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Are Skeletal and Dental Characteristics, as well as Certain Aspects of Treatment, Related to Bony Condylar Changes?

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Are Skeletal and Dental Characteristics, as well as Certain Aspects of Treatment, Related to Bony Condylar Changes?

(Spine Title: Relationship between craniofacial form and TMJ condylar changes)

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Abstract

Introduction: Degenerative joint disease (DJD) is mildly prevalent in a pre-orthodontic population and can contribute to jaw pain and skeletal relapse post-orthodontic treatment.

Purpose: To determine whether craniofacial form or particular treatment modalities are related to TMJ condylar degeneration.

Materials and methods: The cephalometric radiographs of 61 subjects with moderate-severe condylar degeneration (as diagnosed from panoramic radiographs) were traced and treatment factors were recorded.

Results: Cephalometric findings of significance in this study include increased facial convexity, increased ANB, decreased SNB, decreased Pg-NA perpendicular, increased mandibular plane angle, increased gonial angle, increased overjet, and upright lower incisors when compared to cephalometric standards. Treatment modalities of significant prevalence are orthognathic surgery (23%) and Class II or III elastics (61%).

Conclusions: Results from this study, although inconclusive without a control group, indicate a retrognathic dolichofacial type. Patients requiring orthognathic surgery and with dental anteroposterior discrepancies tend to have more condylar degeneration.

Key words: condylar degeneration, prevalence, panoramic radiograph, craniofacial morphology

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Introduction

The exact cause or etiology of temporomandibular joint disorder or TMD is yet unknown, hence the definition of TMD: a group of musculoskeletal conditions that affect the masticatory system and are of multifactorial cause. Information is lacking as to what the true condition really is and in many cases, its source is unclear. Many potential explanations have been explored and offered in the literature. Perhaps the two most accepted etiologies are derangement of the condyle-disc complex (disc displacement or DD) and condylar degeneration (degenerative joint disease or DJD).

The prevalence of DD of the temporomandibular joint (TMJ) in the general population is estimated to range from 10 – 33%[1-8], whereas the prevalence of DD in a population of symptomatic TMD patients is reported as 77 – 84%[4,7,8]. Interestingly, the prevalence of DD in a pre-orthodontic population is believed to be much higher than the general population. Studies have found it to be as high as 45%[9,10]. Condylar resorption, on the other hand, has a much lower prevalence; up to 25% in the general population[3,11-14], and 2 – 16% in a pre-orthodontic population[15-18]. The large variation in prevalence can be attributed to different diagnostic techniques, different grading and scoring systems used to assess severity, as well as different populations studied.

Changes in condylar morphology have been thoroughly examined radiographically as well as anatomically through the assistance of cadaver studies. As the mandibular condyle remodels through a degenerative process, it tends to take on a mushroom shape which leads to vertical shortening of the ramus [16]. This shape is usually quite distinctive radiographically. Two radiographic hallmarks of DJD of the TMJ are articular surface erosions and osteophytes[19]. Erosions are described radiographically as a local area in the condyle with decreased density of the cortical joint surface and adjacent subcortical bone, and represent the early stage of degenerative changes. On the other hand, osteophytes represent the later stage of degenerative changes when the body is adapting to repair the joint. Osteophytes are created to stabilize and broaden the surface of the joint in an attempt to better withstand loading forces [20,21]. They represent areas of new cartilage and bone formation and appear radiographically as a marginal bony outgrowth. Other radiographic findings include flattening of the articular surface, concavity, cyst, subcortical sclerosis, irregular border of the condyle, and deviation in the shape of the condyle[22-25]. The goal of radiographic evaluation is to identify these changes.

Historically, orthodontics for many years was implicated as a direct cause of TMD. Various studies and review papers demonstrated a link between patients who presented with joint pain or dysfunction and previous orthodontic treatment, but most of these were largely anecdotal reports thus needed to be treated with caution[26]. Following a controversial lawsuit in Michigan in the late 1980s, a group of orthodontists and clinical research specialists decided to finally bring to light the true relationship between TMD and orthodontics[27]. Since then a large amount of research has undoubtedly proved that orthodontic treatment cannot be a cause of TMD. Tallents et al.[4] studied a large sample of asymptomatic volunteers and symptomatic TMD patients. The sample of patients was divided into four groups: asymptomatic normal, asymptomatic with disc displacement, symptomatic with disc displacement, and symptomatic normals. They found an equal prevalence of previous orthodontic treatment in all four groups, thus concluding that orthodontic treatment is not an etiological factor in TMD. In similar studies, comparable conclusions were reached[7,28,29]. An extensive review of the literature by Luther[30] demonstrated no observable link between previous orthodontic treatment and dysfunction. If anything, previous orthodontic treatment resulted in more harmonious functional and occlusal status as well as lower clinical dysfunction indices[31-33].

Despite vast research invalidating the link between orthodontic treatment and TMD, patients will still often relate the two in a cause-and-effect manner. This is especially true if they develop pain during or shortly after treatment and time and again, orthodontics gets blamed for this. Because of the uncertainty involved in the cause of TMD and the potential encompassed in orthodontics in changing occlusal factors as well as joint and/or jaw position, it is of utmost importance for orthodontists to recognize and take into consideration risk factors associated with TMD. Risk factors that have been published in the literature include:

1. facial asymmetry[34,35]
2. non-coincident dental midlines[34,35]
3. decreased range of motion and maximal mouth opening <35mm[4,36]
4. reduced protrusive and laterotrusive excursions[36]
5. joint sounds[4,36,37]
6. history of trauma[4]
7. Angle Class II molar relationship[38-40]
8. large maximal intercuspation-retruded contact position slide[41]
9. horizontal overlap of the incisors greater than or equal to 4mm[42], or greater than 6-7mm[43]
10. openbite[40]
11. abnormal wear pattern on teeth[39]
12. bruxism and wear facets[39]
13. balancing contacts[38]
14. missing more than 5 posterior teeth[39,43-46]
15. tilted teeth[39,47]
16. soreness in muscles of mastication[39]
17. other joint problems[4,5]
18. family history of jaw pain[4]
19. pain when chewing, eating or speaking[37]
20. female gender[11,48,49]

It is important to point out that functional occlusal relationship itself is not considered or demonstrated in the literature to be a risk factor for TMD; i.e. no cause-and-effect relationship was established[42,50-52].

Various researchers have examined the skeletal morphology of TMD, DJD, and DD patients radiographically and established the following cephalometric risk factors:

1. horizontal overlap of the incisors greater than or equal to 4mm[42] or greater than 6-7mm[43]
2. mandibular plane greater than 30° [34,53]
3. palatal plane greater than 31° [34,53]
4. gonial angle greater than 130° [34,53]
5. condyles that are tipped back[16,34,53]
6. antigonial notching[16,34]

7. increased angle between the posterior border of the mandibular ramus and Sella-Nasion[53]
8. decrease in Rickett's facial axis[53]
9. reduced posterior facial height[53]
10. reduced ramus height[53]
11. reduced posterior cranial base vertical height[53]
12. increased occlusal plane to Frankfort Horizontal[16,34]
13. increased overjet[34,42,43,54]
14. maxillary[55] and mandibular[34] retrusion
15. increased ANB angle[34]
16. Class II skeletal pattern[18,40,56]

Peltola et al. [18] looked at cephalometric measurements in children with condylar degeneration and compared them to children with normal occlusion and harmonious skeletal relationships; they found that children with condylar changes had decreased gonial angles and increased upper incisor to palatal plane angles compared to normal children. Dibbets et al. [16] found that a TMJ dysfunction group was more retrognathic and had, on average a smaller overall length of the mandible, a shorter posterior face height, a shorter ramus and smaller corpus, a larger gonial angle, and a steeper mandibular plane. Thus, condylar resorption is of particular importance in orthodontics due to its potential to contribute to relapse, posterior mandibular positioning, anterior bite opening, and jaw pain.

Longitudinal changes have been observed in orthodontically treated patients by Dibbets and van der Weele in 1989[57] and later by Peltola et al. in 1995[18]. They both evaluated condylar morphology based on panoramic x-rays at the beginning and end of active treatment, and at 15 years and 12 years after the termination of orthodontic treatment, respectively. Findings in both studies were similar in that most patients with condylar pathology at the end of treatment either stayed the same or got worse with time. No patients showed improvement in condylar morphology.

