The Effects of Curve of Spee in Skeletal Class II Patients Treated with Combined Orthodontics and Surgery

By

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A Thesis submitted to

the Faculty of Graduate Studies of

The University of Manitoba

in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

Department of Preventive Dental Science

College of Dentistry

Division of Orthodontics

University of Manitoba

Winnipeg, Manitoba

Acknowledgements

First of all, I would like to thank my close family members for their great love and support along the way. Without them, I will not be who I am today.

I would also like to thank my supervising committee,

- Dr. Robert Drummond
- Dr. Leland McFadden
- Dr. Susan Tsang

And special thanks to,

- Dr. Tim Dumore
- Loring Chuchmach (biostatistician)
- Dr. Raj Bhullar (research associate dean)
- Kaitlin Maygard (3Shape)
- Full-timers and part-timers, co-residents (past and present), and staff from Graduate Orthodontics and other Graduate programs
- Family and friends

Abstract

Purpose: To perform a retrospective study with the question: Is there a significant correlation between pre-surgical Curve of Spee (COS) and skeletal changes from mandibular bilateral sagittal split osteotomy (BSSO) advancement surgery? Furthermore, in skeletal Class II patients, does initial mandibular plane angle (MPA) make a difference?

Methods: The sample was made up of a group of patients who underwent a single surgical procedure of mandibular BSSO advancement and divided into three groups by mandibular plane angle (MPA). Pre-surgical Curve of Spee (COS) was measured on digital dental models and correlated with skeletal changes from pre-surgical and post-surgical cephalograms using Spearman rank-order analysis. Paired T-test was utilized to identify statistical significance. Regression analysis was performed to estimate the cephalometric change per unit of pre-surgical COS. P-value was set at 0.05.

Results: The sample was composed of 90 subjects; divided into 3 groups: (1) high-MPA (MPA 34.10 ± 3.23°; aged 26.28 ± 17.66 years; n = 30) (2) medium-MPA (MPA 27.85 ± 1.61°; aged 22.04 ± 11.40 years; n = 30) (3) low-MPA (MPA 20.91 ± 3.20°; aged 26.84 ± 15.58; n = 30). Statistical significance was found between pre-surgical Curve of Spee (COS) and both linear and percentage changes of lower face height (LFH) in the low-MPA group ($p < 0.001$). The estimated relationship between COS and LFH was that for each 1mm pre-surgical COS, there was an increase in LFH of 1.629 mm from the surgical procedure ($p = 0.000$).

Conclusion*:* Pre-surgical Curve of Spee is significantly correlated with surgical changes in lower face height in low-MPA subjects. The quantified ratio between them could be applied in simulating surgical outcome clinically.

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Chapter 1

Introduction

1.1 Preamble

As an orthodontist, it is essential to understand the concept of normal growth and development in the craniofacial complex since variations may lead to malocclusions and dentofacial deformities [1]. Fundamentally, orthodontic treatment works on attaining an aesthetically harmonious masticatory system in individuals by maximizing the effectiveness of compensations between different anatomic components [2]. When the degree of skeletal discrepancy and facial imbalance is moderate to severe; combined surgery and orthodontics become the treatment of choice over orthodontic camouflage alone to avoid complications such as occlusal relapse and worsening of the profile, periodontal decline and temporomandibular disorders [3]. A particular type of facial problem the author investigated is mandibular deficiency syndrome, or retrognathism, which is also considered a skeletal Class II [4]. Surgery combined with an orthodontic approach remained the most reasonable treatment choice, especially for more severe discrepancies, with mandibular bilateral sagittal split osteotomy (BSSO) advancement surgery being arguably the most common procedure. Amidst this group of individuals, skeletal characteristics may differ due to the mandibular plane angle (MPA) variation [4]. For instance, for an individual with reduced MPA, the sagittally-deficient mandible is commonly accompanied by decreased vertical dimension in the lower face; in this case, the goal is to treat both deformities with a single surgical procedure. Past research has suggested that there is feasibility in achieving favourable improvement in skeletal discrepancies with a cautious manipulation of the Curve of Spee (COS) [5678910].

Only two studies have researched the impact of COS in surgical orthodontic patients [11,12]. Op De Coul et al. (2010) [11] recruited thirty-seven adult Class II patients who had BSSO mandibular advancement surgery. They were divided into two groups based on the pre-surgical overbite of 3mm. An overbite greater than 3mm before the surgery implies a not-levelled COS, which was associated with less forward movement at the chin and more increase in the lower face height due to downward/backward rotation of the mandible. A retrospective study conducted by Foletti et al. (2018) [12] evaluated the effect of COS in twenty Class II patients with short face syndrome and found significant increases in facial height in all subjects after the treatment. The increase was indirectly correlated with the depth of the curve measured at the pre-surgical time point.

Both studies measured the variables, overbite and the COS, on the pre-surgical cephalograms. These studies though important, were inconclusive with issues relating to the smaller sample size. In addition, the variables, overbite and COS, were measured on pre-surgical cephalograms. This may lead to inaccuracies due to difficulty in identifying landmarks from the overlapping structures or distorted radiographs. Another concern was that the diversity in MPA has not been studied.

1.2 Purpose

The purpose of this retrospective study is to validate repeated claims regarding the skeletal impact of COS with improved study design by assessing the correlation between pre-surgical Curve of Spee (COS), measured on digital dental models, and the skeletal changes produced by mandibular bilateral sagittal split osteotomy (BSSO) advancement surgery in skeletal Class II patients with varied initial mandibular plane angles (MPA) [5,6,7,8,9,10].

1.3 Null Hypotheses

1. There is no significant correlation between pre-surgical Curve of Spee (COS) and mandibular skeletal changes from the surgery in skeletal Class II subjects who received mandibular bilateral sagittal split osteotomy (BSSO) advancement surgery combined with full fixed orthodontic treatment.

2. There is no significant difference among the subjects with different initial mandibular plane angles (MPA).

Chapter 2

Literature Review

2.1 Craniofacial Development

2.1.1 Craniofacial Complex

Human beings' growth pattern is characterized by a "cephalocaudal gradient" present in both the body and the craniofacial complex. This refers to an axis of increased growth extending from the head down [1]. Björk (1955) initiated a series of metallic implant studies from a relatively small sample group of five. The line joining Sella (S) and Nasion (N) was used to interpret the growth pattern of the cranial base. The glenoid fossa undergoes a rearward and downward displacement throughout the cranial base's formative stage, resulting from the differential lowering of both medial and posterior cranial fossae relative to the anterior fossa. Eventually, this leads to changes in jaw position and occlusion [13].

2.1.2 Growth Sites

Fields that play an influential role in the growth process are called growth sites, but growth is not limited to growth sites but occurs on all surfaces [2]. When the head is viewed in Norma lateralis (the lateral view), various growth sites in the facial complex may be pinpointed and further divided by their contribution to either horizontal or vertical planes. These sites within the maxilla and mandible grow by surface remodelling that involves resorption and apposition, except for mandibular condyles. The condyles grow primarily through the proliferation and conversion of cartilage into bone [14].

2.1.3 Maxilla

Nonhuman primates that had been involved in past research have led to advancements in medical and scientific fields. The high similarity in DNA sequence between the two genomes was found to be almost 99 percent identical [15]. In the second part of Brodie's (1942) experiment, inspired by John Hunter's work [16], Alizarine was injected into living monkeys to identify growing sites. Stains were found at the zygomatico-maxillary suture, the floor of the orbits, fronto-maxillary suture, and the transverse palatal suture, representing the maxilla's articulating surfaces. Thus, it was realized that the maxilla's upward and backward growth against the cranium and its processes is essentially causing the net effect of a downward and forward translation. The mandible experiences a push from the maxilla, so it gradually moves away from the cranium [17].

Björk (1968) later conducted a large-scale project on approximately one hundred subjects of all genders with ages ranging from four to twenty-five years old. Small tantalum pins were placed at chosen sites in both jaws while avoiding remodelling resorption areas and teeth' eruption paths [18].

Horizontally, the maxilla lengthens by sutural growth toward the palatine bone, with periosteal apposition at the tuberosity, while no apposition was found on the anterior maxillary surface other than the alveolar process [18].

Vertically, growth in height occurs at the articulations with the frontal and zygomatic processes and by periosteal apposition on the lower border of the alveolar process. The nasal floor is lowered through resorption, combined with apposition on the hard palate; the anterior nasal spine is likewise lowered through resorptive remodeling. This process occurs in the opposite direction on the floor of the orbits, with apposition on the upper and resorption on the lower surface [18].

2.1.4 Mandible

Brodie's (1942) experiment showed that the youngest monkey's mandible was heavily stained with Alizarine on all surfaces, indicating a generalized growth pattern occurring during the early developmental stage. The monkeys corresponding to six-year human dental age had the most evident growth found at sites like condylar heads, posterior border of the ramus, and free alveolar margin. In comparison, the specimens of adult monkeys only differed in the growth rate, which was significantly diminished, but the overall pattern of growth remained consistent [17].

The mandible's principal directions of growth are upward at the alveolar process, backward at the ramus and upward and backward at the condyle, which causes a downward and forward translation of the mandible as the net effect, similar to that seen in the maxilla [17]. In human condyles, the growing direction varies between upward/backward and upward/forward during puberty [19].

After the two halves of the mandible fuse completely at the symphysis after birth [2], the increase in the mandible's width comes from periosteal bone remodeling with resorption at the inner surfaces [13].

In the mandible, vertical growth depends on condyles' vertical growing component and the lowering of the medial and posterior fossae. In contrast, horizontal growth depends on the condyles' sagittal growing component and the temporal bone's dorsal displacement. These two together determine the longitudinal development of the lower face, and in most cases, they counteract each other [13].

2.1.5 Growth Spurt

Compared with the growth in body height, growth at the sutures ceased on average two years before, while growth in condyles ceased later [20]. In contrast, only a weak association existed between pubertal facial growth and dental development [21]. This was verified by a prospective longitudinal study of more than two hundred randomly selected Swedish children, focusing on the factors related to growth spurt. It was also confirmed that a 2-year difference exists between girls and boys in the age at the beginning, peak, and end of the pubertal growth spurt. Hand-wrist films and pubertal development indicators such as menarche and voice change are reliable in determining the peak and end of the growth spurt, but not its beginning [22].

2.1.6 Stable Structures for Superimpositions

To assess the overall effect of growth, stable landmarks at Sella, sphenoid plane, cribriform plate, and the roof of orbits representing the outline of anterior cranial fossa were used for superimpositions [14].

To more accurately assess mandibular growth, Björk (1969) demonstrated the method of superimposing radiographs on natural reference structures in the mandible, including the tip (anterior border) of the chin, the inner cortical structure at the inferior border of the symphysis, trabecular of the mandibular canal, and lower contour of a lower molar germ, et cetera. For instance, the mandibular canal does not remodel as the mandible's outer surface does and remains relatively stable; its curvature can thus reflect the early shape of the mandible [23].

2.1.7 Rotational Changes in Both Jaws

Other than the growth in the three planes of space, it is also necessary to understand the jaws' rotational changes. Björk (1947) compared a group in their early teens with another group in their early twenties and noted a general increase in prognathism, with the lower jaw moving more forward relative to the upper [24]. This finding was reaffirmed by Lande's (1952) serial cephalometric study. The increase normally occurred after seven years of age, accompanied by a decrease in the inclination of the lower mandibular border. Also, no correlation was found between the facial type at seven and seventeen years of age [25].

In another serial cephalogram research conducted by Brodie (1953), it was reported that the nasal floor's inclination tends to remain stable between the ages of eight and seventeen, especially at the junction between the pterygoid process and the tuberosity of the maxilla. The occlusal plane and mandibular border are stable in about half of the cases, while others showed a decrease in the angle; a similar result was found in the Y-axis. Porion exhibits a greater variation, either moving straight backward, straight downward, or between the two, not correlated with the chin point's behaviour [26].

Björk and Skieller (1972) closely analyzed 21 subjects of 9 girls and 12 boys, with multiple metallic implants inserted in both jaws. The observation period was limited to a window of three years before and three years after the maximum pubertal condylar growth. Rotational changes were detected in both jaws. In the maxilla, a forward rotation was present in 18 cases. In the mandible, a forward rotation relative to Sella-Nasion of minus 7 degrees on average was found in 19 subjects. However, the gonial angle decreased by only 2.4 degrees. Overall, the amount of rotation in the mandible was about twice the amount in the maxilla [19].

The inclination of the ramus to Sella-Nasion, unlike the mandible body, was practically unchanged due to remodeling of the ramus to maintain its functional relation to the neck muscles and the spinal column [19].

They concluded that there are three general types of rotation (Figure 2.1) [19]:

A. Forward rotation with stable anterior occlusion: the centre of rotation is located at the mandibular incisors. In the authors' point of view, this is the most suitable type of rotation for normal dentitional development [19];

B. Forward rotation with unstable anterior occlusion: the centre of rotation is located at the mandibular premolars, present with a basal deep bite without differential eruption between molars and incisors [19]; and

C. Backward rotation: the centre of rotation is located at the posterior occluding molars. There is an increase in the anterior lower face height and a decrease in the posterior face height. The incisors erupt further than the molars, to some extent stopped by the tongue, and an open bite is present [19].

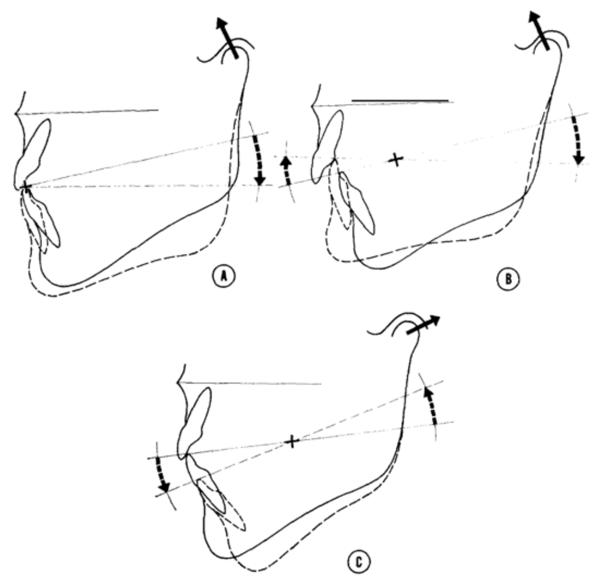


Figure 2.1 **Three types of mandibular rotation** [19]

A strong association between mandibular rotation and the direction of condylar growth was noticed. Condyles in the 19 cases with forward rotation curved forward of 8 degrees on average; in the two cases that showed backward rotation, the condyles curved backward 13 to 15 degrees.

Rotations in both jaws were found to be masked by remodeling at the lower and posterior borders of the mandible and the nasal floor [19].

Björk (1969) summarized seven structural signs in the mandible to assist in predicting extreme growth rotation. For instance, in a subject with forward rotation, one is more likely to see a forward inclined condylar head, less curved mandibular canal compared to the contour of the mandible, convex angle in the lower border, retroclined symphysis, increased interincisal and intermolar angle, and decreased lower face height [23].

2.1.8 Components of Mandibular Rotation

The mandible does not seem to rotate in the same amount relative to different landmarks when examined closer. In the literature, more than one set of terminology has been introduced to describe the components involved in mandibular rotation (Table 2.1) [1272829].

Björk and Skieller (1983) divided mandibular rotation during growth into three components [27]:

- Total rotation is the rotation of the mandibular corpus measured as a change in inclination of a reference line, or implant line, relative to the anterior cranial base. When the reference line rotates forward relative to Sella-Nasion during growth, the degree of total rotation is deemed negative. The centre of total rotation is dependent on the other two centres of rotation [27];

- Matrix rotation expresses the rotation of the mandibular soft tissue matrix relative to the anterior cranial base. It is recorded as negative when the tangential mandibular line rotates forward relative to Sella-Nasion. It sometimes rotates forwards and sometimes backwards in the same subject during the growing period, with the condyles as the centre of rotation and produces a pendulum-like movement [27]; and

- Intramatrix rotation is the difference between the total rotation and the matrix rotation, expressing the remodeling at the mandible's lower border. The centre of the intramatrix rotation is located within the corpus, the exact location depending on several factors: the rotation of the corpus, the rotation of the maxilla, and the occlusion. The forward rotation of the corpus relative to the tangential line is recorded as negative, which lifts the anterior part of the corpus from the soft tissue matrix. The stretching leads to apposition below the symphysis of the anterior lower margin. The posterior part of the corpus is simultaneously pressed down into the matrix, resulting in resorption at the posterior lower border [27].

These rotational changes seen in the maxilla and mandible heavily affect the development of the face, especially in the vertical plane. There is approximately a fifteen-degree internal rotation from age four to adult life in individuals with average vertical facial proportions; meanwhile, the mandibular plane angle, or the total rotation, only decreases by two to four degrees. Out of the fifteen degrees from the internal rotation, about one quarter comes from condylar rotation, while the other three quarters come from the rotation within the mandible body. Surface remodeling (external rotation) compensates for the difference between internal and total rotation [1].

	Ødegaard	*Björk & Skieller*	*Solow & Houston*	*Proffit et al.*

Rotation of mandibular core relative to cranial base	Angle theta (1)	Total rotation (1)	True rotation (1)	Internal rotation (1)
Rotation of mandibular plane relative to cranial base	Angle alpha (2)	Matrix rotation (2)	Apparent rotation (2)	Total rotation (2)
Rotation of mandibular plane relative to core of mandible	Angle epsilon (3)	Intramatrix rotation (3)	Angular remodeling of lower border (3)	External rotation (3)
(2) = (1) – (3)				

Table 2.1 **Terminology for rotational changes in the jaws** [12,27,28,29]

2.1.9 Dental Compensation

Compensatory change in the eruption paths of teeth normally occurs to even out positional changes between the jaws. If such compensation is insufficient, defective occlusion and space anomalies may take place. Eventually, malocclusions are mainly due to incomplete compensatory guidance of eruption than to dysplastic deformation of the dental arches [19].

2.1.10 Mandibular Plane Angle (MPA)

Tweed (1946) was the first to describe the Frankfort-Mandibular Plane Angle (FMA) and provided a range of values to predict orthodontic treatment prognosis. The mandibular plane angle measured to Frankfort horizontal plane has also been used in the Tweed's triangle to examine lower incisors' inclination among different facial types [30]. However, since it is more difficult in tracing Frankfort horizontal plane due to overlapping of the structures, the line connecting Sella and Nasion was later proposed as an alternative for the mandibular plane angle (MPA) or SN-MP angle.

2.1.11 Facial Divergence

The term “facial divergence” was introduced by Schudy (1964). “Hyperdivergent” and “hypodivergent” were used to describe the extremes. Vertical dysplasia results from inharmony in vertical growth, and much of this is reflected in the SN-MP angle [31].

Hypodivergent pattern was found to be dominant in both Class II and III malocclusions. It is highly correlated with increased posterior facial height, ramus height and SNB angle, along with decreased anterior facial height, gonial angle, SN-MP angle, and Y-axis [32].

2.1.12 Facial Type

The development of the facial pattern is governed by relative locations of various sites to each other and the rates and amounts of their growth [14].

Downs (1956) identified three facial types: mesognathic, retrognathic, and prognathic, based on the facial angle. In addition, facial types may be correlated with facial profiles that are expressed by the angle of convexity. [33]

2.1.13 Mandibular Retrognathism/Skeletal Class II

Hunter (1967) compared a group of orthognathic subjects with a group of retrognathic subjects, based on an ANB angle of 4.5 degrees. The mean age was around 11 years old. In the retrognathic group, there was a slight tendency for the maxillary dentoalveolar height to be greater, the mandibular plane angle was slightly larger, and the mandible was found significantly smaller and more posteriorly positioned [34].

Wolford et al. (1978) termed mandibular deficiency syndrome (skeletal Class II) for individuals with idiopathically deficient or retrognathic mandibles, excluding craniofacial syndromes. To be more specific, they were subjects with an average SNA angle and ANB angle of more than 5 degrees. The research team further subcategorized them into three types, Type I, II, III, matching low, medium, and high mandibular plane angles. This is because they possess distinctive aesthetic, skeletal, and occlusal characteristics [4].

Retrognathism from craniofacial development may be largely regulated by genes related to muscles, leading to changes in the mechanical forces on areas of bone where muscles attach. While some genetic evidence related to skeletal muscles with links to mandibular retrognathism has been identified, more investigation is required in the field [35].

