent in the panoramic X-ray, indicating canine root dilaceration.[30]

- **Assessment of skeletal and dental structures**.

In 2008, ***Van Vlijmen et al***. declared that the reproducibility of measurements on cephalometric radiographs acquired from CBCT scans was better than that attained from conventional cephalograms. Multiplanar views are especially beneficial in spotting bilateral landmarks such as condylon, orbitale and gonion which are regularly superimposed in conventional radiographs.[31]

- **Growth assessment.**

CBCT scans can reliably assess skeletal maturity through cervical vertebrae maturity.[32]

- **Temporomandibular Joint Assessment.**

CBCT images of the TMJ have proved greater reliability and accuracy in detecting condylar erosions than tomographic or panoramic views. Temporo-mandibular dysfunction can complicate orthodontic treatment and so careful assessment of TMJ, before, during and after orthodontic treatment is required. [33]

- **Airway Analysis.**

Airway analysis has been carried out conventionally using lateral cephalograms. The CBCT provided a major improvement in the airway analysis, allowing for its 3D volumetric analysis. Three-dimensional airway analysis is an extremely useful in diagnosis and management of some clinical conditions such as sleep apnea and enlarged adenoids.[34]

- **Cleft Lip and Palate.**

CBCT provides the exact cleft anatomic relationships and surrounding bone thickness of existing teeth in proximity to the cleft. This information is valuable for the grafting procedures and for possible movement the existing dentition.[35]

Applications of CBCT in treatment planning:

- **Orthognathic surgical planning.**

CBCT imaging in addition to appropriate software and virtual patent-specific models allows the examination of hard and soft craniofacial tissues in addition to their 3D spatial relationships.[21]

- **Planning for placement of temporary anchorage devices.**

Compared to panoramic radiographs, CBCT images allow accurate and dependable views of the inter-radicular relationships [14]. CBCT data can be used to construct mini-implant placement guides even in anatomically difficult sites [36]. The quality and volume of the bone in placement sites can also be evaluated before insertion of the mini-implants.[37]

- **Fabrication of custom orthodontic appliances.**

CBCT data can be used to produce 3D digital study models It avoids patient discomfort and saves orthodontist's valuable chair time. These models are of higher diagnostic value than other digital models because they include not only the tooth crowns but also roots, impactions, developing teeth and alveolar bone.[38,21]

The construction of custom lingual orthodontic appliances has been exhibited using CBCT data in addition to existing technology of virtual treatment planning and 3D printing technology for custom appliance manufacturing. Orametrix (Richardson, TX) through its SureSmile system also uses CBCT technology to provide the data necessary for planning and implementing technology-assisted treatment [39].

Application of CBCT in assessing treatment progress and outcome:

- **Dentofacial orthopedics.**

3D overlays of superimposed models with the aid of 3D color coded displacement maps offered qualitative and quantitative assessments of growth and orthopedic treatment changes [40].

- **Orthognathic surgery superimposition.**

Findings of surgical treatment outcome can be facilitated by using a new superimposition methods that enables the clinician to superimpose a custom surface mesh of the anterior cranial base of the first CBCT image onto the second one [41].

Application of CBCT in risk assessment:

- **Assessment of orthodontics-induced root resorption.**

Root resorption can be observed accurately in CBCT images, and the image clarity allows orthodontist to classify the grade and type of root resorption. For multiple roots, resorption can be localized to a specific root.[42]

- **Roots fractures**.

With CBCT, the tooth can be viewed in three planes of space making it easier to determine the exact site of root fracture and also the degree of displacement.[43]

- **Investigation of orthodontic-associated sensory disturbances.**

In 2013, A report by ***Chana et al.*** demonstrated the importance of CBCT scans as the sole aid in obtaining a definitive diagnosis of orthodontic treatment-induced transient mental nerve paresthesia [44].

- **Post treatment TMD**[45].

- **Supplementary findings, overlooked findings, and medicolegal implications**[46].

ii- <u>Accuracy of determining MD tooth angulation from CBCT:</u>

Six main parameters describe tooth location 3-dimensionally. Three of them are positional (mesiodistal, occluso-gingival and faciolingual), and the other are angular (mesiodistal angulation, axial rotation and faciolingual inclination).[47,48]

Although 4 of these parameters are dictated by the crowns and can be easily monitored clinically, later research has shown that crowns cannot provide clear indications of the whole tooth angulation and inclination. The roots that constitute about half of the whole tooth must not be ignored, roots should also be assessed to be able to achieve ideal tooth angulation and inclination.[8–10,49]

Orthodontists usually assess root angulations before, during, and after treatment as a guide for establishing proper root position.

Traditionally, panoramic x-rays have been used for this purpose[50,51]. However, studies have found that panoramic radiographs have many limitations and cannot be used as a reliable indication for this purpose and do not actually reflect the true 3-dimensional teeth angulation mainly because the x-ray beam direction that is not always orthogonal to the target teeth [11,52–54].

Teeth position is actually a 3-dimensional issues, ***Andrews*** when assessed the ideal teeth positions he measured the angulation and the inclination of teeth from study models that are 3-dimensional and not from 2-dimentional radiographs [55,56]. Fortunately, this can now be accomplished in an easy and accurate way for roots and whole tooth as well using cone-beam computed tomography (CBCT).

Many studies were conducted to compare mesiodistal root angulations by using panoramic radiographic images and CBCT scans and concluded that the assessment of mesiodistal root angulation with panoramic radiographs should be approached with caution and preferably reinforced by an accurate clinical examination of the dentition.[14,57,58]

Many other articles discussed the use of CBCT panoramic reconstruction to asses mesiodistal root angulations and found that, CBCT panoramic reconstruction images must be used with caution as well and that these images can be reliable for the assessment of mesiodistal root angulations if the volume is properly manipulated while creating a pan-like image.[59,60]

II) Root parallelism.

i- ***Importance of precise MD teeth angulation adjustment and root parallelism.***

In his study, ***Andrews*** found that normal occlusion depends on, among other several factors, the correct mesiodistal angulation (tooth tip). Other investigators have stated that appropriate teeth axial inclinations and root parallelism are critical for proper occlusion, occlusal force distribution, periodontal health and orthodontic treatment stability. [61–65] The relative angulation of the roots of the maxillary and mandibular teeth is a factor in the American Board of Orthodontics examination.

Accurate bracket positioning has the main influence on the result of orthodontic treatment. There are many factors affecting ideal bracket positioning including: tooth shape and malformation, bonding material, technique sensitivity, patient management and general clinic environment.[66,67] Clinician experience, sharpness of sight and manual dexterity can also affect bracket placement precision.[6]

Frequent problems encountered during bracket placement include inaccessibility, morphologic diversity and anatomic variations of the clinical crowns, even for the same tooth. Above and beyond is the traditional use of the clinical