There are multiple methods of radiography to view the TMJ condyles; panoramic x-ray, computed tomography (conventional spiral) which can be divided into axially corrected sagittal tomography and frontal tomography, high resolution ultrasound, sagittal MRI, and more recently, cone-beam computed tomography. Studies have been done looking at the topography and morphology of the TMJ condyle during orthodontic treatment using many of these radiographic and diagnostic modalities. The gold standard for the diagnosis of condylar changes remains to be axially corrected sagittal tomography as condylar imaging is limited in other modalities such as panoramic x-rays and ultrasound[19]. Interestingly, Honey et al. [58] found that the diagnostic accuracy in evaluation of cortical erosion on the mandibular head was greater for panoramic radiographs than linear tomography. CBCT was superior to both in that study. Compared with conventional spiral CT, CBCT appears to be both a cost-effective and dose-effective alternative but more investigation is needed to establish its diagnostic capabilities[59]. On the other hand, Hintze et al. [60] found no significant differences in diagnostic accuracy for the detection of bone changes in the condyle and in the articular tubercle between CBCT images and conventional tomograms. Gold standard for diagnosis of internal derangement remains to be MRI, as this modality provides the clearest view of hard as well as soft tissues.

The question of whether or not a panoramic radiograph can be used to diagnose condylar changes has been debated for many years. Ruf and Pancherz[61] in their study on dry skulls found that it is not reliable, whereas Kjellberg[62] found that a panoramic x-ray can show significant morphologic changes in the condyles as long as the same radiographic machine is used to take the x-ray (Swed Dent J Suppl 1995). Bauer et al. [63] demonstrated that a panoramic x-ray can show significant morphologic condylar changes. Many authors have utilized panoramic radiographs in the literature to assess condylar morphology[18,49,57,64,65] and it has been shown there is less influence by different panoramic machines when evaluating radiographs qualitatively and without any measurements. More importantly, it has been shown over and over again that radiographic examination tends to favor under-diagnosis, thus severe pathologic condylar changes are more likely to be reflected radiographically[25].

Since it is supported in the literature that a panoramic x-ray can be used to diagnose condylar resorption, and this film is taken routinely by the orthodontist prior to treatment to assess tooth development, root form, and pathology, it seems logical to use these radiographs for the evaluation of condylar morphology. In addition, no further radiation will be presented to the patient. Also, the same panoramic x-ray equipment machine and standardized methods are usually used to take these x-rays. Lastly, it is not feasible to take tomograms or MRI's on all patients. As mentioned above, condylar resorption is of particular importance in orthodontics due to its potential to contribute to relapse, posterior mandibular positioning, anterior bite opening, and jaw pain.

The purpose of the present study is two-fold:

i. To identify the prevalence of moderate to severe bony TMJ condylar changes that existed at the initiation of orthodontic treatment or arose at any time during the course of treatment and up to a 2-year follow-up period

ii. To correlate TMJ condylar changes and different aspects involved in treatment with dental and skeletal morphology or craniofacial form before treatment, so as to obtain risk factors or predictive factors involved with condylar changes

Materials and Methods

The sample used in this study was taken from the archived charts of 2018 patients treated at the University of Western Ontario, Department of Orthodontics, in London, Ontario, Canada, between 1983 and 2007. All the patients had panoramic and lateral cephalometric radiographs taken prior to the initiation of treatment, at the time of removal of all appliances (treatment termination), and where available, at a time point of 2 years post-treatment (during the retention period). All available panoramic radiographs were used to assess TMJ condylar morphology and all condyles were designated a condylar assessment score. These scores for were based on a diagnostic method established by Helenius et al.[65] to evaluate the TMJ condyles of patients with rheumatoid arthritis.

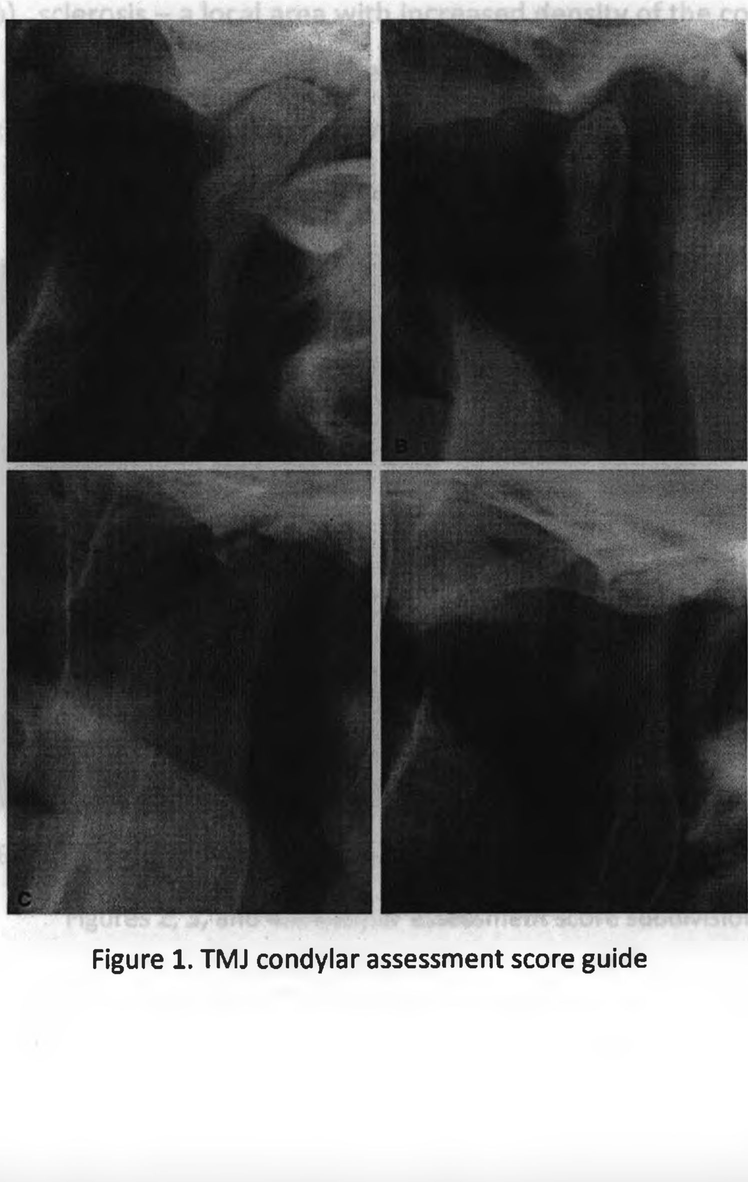


Figure 1. TMJ condylar assessment score guide

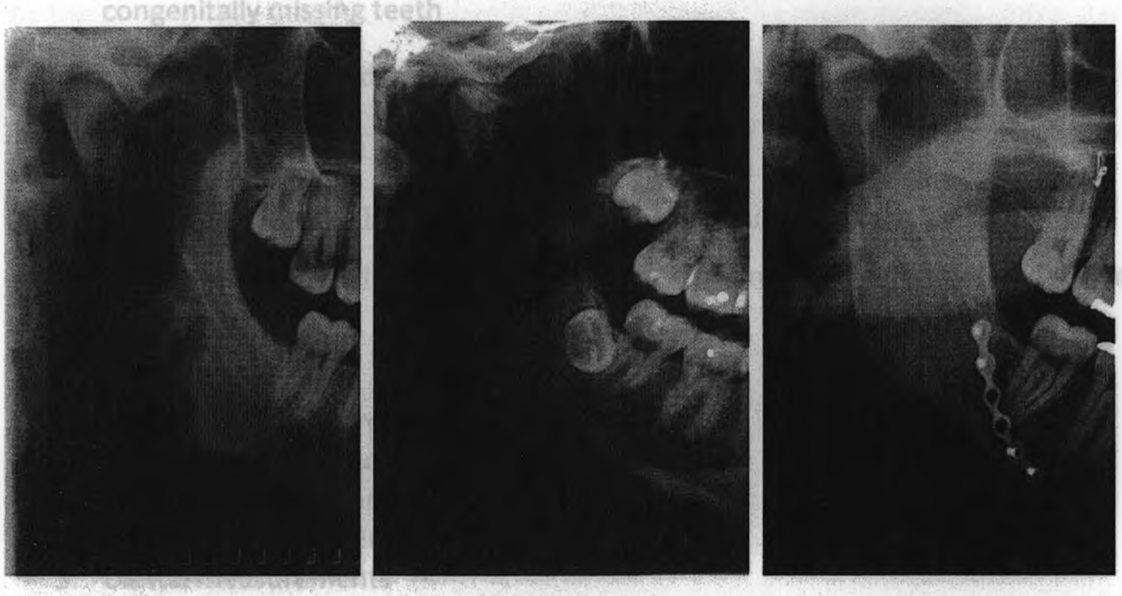
Figure 1. TMJ condylar assessment score guide

Figure 1 Legend: Scores were designated as follows: Grade 0 – no erosion of the TMJ condyle, Grade 1 – very slight erosion of the TMJ condyle (A), Grade 2 – erosion of the top of the TMJ condyle (B), Grade 3 – erosion of half of the TMJ condyle (C), Grade 4 – complete erosion of TMJ condyle (D)

Scores of 0 to 2 were considered to be mild, scores of 3 were considered to be moderate, and scores of 4 were considered to be severe bony condylar changes. For examples of condyle assessment scores from this study, see Appendix I (page 48).