2.1.14 Short Face Syndrome

Lower face height, defined as the height from the anterior nasal spine to Menton (ANS-Me), was found to be 55 percent of the total face height (Nasion to Menton, N-Me) in a harmonious face [36]. In other words, the difference between upper and lower face height will be close to 10 percentiles on average.

Opdebeeck and Bell (1978) coined short face syndrome (SFS) based on a study involving twenty-seven untreated Caucasians with reduced lower face height under clinical impression [37]. According to the findings from Strang and Thompson (1958) [36], Opdebeeck and Bell (1978) used facial proportions index (FPI) as a screening guide, assuming FPI below 10 suggests a tendency for a short face. Out of surprise, they discovered two SFS groups with contradicting characteristics. The first SFS group was characterized by a long ramus, sharply reduced SN-MP angle, an FPI closer to 10, and slightly reduced posterior maxillary height. In contrast, the second SFS group was characterized by short ramus, slightly reduced SN-MP angle, FPI with values around or below zero, and sharply reduced posterior maxillary height. The latter group was designated as vertical maxillary deficiency [37].

Generally, excessive forward mandibular rotation will be seen in individuals with short lower faces, and this phenomenon arises from increased internal rotation and decreased external compensation. Frequently, it is accompanied by a nearly horizontal palatal plane, a low mandibular plane angle, a large gonial angle, deep bite, and crowded incisors [1].

2.2 Application of Surgery in Orthodontics

2.2.1 Surgical Approaches to Mandibular Retrognathism

There are plenty of treatment approaches to mandibular deficiency syndrome, or mandibular retrognathism, involving a combination of surgery and orthodontics. The options of surgical procedures are shown in Table 2.2 [5]. The decision will depend on the desired goals customized to each individual based on a systematic aesthetic evaluation, cephalometric analysis, and malocclusion.

A. Augmentation genioplasty	a. Anteroposterior b. Vertical
B. Anterior maxillary ostectomy	a. Alone b. With augmentation genioplasty
C. Mandibular advancement	a. Modified sagittal ramus osteotomy b. With augmentation genioplasty c. With reduction genioplasty d. Total subapical mandibular advancement
D. Superior repositioning of the maxilla	a. Alone b. With augmentation genioplasty
E. Interior repositioning of the maxilla	a. Alone b. With mandibular advancement
F. Combinations of the above	

Table 2.2 **Surgical approaches to mandibular retrognathism** [5]

2.2.2 History

Combined surgical-orthodontic treatment has become a common approach for patients with unfavourable jaw positions along with malocclusion. The first-ever documentation of orthognathic surgery in literature was conducted by Dr. Simon P. Hullihen (1849) [38], preceding the era of anesthesia and antibiotics. It was also roughly a century before the advent of cephalometric analysis [39]. Early cooperation between orthodontists and oral surgeons was reported by Whipple (1898) [40], where Dr. Edward Angle and surgeon Dr. Blair worked together in St. Louis to treat a case of mandibular prognathism [41].

In the 1950s and 60s, Dr. Trauner and Dr. Obwegeser (1957) [42] introduced the surgical technique of bilateral sagittal split osteotomy (BSSO) and genioplasty via interior incisions [43]. Since then, the application of surgery in orthodontics has advanced even more vigorously.

2.2.3 Epidemiological Analysis

Russel et al. (1999) surveyed consultant orthodontists in the UK, a group of orthodontic specialists who undergo a further two years of training following the attainment of membership in orthodontics. A large data set with close to 26,000 patients were created, and 7% of patients were found to be undergoing combined orthodontic/orthognathic surgery treatment [44]. Proffit et al. (1998) estimated that around 2% of the American population has a malocclusion whose degree of severity is at the limit for what orthodontic on its own can correct [45].

Patients with mandibular skeletal deficiency and Class II malocclusion form the largest single group of patients requiring orthognathic surgery [3]. Eventually, for patients to make an informed decision, they should be given the best information regarding the potential outcome, free from personal bias, and incorporate the pros and cons of each option, including risk and financial information [46].

2.2.4 Influential Factors on Treatment Decisions

Juggins et al. (2005) believed that the demand for orthognathic surgery has risen, owing to the treatment modality being more available, more socially acceptable, and the harsher social and individual standard on the judgement of appearance. Their questionnaire study on the perceived need for orthognathic surgery showed that oral surgeons were the most critical group on appearance, thus perceiving the highest need for treatment that adopts surgery, followed by orthodontists and patients [47]. This result was consistent with Bell et al. (1985), where they found the orthodontists perceived significantly less need for orthognathic surgery than did the oral surgeons [48].

Motegi et al. (2003) compared the psychosocial condition of a group of patients pre-surgically and post-surgically at 2-years and 5-years. They reported a significant improvement in psychosocial aspects, including social interaction, communication, alertness behaviour, and emotional behaviour after surgery, and this was maintained at 5-year post-surgery [49].

The decision-making process on receiving surgical correction may be multi-factorial, especially for the group of patients who fell into the borderline category; they were offered both options of surgical correction and non-surgical orthodontic camouflage to treat their deficient mandible. Psychosocial factors, including body image and self-perception, play a major role in patients' selection of an option. Still, there are other factors such as aesthetic concerns, the difference between the perspectives of an orthodontist and an oral surgeon, cost of treatment, patients' desires for functional improvement, and state of anxiety [4650]. A similar conclusion was drawn that self-perception of the profile influences an individual's decision more than cephalometric measurements and specialists' recommendations [48.]

A follow-up survey on 25 patients who underwent surgery to correct mandible prognathism found that over half of the patients sought treatment for aesthetic purposes, much higher than the second common reason, difficulty in mastication. Once the treatment was complete, 96% of the patients were satisfied and had noticed an improvement in their appearance [51]. On the contrary, a research on over one hundred surgical patients in Finland, with the majority being mandibular retrognathism, concluded that these patients are generally psychologically stable at the beginning of treatment and that functional motives outweighed aesthetic and psychosocial reasons. Similarly, self-satisfaction improved considerably after treatment [52]. There was a large-scale survey on 47 orthognathic maxillofacial surgery clinics in Sweden, reviewing almost 900 patients, with the majority being women around twenty years of age. In this study, function was also found as the main reason over aesthetics for patients to select surgical option, explained by the author that the reason may be their federal financial support policy [53].

2.3 Curve of Spee (COS)

2.3.1 History

In 1890, the concept of Curve of Spee was developed by Ferdinand Graf Spee, who was a prosector at the Anatomy Institute of Kiev [54]. It was rediscovered after almost a century and named after Spee in recognition of his contribution [55]. Through examining skulls, he found a curvature along the maxillary and mandibular teeth and the anterior border of the condyle (Figure 2.2) [56]. In orthodontics, the definition has been modified over time and now refers to the occlusal curve from the mandibular incisors to the molars. With slight variation in the selected reference points, it is usually measured as the deepest depth underneath the occlusal plane tangent to the edge of the mandibular incisors and cusp tips of the mandibular molars in the sagittal view, as shown in Figure 2.3 [57].

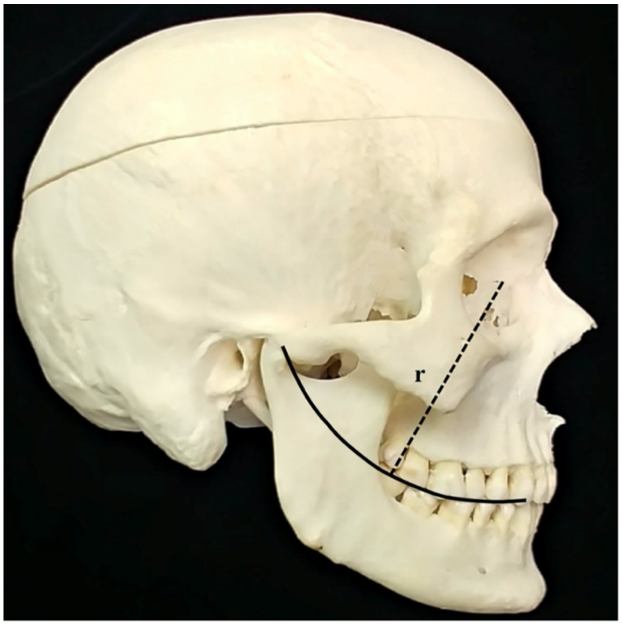


Figure 2.2 **Human skull in Norma lateralis depicting the antero-posterior curvature along the dentition. The dotted line depicts the radius of the Curve of Spee based on its earlier definition** [56]

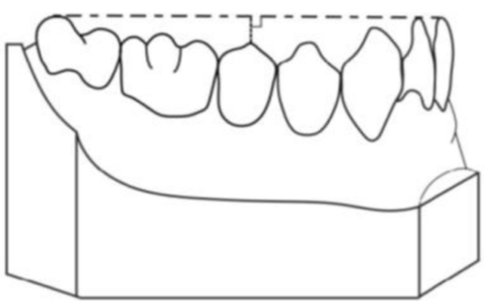


Figure 2.3 **Illustration of an example of the Curve of Spee measurement in Orthodontics** [57]

2.3.2 Development of Curve of Spee (COS)

Curve of Spee typically starts as flat to mild during primary dentition. It increases significantly following the eruption of mandibular incisors and permanent first molars and again deepens into its deepest after permanent mandibular second molars erupt above the occlusal plane. Later on, it reduces slightly as the individual grows into their late adolescence [5859].

No gender difference was noted in Curve of Spee before entering adulthood. It generally remains stable in humans with intact and healthy occlusions, except for a significant decrease found in an untreated male sample between the end of puberty to around the fifth decade of their life [60].

2.3.3 General Considerations of COS in Orthodontics

Based upon the records of two hundred untreated patients, Curve of Spee follows a decreasing order from Class II Division 1, Class II Division 2, Class I, to Class III subjects [61]. Shannon and Nanda (2004) examined fifty Caucasian patients. They established a positive correlation between increased pre-treatment Curve of Spee and low Frankfort mandibular plane angle, deep overbite, increased overjet, and Class II molar malocclusion. By analyzing the pre-treatment, post-treatment, and 2-year post-retention records of the same fifty patients, levelling of the curve was achieved by uprighting the molars, extruding the premolars, and intruding or flaring the lower incisors. Regarding the stability of the levelled curve, less than one-fifth of the examined subjects were reported with a significant relapse [62].

When finalizing occlusion, orthodontists tend to level the curve to reduce the vertical overlap of anterior teeth and prevent future relapse [63]. Based on the six keys of occlusion proposed by Andrew (1972), the intercuspation of teeth would be optimized when the occlusion plane, or the Curve of Spee, is brought close to flat or somewhat reverse at the completion of orthodontic treatment [64].

2.3.4 Considerations of COS for Surgical and Orthodontic Combined Approach

Of the orthodontic patients treated with additional surgery, Curve of Spee can be timely managed to assist in maximizing the treatment result of, in particular, mandibular retrognathism combined with short face syndrome.

A study looking at the stability following BSSO mandibular advancement surgery in fifty-two patients noted that an increase in the anterior facial height was primarily achieved by anteroinferior advancement of the distal segment and concomitant anterosuperior rotation of the proximal segment. Although a slight reduction was found between the release of surgical fixation and two-year follow-up evaluation, the increase in facial height remained stable two years post-surgery [65].

Epker and Fish (1983) proposed three considerations that should be taken when dealing with the decision on surgical versus orthodontic levelling of the Curve of Spee: the morphology of the curve, either stepped or continuous, the predicted treatment time, and the severity of the problem.

Later on, Tuinzing, Greebe, & Dorenbos (1989) noticed that by purposely leaving a deep bite before surgery, the reduction of the deep bite during surgery generates a clockwise rotational movement, which not only favours skeletal stability over counterclockwise movement but also improves the position of the chin [7]. More specifically, Rubenstein, Strauss, Isaacson, & Lindauer (1991) suggested that the degree of the opening rotation of the distal segment is determined by the vertical curve present in the dentition [8]. In other words, when deep Curve of Spee and deep overbite are present, mandibular incisors are mechanically blocked, a full forward translation is not possible; instead, an opening rotation is incorporated into the advancement.

Proffit et al. (2000) discussed the methods and timing regarding levelling the mandibular curve in surgical patients. The ways to decrease the depth of the curve include intrusion of the anterior teeth, extrusion of the posterior teeth, or a combination of both. The timing of levelling can be either during pre-surgical or post-surgical orthodontics. For instance, it is more indicated to stage the levelling procedure until post-surgery for most individuals with short face syndrome [9].

Generally speaking, levelling the curve prior to surgery is suggested in Class II individuals with normal or high mandibular plane angle; on the contrary, it is more indicated to leave the curve until after surgery in Class II individuals with low mandibular plane angle. In Class III subjects, the initial curve is generally insignificant. Therefore, maxillary and mandibular arches can often be well-coordinated before surgery [10]. Arch coordination is an integral aspect of pre-surgical orthodontics. It can be achieved by means of expansion or constriction of the arches to produce favourable post-surgical stability and occlusal interdigitation [66].

2.4 Intraoral Digital Scanner

The conventional impression technique has gradually been replaced by intraoral digital scanning to different extents in various dental fields. An intraoral digital scanner utilizes a device composed of a handheld camera, a computer, and software. The most widely used digital format is open STL (Standard Tessellation Language) [67].

Ender et al. (2016) conducted an in vivo study looking at the precision, calculated in micrometers, of several digital intraoral scanners and impression materials. Conventional impressions of vinylsiloxanether material showed the highest precision, while the lowest precision was found in the irreversible hydrocolloid (alginate) sample, which is also the most common impression material type in orthodontic clinics; digital intraoral impression systems resided in between [68].

Chapter 3

Materials and Methods

3.1 Ethics

The protocol was approved by Health Research Ethics Board (HREB) at the Bannatyne Campus of the University of Manitoba for this retrospective study on June 30, 2020 (Appendix 1).

3.2 Source of Sample

All patients presented to a Winnipeg orthodontic private practice for combined orthodontic and surgical treatment between 2012 and 2020 were reviewed. The patients were chosen chronologically, starting with the most recent cases treated in the orthodontic practice. Self-ligating GAC In-Ovation ® R brackets with 0.022-in slot size (Dentsply Sirona, York, Pennsylvania) were used as the fixed appliance during the entire active treatment phase.

All mandibular bilateral sagittal split osteotomy (BSSO) advancement surgeries were performed by a single oral surgeon with several decades of experience in a hospital setting, assisted by residents at the Oral and Maxillofacial Surgery division. After completing the split, Maxillomandibular Fixation (MMF) was established without interpositional splint to allow Rigid Internal Fixation (RIF) placement. After irrigation, the proximal segments were positioned and fixed with 4-hole titanium plates and 5 mm screws (KLS Martin, Gebrüder Martin GmbH&Co., Tuttlingen, Germany). MMF was then removed, and occlusion was confirmed. Following wound closure, directional guide elastics were placed, and patients were allowed to function and eat as comfortable.

Based on the following inclusion and exclusion criteria, individual record number, initials, gender, age in years and months, dates when each cephalometric radiograph was taken and when fixed appliance was placed for the selected subjects were recorded in an Excel spreadsheet.

3.3 Inclusion Criteria

- Mandibular bilateral sagittal split osteotomy (BSSO) advancement surgery combined with full fixed orthodontic treatment
- No discrimination in gender, age, ethnicity, or whether extraction had taken place

3.4 Exclusion Criteria

- History of head and neck trauma and/or surgery
- Cleft and/or craniofacial anomalies
- Severe Temporomandibular Disorder (TMD) requiring surgical intervention
- Additional surgical procedure to the mandibular BSSO advancement
- Missing teeth that the Curve of Spee could not be measured
- The cusp tips of mandibular second molars have not erupted on the pre-surgical digital cast
- Post-surgical cephalometric radiograph taken more than one month after the surgery

- Low-quality records. For example, the calibration ruler is missing, part of the soft/hard tissue is cut out, or a notably blurry outline of the structures is present that prevents from accurate identification of the landmarks

- Incomplete records. For example, more than one of the four radiographs or one of the two digital models is missing

3.5 Selected Time Points

Ninety subjects who qualified based on the inclusion and exclusion criteria were included in the study. The record of each subject consisted of four lateral cephalometric radiographs, acquired at pre-treatment (R1), pre-surgery (R2), post-surgery (R3), and post-treatment (R4). Each record also included two digital models of the lower dentition, taken at pre-treatment (D1) and pre-surgery (D2). The summary of each collected record is listed in Table 3.1.

	Pre-treatment	Pre-surgery	Post-surgery	Post-treatment
Radiograph	R1	R2	R3	R4
Digital model	D1	D2	x	x

Table 3.1 **Selected time points for each collected individual record**

3.6 Groups

The entire sample was divided into three groups based on the adjusted Mandibular plane angle (MPA) (see details in Section 3.9). Group 1 is made up of 30 subjects with the largest MPA, Group 2 consists of 30 subjects with medium MPA, and the other 30 subjects with the smallest MPA went to Group 3.

3.7 Cephalometric Radiographs

A total of 360 digital lateral cephalometric radiographs, four for each patient, were included in the study. Forty-seven radiographs dated before June 4th, 2014 were taken with PaxReve 3D imaging system (Vatech, Hwaseong-si, Gyeonggi-do, South Korea), while the rest dated after were taken with Pax-i3D Green imaging system (Vatech, Hwaseong-si, Gyeonggi-do, South Korea).

All subjects were in maximum intercuspation and natural head position during the capturing process. Natural head position is a standardized and reproducible position of the head in an upright posture with the eyes focused on a point in the distance at eye level; in this study, it was the wall in front of them, which implies that the visual axis remains horizontal. It has been used by artists and anatomists as early as the Renaissance period, before the concept was introduced into orthodontics in the 1950s [69].

The radiographs were taken with the x-ray beam perpendicular to the subjects' sagittal plane, with the beam entering from the left and the film cassette located on the right. Film magnification was standardized with a 30 mm calibration ruler. Exposure settings were set at 90 kVp and 10 mAs. The subject's head was oriented to the right in every cephalometric radiograph.

The radiograph was automatically transferred as a JPEG format into DolphinTM 11.7 imaging software (Dolphin Imaging and Management Systems, Chatsworth, CA, USA) then saved individually in the computer in the private practice where the samples were acquired. After that, they were re-imported into the same software on a university computer. Finally, the landmarks were manually identified and digitally traced by the primary investigator in the software (See details in Section 3.9). This was complete in a windowless room with basic white lighting.

3.8 Digital Models

All digital models were captured intraorally with iTero® Element (Align Technology Inc., San Jose, CA). A total of 180 digital scans, two for each patient, were included in the study. They were identified and downloaded from MyAligntech website in STL files, then saved on the computer in the private practice. Next, the files were imported into OrthoAnalyzer® software (3Shape®, Copenhagen, Denmark) individually for the Curve of Spee measurement (See details in Section 3.10). This was also complete in a windowless room with basic white lighting.

3.9 Cephalometric Landmarks

Cephalometry uses specific landmarks on the anatomical structure of the skull for quantitative analysis and measurements [70]. Two landmarks join to become a plane, and three landmarks join to become an angle. There are landmarks whose definitions are widely agreed upon in literature. In contrast, there are some other landmarks such as Porion (Po), Gnathion (Gn), and Gonion (Go), whose definitions may vary slightly based on different references.

For digitization, the file of each cephalometric radiograph was opened in DolphinTM 11.7 imaging software. Next, a series of landmarks were identified in order to generate a list of cephalometric values. The values of interest were exported into another Excel spreadsheet.

First, the angle between Sella-Nasion and Frankfort horizontal plane was adjusted to 7 degrees for standardization purpose [26], and SNA, SNB, and mandibular plane angle (MPA) were modified accordingly. After that, all subjects were arranged in a descending order based on the adjusted MPA and divided into three groups as described in Section 3.6. The hard tissue landmarks, planes, angular and linear variables employed in this study were listed in Tables 3.2 to 3.5. Figure 3.1 showed a digitized cephalogram.