Subdivisions were also added mainly for condylar surfaces with irregularities[24,25,66]. These included:

a) osteophyte – a marginal bony outgrowth[24,25,66]
b) sclerosis – a local area with increased density of the cortical bony joint surface extending into the subcortical bone[24,25,66]
c) irregular border or concavity – a hollowed out area on the bony contour with a well-defined cortical outline of the joint surface[24,25,66]



OSTEOPHYTE (a) SCLEROSIS (b) IRREGULAR BORDER (c)

Figures 2, 3, and 4. Condylar assessment score subdivisions

If a subject was assigned a grade of 2 with a subdivision (a, b, or c), grade 3, or grade 4, there were to be included in the sample. Scoring of all sample subjects was done by one author (DZB). When a subject had a score that was on the borderline between 2 and 3, a second author was consulted (AHM).

Charts of all subjects included in the sample were reviewed by one author (DZB) and the following information was recorded:

1. Gender
2. Racial background
3. Age at initiation of treatment
4. Age at termination of treatment or deband (where available)
5. Age at 2 years post-treatment (where available)
6. Treatment duration
7. Appliances used during treatment (headgear, functional appliance, Class II or III elastics, palatal expansion appliance such as a hyrax or quad helix, and anterior or posterior bite plate)
8. Treatment modalities (orthognathic surgery and extraction of permanent premolar teeth)
9. Other data noted was impaction of canines, orofacial trauma, pain prior to or during treatment, occlusal splint treatment prior to or during treatment, and congenitally missing teeth

All lateral cephalometric radiographs were traced by one author (DZB) using Dolphin Imaging 10.0.

Cephalometric variables to be utilized in the analysis of subjects were divided into 5 groups and included the following: (for specific measurements, see Table 1, page 33 and Appendix II, page 51)

1. Cranial base measurements
2. Soft tissue profile measurements
3. Vertical measurements
4. Skeletal measurements
5. Dental measurements

Specific cephalometric measurements were included for the purpose of evaluating overall soft tissue, skeletal, and dental pattern of each subject, as well as for the purpose of comparison to previously published studies.

All statistical testing was performed on the program JMP 7. Statistical analysis was descriptive in nature; ie. measures of central tendency (mean and standard deviation). Associations (Y by X) were also used to describe data. The Tukey-Kramer test was used where applicable to investigate whether or not associations were significant (p-value 0.05 needed for significance).

Error study

Cephalometric analysis has been thoroughly investigated since its introduction into orthodontics by Hofrath and Broadbent in 1934[67]. When compared to measurements on dry skulls, Barber et al. [68] found that measurements from oblique radiographs varied less than 0.3mm. Stellingsma et al. [69] found that when Frankfort Horizontal was altered from −20° to +20°, the image changed less than 1%. Additional innate potential errors in this study included the tracing and location of the points. Therefore, 16 cephalometric radiographs were re-traced 1 year after the initial tracing by the same author (DZB) to calculate reproducibility of the measurements (intra-class correlation coefficient or R). The intra-operator coefficient correlation R =0.934, which is deemed acceptable. For more specific description of the error study, see Appendix III (page 53).

Results

Sixty-one subjects were selected from a pool of 2018 patients as having a TMJ condylar assessment score of grade 2 with a subdivision (a, b, or c), grade 3, or grade 4. Thus the prevalence of *moderate to severe* TMJ condylar degeneration, as diagnosed from a panoramic radiograph, in a pre-orthodontic population at the University of Western Ontario in London, Ontario, Canada from 1983 to 2007 was 3.02%.

Subject Demographics

Gender distribution

There were 40 females (66%) and 21 males (34%) in the study sample (Figure 5, page 36).

Racial Background

The predominant race in this sample was Caucasian; 60 subjects (98%). The other remaining subject was East Indian (2%).

Age at initiation of treatment (months)

The mean age at initiation of treatment for this sample was about 14 years or 168 ± 43 months (Figure 6, below).

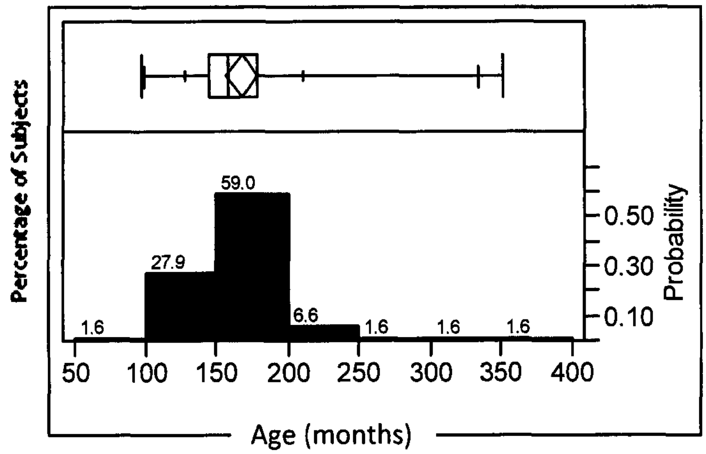


Figure 6. Age distribution of the sample at initiation of treatment

Age at termination of treatment (months)

The mean age at deband was about 17 years and 3 months or 207 ± 40 months (Figure 7, below).

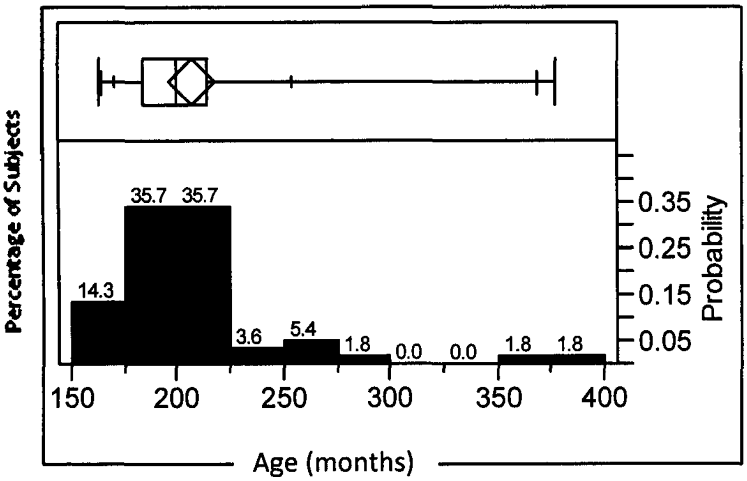


Figure 7. Age distribution of the sample at termination of treatment (deband)

Treatment duration

The mean treatment duration in full-fixed appliances (not including functional appliance, headgear, splint, or expansion appliance used alone as part of phase 1) was 30.9 months or 2 years and 7 months ± 10 months (Figure 8, below).

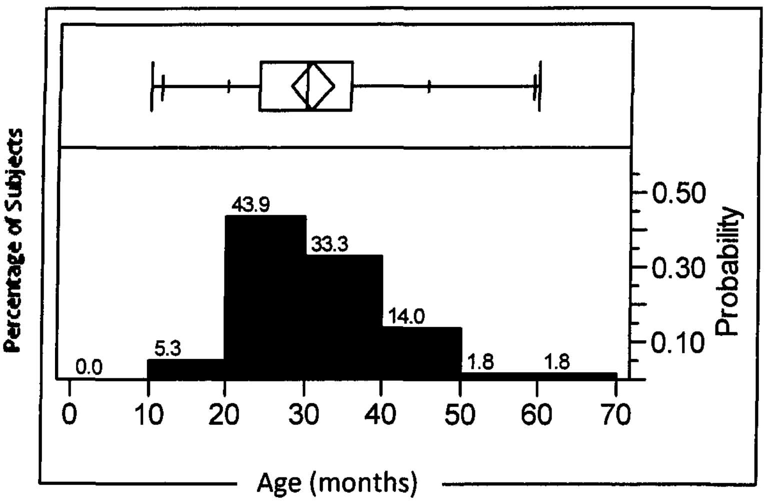


Figure 8. Treatment duration of the sample

Distributions of Treatment Variables

Headgear

Eighteen subjects or 30% of subjects in this sample were treated with a headgear (Figure 9, page 38).

Class II or III elastics

Thirty-seven subjects or 61% of subjects in this sample were treated with Class II or III elastics (Figure 10, page 39).

Functional appliance

Five subjects or 8% of subjects in this sample were treated with a functional appliance (Figure 11, page 39).

Orthognathic surgery

Forty-seven subjects (77%) of subjects in this sample were treated non-surgically. 14 subjects (23%) of subjects were treated with orthognathic surgery. 5 subjects (8%) had surgery consisting of one jaw and 9 subjects (15%) had surgery consisting of both jaws (Figure 12, below).

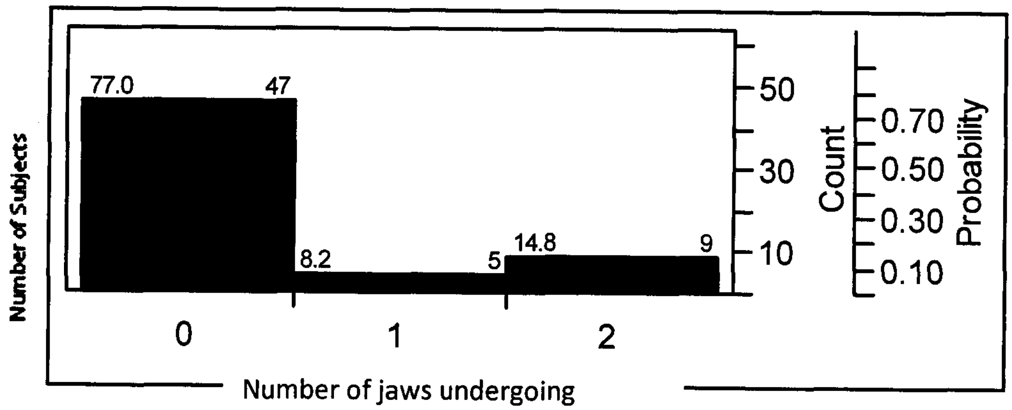


Figure 12. Prevalence of orthognathic surgery in the sample

Splint treatment

Nine subjects or 15% of subjects in this sample had splint treatment prior to or during orthodontics treatment (Figure 13, page 40).

Pain at any time during treatment

Six subjects or 10% of subjects in this sample experienced TMJ/muscular pain during orthodontic treatment (Figure 14, page 40).

Palatal expansion (RPE or Hyrax)

Eight subjects or 13% of subjects in this sample were treated with palatal expansion with a Hyrax or a quad helix appliance (Figure 15, page 40).

Bite plate

Four subjects or 7% of subjects in this sample had an anterior or posterior bite plate at some point during treatment (Figure 16, page 41).

History of orofacial trauma

One subject or 2% of subjects in this sample had a history of orofacial trauma prior to orthodontic treatment (Figure 17, page 41).

Premolar extractions (# of premolar teeth extracted)

Thirty-four subjects (56%) were treated with non-extraction orthodontic therapy. 2 subjects (3%) had one premolar extracted as part of their orthodontic treatment. 14 subjects (23%) had two premolar extracted, 2 subjects (3%) had three premolar extracted, and 9 subjects (15%) had four premolar extracted as part of their orthodontic treatment (Figure 18, below).

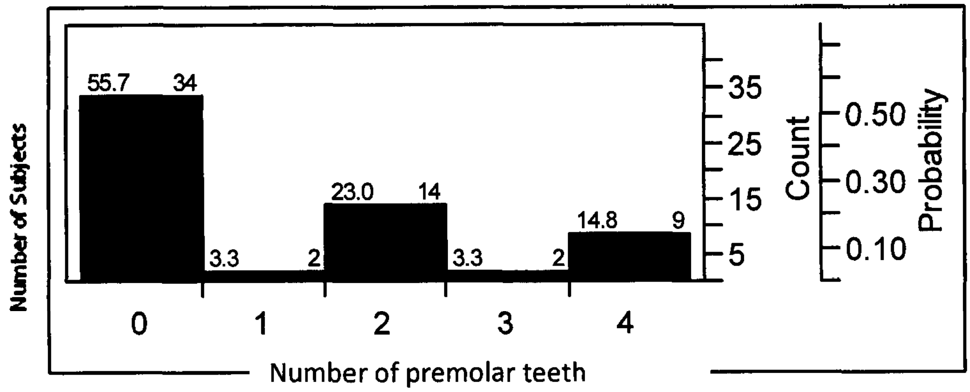


Figure 18. Prevalence of extraction of premolar teeth in the sample

Congenitally missing teeth

Two subjects (3%) in this sample were congenitally missing 2 teeth and 1 subject (2%) was missing 8 teeth (Figure 19, page 42).

Canine impaction

Two subjects (3%) in this sample had one impacted canine and 1 subject (2%) had two impacted canines (Figure 20, page 42).

Cephalometric characteristics

Table 2. Soft tissue profile measurements

Measurement *Soft Tissue Profile*	**Sample population Mean (SD)**	**Cephalometric standard (Dolphin 10.0)**
Nasolabial angle (°)	114.0 (9.4)	102.0
Facial angle (FH-NPo) (°)	86.1 (3.2)	87.2
Facial convexity (A-NPo) (°)	3.2 (2.7)	1.3
Lower lip – E plane (mm)	-0.2 (3.2)	-2.0

Table 3. Cranial Base Measurements

Measurement *Cranial Base*	Sample Population Mean (SD)	Cephalometric Standard (Dolphin 10.0)
NSBa (°)	130.5 (4.1)	131

Table 4. Skeletal Measurements

Measurement *Skeletal*	Sample Population Mean (SD)	Cephalometric Standard (Dolphin 10.0)
SNA (°)	80.2 (3.2)	82
SNB (°)	75.9 (3.4)	80.9
ANB (°)	4.3 (2.2)	1.6
A-Na perpendicular (mm)	-0.8 (3.4)	0
Pg-Na perpendicular (mm)	-7.4 (6.1)	-4.0
Wits (mm)	2.4 (3.9)	-1.0
Maxillary length (Co-A) (mm)	84.5 (3.7)	90
Mandibular length (Co-Gn) (mm)	114.9 (14.5)	113.0-125.0
Mx/Md Difference (mm)	27.7 (5.5)	18.0-25.0
Articular Angle (°)	140.5 (7.4)	143.6

Table 5. Dental Measurements

Measurement *Dental*	Sample Population Mean (SD)	Cephalometric Standard (Dolphin 10.0)
U1-SN (°)	103.9 (8.3)	102.4
U1-NA (°)	23.6 (8.0)	22.8
U1-NA (mm)	5.5 (2.9)	4.3
U1-PP (°)	111.5 (7.7)	110
U1-L1 (°)	130.0 (1.4)	130
L1-APo (mm)	1.3 (2.7)	2.7
IMPA (°)	88.3 (7.3)	95
Overbite (mm)	2.9 (2.4)	2.5
Overjet (mm)	6.9 (3.5)	2.5

Table 6. Vertical Measurements

Measurement *Vertical*	Sample Population Mean (SD)	Cephalometric Standard (Dolphin 10.0)
	Palatal Plane	
SN-PP (°)	7.5 (3.2)	7.3
PP-MP (°)	30.4 (5.9)	25
PP-OP (°)	9.5 (4.1)	10
	Occlusal Plane	
SN-OP (°)	17.0 (4.8)	14.4
FH-OP (°)	8.0 (4.7)	9.4
	Mandibular Plane	
SN-MP (°)	37.9 (5.3)	33
FMA (°)	28.9 (5.)	25.3
	Gonial angle	
Ar-Go-Me (°)	132.9 (7.4)	125
Ar-Go-Gn (°)	126.9 (5.5)	119.1
Ramus Height (Ar-Go) (mm)	45.8 (6.1)	38.0 – 48.0
Rickett's Facial Axis (°)	-2.3 (3.9)	0
Y-axis (Down's) SGn-FH (°)	60.4 (3.3)	60.0 – 61.0
Y-axis SGn-SN (°)	69.4 (3.6)	67
AFH (NaMe) (mm)	118.8 (7.5)	111.0 – 125.0
PFH (SGo) (mm)	74.3 (6.5)	71.0 – 85.0
P-AFH (%)	62.5 (4.3)	65
UFH (%)	43.9 (2.2)	43
LFH (%)	56.1 (2.2)	57

Associations

Associations(Y by X) were made in this study with the intent of describing the data. It is important to point out that one cannot draw conclusions that apply to the general population as this information applies to this particular data set or sample only.