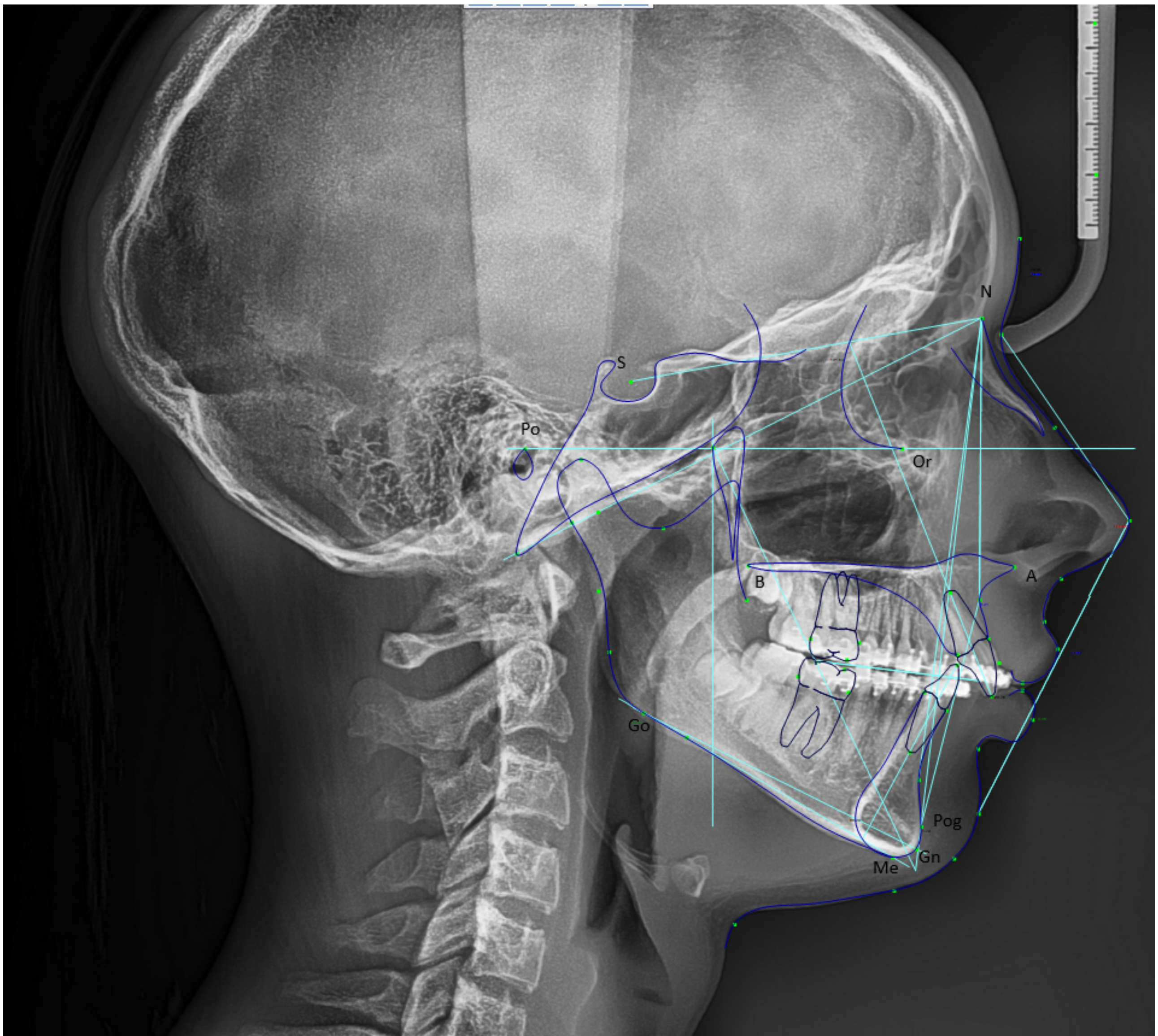


***Figure** 3.1* **Illustration of a digitized cephalogram**

Landmark	Definition	Reference
Sella (S)	The center of sella turcica: Located by inspection of the profile image of the fossa	71
Nasion (N)	The most anterior point of the frontonasal suture in the midsagittal plane	71
Orbitale (Or)	The lowest point on the infraorbital margin	71
Porion (Po)	The highest point on the superior surface of the external auditory meatus	71
Point A (A)	The deepest midline point on the premaxilla between the anterior nasal spine (ANS) and prosthion (The transition point between the crown of the most prominent medial maxillary incisor and the alveolar projection) [24]	71
Point B (B)	The deepest midline point on the mandible between dental alveolus and Pogonion	71
Pogonion (Pog)	The most anterior point on the mandible in the midsagittal plane	71
Gnathion (Gn)	The most anterior inferior point in the lateral shadow of the chin, usually best determined by selecting the midpoint between Pogonion and Menton on the contour of the chin	72
Menton (Me)	Lower most point of the contour of the chin	73
Gonion (Go)	The lowest, most posterior point on the mandible with the teeth in occlusion	17

Table 3.2 Definition of hard tissue landmarks

Plane/Line	Definition	Reference
Mandibular Plane (MP)	Formed by Menton and Gonion	[69]
Frankfort Horizontal Plane (FH)	Formed by Orbitale and Porion	[69]
Facial Plane	Formed by Nasion and Pogonion	[69]

Table 3.3 **Definition of planes/lines**

Angular Measurement	Definition	Reference
Mandibular Plane Angle (MPA)	The angle between Sella/Nasion and mandibular plane	[69]
SNA	The angle formed by Sella, Nasion, Point A	[74]
SNB	The angle formed by Sella, Nasion, Point B	[74]
ANB	The angle formed by Point A, Nasion, Point B	[74]
Facial Angle (FA)	The inner angle formed by the intersection of the facial plane and Frankfort Horizontal Plane	[71]
Frankfort Mandibular Angle (FMA)	The angle between Frankfort Horizontal Plane and mandibular plane	[30]
Y-Axis	The angle between Sella/Nasion and Sella/Gnathion	[69]

Table 3.4 **Definition of angular measurements**

Linear Measurement	Definition	Reference
Convexity	The linear distance from Point A to facial plane	[75]
Lower Facial Height (LFH)	The linear distance from ANS to Menton	[36]
Total Facial Height (TFH)	The linear distance from Nasion to Menton	[36]

Table 3.5 **Definition of linear measurements**

3.10 Curve of Spee Measurement

In the OrthoAnalyzer® software, the file of a mandibular digital scan was opened and oriented at the right sagittal view for assessment. First, "Plane icon" was selected to create a plane by identifying three points: midpoint of the higher incisal edges (either the lower right central or lateral incisor) and the distal cusp tips of the lower right second molar. If it had not fully erupted, the first molar would be used instead. The scanning model was zoomed in, altered between sagittal and occlusal views, and rotated as needed to ensure accuracy in identification of the points.

Next, the "Point to plane icon" was utilized to calculate the linear measurement (mm) from the plane to the deepest buccal cusp tip underneath (Figure 3.2). The result was recorded to an accuracy of 0.01mm as the Curve of Spee (COS) value for the right side, and the same procedure was repeated for the left side. The final COS value was the sum of both numbers.

3.11 Reliability

3.11.1 Intra-rater Reliability

10% of the sample were randomly selected by an online random number generator, and their radiographs and digital scans were re-traced and re-measured by the primary investigator at two-week intervals from the end of initial data collection.

3.11.2 Inter-rater Reliability

Inter-rater reliability was not estimated as the purpose of the study does not focus on assessing the diagnostic ability of the investigator; thus, it was unnecessary.

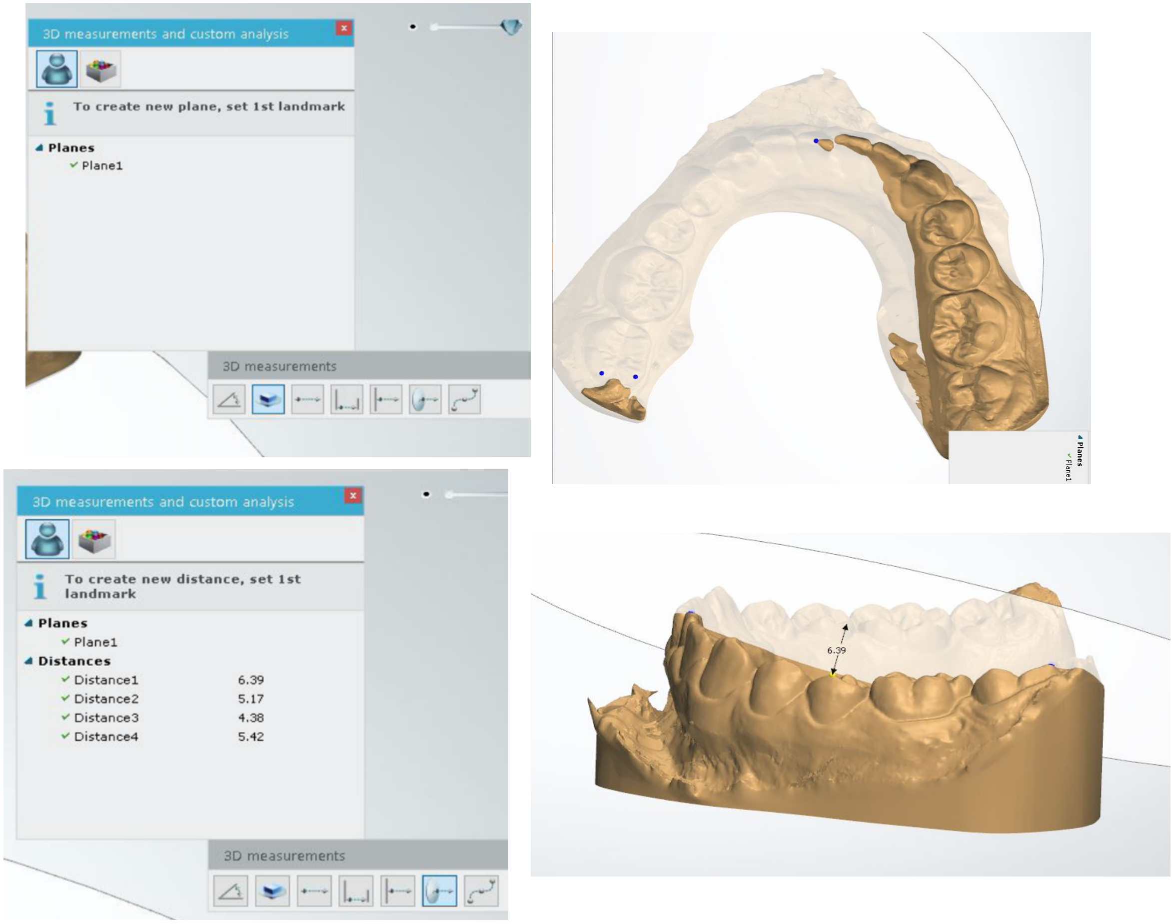


Figure 3.2 **Demonstration of Curve of Spee measurement in the OrthoAnalyzer software.**
Top left: "Plane icon" was selected.
Top right: Three points were identified for the plane.
Bottom left: "Point to plane icon" was selected.
Bottom right: The distance between the deepest buccal cusp underneath the plane to the plane was displayed.

3.12 Statistical Analysis

3.12.1 Sample Size Calculation

Spearman correlation between the pre-surgical COS and several cephalometric values was conducted by Foletti et al. [12], and the correlation coefficient was found to be ranging from 0.55 - 0.70. By performing an estimation for 0.6 correlation, at 90% power and $\alpha < 0.05$, the minimum required sample size is approximately 24. Based on this, 30 subjects were recruited for each group, adding up to a total of 90 subjects in the study.

3.12.2 General Statistics

All statistical analyses were conducted with IBM SPSS Statistics for Windows, Version 27.0, released in 2020 (Armonk, NY: IBM Corp) in consultation with an experienced biostatistician from the Centre for Healthcare Innovation at the University of Manitoba.

Mean and standard deviation (SD) were calculated for continuous variables with 95% confidence interval. One-way analysis of variance (ANOVA) was used to determine the significance of difference in the pre-treatment and pre-surgical Curve of Spee (COS) values among different groups.

Spearman rank-order correlation analysis was adopted for the correlation between pre-surgical COS and cephalometric changes between pre-surgery (R2) and post-surgery (R3). Spearman correlation was chosen over Pearson analysis due to the nature of our sample not following normal distribution. Paired T-test was utilized to identify statistical significance for the correlation analysis. P-value was considered significant when $\alpha < 0.05$.

For the cephalometric variable that was found significant by Spearman's correlation, regression analysis was performed to estimate the cephalometric change per unit of pre-surgical COS.

Intraclass Correlation Coefficient (ICC) was employed to test the intra-rater reliability of the repeated 10% measurements.

Chapter 4

Results

4.1 Descriptive statistics

A total of 90 surgical-orthodontically treated patients, mainly Caucasians, were included in the sample. They were further divided into three groups according to the initial mandibular plane angle (MPA). Mean values and standard deviation for the age and gender of each group were shown in Table 4.1. The treatment time of the presurgical orthodontic and the entire active treatment were also recorded respectively.

The mean age of the subjects in the study was 25.06 ± 15.09 years old. The total sample was comprised of 58 females (64.4%) and 32 males (35.6%). Females were found to be the majority in group 1, more females were included in group 2, and slightly more males were seen in group 3. The average treatment duration was 30.26 ± 4.95 months, and the pre-surgical orthodontic phase averaged at 21.33 ± 4.95 months. Subjects who required extraction in the mandibular dentition made up almost half the entire group (47.78%), and the major extraction pattern was extracting two mandibular first premolars (81.40%).

Curve of Spee (COS) was measured from digital casts in the OrthoAnalyzer® software. Each cast was measured from both left and right then averaged into a final value. As shown in Table 4.2, the average pre-treatment COS value was 3.56 ± 1.31 mm, and the average pre-surgical COS value was 2.50 ± 0.80 mm. On average, approximately 1mm of COS was levelled during the pre-surgical orthodontic phase for each group.

Based on one-way ANOVA, there did not appear to be a significant difference between the COS values among the groups at pre-treatment ($F(2,87) = 0.120$, $p = 0.887$). Similarly, there was no significant difference among the groups at pre-surgical ($F(2,87) = 0.620$, $p = 0.540$).

Table 4.1 Demographics and Treatment Duration

Variables	All Groups (n=90)	Group 1 (n=30)	Group 2 (n=30)	Group 3 (n=30)
Age (years)	25.06 (15.09)	26.28 (17.66)	22.04 (11.40)	26.84 (15.58)
Gender	M=32, 35.6% F=58, 64.4%	M=4, 13.3% F=26, 86.7%	M=12, 40.0% F=18, 60.0%	M=16, 53.3% F=14, 46.7%
Pre-surgical Treatment Duration (months)	21.33 (4.95)	21.93 (4.03)	22.00 (4.74)	20.07 (5.82)
Full Treatment Duration (months)	30.26 (5.22)	30.47 (4.36)	30.77 (4.31)	29.53 (6.71)

Table 4.2 Curve of Spee (COS) measurement
Standard deviations displayed in brackets

Variables	All Groups (n=90)	Group 1 (n=30)	Group 2 (n=30)	Group 3 (n=30)
Pre-treatment COS (mm)	3.56 (1.31)	3.61 (1.28)	3.47 (1.36)	3.62 (1.34)
Pre-surgical COS (mm)	2.50 (0.80)	2.41 (0.82)	2.63 (0.85)	2.46 (0.72)

Table 4.3 showed the mean and standard deviation of the pre-treatment cephalometric values. The groups were created according to their initial MPA. Group 1 consisted of 30 subjects who had the highest MPA values, averaged at 34.10 ± 3.23°. In contrast, group 3 consisted of 30

subjects with the lowest MPA values, averaging 20.91 ± 3.20°. Because MPA was adjusted to 7° between Sella/Nasion and Frankfort horizontal plane, the difference between MPA and FMA appeared to be approximately 7°.

Except for SNA, which is not directly related to the lower jaw, all other measurements followed a trend, either increasing or decreasing from groups 1 to 3. The variables that demonstrated an increasing trend were SNB, FA, and Pog to NB. The variables that demonstrated a decreasing trend were ANB, FMA, Y-axis, convexity, LFH, and LFH/TFH.

Table 4.3 Pre-treatment (R1) cephalometric values
Standard deviations displayed in brackets

Variables	All Groups (n=90) R1	Group 1 (n=30) R1	Group 2 (n=30) R1	Group 3 (n=30) R1
MPA (°)	27.62 (6.08)	34.10 (3.23)	27.85 (1.61)	20.91 (3.20)
Range of MPA (°)	41.9 - 13.7	41.9 - 30.5	30.4 - 25.2	25.1 - 13.7
SNA (°)	83.73 (2.47)	83.53 (2.70)	83.33 (2.27)	84.32 (2.41)
SNB (°)	78.61 (2.31)	77.85 (2.21)	78.11 (2.32)	79.86 (1.93)
ANB (°)	5.11 (2.11)	5.66 (2.23)	5.23 (1.94)	4.46 (2.03)
FA (°)	87.12 (2.57)	85.87 (2.03)	86.56 (2.39)	88.94 (2.26)
FMA (°)	20.62 (6.08)	27.1 (3.22)	20.85 (1.63)	13.91 (3.21)
Y-axis (°)	67.05 (4.12)	69.20 (3.53)	68.45 (3.09)	63.50 (3.21)
Convexity (mm)	3.5 (2.57)	4.54 (2.18)	3.72 (2.37)	2.25 (2.67)
Pog to NB (mm)	2.64 (1.68)	1.83 (1.13)	2.59 (1.59)	3.5 (1.86)
LFH (mm)	60.51 (6.80)	64.51 (6.48)	61.34 (4.27)	55.67 (6.33)
LFH/TFH (%)	53.75 (2.66)	54.94 (2.59)	53.80 (2.57)	52.51 (2.31)

4.2 Intraclass Correlation Coefficient (ICC)

As listed in Table 4.4, ICC turned out to be highly consistent between the first entry and the 10% repeated measurements, ranging from 0.934 to 0.999. Therefore, we are confident in the reliability of the presented data.

Table 4.4 **ICC reliability**

Variables	R1	R2	R3	R4
SNA (°)	0.976	0.954	0.988	0.967
SNB (°)	0.991	0.978	0.996	0.980
ANB (°)	0.965	0.934	0.984	0.994
FA (°)	0.983	0.967	0.983	0.978
FMA (°)	0.995	0.992	0.995	0.992
MPA (°)	0.995	0.993	0.997	0.994
Y-axis (°)	0.997	0.993	0.998	0.992
Convexity (mm)	0.982	0.971	0.987	0.997
Pog to NB (mm)	0.966	0.992	0.995	0.991
LFH (mm)	0.999	0.997	0.994	0.998
LFH/TFH (%)	0.994	0.989	0.978	0.979
Pre-treatment COS (mm)	0.998			
Pre-surgical COS (mm)	0.980			

4.3 Cephalometric Changes between Time Points

4.3.1 Changes between Pre-treatment (R1) and Pre-surgical (R2) (Table 4.5)

All skeletal changes were below 1°, 1mm, or 1 percent during this phase, except for the linear measurement of lower face height (LFH). On average, LFH increased by 1.56 ± 3.74 mm. There was a rising trend from groups 1 to 3, with the average increase being 0.87 ± 2.07 mm, 1.52 ± 2.12 mm, and 2.30 ± 5.75 mm, respectively. Since MPA was adjusted to Frankfort horizontal plane, the changes in FMA and MPA were similar, which was also true for Tables 4.6-4.8.

Table 4.5 **Changes between pre-treatment (R1) and pre-surgical (R2)**
Standard deviations displayed in brackets

Variables	All Groups (n=90) R1/R2	Group 1 (n=30) R1/R2	Group 2 (n=30) R1/R2	Group 3 (n=30) R1/R2
SNA (°)	-0.29 (1.14)	-0.33 (1.41)	-0.39 (0.90)	-0.15 (1.08)
SNB (°)	0.01 (1.17)	0.13 (1.19)	-0.05 (1.23)	-0.06 (1.12)
ANB (°)	-0.30 (1.20)	-0.46 (1.27)	-0.33 (1.21)	-0.09 (1.14)
FA (°)	0.25 (1.12)	0.42 (1.09)	0.13 (1.24)	0.20 (1.02)
FMA (°)	-0.15 (1.47)	-0.28 (1.45)	0.10 (1.64)	-0.26 (1.31)
MPA (°)	-0.21 (1.49)	-0.36 (1.46)	0.10 (1.64)	-0.38 (1.35)
Y-axis (°)	0.03 (1.14)	-0.24 (1.19)	0.27 (1.13)	0.04 (1.07)
Convexity (mm)	-0.49 (1.06)	-0.71 (1.09)	-0.40 (1.08)	-0.35 (1.01)
Pog to NB (mm)	0.59 (1.03)	0.70 (0.90)	0.41 (0.79)	0.65 (1.32)
LFH (mm)	1.56 (3.74)	0.87 (2.07)	1.52 (2.12)	2.30 (5.75)
LFH/TFH (%)	0.35 (0.78)	0.28 (0.68)	0.29 (0.95)	0.48 (0.69)

4.3.2 Changes between Pre-surgical (R2) and Post-surgical (R3) (Table 4.6)

Generally, all post-surgical radiographs were expected to be taken two weeks after the surgery; however, nine radiographs were taken only one week after, three were taken three weeks later, and only one radiograph was taken a month after surgery.