Headgear by sex

Eighteen subjects (30%) in this sample were treated with a headgear. Of those subjects treated with a headgear, 78% were female (Figure 21, page 43). Thus females were two time more likely to be treated with a headgear than males.

Functional appliance by sex

Five patients (8%) in this sample were treated with a functional appliance. Of those subjects treated with a functional appliance, 80% were male (Figure 22, page 43). Thus males were four times more likely to be treated with a functional appliance than females.

Premolar extractions by sex

Fifty percent of the females and 67% of the males in this sample were treated with non-extraction therapy (0 teeth extracted). Of all patients treated non-extraction (34 patients), 59% were female and 41% were male. Of all patients treated by extraction of 2 premolars (14 patients), 64% were female and 36% were male. Of all patients treated by extraction of 4 premolars (9 patients), 89% were female, 11% were male (Figure 23, below). Proportionally, about half of the females and one-third of the males were treated with extraction of premolars.

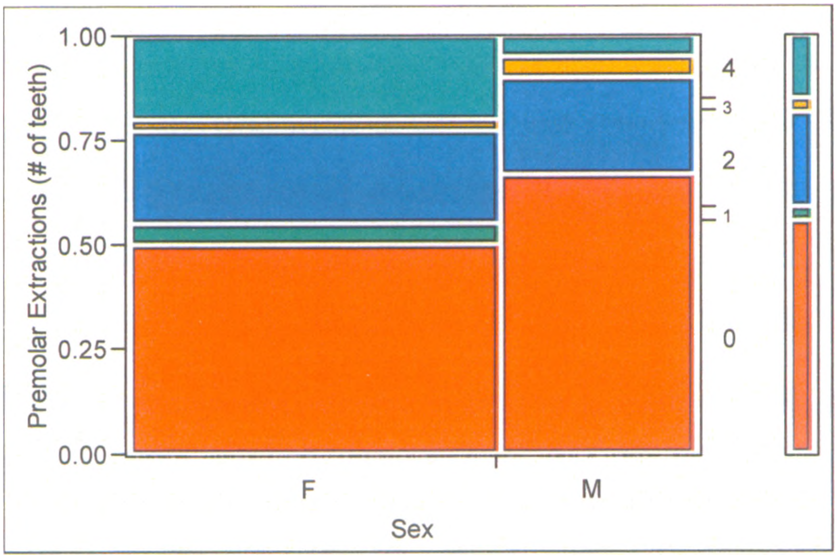


Figure 23. Association of premolar extraction treatment by sex

Orthognathic surgery by sex

Eighty percent of females and 71% of males in this sample were treated non-surgically (0 jaws). Of all non-surgical patients (47 subjects), 68% were female and 32% were male. Of all patients treated surgically, one or two jaw (14 patients), 32% were female and 68% were male (Figure 24, below). Proportionally, males were almost two times more likely to have orthognathic surgery than females.

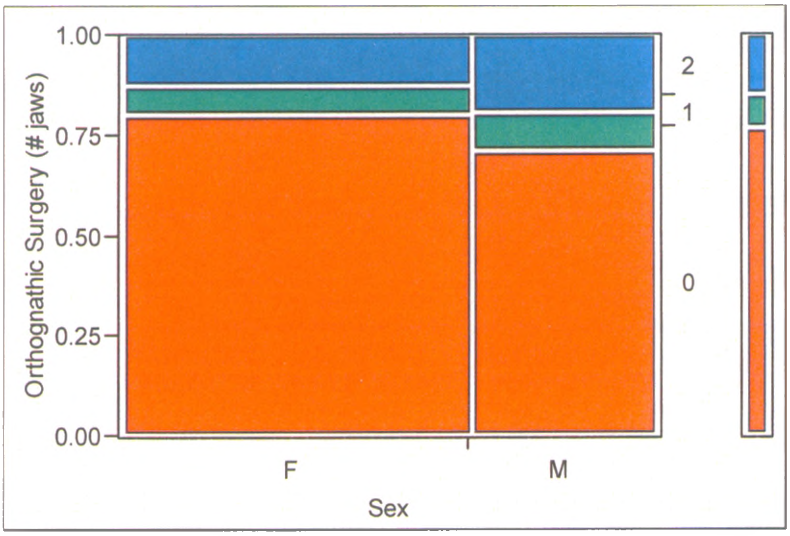


Figure 24. Association of orthognathic surgery treatment by sex

Pain by sex

Only 6 subjects (10%) in this sample had pain prior to or during treatment. All of the subjects with pain were female (Figure 25, page 45).

ANB by sex

The Tukey-Kramer test was used to determine whether females had a higher ANB on average than males in this sample. The green diamonds on the left side of the diagram indicate the sample mean (horizontal center line of the diamond) plus 2 standard deviations (vertical upper and lower points of the diamond). The result was non-significant (p>0.05 as the two circles on the right part of the diagram overlap) but there was a tendency for females to have a higher ANB than males (Figure 26, below).

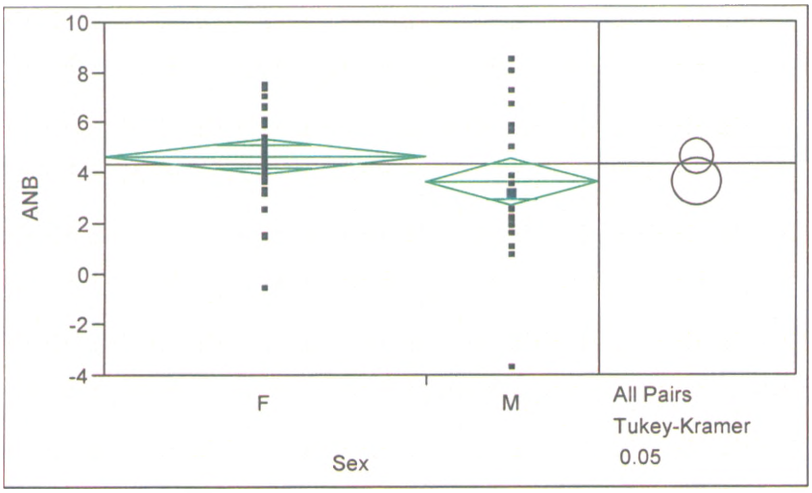


Figure 26. Association of the cephalometric measurement of ANB by sex

Wits by sex

The Tukey-Kramer test was used to determine whether females had a higher Wits value on average than males in this sample. The result was non-significant, p>0.05 (Figure 27, page 46).

SNB by sex

The Tukey-Kramer test was used to determine whether females had a smaller SNB on average than males in this sample. The result was non-significant (p>0.05) but there was a tendency for females to have a smaller SNB than males (Figure 28, below).

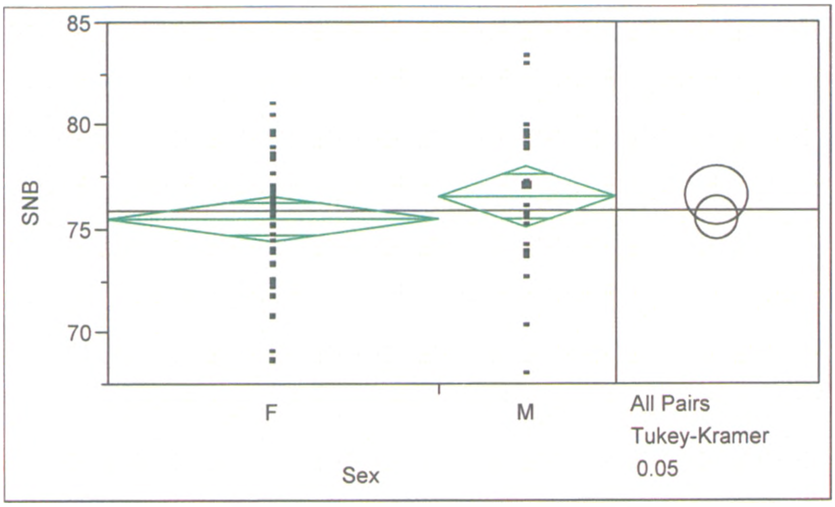


Figure 28. Association of the cephalometric variable of SNB by sex

Overjet by sex

The Tukey-Kramer test was used to determine whether females had a larger overjet on average than males in this sample. The result was non-significant ($p>0.05$) (Figure 29, below).