There was negligible change in SNA, followed by Y-axis, which showed a change averaged below 1°. The remaining skeletal measurements indicated a more significant change. Most measurements (SNB, ANB, FA, FMA, convexity, Pog to NB, LFH, and LFH/TFH) followed an increasing trend, with a bigger difference in the low-angle Group 3 than the high-angle Group 1.

Looking at the entire sample, the largest change in degrees was found in ANB, with a mean decrease of 3.28 ± 1.30°. The second-largest change in degrees was found in SNB, averaged at 3.18 ± 1.29°. The largest linear change in millimetres was found in convexity, with an averaged decrease of 2.52 ± 1.12 mm, followed by LFH, with a mean increase of 2.15 ± 1.59 mm.

In groups 1 and 2, the two largest change in degrees were ANB and SNB. Similarly, convexity and LFH saw the largest change in millimetres. With a slight difference in group 3, who started with the lowest MPA, the two largest changes in degrees were found in MPA and ANB. The largest linear change in millimetres was found in LFH (2.87 ± 1.88 mm).

Table 4.6 **Changes between pre-surgical (R2) and post-surgical (R3)**
Standard deviations displayed in brackets

Variables	All Groups (n=90) R2/R3	Group 1 (n=30) R2/R3	Group 2 (n=30) R2/R3	Group 3 (n=30) R2/R3
SNA (°)	-0.10 (0.76)	-0.14 (0.80)	-0.04 (0.72)	-0.12 (0.78)
SNB (°)	3.18 (1.29)	2.75 (1.37)	3.25 (1.05)	3.53 (1.34)
ANB (°)	-3.28 (1.30)	-2.89 (1.29)	-3.30 (1.40)	-3.64 (1.13)
FA (°)	2.51 (1.09)	2.26 (1.27)	2.56 (0.93)	2.70 (1.04)
FMA (°)	2.86 (1.42)	2.50 (1.38)	2.51 (1.48)	3.56 (1.14)
MPA (°)	2.93 (1.42)	2.63 (1.33)	2.49 (1.51)	3.67 (1.13)
Y-axis (°)	-0.90 (0.96)	-0.80 (1.03)	-1.23 (0.89)	-0.69 (0.90)
Convexity (mm)	-2.52 (1.12)	-2.26 (1.15)	-2.62 (1.23)	-2.67 (0.97)
Pog to NB (mm)	-1.25 (0.63)	-1.09 (0.63)	-1.22 (0.55)	-1.42 (0.67)
LFH (mm)	2.15 (1.59)	1.76 (1.16)	1.82 (1.43)	2.87 (1.88)
LFH/TFH (%)	1.23 (0.84)	1.01 (0.57)	1.17 (0.78)	1.50 (1.04)

4.3.3 Changes between Post-surgical (R3) and Post-treatment (R4) (Table 4.7)

Minimal skeletal changes were found in all variables. All values were averaged below one degree, one millimetre, or one percent, implying that the surgery results remained greatly stable during the post-surgical orthodontic phase.

Table 4.7 **Changes between post-surgical (R3) and post-treatment (R4)**
Standard deviations displayed in brackets

Variables	All Groups (n=90) R3/R4	Group 1 (n=30) R3/R4	Group 2 (n=30) R3/R4	Group 3 (n=30) R3/R4
SNA (°)	0.04 (0.85)	0.01 (0.77)	0.10 (0.84)	0.02 (0.95)
SNB (°)	-0.64 (0.95)	-0.69 (1.03)	-0.68 (0.86)	-0.55 (0.97)
ANB (°)	0.69 (0.95)	0.71 (0.93)	0.79 (1.06)	0.58 (0.88)
FA (°)	-0.58 (0.90)	-0.70 (1.00)	-0.50 (0.81)	-0.53 (0.88)
FMA (°)	0.46 (1.17)	0.51 (1.30)	0.45 (1.05)	0.42 (1.18)
MPA (°)	0.41 (1.16)	0.36 (1.28)	0.43 (1.11)	0.43 (1.13)
Y-axis (°)	0.33 (0.89)	0.40 (1.05)	0.31 (0.85)	0.29 (0.78)
Convexity (mm)	0.57 (0.94)	0.59 (0.87)	0.58 (1.08)	0.55 (0.89)
Pog to NB (mm)	0.22 (0.46)	0.25 (0.37)	0.38 (0.48)	0.04 (0.46)
LFH (mm)	0.28 (1.78)	0.38 (1.60)	0.41 (1.88)	0.06 (1.89)
LFH/TFH (%)	-0.01 (0.87)	-0.03 (0.73)	0.14 (0.76)	-0.15 (1.08)

4.3.4 Changes between Pre-treatment (R1) and Post-treatment (R4) (Table 4.8)

Looking at the entire active treatment phase, the least changes were found in SNA, Y-axis, and Pog to NB, with values below 1 degree or 1 millimetre no matter when viewed as a group or as a whole.

Most measurements (SNB, ANB, FA, FMA, MPA, convexity, Pog to NB, LFH, and LFH/TFH) followed an increasing trend, with a bigger difference in the low-angle group than the high-angle group. On the contrary, only SNA followed a decreasing trend. The two largest changes in degrees were reported in FMA and MPA when examining the entire sample, and the largest linear change in millimetres was reported in LFH. The same was found in the individual groups.

Table 4.8 **Changes between pre-treatment (R1) and post-treatment (R4)**
Standard deviations displayed in brackets

Variables	All Groups (n=90) R1/R4	Group 1 (n=30) R1/R4	Group 2 (n=30) R1/R4	Group 3 (n=30) R1/R4
SNA (°)	-0.35 (1.36)	-0.47 (1.50)	-0.33 (1.17)	-0.25 (1.43)
SNB (°)	2.54 (1.51)	2.19 (1.72)	2.52 (1.28)	2.92 (1.47)
ANB (°)	-2.88 (1.41)	-2.64 (1.30)	-2.85 (1.43)	-3.15 (1.50)
FA (°)	2.18 (1.51)	1.98 (1.75)	2.19 (1.31)	2.37 (1.45)
FMA (°)	3.17 (1.82)	2.73 (2.09)	3.05 (1.90)	3.72 (1.29)
MPA (°)	3.12 (1.80)	2.63 (2.02)	3.02 (1.92)	3.72 (1.24)
Y-axis (°)	-0.54 (1.47)	-0.63 (1.81)	-0.64 (1.27)	-0.35 (1.30)
Convexity (mm)	-2.43 (1.38)	-2.39 (1.17)	-2.44 (1.39)	-2.47 (1.58)
Pog to NB (mm)	-0.44 (1.04)	-0.15 (0.91)	-0.43 (0.89)	-0.73 (1.22)
LFH (mm)	4.00 (4.27)	3.01 (2.93)	3.75 (3.20)	5.23 (5.87)
LFH/TFH (%)	1.56 (1.13)	1.26 (0.90)	1.60 (1.21)	1.83 (1.20)

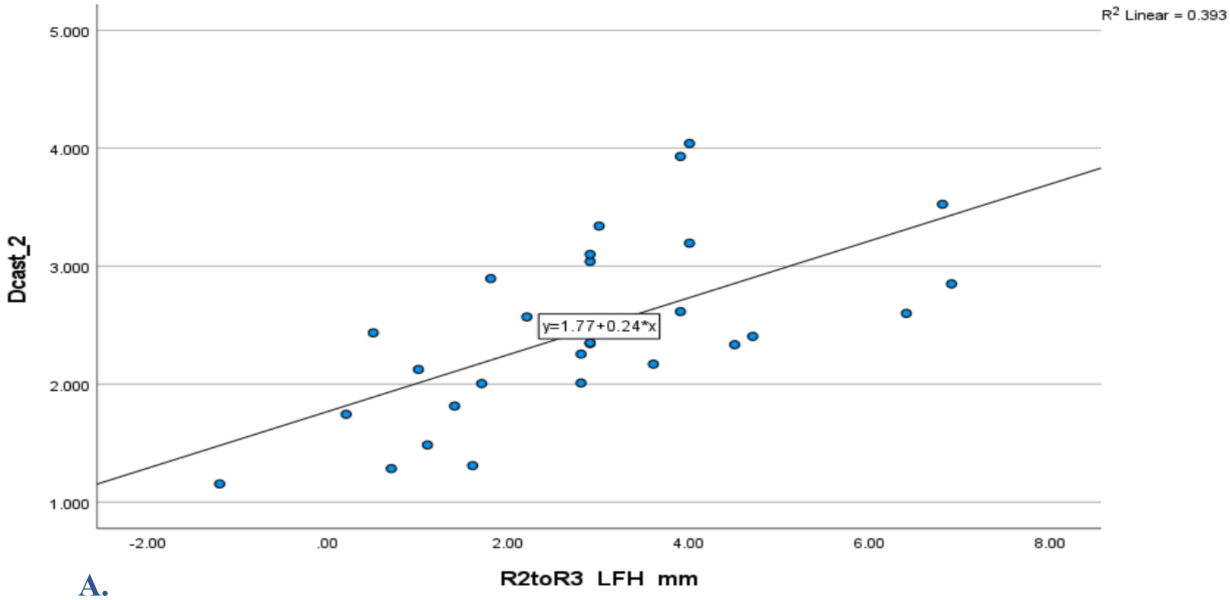
4.4 Correlations

Spearman rank-order correlation coefficient (r) was calculated between the cephalometric changes from pre-surgical (R2) to post-surgical (R3) and the pre-surgical COS, as shown in Table 4.9. When viewed as a whole (n=90), a relatively weak correlation was found among all variables, ranging from -0.054 to 0.198. Similarly, generally weak correlations were noted in groups 1 and 2.

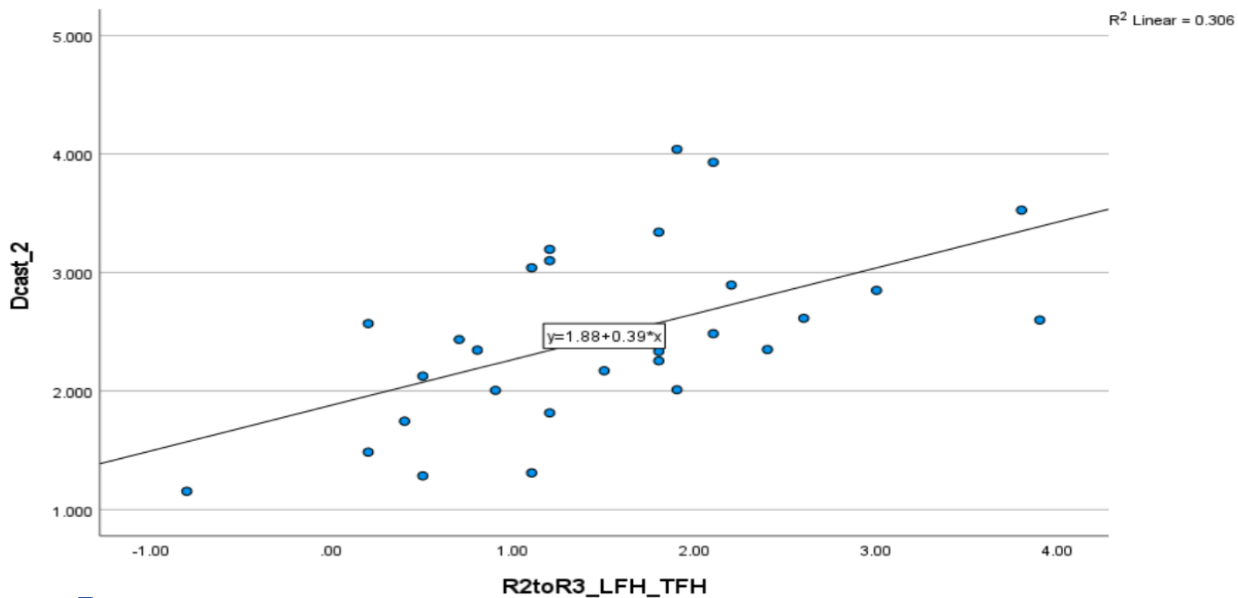
In group 3, moderate correlations were found for FMA ($r = 0.319$), MPA ($r = 0.336$), and Y-axis ($r = 0.311$). Strongest correlations were noted for LFH ($r = 0.682$) and LFH/TFH ($r = 0.566$) measurements of lower face height (LFH) with statistical significance ($P < 0.001$). This implies that as the pre-surgical COS increases in low-MPA group, there will be a simultaneous increase in three variables related to mandibular plane rotation: FMA, MPA, Y-axis, and a more pronounced increase in LFH. Scatter plots for the LFH measurements were illustrated in Figure 4.1.

Table 4.9 **Correlations between R2/R3 Change and pre-surgical COS**
Spearman correlations. ***P < 0.001

	All Groups (n=90) R2/R3		Group 1 (n=30) R2/R3		Group 2 (n=30) R2/R3		Group 3 (n=30) R2/R3	
Variables	Spearman's Rank Value	P Value	Spearman's Rank Value	P Value	Spearman's Rank Value	P Value	Spearman's Rank Value	P Value
SNA (°)	0.196	0.064	0.167	0.377	0.238	0.204	0.131	0.490
SNB (°)	0.068	0.522	-0.052	0.784	0.057	0.764	0.207	0.273
ANB (°)	0.083	0.436	0.184	0.331	0.099	0.603	-0.157	0.408
FA (°)	0.063	0.555	-0.046	0.809	0.079	0.676	0.195	0.302
FMA (°)	0.102	0.340	-0.015	0.938	0.112	0.556	0.319	0.085
MPA (°)	0.143	0.177	0.021	0.913	0.174	0.358	0.336	0.070
Y-axis (°)	0.064	0.546	0.117	0.539	-0.013	0.945	0.311	0.094
Convexity (mm)	0.161	0.130	0.266	0.156	0.112	0.555	-0.008	0.966
Pog to NB (mm)	-0.054	0.616	0.086	0.653	0.019	0.920	-0.261	0.164
LFH (mm)	0.198	0.061	0.021	0.913	-0.055	0.775	0.682***	0.000
LFH/TFH (%)	0.136	0.203	-0.170	0.368	0.022	0.907	0.566***	0.001



A.



B.

Figure 4.1 **Scatter plots between cephalometric changes from pre-surgical (R2) to post-surgical (R3) time points (X-axis) and pre-surgical COS (Y-axis)**

A. Lower face height (LFH) in linear measurement

B. Lower face height (LFH/TFH) in percentage measurement.

Strongest Spearman correlation coefficients (r) were discovered in these two variables, both statistically significant ($P < 0.001$)

4.5 Regression analysis

Since lower face height (LFH) was identified as the only significant variable in Spearman's correlation, regression analysis was further performed (Figure 4.2). Based on the regression analysis of linear LFH change from R2 to R3 and pre-surgical COS, COS had a significant relationship with LFH, b = 1.629, t(28) = 4.25, $p < 0.001$. It also explained a significant proportion of variance in LFH, R2 = 0.393, F(1, 28) = 18.10, $p < 0.001$. An R Square value of 0.393 suggests that 39.3% of the variance between these variables may be explained by the regression model. The estimated relationship between COS and LFH was for each 1mm pre-surgical COS; there was an increase in LFH of 1.629 mm from the surgical procedure. P-value (= 0.000) was statistically significant.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.627[a]	.393	.371	1.49410

a. Predictors: (Constant), Dcast_2

b. Dependent Variable: R2toR3_LFH_mm

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.139	.981		-1.161	.255
	Dcast_2	1.629	.383	.627	4.254	.000

a. Dependent Variable: R2toR3_LFH_mm

Figure 4.2 **Regression analysis of linear LFH change from R2 to R3 and pre-surgical COS**

Chapter 5

Discussion

This retrospective study aims to understand the skeletal effects of Curve of Spee (COS) in skeletal Class II patients with various mandibular plane angles (MPA) treated with combined orthodontic and orthognathic surgery. Ninety patients from a single source who underwent mandibular bilateral sagittal split osteotomy (BSSO) advancement surgery were divided into three groups by initial MPA. COS was measured from digital dental models at pre-surgical, and its correlation with cephalometric changes between pre-surgical and post-surgical lateral cephalograms was investigated. Of the skeletal measurements we explored, linear lower face height (LFH) and the ratio of lower face height to total face height (LFH/TFH) in the low-MPA group were the two variables found of statistical significance.

5.1 Landmarks

As shown previously in Tables 3.2 - 3.5, the selection of landmarks for angular, linear, and percentage measurements was based on several widely recognized references. Nevertheless, there are landmarks with more variation in definition, which are discussed below.

5.1.1 Mandibular Plane Angle (MPA)

Mandibular plane angle (MPA) varies according to the chosen mandibular plane, which in turn depends on the chosen Gonion (Go). The second variation is the usage between Menton (Me) and Gnathion (Gn). Our mandibular plane was constructed by connecting the most inferior point on the symphysis (Me) and the most inferior point at the gonial angle (Go). The same method has been demonstrated in early literature [1417]. Another popular way of defining Go is by bisecting the angle formed by lines tangent to the posterior ramus and the inferior border of the mandible [69]. If Go is identified with the bisecting technique, the outcome will be more vertical. On the other hand, if the mandibular angle is constructed from Go to Gn instead of Me, the outcome will be more horizontal.

5.1.2 Lower Face Height (LFH)

Lower face height (LFH) was measured as the linear distance between anterior nasal spine (ANS), the most anterior point of the maxilla in the sagittal plane, and Menton (Me). The same landmarks were utilized in several studies [313637]. Another variation is to measure LFH from ANS to Gnathion (Gn) rather than Menton (Me), which will generate a shorter LFH.

5.1.3 Curve of Spee (COS)

Lastly, Curve of Spee (COS) values were derived from measuring digital models for the reason of accuracy. Previous studies mostly measured it from dental cast models [6276], photos of cast models [77], or lateral cephalometric radiographs [12]. After digital scanners were introduced in dentistry, more studies started to measure COS digitally with different choices of scanners and software [617879].

Currently, there is still a lack of consensus regarding the measurement of COS. The first variation is whether the procedure is conducted on 2D photos/radiographs or 3D dental models/digital models. There has not been any study comparing the validity and reliability of COS measurement among these methods. Intuitively, measuring on 3D digital models should be the most accurate, especially when alginate impressions were found to be significantly imprecise compared to digital scanning methods [68]. Whenever a three-dimensional object is projected into two-dimensional space, information can be lost during the conversion, along with other factors like patient position for radiographs or orientation of the models for photos.

The second variation is the choice of the occlusal plane. Some used tripod landmarks on the distobuccal cusps of the left and right second molars and the midpoint between the central incisors [61627879], while some constructed a line from the incisal edge to the highest cusp tip of the first or second molar on lateral cephalograms or photos from a sagittal view [1277]. Most studies measured both right and left sides then calculated a mean value. Our method utilized two different occlusal planes by connecting three landmarks in the digital software on both right and left sides; there may be a slight difference from the method where only one occlusal plane was used for both sides.

Thirdly, the measurement of the COS differs. One averaged the distance from the plane to the buccal cusp tips of the premolars and the first molar [62], one measured to the deepest point in the dentoalveolar ridge from the sagittal view [79], while most simply identified the deepest buccal cusp tip [1261777880]. The majority was measuring to the deepest buccal tip underneath the constructed plane. The first method may underestimate the value of the COS, while the second method may overestimate.

Again, further research may examine and compare different methods. Without a doubt, it would be beneficial if a universal COS measuring method can be decided and popularized among researchers and clinicians for less confusion clinically and the research outcomes will be more comparable.

5.2 Sample

5.2.1 Gender

Without predisposition to either gender, females (F) ended up the majority (64.4%) of the sample; the ratio between females and males was 1.8:1. This was even exaggerated in the high-MPA group (F = 86.7%). In group 2, the percentage of females dropped to 60%. In low-MPA group, it was near even distribution between both sexes, with males (53.3%) surpassing females.