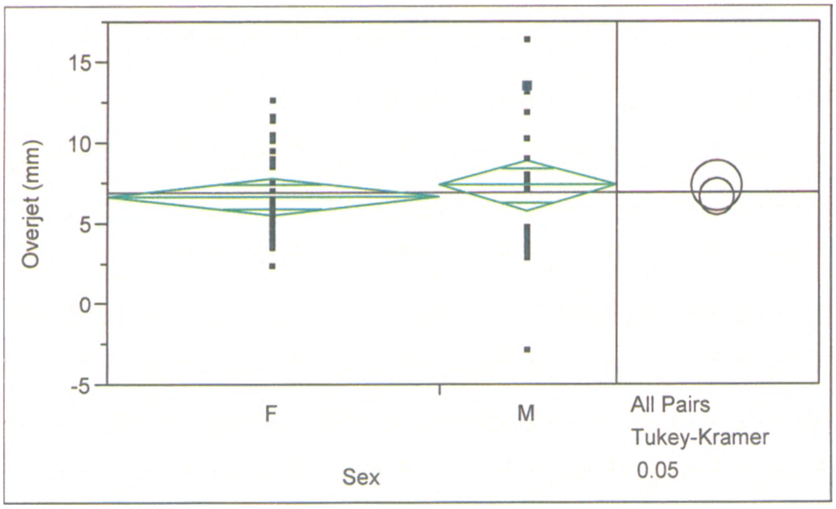


Figure 29. Association of the cephalometric measurement of overjet by sex

Headgear by SNA

The Tukey-Kramer test was used to determine whether headgear was more often used in patients with increased SNA values. The result was non-significant, $p>0.05$ (Figure 30, page 47).

Discussion

Growth of the mandible, as stated by Dibbets and Carlsson[29] is most important for proper development of the face. Mandibular growth is dependent upon two processes: a slow remodeling of bone and rapid proliferation of condylar cartilage followed by endochondral ossification. During a period of rapid growth of the face, synchronous coordination in growth of the condyle is of utmost importance. When proliferation of the condyle is affected due to a degenerative process, then the anticipated condylar response will either fail to develop or will occur to a lesser degree. When TMJ degeneration or dysfunction exists, the result of this pathologic process will influence mandibular size to a negative degree and result in aberrant facial growth and form. Dibbets et al.[16] were able to demonstrate this through long term follow up studies of growing subjects with TMJ x-ray deformities. They observed a downward and backward rotation of the mandible as the subjects grew, resulting in an increase in the mandibular plane, antigonial notching, distinctively smaller mandibles, higher articulare, anterior bite opening, clockwise rotation of the occlusal plane, and elongation of the lower face. They also found that subjects with x-ray deformities had more craniofacial deviations from normal than subjects with TMJ dysfunction symptoms. Findings from our study will be further discussed below.

Condylar resorption has been demonstrated to be more prevalent in the general population than one may think[3,11-14]. Its occurrence, as viewed in this study appears to be similar to that of pre-orthodontic patients in other studies[15-18]. The importance of this can be in relation to many factors associated with condylar resorption, for example pain from TMD. Katzberg et al. [70] demonstrated degenerative arthritis in 13 of 31 (42%) symptomatic children presenting with pain and dysfunction, ages 8-16 years. Ogus[71] studied patients with osteoarthritis and found that 33% were under the age of 40 years and Toller[72] found that 50% of symptomatic patients with osteoarthritis presented before the age of 45 years. This can lead one to conclude that condylar resorption or pathology tends to occur at a younger age than osteoarthritis of other joints. A relationship between osteoarthritis and disc displacement has also been established in the literature thus further implicating its prevalence in young adolescent people[14]. This study demonstrated a prevalence of condylar degeneration of 3% in the population we studied. This is comparable to the prevalence found by Dibbets and van der Weele[17] of 5% and Peltola et al.[18] of 2.2%. In another study, Peltola et al.[66] found the prevalence of condylar findings to be 21% for all treated patients and 10% in a control (untreated) group. Some of the other studies found higher prevalences; the large variation can be attributed to many factors; diagnostic modality, diagnostic criteria, and population studied, to name a few.

The gender ratio observed in this study was 2:1, females versus males (Figure 5, page 36). Warren and Fried[73] stated that extensive literature suggests the TMD is 1.5-2 times more prevalent in women than in men, and that 80% of patients treated for TMD are women. It is also well accepted in the literature that considerably more females than males report and/or seek treatment for TMD related pain. Wiese et al.[74] found that gender was related to degenerative findings diagnosed from tomograms, as was diagnosis of osteoarthritis. Oakley and Vieira[75] suggest genetic contribution as an explanation to why females tend to report more pain, saying that female hormones are to blame. Wang et al.[76] offer a potential explanation with particular focus on the hormone estrogen: It has been reported that estrogen could influence the development, restitution and metabolism of the temporomandibular joint and associated structures such as bone, cartilage and articular disc. Estrogen can also influence the regulative mechanism of pain. Nilsson[77] found that the perceived need for TMD treatment was significantly higher overall in girls than in boys. Interestingly in our study, the patients that reported pain prior to or during treatment (10%) were female (Figure 25, page 45). When considering severity of craniofacial deviation from normal, it did not appear that females were more acute than males, as evidenced by relatively equal SNB, ANB, Wits, and overjet values, although there was a tendency for an increased ANB in females but it was not significant (Figures 26, 27, 28, and 29, pages 45, 46, and 47).

In this study the average treatment duration in full-fixed appliances was about 31 ± 10 months. Any amount of time appliances such as headgear, functional appliance, hyrax, quad helix, or splint was used alone prior to full fixed appliances; it was not included in this tally. The average treatment time was estimated to be 23-28 months for most orthodontic private practitioners[78,79]; whereas the average treatment time in a graduate clinic was about 29-30 months with a large range[80]. This was in agreement with the range found in our study.

Pain did not appear to be very ubiquitous in this study. Only 6 subjects (10%) experienced pain prior to or during treatment (Figure 14, page 40). Also as mentioned above, all 6 subjects were female. This can be well explained by Wiese et al. [74] who found that pain was not associated with increased risk of degenerative findings in TMJ tomograms. Although some association does exist as shown in this study and by Kurita et al. [81] who observed a higher prevalence of joint pain on function in joints with radiographic evidence of bone changes at the articular surface than in those without.

Several treatment factors or modalities were recorded for each subject. Growth modification is a treatment modality commonly used to treat growing Class II patients. In our study, 30% of subjects were treated with HG, mostly females (78%) (Figures 9 and 21, pages 38 and 43). Upon examination of the cephalometric value of SNA, no significant differences were found between those subjects treated with headgear and those treated without headgear (Figure 30, page 47). Peltola et al. [66] found that the frequency of condylar findings to be 24% in a group treated with HG. Another method of growth modification used on our subjects was functional appliances. In our study 8% of subjects were treated with a functional appliance, mostly males (80%) (Figures 11 and 22, pages 39 and 43). When examining SNB, females tended to have a lower SNB but again this difference was not statistically significant (Figure 28, pages 21 and 46). Peltola et al. [66] found the frequency of condylar findings was 35% in a group treated with an Activator, and 11% for functional corrector. This may lead one to pose the question: Does a functional appliance increase the risk of development of TMD? Ruf and Pancherz[82] did a follow-up study on 20 patients four years after Herbst tx. They found that incidence of anamnestic and clinical signs and symptoms of TMD were within the range of "normal" reported in the literature. The frequency of disk displacement was not higher than in asymptomatic populations. Ruf and Pancherz[83] also did a prospective longitudinal study on 62 consecutively treated Class II malocclusions to determine whether bite-jumping causes TMD. Function of the TMJ was assessed anamnestically, clinically, and by means of MRIs taken before, after, and 1 year after Herbst treatment. Over the entire observation period from before treatment to 1 year after treatment, bite-jumping with the Herbst appliance did not result in any muscular TMD and it reduced the prevalence of capsulitis and structural condylar bony changes. They concluded that a pretreatment total disc displacement with or without reduction did not, however, seem to be a contraindication for Herbst treatment. Also bite-jumping using the Herbst appliance does not have a deleterious effect on TMJ function and does not induce TMD on a short-term basis. A long-term radiographic study of morphologic condylar changes on 100 pts treated with a Herbst was done by Paulsen[84]. The orthopedic effects observed in his study included; changes in morphology of the condyle and double contour in the distocranial part of the condyle and at the distal surface of the ramus. The newly formed bone was stable and no TMJ problems were observed.

Class II and/or Class III elastics were used in about two thirds of our sample (61%) (Figure 10, page 39). Many patients will report jaw pain while they are wearing elastics. This suggests that elastics may be placing force or pressure on the TMJ, thus causing potential for damage. A longitudinal prospective study was done by O'Reilly et al. [85]. 60 experimental subjects receiving orthodontic treatment with edgewise straight wire appliances, extractions, and retraction of anterior maxillary teeth with Class II elastics from canines to mandibular 2nd molars were compared to 60 controls (untreated). TMD signs and symptoms collected before initiation of treatment, 8-10 months into treatment, 12-16 months into treatment and no later than 2 months after appliance removal. The only significant finding in this study was mild pain on palpation "lateral to the TMJ capsule" at 8-10 months into treatment. This was present for 40% of the orthodontically treated group. The possible explanation offered by the authors was that during that period in treatment, treated subjects were beginning to have extraction spaces closed and their teeth and jaws may have been sore due to that.

An interesting finding was the prevalence of orthognathic surgical treatment in our sample; almost a quarter of all patients (23%) were treated surgically (Figure 12, pages 13 and 39). This may suggest that surgery can contribute to condylar degeneration or, on the other hand, that condylar degeneration may preclude orthodontic treatment; thus actually causing such skeletal malformations that require surgical correction. Schellhas et al. [86] proposed that in the growing facial skeleton, disc displacement either retards or arrests condylar growth, resulting in decreased vertical dimension in proximal mandibular segments and ultimately causing mandibular deficiency; Class II skeletal pattern in the case of bilateral DD or mandibular asymmetry in the case of unilateral DD. This is further supported by Link and Nickerson who studied a group of 39 pre-orthognathic surgery patients[87]. They found that 38 patients had disc displacement prior to surgery. More significantly, they found that all of their open bite patients and 88% of Class II malocclusion patients had bilateral disc displacement. This led to the suggestion that disc displacement may be a contributing factor in the development of dentofacial deformities through the mechanism of loss of condylar height or growth (or both) secondary to the disc displacement. Schellhas et al. [86] also found that the degree of joint degeneration directly paralleled the severity of retrognathia, further supporting this correlation. Another interesting finding in our study was that there were twice as many male than female surgical patients (Figure 24, pages 19 and 44). Some orthodontists believe that it is easier to orthodontically compensate Class II females than males; males more often require orthognathic surgery for acceptable esthetics.

Because of the 1987 Michigan lawsuit[27] referred to in the introduction, the topic of extraction treatment and whether or not it precludes TMD has been thoroughly explored at the University of Michigan and has been disproven without a doubt. 44% of subjects in our sample underwent extraction of premolars (41% had extraction of at least two premolars) (Figure 18, pages 15 and 41). Also more males than females underwent extraction therapy (Figure 23, pages 18 and 44). Peltola et al.[66] found the frequency of condylar findings to be 20% in an extraction group. It is difficult to compare the findings in our study to Peltola et al.[66] because sample selection techniques were different as we chose our subjects according to condylar findings and they chose according to appliance used.

Other treatment variables noted in our study included palatal expansion (13%) (Figure 15, page 40), splint treatment (15%) (Figure 13, page 40), bite plate (7%) (Figure 16, page 41), history of orofacial trauma (2%) (Figure 17, page 41), congenitally missing teeth (5%) (Figure 19, page 42), and impacted canines (5%) (Figure 20, page 42). These variables were noted as a means of comparison to a control group which was not included in the study at this time.

Cephalometric values obtained during analysis of subjects were chosen based on their importance as deemed by the authors as well as for the sake of comparison to other studies published in the literature. The two main studies used for comparison are Gidarakou et al.[34] and Peltola et al.[18], who studied subjects with bilateral degenerative joint disease and pathologic condylar characteristics respectively. Results are summarized in Table 7, page 34).

__Cranial base, Soft tissue profile, and Skeletal Measurements:__ (see Table 7, page 34)

Upon soft tissue profile exam, we found a mean facial angle (FH-NPo) of 86.1°, which was higher than Gidarakou et al.[34], making our subjects appear to be slightly less retrognathic. We also found mean SNB and ANB angles of 75.9° and 4.3°, respectively. These values were similar to Gidarakou et al.[34] but more Class II compared to Peltola et al.[18]. Our subjects' skeletal malocclusion seemed to be more similar to those of

Gidarakou et al.'s [34] sample in that they were both mildly mandibular retrognathic on average.

Dental Measurements: (see Table 7, page 34)

Our subjects demonstrated a mean upper incisor angulation which was similar to subjects of Gidarakou et al.'s [34] sample but more upright compared to subjects of Peltola et al.'s [18] sample. Our subjects lower incisor position and angulation was more retruded and retroclined compared to the subjects from both of the other studies. We found a mean overbite of 2.9mm in our subjects, which was similar to Gidarakou et al. [34] (2.5mm). We found a mean overjet of 6.9mm, which was much higher than Gidarakou et al. [34] (4.7mm).

Vertical Measurements: (see Table 7, page 34)

Our subjects demonstrated mean mandibular and palatal plane angulations, as well as gonial angles which were lower compared to the sample of Gidarakou et al. [34], but higher compared to the sample of Peltola et al. [18]. The mean occlusal plane angulation of our sample was lower than that of Gidarakou et al. [34]. We found a mean ramus height that was similar to Gidarakou et al. [34]. Our Y-axis (SGn-FH) mean was much lower than Gidarakou et al. [34]. Lastly, we found a mean P-AFH ratio of 62.5%, which is much lower than Peltola et al. (68%)[18]. It seems that subjects in our sample had a more vertical facial pattern than those of Peltola et al. [18], but not quite as vertical as those of Gidarakou et al. [34].

Other studies which did not report the quantity of their cephalometric values, rather just the quality can also be compared to our study. We were in agreement with a study by Nebbe et al. [53] who looked at pre-orthodontic female patients with bilateral DD, where they found decreased Rickett's facial axis (posterior displacement of gnathion) and increased mandibular plane to SN. Findings that were not in agreement with our study were decreased ramus height, increased palatal plane to SN, and decreased posterior face height (where we had a tendency but it was not significant). Our findings also support a study done by Dibbets et al.[16] who found that a TMJ dysfunction group was more retrognathic and had, on average a downward and backward rotation of the mandible, a shorter posterior face height, a larger gonial angle, and a steeper mandibular plane.

Kahn et al.[42] showed that horizontal overlap (OJ) equal to or greater than 4mm was more prevalent in symptomatic subjects and McNamara et al.[43] found that overjet greater than 6-7mm was associated with specific diagnostic groups of TMD conditions. The mean overjet in our group was 6.9mm which is in agreement with both of these studies.

The overall cephalometric profile of our subjects generated a facial pattern characterized by mandibular retrognathia superimposed on a dolichofacial pattern, with a steep mandibular plane and large gonial angle. Dentally, the mandibular incisors were upright with increased overjet.

Future direction for research

In order to perform statistical analysis which would enable us to draw appropriate conclusions, a control group is necessary. Two control groups could be used for more accurate analysis; subjects with no condylar changes or normal joints (Grades 0) and subjects with mild condylar changes (Grades 1 and 2). These 2 groups could be compared to our sample with moderate-severe condylar changes in order to ascertain which diagnostic characteristics, cephalometric measurements and treatment modalities are more consistent in the moderate-severe condylar changes group. With this information in hand, one could possibly be able to obtain risk factors or take in to account which particular cephalometric values tend to be associated with moderate-severe condylar pathology.

Another direction for further research would be to observe condylar changes in the short term (during treatment and up to a two year follow-up period) to see if condylar changes can be correlated to skeletal morphological changes of the face as well as occlusal changes and dental relapse.

Conclusions

Results from this study are inconclusive without a control group but the following observations can be made:

1. The prevalence of *moderate to severe* TMJ condylar degeneration, as diagnosed from a panoramic radiograph, in a pre-orthodontic population at the University of Western Ontario in London, Ontario, Canada from 1983 to 2007 was 3.02%
2. Subjects with moderate to severe TMJ condylar degeneration demonstrated:
    a. Mandibular retrognathia (increased facial convexity, decreased Pg-Na perpendicular, decreased SNB, increased ANB, and increased overjet when compared to established cephalometric standards)
    b. Upright mandibular incisors (decreased lower incisors – mandibular plane angle and increased overjet when compared to established cephalometric standards)
    c. Dolichofacial pattern and vertical growth pattern (increased mandibular plane angle, increased gonial angle and decreased Rickett's facial axis when compared to established cephalometric standards)
3. Females are at risk for developing TMJ condylar changes
4. Subjects requiring orthognathic surgery may be at risk for developing TMJ condylar changes
5. The use of Class II or III elastics may increase the risk of developing TMJ condylar changes