Siriwat and Jarabak's [32] work of five hundred untreated random samples concluded that the majority of females demonstrate a neutral facial pattern, whereas the majority of males demonstrate a hypodivergent pattern. They also reported that the numbers of females exceeded males in both hyperdivergent and neutral groups, while males exceeded females only in the hypodivergent group. Our finding was in agreement with theirs, although they utilized a more general sample and based facial divergence on the ratio between posterior face height (S-Go) and anterior face height (N-Me). More recently, Hardin et al. [81] divided more than seven hundred untreated subjects into three facial divergence groups based on MPA. Both hyper and normo-divergent groups consisted of more females, while more males were found in the hypo-divergent group. Similar gender distribution in each group was observed between our study and theirs.

Consensus was seen with previous research especially as we narrow the scope down. After filtering subjects of mandibular deficiency syndrome (skeletal Class II) from the Philadelphia and Michigan extensive facial growth database, female subjects were found to be almost three times the number of male subjects. However, the authors contributed this to the feature of the database [4]. The highest consistency regarding the overall ratio of females to males between our study (1.8:1) and others was found in those adopting similar methodology: recruiting samples of skeletal Class II patients treated with mandibular advancement surgery [498283]. The decreasing order in the number of females from our high to low-MPA group was well aligned with a study employing the same method in grouping; their samples were ranked and divided into three groups by MPA [83]. It appears that the closer the methods of grouping and inclusion criteria, the more consistent the ratio between females and males will be.

From a different perspective, women tend to access medical care more frequently [84]. More females was found to seek combined orthodontic and surgical treatment [5385]. There was also a higher chance for women to accept the option of orthognathic surgery whenever it was offered to them [8687]. The fact that females (n = 58, 64.4%) almost doubled the number of males (n = 32, 35.6%) in our sample group may be partly due to this reason.

5.2.2 Age

We did not exclude any patient due to their age. The mean age at pre-treatment for the entire sample was 25.06 ± 15.09 years old, agreeing with Andrup [53] that women around twenty years of age made up the majority of surgical orthodontic patients. However, there were subjects as young as ten years old and went for surgery at twelve years old. Schendel et al. evaluated twelve children with deficient mandible, aged between eight and sixteen years old, all treated with mandibular advancement surgery; it was concluded that pre-pubertal intervention produced stable results and, most importantly, would not affect subsequent growth [88]. Nonetheless, whenever mandibular advancement surgery is planned on younger children, anatomic structures and certain technical aspects must be considered. For instance, their lingula and inferior alveolar foramen are located more superior and posterior in the ramus than adults, their mandibular molars are positioned more laterally in the mandible, the mandibular cortical bone is thinner, and the mandible is smaller. Therefore, the sagittal portion of the osteotomy has to be directed as close to the lateral cortical plate as possible so that the second and third molars will not be accidentally injured. Also, clean fracture lines are more difficult to produce on these patients, and the incision requires more accuracy due to the smaller size of the mandible [89].

5.2.3 Extraction

About half of the group required extractions in the mandibular dentition, of which over 80% had two mandibular first premolars removed. Occasionally, there were other reasons for extraction, such as a tooth with a poor prognosis or retained primary tooth. Extraction of the lower first premolars in the mandibular arch is indicated when it is essential to upright the anterior teeth and/or eliminate crowding in preparation for mandibular advancement surgery [5].

5.2.4 Treatment duration

The duration of active treatment, calculated from the day the fixed appliance was bonded to the teeth to the day it was removed, averaged at 30.26 ± 5.22 months for the entire group. The pre-surgical phase averaged at 21.33 ± 4.95 months. Both were shorter than the treatment length reported from a multi-centre, prospective cohort study on more than a hundred patients who received combined surgery and orthodontic treatment across the UK within a five-year time frame [90]. However, even shorter average treatment times were found to be 21.3, 24.5, and 30.1 months, respectively, in the faculty practise at the University of North Carolina Dentofacial Program, its university clinic, and outside the university. The reported pre-surgical orthodontic treatment duration was 13, 16.1, and 19 months; all of which were shorter than our findings [91].

Nevertheless, the validity is questioned when comparing treatment length among different settings or within a single setting but different clinicians due to several reasons. For instance, the criteria as to when to end either the pre-surgical orthodontics or the post-surgical orthodontics will affect the length of treatment. Also, the degree of malocclusion, the number of extraction cases, the type of fixed appliance and wires used, treatment philosophy, patient compliance, communication with the surgeon, wait time between appointments, patients' satisfaction et cetera. From the fact that our treatment duration is well-situated between the two aforementioned studies that both had a considerable number of surgically treated patients, our results appear reasonable for future reference to estimate the length of combined orthodontic and surgical treatment.

Interestingly, the duration of both pre-surgical orthodontics and full treatment seemed highly alike between the high and median-MPA groups, and both had longer treatment duration than the low-MPA group in the pre-surgical phase. In contrast, the post-surgical orthodontics appeared to take the longest in the low-MPA group. This indicates that it took about two months less to prepare low-MPA patients for surgery and slightly more time during the post-surgical phase to complete the treatment than patients with higher MPA. However, the difference between extraction and non-extraction cases was not investigated in our study, which could affect the duration of both pre-surgical orthodontics and full treatment. In addition, the wait time between the end of pre-surgical orthodontics and the surgical date was not considered. No previous study has investigated the treatment length of surgically-treated patients exclusively while taking initial MPA into consideration.

Rozzi et al. [79] studied ninety orthodontically-treated patients of Caucasian heritage. They reported that levelling of the COS in low-angle subjects mainly occurs through the intrusion of the mandibular incisors, while in high-angle subjects, it mostly occurs through extrusion and uprighting of the posterior teeth. Bear in mind that they did not study surgical patients specifically. When intruding anterior teeth, optimal magnitudes of force must be considered [92]. Intrusion causes about four times more root resorption than extrusion in the same patient [93]. Therefore, in general, intrusion force has to be kept lower than half of the extrusion force [1].

Although the difference in initial COS and pre-surgical COS was not significant among the groups, an explanation for the difference in the length of pre-surgical orthodontics is that anterior intrusion was avoided during the pre-surgical phase in low-MPA group to achieve more increase in LFH later from the surgery. Meanwhile, some posterior extrusion may have occurred during the pre-surgical phase that contributed to the leveling of the COS seen in our study. On the contrary, more anterior intrusion was attempted with lighter force over a more extended period in the high-MPA group, along with some posterior extrusion, that both contributed to the leveling of the COS during the pre-surgical orthodontics. One thing to keep in mind is that no case is the same thus the explanation may not apply to every single patient. Rubenstein et al. described that for those who cannot tolerate an increase in LFH, presurgical overbite correction should be accomplished by the orthodontic intrusion of incisors. When an increase in LFH is required, a vertical occlusal curve should be maintained during the pre-surgical orthodontics [8].

After the surgery, one of the goals is to deal with the remaining COS. In addition, lateral open bite will most often be created following the clockwise rotational movement from the surgery in low-MPA patients, which requires more treatment time to allow posterior extrusion in order to close the open bite. This may explain why it took approximately an extra month for the low-MPA group to complete the post-surgical orthodontics. Again, there are other factors to consider. Overall, low-angle subjects still finished the treatment about a month faster than the other two groups.

5.2.5 Curve of Spee (COS)

The difference in COS among the three groups appeared non-significant at both pre-treatment and pre-surgical time points. Approximately 1mm of COS was levelled in every group during pre-surgical orthodontics.

Since the angle between Sella-Nasion and Frankfort horizontal plane was set to 7 degrees in our study, and MPA was adjusted accordingly, any study looking at the relation between Frankfort mandibular plane angle (FMA) and COS should be taken into account. Our findings contradict Shannon & Nanda's, where a positive correlation was established between low FMA and increased pre-treatment COS. However, their values were collected from a group of non-surgically treated patients with either Class I or II malocclusion. They reported the pre-treatment COS of fifty patients being 2.54 mm, which is 1mm less than our average pre-treatment COS (3.56 ± 1.31 mm) [62]. One study looking at forty-nine untreated Korean subjects with mild malocclusion, while measured the COS on digital models, reported the COS as 1.6 mm on average, which is about 2mm less than our pre-treatment value [78]. A study on Pakistani population and another study on Turkish population found pre-treatment COS to be 1.40/1.94 mm, 2.33/2.46 mm, 2.80/2.40 mm, and 1.55/1.77 mm, for Class I, Class II division 1, Class II division 2, and Class III patients respectively, all were less than our pre-treatment value [61,80].

Our sample consisted entirely of skeletal Class II patients, mainly Caucasians, who required mandibular BSSO advancement surgery. Regardless of the initial MPA, they appeared to have the deepest COS compared with other types of malocclusion in non-surgically treated patients. Both dental and skeletal classification seemed to play a role in the severity of COS, but only dental malocclusion was considered in most previous studies [61,62,78,80].

Our finding in pre-surgical COS (2.50 ± 0.8 mm) was similar to that from Foletti et al. [12], where they measured twenty skeletal Class II short face patients requiring BSSO advancement and reported the value being 2.57 mm on average.

5.2.6 MPA and Groups

Our method in dividing groups was inspired by Wolford et al. [4]. They utilized MPA as the grouping criteria among patients with mandibular deficiency syndrome. This is because the difference in MPA can lead to considerable heterogeneity in aesthetic and skeletal characteristics. Their cutouts for the groups were derived from the populace distribution of MPA of 1446 female subjects, ranging from 7 to 17 years. In their study, low angle group (MPA < 32°, mean = 29.08°) was assigned as Type I, median angle group (mean MPA = 35.2°) was assigned as Type II, and high angle group (MPA > 38°, mean = 41.95°) as Type III.

Considering the much smaller sample size in our study, we spread our subjects in descending order based on the adjusted MPA values and assigned high-angle group as group 1 (MPA > 30.5°, 34.1 ± 3.23°), median-angle group as group 2 (27.85 ± 1.61°), and low-angle group as group 3 (MPA < 25.1°, 20.91 ± 3.2°). It is fair to say that our high-angle group matches more to their Type II median-angle group, our median-angle group matches more to their Type I low-angle group, and our low-angle group is a more extreme Type I low-angle group.

In hindsight, our method was the same as the one used by Mobarak et al. [83]. They grouped 61 subjects who required BSSO advancement surgery based on adjusted MPA (7° between Sella-Nasion and Frankfort horizontal plane) into low-MPA (20.8 ± 4.9°), median-MPA (32.4 ± 3.11°), and high-MPA (43.0 ± 4.0°) groups. This time, our low-angle group matches their low-angle group, our high-angle group matches their median-angle group, and our median-angle group is somewhere between their median and low-angle groups.

It may seem that our database comprised more low-MPA subjects than other sources and lacked high-MPA subjects. In fact, several high-MPA subjects from our database required an additional genioplasty which violated one of the inclusion/exclusion criteria and had to be excluded. Genioplasty combined with BSSO advancement was found to be significantly correlated with increased MPA [94].

5.2.7 Pre-treatment Cephalometric Values

The low-MPA group had the greatest SNA angle (84.32 ± 2.41°) that was greater than the norm of 82° [74], and the greatest SNB angle (79.86 ± 1.93°) that was nearly the same as the norm of 80° [74] . This partially agrees with Wolford et al. [4] that Type I low-angle patients tend to have a greater SNA angle, an SNB angle close to normal, and an ANB angle showing the same sagittal discrepancy as the other two subtypes, resulting from a flatter cranial base. In our study, median and high-angle groups had SNA angles closer to the norm, and SNB angles less than the norm, with the high-MPA group having the smallest pre-treatment SNB angle. As a result, high-MPA subjects ended up with the largest ANB (5.66 ± 2.23°), while low-MPA subjects had the smallest ANB (4.46 ± 2.03°). This again agrees with Wolford et al. that in Type II median-angle group, the SNA angle is more normal and the SNB angle is less than normal when compared with Type I low-angle group; an increased ANB in high-angle subjects was also described [4].

Short face syndrome is defined as the ratio between lower face height and total face height (LFH/TFH) being less than 55 and characterized by reduced MPA [37]. The linear LFH (ANS-Me) measurement of fifty-six untreated dental and skeletal Class I adult Caucasians was 70.4 ± 4.8 mm for males and 66.1 ± 3.4 mm for females [95]. It seems that most of our subjects in the median and low-angle groups may have short face syndrome, with low-MPA subjects being the most severe. Considering our high-angle group comprised predominantly females (86.7%), both their initial linear (64.51 ± 6.48 mm) and percentage (54.94 ± 2.59 %) LFH measurements were well within the normal range, with some even having a long lower face. Our findings generally aligned with Wolford and colleagues' description that facial proportions are relatively normal in Type II median-angle subjects, decreased in Type I low-angle subjects, and significantly increased in Type III high-angle subjects [4]. According to a study based on the Burlington Growth Centre database, upper anterior face height is primarily correlated with growth changes in the cranial base, whereas lower anterior face height depends on the direction of mandibular growth and neuromuscular factors, including mouth breathing and head posture [96].

5.3 Changes

5.3.1 Changes between Pre-treatment (R1) and Pre-surgical (R2)

During this phase, all skeletal changes appeared to be negligible clinically except for LFH. It was possible for the low-angle subjects to acquire as much as 2.30 ± 5.75 mm of increase in LFH during the pre-surgical orthodontics, while the high-angle group saw little change on average. In fact, literature had demonstrated similar increase in LFH merely with orthodontics. Parker et al. reported an increase in LFH of 4.04 ± 2.76 mm, 3.20 ± 3.26 mm, 3.07 ± 1.95 mm, respectively, for a group of Class II division 1, Class II division 2, and Class I patients, all treated orthodontically [97]. One recent study found that LFH increased 3.70 ± 1.26 mm in twenty-two Class II division 1 deep bite orthodontically-treated patients, and the change was primarily due to posterior extrusion from rectangular arch wires and vertical elastics [98].

Because of the usage of Class III elastics to aid in the decompensation, extrusion of maxillary first molars would contribute to the increase in LFH. Furthermore, more posterior extrusion and less anterior intrusion in low-angle subjects during the pre-surgical orthodontics may be one of the reasons why their LFH increased more than the high-angle subjects. For growing children in the sample, this may also be explained by Björk's observation regarding the vertical increase in both jaws during normal growth and development [18]. However, a decrease in LFH was found in some low-angle subjects, which could result from rotational changes in the jaws and remodeling at the lower border of the mandible during growth [192526].

5.3.2 Changes between Pre-surgical (R2) and Post-surgical (R3)

Post-surgical cephalograms were generally taken two weeks after the surgery as the protocol in the private practice of our source. The reasons why the radiographs were not taken earlier include post-surgery swelling, pain, and discomfort, difficulty in achieving normal mouth-opening, and unstable bite and musculature. 50% of the initial swelling resolved after the third postoperative week, while 20% of the initial edema can remain until after 3 months [99]. Luckily, any soft tissue swelling present in the post-surgical radiographs would not affect our outcome because only skeletal changes were investigated in the study.

Changes in SNB and ANB in the low-angle group (3.53°/-3.64°) aligns with the findings from Mobarak and colleagues' low-MPA group (3.31°/-3.39°) [83]. However, the results were contradicting in high-angle subjects, where they found more increase in SNB and more decrease in ANB compared to our high-angle group.

All groups saw an increase in MPA and FMA in our study, which disagrees with the negative change (-2.69 ± 2.67°) in MPA reported by Mobarak and colleagues in their high-angle subjects [83]. Generally, whenever a positive overbite is present at pre-surgery, the distal segment will be manipulated in clockwise direction during the surgery, which increases MPA and FMA simultaneously. On the contrary, when zero to negative overbite is present at pre-surgery, the distal segment will most likely be rotated in the opposite direction, which decreases both MPA and FMA. To verify this, the values of pre-surgical overbite will be necessary, which are not given in their study.

Since the clockwise rotation of the mandibular plane was noted in all subjects, as Menton moved downward and backward, it is not surprising that LFH increased accordingly. There was also a rising trend in the values from the high-angle to the low-angle group. In other words, the low-angle group saw both the largest clockwise rotation and the largest increase in LFH. There seems to be a quantifiable relationship between the rotation of the mandibular plane and the change in LFH, which is worthwhile further investigation in future research.

Even though there was considerable amount of increase in LFH during the pre-surgical phase in both low and moderate-angle groups, on average, the increase in LFH from the surgery was still larger. This may be explained by the envelope of discrepancy that described larger movements are achieved with surgery [1].

Op De Coul et al. reported the change in LFH as 2.2 mm and 3.7 mm respectively for the level and deep bite groups, the difference from our method being that they measured the change between pre-surgery and post-treatment rather than between pre-surgery and post-surgery [11]. Mobarak et al. found Menton moved down 1.8 ± 1.3 mm in their high-MPA group, to which our high and median-angle groups are comparable. However, Menton moved down 5.4 ± 2.6 mm in their low-MPA group, almost twice the amount we reported in our low-angle subjects. Several explanations include that their values were examined only one week after the surgery, all radiographs were hand-traced on acetate paper, and the method was different. They superimposed at the cribriform plate and the anterior wall of the sella turcica and registered x and y-coordinates for the landmarks [83]. Berger et al. reported a mean increase of 2.1 mm in thirty adult patients who underwent BSSO advancement, which is similar to our mean LFH increase (2.15 ± 1.59 mm) for the entire group. Both studies measured from anterior nasal spine to Menton and looked at the difference specifically between pre-surgery and post-surgery [100].

5.3.3 Changes between Post-surgical (R3) and Post-treatment (R4)

All variables showed minimal changes that are less than one degree or one millimetre on average. Most cephalometric values showed greater change in the high-angle than low-angle group, although the difference was no more than 0.2°, which may be deemed clinically insignificant. Research has suggested that factors such as mandibular plane angle and open bite are related to the stability following orthognathic surgery. High pre-treatment MPA is associated with more relapse due to the shorter ramus height and mandibular length [65]. Less ability to resist and adapt to the additional load on condyles in high-angle individuals was also suspected to be contributing to the higher rate of relapse [83]. Again, the changes between post-surgical and post-treatment in SNA, SNB, ANB, LFH, and MPA were comparable to Berger and colleagues' findings [100].

According to Joss & Vassalli's [101] systematic review, the etiology of relapse is multifactorial, involving the proper seating of condyles, the amount of advancement, the soft tissue and muscles, the mandibular plane angle, the remaining growth and remodeling, the skill of the surgeon, and preoperative age. Patients with low MPA are prone to increased vertical relapse, whereas patients with high MPA are prone to increased horizontal relapse. A long-term follow-up of our study sample will be necessary to verify the extent of relapse. On average, during the nine-month post-surgical orthodontics, little skeletal changes were found in our study, suggesting the surgical results being relatively stable within this period.

5.3.4 Changes between Pre-treatment (R1) and Post-treatment (R4)

Interestingly, the increase in LFH during pre-surgical orthodontics almost coincides with the increase during the surgery for both median and low-MPA groups. In contrast, the pre-surgical increase in LFH was only half the increase achieved through surgery in the high-angle group.

Thus, it is essential to differentiate between different MPA groups when formulating surgical visual treatment objectives (VTO), especially when estimating the change in LFH.

A technique of visualizing the rotational movement of the distal segment during the surgery was proposed by Rubenstein and colleagues [8]. The X-axis was drawn as the occlusal plane at the lower first molar, and the Y-axis was drawn as the perpendicular plane passing through the furcation of the lower first molar. Generally, the closer the Centre of rotation is to the X-axis, the more rotational movement of the distal segment will be achieved.

5.4 Correlations between Pre-surgical COS and Skeletal Changes

Pre-surgical COS was found to be significantly correlated with both linear (LFH) and percentage (LFH/TFH) changes in lower face height (LFH) during the surgery in the low-angle group. Our findings disagree with Foletti et al. where they reported that the pre-surgical COS is not directly correlated with the increase in LFH [12]. However, they measured the soft tissue LFH from Subnasale to soft tissue Menton, whereas we measured skeletal LFH from anterior nasal spine to Menton. Maal and colleagues' Cone Beam CT study on eighteen patients who had BSSO advancement surgery confirmed the positive correlation between the surgery and the changes in hard tissues, while only a weak correlation was found for the volumetric changes in soft tissues [102]. A few reasons that contribute to the complexity in the relationship between hard and soft tissue changes include variation in soft tissue morphologies from person to person and among different ethnic groups, weight changes, posture, muscle elasticity and tonicity, post-surgical swelling, et cetera [103]. Therefore, measuring hard tissue landmarks appears to be a more predictable option. Another disagreement with Foletti et al. [12] was that we did not find pre-surgical COS significantly associated with changes in neither ANB nor SNB in any group. It seemed that both ANB and SNB have more to do with initial MPA in our study. For instance, low-MPA subjects saw the most increase in SNB and the most decrease in ANB.

Op De Coul et al. [11] found that maintaining a deep bite (overbite > 3 mm) before surgery led to a significant increase in LFH and a more marked opening rotation of the mandible compared to the levelled group (overbite < 3mm). In their study, pre-surgical overbite was measured instead of COS. Although measuring overbite seems more straightforward, the importance of COS should be emphasized as it considers both the anterior and posterior teeth, which together affect the surgical procedure.

Overall, our findings reinforce and resonate with several early statements and descriptions in the literature regarding the favourable effect of clockwise rotation of the mandibular distal segments in skeletal Class II vertical dysplastic (low-angle) patients. Following the surgical movements, a tripod contact is created, with up to 4-5 mm of lateral open bite at the canines and premolars region. With the usage of vertical elastics during the post-surgical phase, the vertical spaces will gradually close down by extrusion of the dentoalveolar segments within approximately six weeks, depending on the extent of the lateral open bite [5678910].

5.5 Regression Analysis

Regression analysis was performed to quantify the correlation between pre-surgical COS and the LFH change from the BSSO advancement surgery in the low-MPA group. This can be applied clinically to simulate the surgical outcome and visualize the skeletal changes more precisely. To date, no other literature has calculated this relation.

5.6 Strengths and Limitations

The limitations stem from the retrospective nature of our study. Also, we did not exclude growing patients nor differentiate between non-extraction and extraction cases, and the study group was comprised of mostly Caucasians. There was a lack of extremely vertical patients with high MPA because many had additional surgical procedures. The precise orthodontic movements were not quantified, the amount of surgical movement in all planes was not specified, and their impacts on the outcome were not investigated.

Moreover, 2D cephalograms were used to calculate surgical changes rather than Cone Beam CT, and the subjects were not recalled after the completion of active treatment to evaluate the stability of the results.

Strengths of our study include the differentiation of initial mandibular plane angles among a group of skeletal Class II subjects. There was a reasonable number of subjects in each group. Furthermore, all subjects were treated at a single orthodontic practice and by the same oral surgeon over the years. Four time points were investigated, which provided a clear picture of the progress of not only the surgical phase but also the pre-surgical and post-surgical orthodontic phases. In addition, COS values were measured on digital models rather than plaster models poured from alginate impressions, photos taken from the plaster models, or cephalograms, which is essentially a 2D tool presenting 3D anatomy with overlapping of structures and potential inaccuracy caused by patient positioning.

To the best of our knowledge, this is the first study comparing pre-surgical COS with skeletal changes between pre-surgical and post-surgical cephalograms. Most importantly, the numeric relation between pre-surgical COS and the increase of LFH from the surgery was quantified.

5.7 Revisiting the Null Hypotheses

1. There is no significant correlation between pre-surgical Curve of Spee (COS) and mandibular skeletal changes from the surgery in skeletal Class II subjects who received mandibular bilateral sagittal split osteotomy (BSSO) advancement surgery combined with full fixed orthodontic treatment.

    - A significant correlation ($P < 0.001$) was found between pre-surgical COS and the linear and percentage changes in lower face height (LFH) from mandibular BSSO advancement surgery. Therefore, the first null hypothesis is rejected.

2. There is no significant difference among the subjects with different initial mandibular plane angles (MPA).

    - The aforementioned significant correlation ($P < 0.001$) was only found in the low-MPA group. Therefore, the second null hypothesis is rejected.

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

In a group of ninety skeletal Class II subjects who required mandibular BSSO advancement surgery:

1. MPA is a parameter that can be used to differentiate individuals with varying skeletal characteristics and predict different extent of skeletal changes from the surgery;
2. Generally, more skeletal changes were reported from the surgery than the pre-surgical orthodontics in all groups (except for LFH, which may be due to growth in some cases);
3. Low-MPA subjects saw the most increase in LFH from both pre-surgical and surgical phases;
4. In low-MPA subjects, pre-surgical COS was significantly correlated with the linear (LFH) and percentage (LFH/TFH) changes in LFH from the surgery, and,
5. In low-MPA subjects, 1mm pre-surgical COS led to an estimated increase of 1.629 mm in LFH from the surgery, which may be applied clinically to predict the surgical outcomes more precisely.

In conclusion, when mandibular BSSO advancement surgery is indicated for severe Class II skeletal relationship, it is essential to differentiate between individuals with different MPA at the diagnostic stage in order to plan the treatment accordingly. Discrepancy in all three planes should be considered. For example, both sagittal and vertical discrepancies should be addressed if they appear together. Generally, a short lower face is likely to be seen in most low-MPA subjects. It has been found that for these individuals, in addition to the increase in LFH that may be gained in pre-surgical orthodontics, COS must be strategically maintained during the pre-surgical orthodontics to achieve an optimum increase in LFH from the surgery in order to acquire a harmonious skeletal relationship and a favourable outcome.

6.2 Recommendations

Future research could investigate the following:

1. Correlating overbite with COS to assess the separate and combined effects on skeletal changes.
2. Comparing techniques for COS measurement.
3. Quantify anterior and posterior orthodontic movements during the pre-surgical phase among different MPA groups and define their impacts on COS and the eventual skeletal changes.
4. The effects of pre-surgical COS on soft tissue changes.
5. Long-term stability of the changes in COS, skeletal and soft tissues from the surgery.
6. The effects in other ethnic groups.
7. Using Cone Beam CT to define both skeletal and soft tissue changes at each stage.

Chapter 7

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Chapter 8

Appendices

8.1 Ethics Approval

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HEALTH RESEARCH ETHICS BOARD (HREB)
CERTIFICATE OF FINAL APPROVAL FOR NEW STUDIES
Delegated Review

PRINCIPAL INVESTIGATOR:	INSTITUTION/DEPARTMENT:	ETHICS #:
Dr. Ping-Hsiang Kuo	U of M/Dentistry/Graduate Orthodontics	HS23974 (H2020:260)
APPROVAL DATE: June 30, 2020	**EXPIRY DATE:** June 30, 2021	
STUDENT PRINCIPAL INVESTIGATOR SUPERVISOR (If applicable): Dr. Robert Drummond		

PROTOCOL NUMBER:	PROJECT OR PROTOCOL TITLE;
NA	The association between profile changes and Curve of Spee levelling in patients treated with combined orthodontics and orthognathic surgery
SPONSORING AGENCIES AND/OR COORDINATING GROUPS: NA	

Submission Date of Investigator Documents:	HREB Receipt Date of Documents:
April 29 and June 26, 2020	May4 and June 26 2020 (Email)

THE FOLLOWING ARE APPROVED FOR USE:

Document Name	Version(If applicable)	Date
Protocol:		
Proposal Including Clarifications as per Letter dated June 26, 2020		submitted June 26, 2020
Consent and Assent Form(s):		
Other:		
Data Collection/Capture Sheet (Undated)		submitted April 29, 2020
Master List (Undated)		submitted April 29, 2020

CERTIFICATION
The above named research study/project has been reviewed in a ***delegated manner*** by the University of Manitoba (UM) Health Research Board (HREB) and was found to be acceptable on ethical grounds for research involving human participants. The study/project and documents listed above was granted final approval by the Chair or Acting Chair, UM HREB.

HREB ATTESTATION
The University of Manitoba (UM) Research Board (HREB) is organized and operates according to Health Canada/ICH Good Clinical Practices, Tri-Council Policy Statement 2, and the applicable laws and regulations of Manitoba. In respect to clinical trials, the HREB complies with the membership requirements for Research Ethics Boards defined in Division 5

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of the Food and Drug Regulations of Canada and carries out its functions in a manner consistent with Good Clinical Practices.

QUALITY ASSURANCE
The University of Manitoba Research Quality Management Office may request to review research documentation from this research study/project to demonstrate compliance with this approved protocol and the University of Manitoba Policy on the Ethics of Research Involving Humans.

CONFLICT OF INTEREST
Any Principal or Co-Investigators of this study who are members of the UMHREB did not participate in the review or voting of this study.

CONDITIONS OF APPROVAL:

1. The study is acceptable on scientific and ethical grounds for the ethics of human use only. ***For logistics of performing the study, approval must be sought from the relevant institution(s).***
2. This research study/project is to be conducted by the local principal investigator listed on this certificate of approval.
3. The principal investigator has the responsibility for any other administrative or regulatory approvals that may pertain to the research study/project, and for ensuring that the authorized research is carried out according to governing law.
4. **This approval is valid until the expiry date noted on this certificate of approval.** **A Bannatyne Campus Annual Study Status Report** must be submitted to the HREB within 15-30 days of this expiry date.
5. Any changes of the protocol (including recruitment procedures, etc.), informed consent form(s) or documents must be reported to the HREB for consideration in advance of implementation of such changes on the **Bannatyne Campus Research Amendment Form.**
6. Adverse events and unanticipated problems must be reported to the HREB as per Bannatyne Campus Research Boards Standard Operating procedures.
7. The UM HREB must be notified regarding discontinuation or study/project closure on the **Bannatyne Campus Final Study Status Report.**

Sincerely,

[redacted]

John Arnett, PhD. C. Psych.
Chair, Health Research Ethics Board
Bannatyne Campus

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Please quote the above Human Ethics Number on all correspondence.
Inquiries should be directed to the REB Secretary **Telephone:** (204) 789-3255/ **Fax:** (204) 789-3414

8.2 Manuscript Submission

Journal of Oral and Maxillofacial Surgery

The Effects of Curve of Spee in Skeletal Class II Patients Treated with Combined Orthodontics and Surgery

--Manuscript Draft--

Manuscript Number:	YJOMS-D-21-01626
Article Type:	Full Length Article
Section/Category:	Craniomaxillofacial Deformities/Sleep Disorders/Cosmetic Surgery

8.3 Journal Article

Purpose: To perform a retrospective study with the question: Is there a significant correlation between pre-surgical Curve of Spee (COS) and skeletal changes from mandibular bilateral sagittal split osteotomy (BSSO) advancement surgery? Furthermore, in skeletal Class II patients, does initial mandibular plane angle (MPA) make a difference?

Methods: The sample was made up of a group of patients who underwent a single surgical procedure of mandibular BSSO advancement and divided into three groups by mandibular plane angle (MPA). Pre-surgical Curve of Spee (COS) was measured on digital dental models and correlated with skeletal changes from pre-surgical and post-surgical cephalograms using Spearman rank-order analysis. Paired T-test was utilized to identify statistical significance. Regression analysis was performed to estimate the cephalometric change per unit of pre-surgical COS. P-value was set at 0.05.

Results: The sample was composed of 90 subjects; divided into 3 groups: (1) high-MPA (MPA 34.10 ± 3.23°; aged 26.28 ± 17.66 years; n = 30) (2) medium-MPA (MPA 27.85 ± 1.61°; aged 22.04 ± 11.40 years; n = 30) (3) low-MPA (MPA 20.91 ± 3.20°; aged 26.84 ± 15.58; n = 30). Statistical significance was found between pre-surgical Curve of Spee (COS) and both linear and percentage changes of lower face height (LFH) in the low-MPA group ($p < 0.001$). The estimated relationship between COS and LFH was that for each 1mm pre-surgical COS, there was an increase in LFH of 1.629 mm from the surgical procedure ($p = 0.000$).

Conclusion: Pre-surgical Curve of Spee is significantly correlated with surgical changes in lower face height in low-MPA subjects. The quantified ratio between them could be applied in simulating surgical outcome clinically.

Variations in growth and development in the craniofacial complex may lead to malocclusions and dentofacial deformities [1]. Fundamentally, orthodontic treatment works on attaining an aesthetically harmonious masticatory system in individuals by maximizing the effectiveness of compensations between different anatomic components [2]. When the degree of skeletal discrepancy and facial imbalance is moderate to severe; combined surgery and orthodontics become the treatment of choice over orthodontic camouflage alone to avoid complications such as occlusal relapse, worsening of the profile, periodontal decline and temporomandibular disorders [3].

A particular type of facial skeletal discrepancy the authors investigated is mandibular deficiency syndrome, or retrognathism; which is also considered a skeletal Class II syndrome [4]. Surgery combined with orthodontic approach is constantly proposed as the treatment choice, especially for more severe discrepancies, with mandibular bilateral sagittal split osteotomy (BSSO) advancement surgery being arguably the most common procedure. Amidst this group of individuals, skeletal characteristics may differ due to the mandibular plane angle (MPA) variation [4]. For instance, for an individual with reduced MPA, the sagittally-deficient mandible is commonly accompanied by decreased vertical dimension in the lower face; in this case, the goal is to treat both deformities with a single surgical procedure. Past research has suggested that there is feasibility in achieving favourable improvement in skeletal discrepancies with a cautious manipulation of the Curve of Spee (COS) [5678910].

In 1890, the concept of COS was developed by Ferdinand Graf Spee [11], a prosector at the Anatomy Institute of Kiev. Through examining skulls, he found a curvature along the maxillary and mandibular teeth and the anterior border of the condyle. The definition has evolved over time in orthodontics, where it now refers to the occlusal curve from the mandibular incisors to the molars, often measured as the deepest depth underneath the occlusal plane in the sagittal view. Tuinzing, Greebe, & Dorenbos [7] noticed that by purposely leaving a deep bite before surgery, the reduction of the deep bite during the surgery will generate a clockwise rotational movement which not only favours skeletal stability over counterclockwise movement but also improves the position of the chin.

To the best of our knowledge, only two studies have researched the impact of COS in surgical orthodontic patients [1213]. The variables being used were overbite and COS, respectively, measured on pre-surgical cephalograms. This may lead to inaccuracies due to difficulty in identifying landmarks from the overlapping structures or distorted radiographs. Other concerns were the smaller sample size and that the diversity in MPA has not been studied.

The purpose of this retrospective study is to validate repeated claims regarding the skeletal impact of COS with improved study design by assessing the correlation between pre-surgical Curve of Spee (COS), measured on digital dental models, and the skeletal changes produced by mandibular bilateral sagittal split osteotomy (BSSO) advancement surgery in skeletal Class II patients with varied initial mandibular plane angles (MPA) [5678910].

The null hypotheses were that (1) There is no significant correlation between pre-surgical COS and skeletal changes from the surgery (2) There is no significant difference among the subjects with different initial MPA.

MATERIALS AND METHODS

The protocol was approved by the Health Research Ethics Board at the University of Manitoba (HS23974) before the commencement of the study.

Study Sample

The sample of this retrospective cephalometric study derived from ninety patients who received treatment from a Winnipeg orthodontic practice between 2012 and 2020. The patients were chosen chronologically, starting with the most recent cases treated in the orthodontic practice. The subjects had mandibular bilateral sagittal split osteotomy (BSSO) advancement surgery combined with a full fixed orthodontic treatment, that disregarded gender, age, ethnicity, or whether extraction had taken place. The reasons that patients were excluded from the study were based on the following criteria: (1) history of head and neck trauma and/or surgery; (2) cleft and/or craniofacial anomalies; (3) severe Temporomandibular Disorder (TMD) requiring surgical intervention; (4) additional surgical procedure to the mandibular BSSO advancement; (5) missing teeth that the Curve of Spee could not be measured; (6) the cusp tips of mandibular second molars have not erupted on the pre-surgical digital cast; (7) post-surgical cephalometric radiograph taken more than one month after the surgery; (8) low-quality records; and (9) incomplete records.

Surgical Procedure

All surgeries were performed by an experienced oral surgeon in a hospital setting, assisted by residents at the Oral and Maxillofacial Surgery division. After completion of the split, Maxillomandibular Fixation (MMF) was established without interpositional splint to allow placement of Rigid Internal Fixation (RIF). After irrigation, the proximal segments were positioned and fixed with 4-hole titanium plates and 5 mm screws (KLS Martin, Gebrüder Martin GmbH&Co., Tuttlingen, Germany). MMF was then removed and the occlusion was confirmed. Following wound closure, directional guide elastics were placed, and patients were allowed to return to daily functions such as normal eating.

Study Variables

Demographic variables were gender and age when the full fixed appliances were placed. Time variables were the length of pre-surgical orthodontic treatment, calculated from the placement of full fixed appliances to taking the pre-surgical cephalometric radiograph, and the length of total treatment, calculated from the placement to the removal of the full fixed appliances. Another variable was initial Curve of Spee, measured on the pre-treatment digital casts in millimetres (mm). Predictor variables were pre-surgical Curve of Spee, measured on the pre-surgical digital casts in millimetres. Primary outcome variables included the change of several skeletal measurements between pre-surgical (R2) and post-surgical (R3) cephalometric radiographs: mandibular plane angle (MPA), SNA, SNB, ANB, facial angle (FA), Frankfort mandibular plane angle (FMA), Y-axis, convexity, Pogonion to NB, linear lower face height (LFH), and the ratio of lower face height (LFH) to total face height (TFH).

Data Collection

The record of each subject consisted of four lateral cephalometric radiographs, acquired at pre-treatment (R1), pre-surgery (R2), post-surgery (R3), and post-treatment (R4). Post-surgery radiographs were generally taken two weeks after the surgery. Each record also included two digital models of the lower dentition, taken at pre-treatment

(D1) and pre-surgery (D2) (Table 1). All radiographs and digital models were labelled with initials and a unique record number in an Excel spreadsheet.

Cephalometric Digitization

The lateral cephalometric radiographs before June 4th, 2014 were taken with PaxReve 3D imaging system (Vatech, Hwaseong-si, Gyeonggi-do, South Korea), and the rest were taken with Pax-i3D Green imaging system (Vatech, Hwaseong-si, Gyeonggi-do, South Korea). All subjects were biting in maximum intercuspation and in natural head position. X-ray beam was perpendicular to the subjects' sagittal plane, entering from the left to the film cassette located on the right. Film magnification was standardized with a 30 mm calibration ruler. Exposure settings were set at 90 kVp and 10 mAs. The head was oriented to the right in every radiograph. Each radiograph was automatically transferred as a JPEG format into DolphinTM 11.7 imaging software (Dolphin Imaging and Management Systems, Chatsworth, CA, USA) and displayed for digitization in a windowless room with essential white lighting. Definition of landmarks and measurements were shown in Tables 2 and 3. A list of cephalometric values was generated once the digitization process was completed, and the values of interest were exported into a different Excel spreadsheet.

The angle between Sella-Nasion and Frankfort plane was adjusted to 7 degrees for standardization purposes [14]; SNA, SNB, and mandibular plane angle (MPA) were modified accordingly. After that, all subjects were arranged in a descending order by the adjusted MPA, from which three groups were generated. The 30 subjects with the highest MPA values were Group 1, followed by Group 2 consisting of 30 subjects with medium MPA values, and Group 3 with the remaining 30 subjects with the lowest MPA values.

Digital Models

All digital models were captured intraorally with iTero® Element (Align Technology Inc., San Jose, CA). The STL files were downloaded from MyAligntech website, labelled, saved, and imported into OrthoAnalyzer® software (3Shape®, Copenhagen, Denmark). This was also completed in a windowless room with essential white lighting.

In the OrthoAnalyzer® software, the file of a mandibular digital scan was opened and oriented at the right sagittal view for assessment (Figures 1-4). First, "Plane icon" was selected to create a plane by identifying three points: midpoint of the higher incisal edges (either the lower right central or lateral incisor) and the distal cusp tips of the lower right second molar. If it had not fully erupted, the first molar would be used instead. The scanning model was zoomed in, altered between sagittal and occlusal views, and rotated as needed to ensure accuracy in identification of the points.

Next, the "Point to plane icon" was utilized to calculate the linear measurement (mm) from the plane to the deepest buccal cusp tip underneath. The result was recorded to an accuracy of 0.01mm as the Curve of Spee (COS) value for the right side, and the same procedure was repeated for the left side. The final COS value was the sum of both numbers.

Intra-rater Reliability

10% of the samples were randomly selected by an online number generator, and their radiographs and digital scans were re-traced and re-measured by the primary investigator at two-week intervals from the end of initial data collection.

Sample Size Estimation

Spearman correlation between pre-surgical Curve of Spee and several cephalometric values was conducted by Foletti et al. [13], and the correlation coefficient was found to be ranging from 0.55 - 0.70. By performing an estimation for 0.6 correlation, at 90% power and $\alpha < 0.05$, the minimum required sample size is approximately 24. Based on this, 30 subjects were recruited for each group, adding up to 90 subjects in the study.

Statistical Analysis

All statistical analyses were conducted with IBM SPSS Statistics for Windows, Version 27.0, released in 2020 (Armonk, NY: IBM Corp) in consultation with an experienced biostatistician from the Centre for Healthcare Innovation at the University of Manitoba.

Mean and standard deviation (SD) were calculated for continuous variables with 95% confidence interval. One-way analysis of variance (ANOVA) was used to determine the significance of difference in the pre-treatment and pre-surgical Curve of Spee (COS) values. Spearman rank-order correlation analysis was adopted for the correlation between pre-surgical COS and cephalometric changes between pre-surgery (R2) and post-surgery (R3). Paired T-test was utilized to identify statistical significance for the correlation analysis. P-value was considered significant when $\alpha < 0.05$. For the cephalometric variable that was found to be statistically significant by Spearman's correlation, a regression analysis was performed to estimate the cephalometric change per unit of pre-surgical COS. Intraclass Correlation Coefficient (ICC) was employed to test the intra-rater reliability of the repeated 10% measurements.

RESULTS

Ninety subjects who met the eligibility criteria were included in the study, with a mean age of 25.06 ± 15.09 years, and 58 (64.4%) were female. They were divided into three groups by the pre-treatment mandibular plane angle (MPA). Demographic and treatment duration measurements were shown in Table 4. The pre-treatment and pre-surgical Curve of Spee were shown in Table 5. On average, each group levelled approximately 1mm of Curve of Spee (COS) during the pre-surgical orthodontic phase. Based on one-way ANOVA, there did not appear to be a significant difference between the COS values among the three groups at the pre-treatment ($F(2,87) = 0.120$, $p = 0.887$) nor the pre-surgical time point ($F(2,87) = 0.620$, $p = 0.540$). Intraclass Correlation Coefficient (ICC) was highly consistent between the first entry and the 10% repeated measurements, ranging from 0.934 to 0.999. Therefore, we are confident in the reliability of the presented data.

Pre-treatment cephalometric values were shown in Table 6. Except for SNA, which is not directly related to the lower jaw, all other measurements followed an increasing or decreasing trend. Changes between pre-treatment (R1) and pre-surgical (R2) were shown in Table 7. All skeletal changes were of clinical insignificance, except for the linear measurement of lower face height (LFH). On average, LFH increased by 1.56 ± 3.74 mm, with a rising trend from group 1 to 3. Changes between pre-surgical (R2) and post-surgical (R3) were shown in Table 8. Except for SNA and Y-axis showing negligible change, other skeletal measurements indicated a more significant change. Most measurements (SNB, ANB, FA, FMA, convexity, Pog to NB, LFH, and LFH/TFH) followed an increasing trend, with a bigger difference in the low-angle Group 3 than the high-angle Group 1. Changes between post-surgical (R3) and post-treatment (R4) were shown in Table 9. Minimal skeletal changes were found in all variables, implying that the surgery results remained greatly stable during the post-surgical orthodontic phase. Changes between pre-treatment (R1) and post-treatment (R4) were shown in Table 10. Similar to the changes between pre-surgical (R2) and post-surgical (R3), most measurements (SNB, ANB, FA, FMA, MPA, convexity, Pog to NB, LFH, and LFH/TFH) followed an increasing trend, while only SNA followed a decreasing trend. FMA and MPA were the largest changes in degrees found in the entire sample and individual groups, and the largest linear change in millimetres was reported in LFH in the entire sample and individual groups.

Correlations between R2/R3 Change and pre-surgical COS were shown in Table 11. Strongest correlations were noted for LFH ($r = 0.682$) and LFH/TFH ($r = 0.566$) measurements of lower face height (LFH) with statistical significance ($P < 0.001$) in Group 3. Based on the regression analysis of linear LFH change from R2 to R3 and pre-surgical COS, COS had a significant relationship with LFH [$b = 1.629$, $t(28) = 4.25$, p <

0.001]. It also explained a significant proportion of variance in LFH [$R^2 = 0.393$, $F(1, 28) = 18.10$, $p < 0.001$]. The estimated relationship between COS and LFH was for each 1mm pre-surgical COS, there was an increase in LFH of 1.629 mm from the surgical procedure. P-value (= 0.000) was statistically significant.

DISCUSSION

This retrospective study aims to understand the skeletal effects of Curve of Spee (COS) in skeletal Class II patients with different initial mandibular plane angles (MPA) treated with combined orthodontic and orthognathic surgery. Ninety patients from a single source who underwent mandibular bilateral sagittal split osteotomy (BSSO) advancement surgery were divided into three groups by MPA. Pre-surgical COS was measured from digital dental models and its correlation with cephalometric changes between pre-surgical and post-surgical cephalograms was investigated. It was hypothesized that (1) There is no significant correlation between pre-surgical COS and skeletal changes from the surgery (2) There is no significant difference among the subjects with different initial MPA.

Of the skeletal measurements we explored, linear lower face height (LFH) and the ratio of lower face height to total face height (LFH/TFH) in the low-MPA group were the two variables found of statistical significance, which rejected both hypotheses. Based on the results, pre-surgical COS is significantly correlated with an increase in lower face height from the surgery in subjects with low MPA.

Sample Group

Females were the majority (64.4%) of the sample, including both high-MPA (86.7%) and medium-MPA (60.0%) groups, while males (53.3%) were slightly more than females in the low-MPA group. This agrees with Siriwat and Jarabak's [15] work of five hundred untreated random samples, concluding that the majority of females demonstrate a neutral facial pattern, whereas the majority of males demonstrate a hypodivergent pattern. More recently, the project conducted by Hardin et al. [16] divided more than seven hundred untreated subjects into three facial divergence groups based on MPA. Both hyper and normo-divergent groups consisted of more females, while more males were found in the hypo-divergent group. Similar gender distribution in each group was observed between our study and theirs.

The mean age at pre-treatment for the entire group was 25.06 ± 15.09 years old, agreeing with Andrup [17] that women around twenty years of age made up the majority of surgical orthodontic patients. However, there were subjects as young as ten years old and went for surgery at twelve years old. Early research evaluated twelve children with deficient mandibles aged between eight and sixteen, all treated with mandibular advancement surgery. It was concluded that pre-pubertal intervention produced stable results and, most importantly, would not affect subsequent growth [18].

The treatment duration we reported is well-situated between two previous studies that had a considerable number of surgically treated patients [1920]. Nevertheless, the validity is questioned when it comes to comparing treatment length among different settings or clinicians due to factors like the standard for finishing treatment, the degree of malocclusion of the patients, the number of extraction cases, the wait time between appointments, and patient compliance etcetera.

Curve of Spee (COS) Landmarks

Previous studies mostly measured COS from dental cast models [21][22], photos of cast models [23], or cephalometric radiographs [13]. After digital scanners were introduced to dentistry, more studies measured COS digitally with different choices of scanners and software [24][25][26].

Currently, there is a lack of consensus regarding the measurement of COS. The first variation is whether the procedure is conducted on 2D photos/radiographs or 3D dental models/digital models. There has not been any study comparing the validity and reliability of COS measurement among these methods. Intuitively, measuring on 3D digital models is the most accurate, when alginate impressions were found to be significantly imprecise compared to digital scanning methods [27]. Also, whenever a three-dimensional object is projected onto two-dimensional space, information can be lost during the conversion, along with other factors like patient position for radiographs or orientation of the models for photos.

The second variation is the choice of the occlusal plane. Some used tripod landmarks on the distobuccal cusps of both second molars and the midpoint of the central incisors [22][24][25][26]; while some constructed a line from the incisal edge to the highest cusp tip of the molars on cephalograms or photos from a sagittal view [13][23]. Our method utilized two different occlusal planes by connecting three landmarks in the digital software on both right and left sides; there may be a slight difference from the method where only one occlusal plane was used for both sides.

Thirdly, the measurement of the COS differs. One averaged the distance from the plane to the buccal cusp tips of the premolars and the first molar [22], one measured to the deepest point in the dentoalveolar ridge from the sagittal view [26], while most simply identified the deepest buccal cusp tip [1323242528]. The first method may underestimate the severity of the COS, while the second method may generate a greater COS than others.

Again, further research may examine and compare different methods. Without a doubt, it would be beneficial if a universal COS measuring method can be decided and popularized among researchers and clinicians for less confusion clinically and the research outcomes will be more comparable.

Curve of Spee (COS) Values

The difference in COS among the three groups appeared non-significant at both pre-treatment and pre-surgical time points. Approximately 1mm of COS was levelled in every group during pre-surgical orthodontics. Our findings contradict that of Shannon & Nanda's [22], where a positive correlation was established between low FMA and increased pre-treatment COS. However, their values were collected from a group of non-surgically treated patients. They reported the pre-treatment COS of fifty patients being 2.54 mm, which is 1mm less than our average pre-treatment COS (3.56 ± 1.31 mm). One study looking at forty-nine untreated Korean subjects with mild malocclusion employed a similar digital measuring technique and reported the average COS as 1.6 mm, about 2mm less than our pre-treatment value [24]. Two more studies on Pakistani and Turkish populations found pre-treatment COS ranged from 1.40 to 2.80 mm for patients with all types of dental malocclusion, and all were less than our pre-treatment values [2528].

Our study group consisted entirely of skeletal Class II patients, mainly Caucasians, who required mandibular BSSO advancement surgery. They appeared to have the deepest COS when compared with previous research, regardless of the initial MPA. Both dental and skeletal classification seemed to play a role in the COS, but only dental malocclusion was considered in most studies. Our pre-surgical COS (2.50 ± 0.8 mm) was close to Foletti et al. [13], where they measured twenty skeletal Class II short face patients requiring BSSO advancement and reported the value being 2.57 mm.

Mandibular Plane Angle (MPA)

Our grouping method was inspired by Wolford et al. [4]. They utilized MPA as the grouping criteria among patients with mandibular deficiency syndrome. This is because the difference in MPA can lead to considerable heterogeneity in terms of aesthetic and skeletal characteristics. The difference is that our high-angle group matches more to their Type II median-angle group, our median-angle group matches more to their Type I low-angle group, and our low-angle group is a more extreme Type I low-angle group. The method we employed appeared highly coincident with what Mobarak et al. [29] used. They grouped 61 subjects who required BSSO advancement surgery based on adjusted MPA (7° between Sella-Nasion and Frankfort horizontal plane) into low-MPA (20.8 ± 4.9°), median-MPA (32.4 ± 3.11°), and high-MPA (43.0 ± 4.0°). This time, our low-angle group matches their low-angle group, our high-angle group matches their median-angle, and our median-angle group is somewhere between their median and low-angle groups.

It may seem that we had more low-MPA subjects than other sources and lacked subjects with higher MPA. Many high-MPA subjects from our database required additional maxillary surgery and/or genioplasty, which would have to be excluded. Genioplasty combined with BSSO advancement has been found to be significantly correlated with increased MPA [30].

Pre-treatment Cephalometric Values

The low-MPA group started with the greatest SNA angle (84.32 ± 2.41°) that was greater than the norm of 82° [31], and the greatest SNB angle (79.86 ± 1.93°) that was nearly the same as the norm of 80° [31]. This agrees with Wolford et al. [4] that Type I low-angle patients tend to have a greater SNA angle, an SNB angle closer to normal, and an ANB angle showing the same sagittal discrepancy as the other two subtypes, resulting from a flatter cranial base. In our study, median and high-angle groups had an SNA angle closer to the norm, and an SNB angle less than the norm, with the high-MPA group having the smallest pre-treatment SNB angle. As a result, high-MPA subjects ended up with the largest ANB (5.66 ± 2.23°), as opposed to the low-MPA subjects (4.46 ± 2.03°). This again agrees with Wolford et al. [4] that in the Type II median-angle group, their SNA angle is more normal and SNB angle is less than normal when compared with Type I low-angle group; an increased ANB in high-angle subjects was also described in their study.

Our findings regarding lower face height were in line with Wolford and colleagues' [4] description that facial proportions are relatively normal in Type II median-angle, decreased in Type I low-angle, and significantly increased in Type III high-angle. This can be explained by a study based on Burlington Growth Centre database, concluding that lower anterior face height being dependant on the direction of mandibular growth and neuromuscular factors, including mouth breathing and head posture [32].

Changes between Pre-treatment (R1) and Pre-surgical (R2)

During this phase, it appears feasible for the low-angle subjects to acquire as much as 2.30 ± 5.75 mm of increase in LFH, while the high-angle group saw little change on average. The extremes may be explained by the direction of growth in growing patients. In fact, literature had demonstrated similar increase in LFH merely with orthodontics. Parker et al. [33] reported an increase in LFH of 4.04 ± 2.76 mm, 3.20 ± 3.26 mm, 3.07 ± 1.95 mm, respectively, for a group of orthodontically-treated Class II division 1, Class II division 2, and Class I patients. One recent study found that LFH increased 3.70 ± 1.26 mm in twenty-two Class II division 1 deep bite orthodontically-treated patients, and the change was contributed by posterior extrusion with rectangular archwires and vertical elastics [34].

Changes between Pre-surgical (R2) and Post-surgical (R3)

All groups saw an increase in MPA and FMA in our study, which disagrees with the negative changes (-2.69 ± 2.67°) in MPA reported by Mobarak and colleagues' [29] in their high-angle subjects. Generally, whenever a positive overbite is present at pre-

surgery, the distal segment will be manipulated in a clockwise direction during the surgery, which increases MPA and FMA simultaneously. On the contrary, when zero to negative overbite is present at pre-surgery, the distal segment will most likely be rotated in the opposite direction, which decreases both MPA and FMA. To verify this, pre-surgical overbite values are necessary, which are not presented in their study.
Despite the notable increase in LFH during pre-surgical orthodontic phase in both low- and moderate-angle groups, on average, the increase in LFH from the surgery was still larger than the increase in the pre-surgical phase. This verifies the envelope of discrepancy between orthodontic movement and surgical movement; in other words, larger movements are achieved by surgery [1].

Since the clockwise rotation of the mandibular plane was noted in all subjects, it is not surprising that LFH increased accordingly as Menton moved downward and backward with the clockwise rotation of the mandible. Therefore, an increase in LFH was found in all groups (2.15 ± 1.59 mm), with a rising trend from the high-angle (1.76 ± 1.16 mm) to the low-angle group (2.87 ± 1.88 mm).

Op De Coul et al. [12] reported the change in LFH as 2.2 mm and 3.7 mm respectively for the level and deep bite groups, the difference being that they measured the change between R2 and R4 rather than between R2 and R3. Mobarak et al. [29] found Menton moved down 1.8 ± 1.3 mm in their high-MPA group, to which our high and median-angle groups are comparable. However, Menton moved down 5.4 ± 2.6 mm in their low-MPA group, almost twice the amount we reported in our low-angle subjects. Their values were examined only one week after the surgery, all radiographs were hand-traced on acetate paper, and the method was different. They superimposed at the cribriform plate and the anterior wall of the sella turcica and registered x and y-coordinates for the landmarks. Berger et al. [35] reported a mean increase of 2.1 mm in thirty adult patients who underwent BSSO advancement, which is similar to our mean LFH increase (2.15 ± 1.59 mm) for the entire group. Both studies measured from anterior nasal spine to Menton and looked at the difference specifically between R2 and R3.

Changes between Post-surgical (R3) and Post-treatment (R4)

All variables showed minimal changes that are less than one degree or one millimetre on average, indicating that the surgery results remained stable during the post-surgical orthodontic phase. Most cephalometric values showed greater change in the high-angle than low-angle group, although the difference was no more than 0.2°, which may be deemed clinically insignificant. Research has suggested that factors such as mandibular plane angle and open bite are related to the stability following orthognathic surgery. High pre-treatment MPA is associated with more relapse due to the shorter ramus height and mandibular length [36]. Less ability to resist and adapt to the additional load on condyles in high-angle individuals was also suspected to be contributing to the higher rate of relapse [29]. To assess the extent of relapse, a long-term follow-up study will be necessary. Again, the changes between post-surgical (R3) and post-treatment (R4) in SNA, SNB, ANB, LFH, and MPA were comparable to Berger and colleagues' [35] findings.

Changes between Pre-treatment (R1) and Post-treatment (R4)

Interestingly, the increase in LFH during pre-surgical orthodontics almost coincides with the increase during the surgery for both median and low-MPA groups. In contrast, the pre-surgical increase in LFH was only half the increase achieved through surgery in the high-angle group. Thus, it is essential to differentiate between different MPA groups when formulating surgical visual treatment objectives (VTO), especially when estimating the change in LFH.

Correlations

Pre-surgical COS was found to be significantly correlated with both linear (LFH) and percentage (LFH/TFH) changes in lower face height (LFH) during the surgery in the low-angle group. Our findings disagree with Foletti et al. [13] where they reported that the pre-surgical COS is not directly correlated with the increase in LFH. However, they measured the soft tissue LFH from Subnasale to soft tissue Menton, whereas we measured skeletal LFH from anterior nasal spine to Menton. Maal and colleagues' [37] Cone Beam CT study on eighteen patients who had BSSO advancement surgery confirmed the positive correlation between the surgery and the changes in hard tissues, while only a weak correlation was found for the volumetric changes in soft tissues. Therefore, measuring hard tissue landmarks appears to be a more predictable option. Another disagreement with Foletti et al. [13] was that we did not find pre-surgical COS significantly associated with changes in neither ANB nor SNB in any group. It seemed that both ANB and SNB have more to do with initial MPA in our study. For instance, low-MPA subjects saw the most increase in SNB and the most decrease in ANB.

Op De Coul et al. [12] found that maintaining a deep bite (overbite > 3 mm) before surgery led to a significant increase in LFH and a more marked opening rotation of the mandible compared to the levelled group (overbite < 3mm). In their study, pre-surgical overbite was measured instead of COS. Although measuring overbite seems more straightforward, the importance of COS should be emphasized as it considers both the anterior and posterior teeth, which together affect the surgical procedure.

Overall, our findings reinforce and resonate with several early statements and descriptions in the literature regarding the favourable effect of clockwise rotation of the mandibular distal segments in skeletal Class II vertical dysplastic patients (low-angle) [5678910].

Regression Analysis

Regression analysis was performed to quantify the correlation between pre-surgical COS and the LFH change from the BSSO advancement surgery in the low-MPA group. This can be applied clinically to simulate the surgical outcome and visualize the skeletal changes more precisely. To date, no other literature has calculated this relation.

Strength and Limitations

The limitations stem from the retrospective nature of our study. Also, we did not exclude growing patients nor differentiate between non-extraction and extraction cases, and the study group was comprised of mostly Caucasians. There was a lack of extremely vertical patients with high MPA because many had additional surgical procedures. The precise orthodontic movements were not quantified, the amount of surgical movement in all planes was not specified, and their impacts on the outcome were not investigated.

Moreover, 2D cephalograms were used to calculate surgical changes rather than Cone Beam CT, and the subjects were not recalled after the completion of active treatment to evaluate the stability of the results.

Strengths of our study include the differentiation of initial mandibular plane angles among a group of skeletal Class II subjects. There was a reasonable number of subjects in each group. Furthermore, all subjects were treated at a single orthodontic practice and by the same oral surgeon over the years. Four time points were investigated, which provided a clear picture of the progress of not only the surgical phase but also the pre-surgical and post-surgical orthodontic phases. In addition, COS values were measured on digital models rather than plaster models poured from alginate impressions, photos taken from the plaster models, or cephalograms, which is essentially a 2D tool presenting 3D anatomy with overlapping of structures and potential inaccuracy caused by patient positioning.

To the best of our knowledge, this is the first study comparing pre-surgical COS with skeletal changes between pre-surgical and post-surgical cephalograms. Most importantly, the numeric relation between pre-surgical COS and the increase of LFH from the surgery was quantified.

CONCLUSION

In a group of ninety skeletal Class II subjects who required mandibular BSSO advancement surgery:

1. MPA is a parameter that can be used to differentiate individuals with varying skeletal characteristics and predict different extent of skeletal changes from the surgery;
2. Generally, more skeletal changes were reported from the surgery than the pre-surgical orthodontics in all groups (except for LFH, which may be due to growth in some cases);
3. Low-MPA subjects saw the most increase in LFH from both pre-surgical and surgical phases;
4. In low-MPA subjects, pre-surgical COS was significantly correlated with the linear (LFH) and percentage (LFH/TFH) changes in LFH from the surgery, and,
5. In low-MPA subjects, 1mm pre-surgical COS led to an estimated increase of 1.629 mm in LFH from the surgery, which may be applied clinically to predict the surgical outcomes more precisely.

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	Pre-treatment	Pre-surgery	Post-surgery	Post-treatment
Radiograph	R1	R2	R3	R4
Digital model	D1	D2	x	x

Table 1. Selected time points for each collected individual record

Landmark	**Definition**
Sella (S)	The center of sella turcica: Located by inspection of the profile image of the fossa
Nasion (N)	The most anterior point of the frontonasal suture in the midsagittal plane

Orbitale (Or)	The lowest point on the infraorbital margin
Porion (Po)	The highest point on the superior surface of the external auditory meatus
Point A (A)	The deepest midline point on the premaxilla between the anterior nasal spine and prosthion
Point B (B)	The deepest midline point on the mandible between dental alveolus and Pogonion
Pogonion (Pog)	The most anterior point on the mandible in the midsagittal plane
Gnathion (Gn)	The most anterior inferior point in the lateral shadow of the chin, usually best determined by selecting the midpoint between Pogonion and Menton on the contour of the chin
Menton (Me)	Lower most point of the contour of the chin
Gonion (Go)	The lowest, most posterior point on the mandible with the teeth in occlusion

Table 2. Definition of hard tissue landmarks

Measurements	**Definition**

Mandibular Plane Angle (MPA)	The angle between Sella/Nasion and mandibular plane (formed by Menton and Gonion)
SNA	The angle formed by Sella, Nasion, and Point A
SNB	The angle formed by Sella, Nasion, and Point B
ANB	The angle formed by Point A, Nasion, and Point B
FA	The inner angle formed by the intersection of the facial plane (Nasion to Pogonion) and the Frankfort Horizontal Plane (Orbitale to Porion)
FMA	The angle between Frankfort Horizontal Plane and mandibular plane
Y-axis	The angle between Sella/Nasion and Sella/Gnathion
Convexity	The linear distance from Point A to facial plane (Nasion to Pogonion)
Pog to NB	The linear distance from Pogonion to the line formed between Nasion and Point B
Lower Facial Height (LFH)	The linear distance from anterior nasial spine to Menton

Total Facial Height (TFH)	The linear distance from Nasion to Menton

Table 3. Definition of linear measurements

Variables	**All Groups (n=90)**	**Group 1 (n=30)**	**Group 2 (n=30)**	**Group 3 (n=30)**
Age (year)	25.06 (15.09)	26.28 (17.66)	22.04 (11.40)	26.84 (15.58)
Gender	M=32, 35.6% F=58, 64.4%	M=4, 13.3% F=26, 86.7%	M=12, 40.0% F=18, 60.0%	M=16, 53.3% F=14, 46.7%
Pre-surgical Treatment Duration (month)	21.33 (4.95)	21.93 (4.03)	22.00 (4.74)	20.07 (5.82)
Full Treatment Duration (month)	30.26 (5.22)	30.47 (4.36)	30.77 (4.31)	29.53 (6.71)

Table 4. Demographics and Treatment Duration

Standard deviations displayed in brackets

Variables	**All Groups (n=90)**	**Group 1 (n=30)**	**Group 2 (n=30)**	**Group 3 (n=30)**
Pre-treatment COS (mm)	3.56 (1.31)	3.61 (1.28)	3.47 (1.36)	3.62 (1.34)
Pre-surgical COS (mm)	2.50 (0.80)	2.41 (0.82)	2.63 (0.85)	2.46 (0.72)

Table 5. Curve of Spee measurement

Standard deviations displayed in brackets

Variables	All Groups (n=90) R1	Group 1 (n=30) R1	Group 2 (n=30) R1	Group 3 (n=30) R1
MPA (°)	27.62 (6.08)	34.10 (3.23)	27.85 (1.61)	20.91 (3.20)
Range of MPA (°)	41.9 - 13.7	41.9 - 30.5	30.4 - 25.2	25.1 - 13.7
SNA (°)	83.73 (2.47)	83.53 (2.70)	83.33 (2.27)	84.32 (2.41)
SNB (°)	78.61 (2.31)	77.85 (2.21)	78.11 (2.32)	79.86 (1.93)
ANB (°)	5.11 (2.11)	5.66 (2.23)	5.23 (1.94)	4.46 (2.03)
FA (°)	87.12 (2.57)	85.87 (2.03)	86.56 (2.39)	88.94 (2.26)
FMA (°)	20.62 (6.08)	27.1 (3.22)	20.85 (1.63)	13.91 (3.21)
Y-axis (°)	67.05 (4.12)	69.20 (3.53)	68.45 (3.09)	63.50 (3.21)
Convexity (mm)	3.5 (2.57)	4.54 (2.18)	3.72 (2.37)	2.25 (2.67)
Pog to NB (mm)	2.64 (1.68)	1.83 (1.13)	2.59 (1.59)	3.5 (1.86)
LFH (mm)	60.51 (6.80)	64.51 (6.48)	61.34 (4.27)	55.67 (6.33)
LFH/TFH (%)	53.75 (2.66)	54.94 (2.59)	53.80 (2.57)	52.51 (2.31)

Table 6. Pre-treatment (R1) cephalometric values

Standard deviations displayed in brackets

Variables	All Groups (n=90) R1/R2	Group 1 (n=30) R1/R2	Group 2 (n=30) R1/R2	Group 3 (n=30) R1/R2
SNA (°)	-0.29 (1.14)	-0.33 (1.41)	-0.39 (0.90)	-0.15 (1.08)

SNB (°)	0.01 (1.17)	0.13 (1.19)	-0.05 (1.23)	-0.06 (1.12)
ANB (°)	-0.30 (1.20)	-0.46 (1.27)	-0.33 (1.21)	-0.09 (1.14)
FA (°)	0.25 (1.12)	0.42 (1.09)	0.13 (1.24)	0.20 (1.02)
FMA (°)	-0.15 (1.47)	-0.28 (1.45)	0.10 (1.64)	-0.26 (1.31)
MPA (°)	-0.21 (1.49)	-0.36 (1.46)	0.10 (1.64)	-0.38 (1.35)
Y-axis (°)	0.03 (1.14)	-0.24 (1.19)	0.27 (1.13)	0.04 (1.07)
Convexity (mm)	-0.49 (1.06)	-0.71 (1.09)	-0.40 (1.08)	-0.35 (1.01)
Pog to NB (mm)	0.59 (1.03)	0.70 (0.90)	0.41 (0.79)	0.65 (1.32)
LFH (mm)	1.56 (3.74)	0.87 (2.07)	1.52 (2.12)	2.30 (5.75)
LFH/TFH (%)	0.35 (0.78)	0.28 (0.68)	0.29 (0.95)	0.48 (0.69)

Table 7. Changes between pre-treatment (R1) and pre-surgical (R2)

Standard deviations displayed in brackets

Variables	**All Groups (n=90) R2/R3**	**Group 1 (n=30) R2/R3**	**Group 2 (n=30) R2/R3**	**Group 3 (n=30) R2/R3**
SNA (°)	-0.10 (0.76)	-0.14 (0.80)	-0.04 (0.72)	-0.12 (0.78)
SNB (°)	3.18 (1.29)	2.75 (1.37)	3.25 (1.05)	3.53 (1.34)
ANB (°)	-3.28 (1.30)	-2.89 (1.29)	-3.30 (1.40)	-3.64 (1.13)
FA (°)	2.51 (1.09)	2.26 (1.27)	2.56 (0.93)	2.70 (1.04)
FMA (°)	2.86 (1.42)	2.50 (1.38)	2.51 (1.48)	3.56 (1.14)
MPA (°)	2.93 (1.42)	2.63 (1.33)	2.49 (1.51)	3.67 (1.13)
Y-axis (°)	-0.90 (0.96)	-0.80 (1.03)	-1.23 (0.89)	-0.69 (0.90)

Convexity (mm)	-2.52 (1.12)	-2.26 (1.15)	-2.62 (1.23)	-2.67 (0.97)
Pog to NB (mm)	-1.25 (0.63)	-1.09 (0.63)	-1.22 (0.55)	-1.42 (0.67)
LFH (mm)	2.15 (1.59)	1.76 (1.16)	1.82 (1.43)	2.87 (1.88)
LFH/TFH (%)	1.23 (0.84)	1.01 (0.57)	1.17 (0.78)	1.50 (1.04)

Table 8. Changes between pre-surgical (R2) and post-surgical (R3)

Standard deviations displayed in brackets

Variables	**All Groups (n=90)** **R3/R4**	**Group 1 (n=30)** **R3/R4**	**Group 2 (n=30)** **R3/R4**	**Group 3 (n=30)** **R3/R4**
SNA (°)	0.04 (0.85)	0.01 (0.77)	0.10 (0.84)	0.02 (0.95)
SNB (°)	-0.64 (0.95)	-0.69 (1.03)	-0.68 (0.86)	-0.55 (0.97)
ANB (°)	0.69 (0.95)	0.71 (0.93)	0.79 (1.06)	0.58 (0.88)
FA (°)	-0.58 (0.90)	-0.70 (1.00)	-0.50 (0.81)	-0.53 (0.88)
FMA (°)	0.46 (1.17)	0.51 (1.30)	0.45 (1.05)	0.42 (1.18)
MPA (°)	0.41 (1.16)	0.36 (1.28)	0.43 (1.11)	0.43 (1.13)
Y-axis (°)	0.33 (0.89)	0.40 (1.05)	0.31 (0.85)	0.29 (0.78)
Convexity (mm)	0.57 (0.94)	0.59 (0.87)	0.58 (1.08)	0.55 (0.89)
Pog to NB (mm)	0.22 (0.46)	0.25 (0.37)	0.38 (0.48)	0.04 (0.46)
LFH (mm)	0.28 (1.78)	0.38 (1.60)	0.41 (1.88)	0.06 (1.89)
LFH/TFH (%)	-0.01 (0.87)	-0.03 (0.73)	0.14 (0.76)	-0.15 (1.08)

Table 9. Changes between post-surgical (R3) and post-treatment (R4)

Standard deviations displayed in brackets

Variables	All Groups (n=90) R1/R4	Group 1 (n=30) R1/R4	Group 2 (n=30) R1/R4	Group 3 (n=30) R1/R4
SNA (°)	-0.35 (1.36)	-0.47 (1.50)	-0.33 (1.17)	-0.25 (1.43)
SNB (°)	2.54 (1.51)	2.19 (1.72)	2.52 (1.28)	2.92 (1.47)
ANB (°)	-2.88 (1.41)	-2.64 (1.30)	-2.85 (1.43)	-3.15 (1.50)
FA (°)	2.18 (1.51)	1.98 (1.75)	2.19 (1.31)	2.37 (1.45)
FMA (°)	3.17 (1.82)	2.73 (2.09)	3.05 (1.90)	3.72 (1.29)
MPA (°)	3.12 (1.80)	2.63 (2.02)	3.02 (1.92)	3.72 (1.24)
Y-axis (°)	-0.54 (1.47)	-0.63 (1.81)	-0.64 (1.27)	-0.35 (1.30)
Convexity (mm)	-2.43 (1.38)	-2.39 (1.17)	-2.44 (1.39)	-2.47 (1.58)
Pog to NB (mm)	-0.44 (1.04)	-0.15 (0.91)	-0.43 (0.89)	-0.73 (1.22)
LFH (mm)	4.00 (4.27)	3.01 (2.93)	3.75 (3.20)	5.23 (5.87)
LFH/TFH (%)	1.56 (1.13)	1.26 (0.90)	1.60 (1.21)	1.83 (1.20)

Table 10. Changes between pre-treatment (R1) and post-treatment (R4)

Standard deviations displayed in brackets

	All Groups (n=90) R2/R3		**Group 1 (n=30) R2/R3**		**Group 2 (n=30) R2/R3**		**Group 3 (n=30) R2/R3**	
Variables	Spearman's Rank Value	P Value	Spearman's Rank Value	P Value	Spearman's Rank Value	P Value	Spearman's Rank Value	P Value

SNA (°)	0.196	0.064	0.167	0.377	0.238	0.204	0.131	0.490
SNB (°)	0.068	0.522	-0.052	0.784	0.057	0.764	0.207	0.273
ANB (°)	0.083	0.436	0.184	0.331	0.099	0.603	-0.157	0.408
FA (°)	0.063	0.555	-0.046	0.809	0.079	0.676	0.195	0.302
FMA (°)	0.102	0.340	-0.015	0.938	0.112	0.556	0.319	0.085
MPA (°)	0.143	0.177	0.021	0.913	0.174	0.358	0.336	0.070
Y-axis (°)	0.064	0.546	0.117	0.539	-0.013	0.945	0.311	0.094
Convexity (mm)	0.161	0.130	0.266	0.156	0.112	0.555	-0.008	0.966
Pog to NB (mm)	-0.054	0.616	0.086	0.653	0.019	0.920	-0.261	0.164
LFH (mm)	0.198	0.061	0.021	0.913	-0.055	0.775	**0.682*****	**0.000**
LFH/TFH (%)	0.136	0.203	-0.170	0.368	0.022	0.907	**0.566*****	**0.001**

Table 11. Correlations between R2/R3 Change and pre-surgical COS

Spearman correlations. ***P<0.001

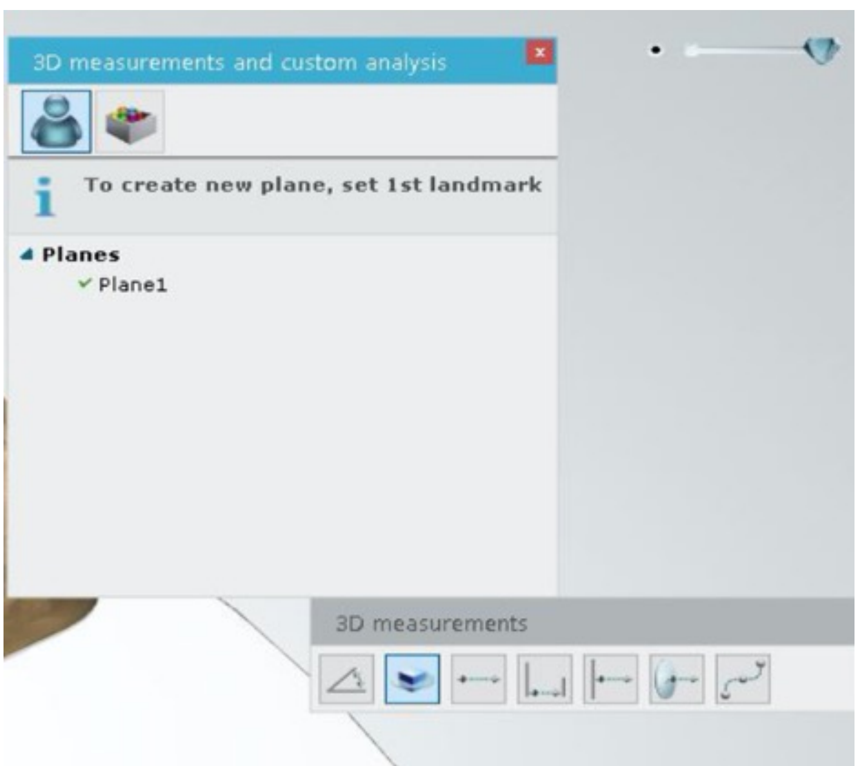

Figure 1. In the OrthoAnalyzer software, "Plane icon" was selected for Curve of Spee measurement.

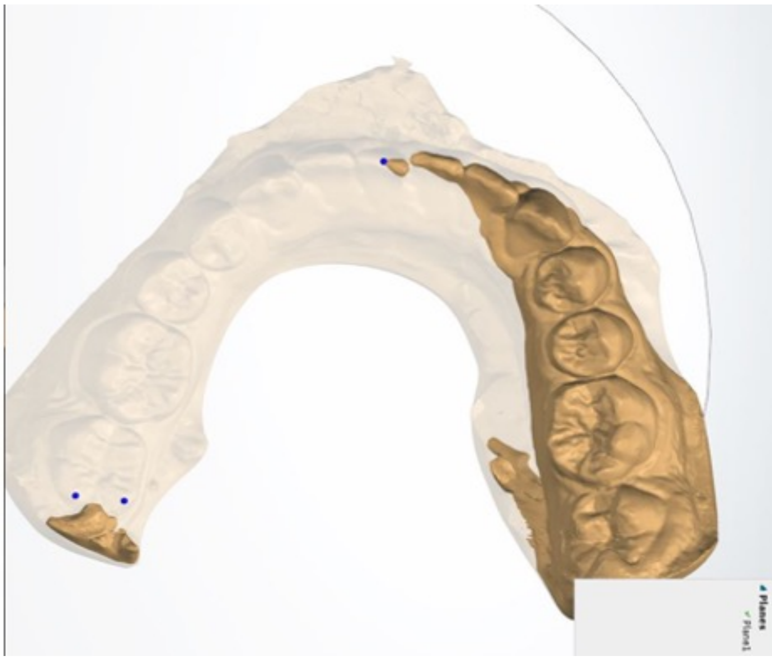

Figure 2. In the OrthoAnalyzer software, three points were identified for the plane.

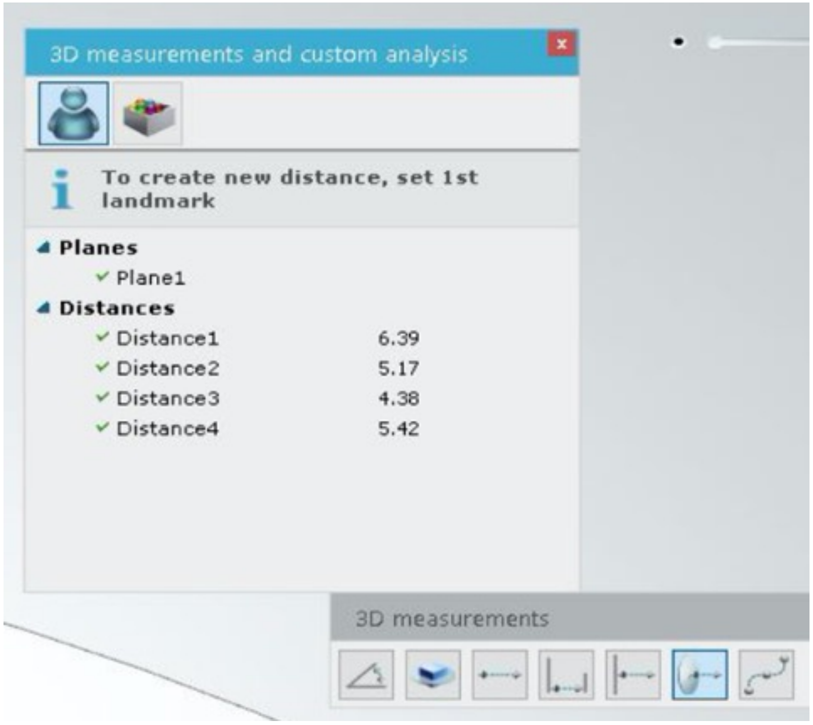

Figure 3. In the OrthoAnalyzer software, "Point to plane icon" was selected.

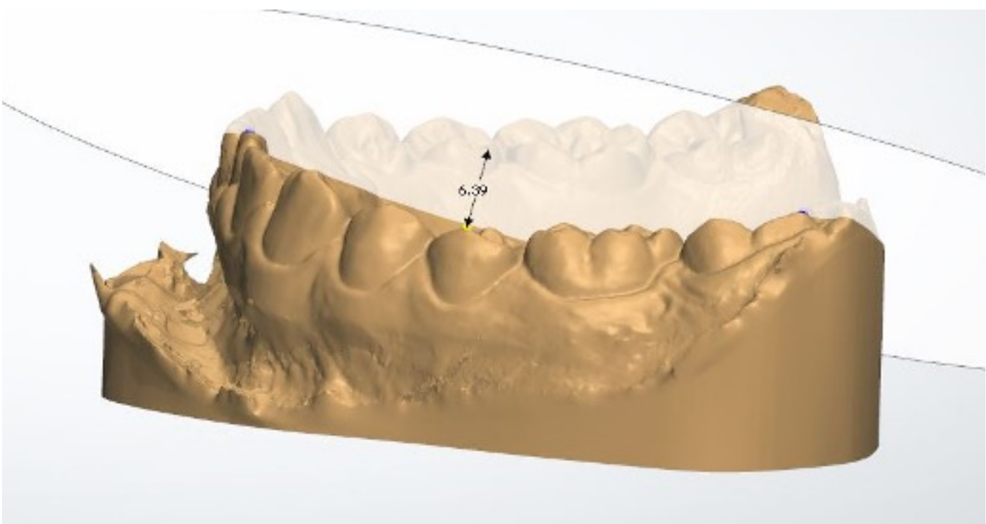

Figure 4. In the OrthoAnalyzer software, the distance between the deepest buccal cusp underneath the plane to the plane was displayed.