Tables

Table 1. Cephalometric measurements used

Soft Tissue Profile Measurements	***Cranial Base Measurements***	***Skeletal Measurements***	***Dental Measurements***	***Vertical Measurements***
Nasolabial angle (°)	Articular angle (Na-S-Ba) (°)	SNA (°)	U1-SN (°)	*Palatal plane:* SN-PP (°) FH-PP (°) PP-MP (°)
Facial angle (FH-NPo) (°)		SNB (°)	U1-NA (°)	
Facial convexity (A-NPo) (mm)		ANB (°)	U1-NA (mm)	*Mandibular Plane:* SN-MP (°) FH-MP (°)
Lower lip – E plane (mm)		Na-A perpendicular (mm)	U1-PP (°)	
		Na-Pg perpendicular (mm)	U1-L1 (°)	*Occlusal Plane:* SN-OP (°) FH-OP (°)
		Wits (mm)	L1-APo (mm)	
		Articular angle (SN-ArGo) (°)	IMPA (°)	*Gonial angle:* Ar-Go-Me (°) Ar-Go-Gn (°)
		Maxillary length (Co-A) (mm)	OB (mm)	
		Mandibular Length (Co-Gn) (mm)	OJ (mm)	*Ramus height* (ArGo) (mm)
		Maxillo-mandibular differential (mm)		*Y-axis* Down's (SN-SGn) (°) (FH-SGn) (°)
				Upper Face Height (UFH) Na-ANS (mm)
				Lower Face Height (LFH) ANS-Me (mm)
				Anterior Face Height (Na-Me) (mm)
				Posterior Face Height (SGo) (mm)
				Posterior-Anterior Face Height
				Rickett's Facial Axis (NaBa-PtmGn) (°)

Table 7. Comparison of Values

	Cephalometric Measurement	UWO Sample	Gidarakou et al.	Peltola et al.
Cranial Base	NaSBa (°)	130.6°	131.1°	
Soft Tissue Profile	Facial angle (FH-NPo) (°)	86.1°	84.0°	
Skeletal	SNB (°)	75.9°	74.2°	77.8°
	ANB (°)	4.3°	4.4°	3.4°
Dental	U1-SN (°)	103.9°	101.8°	
	U1-PP (°)	111.5°	109.0°	114.4°
	U1-L1 (°)	130.0°	125.1°	
	L1-APo (mm)	1.3mm	3.5mm	
	IMPA (°)	88.3°		96.6°
	Overbite (mm)	2.9mm	2.5mm	
	Overjet (mm)	6.9mm	4.7mm	
Vertical	SN-MP (°)	37.9°		29.6°
	FH-MP (°)	28.9°	34.5°	
	PP-MP (°)	30.4°	34.1°	23.0°
	PP-OP (°)	9.5°	15.0°	
	FH-OP (°)	8.0°	13.1°	
	Ar-Go-Gn (°)	126.9°	129.9°	
	Ar-Go-Me (°)	132.9°		122.3°
	Ramus height (mm)	45.8mm	44.5mm	
	Y-axis (SGn-FH) (°)	60.4°	64.0°	
	P-AFH (%)	62.5%		68%

Figures

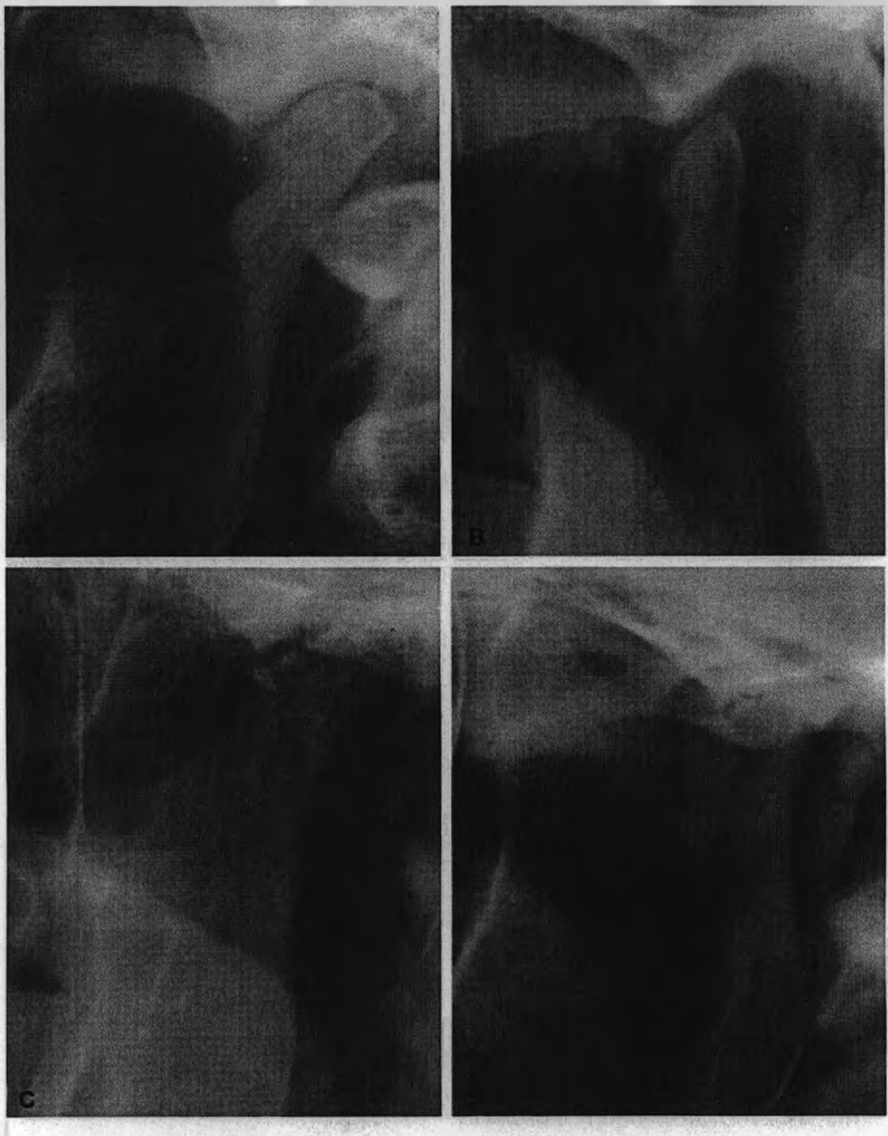
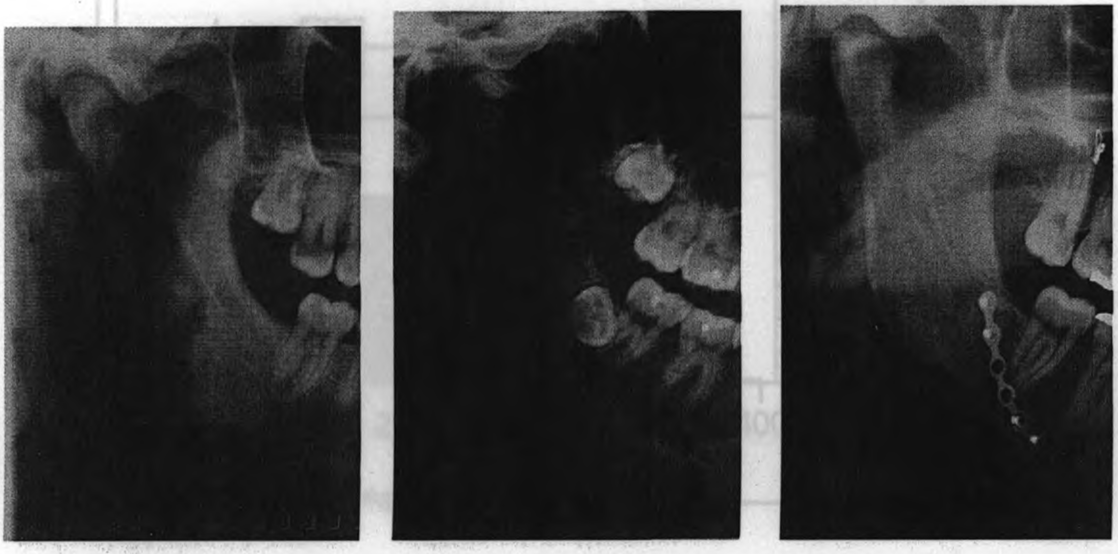


Figure 1. TMJ condylar assessment score guide

Figure 1 Legend: Scores were designated as follows: Grade 0 – no erosion of the TMJ condyle, Grade 1 – very slight erosion of the TMJ condyle (A), Grade 2 – erosion of the top of the TMJ condyle (B), Grade 3 – erosion of half of the TMJ condyle (C), Grade 4 – complete erosion of TMJ condyle (D)



OSTEOPHYTE (a) *SCLEROSIS (b)* *IRREGULAR BORDER (c)*

Figure 2, 3, and 4. Condylar assessment score subdivisions

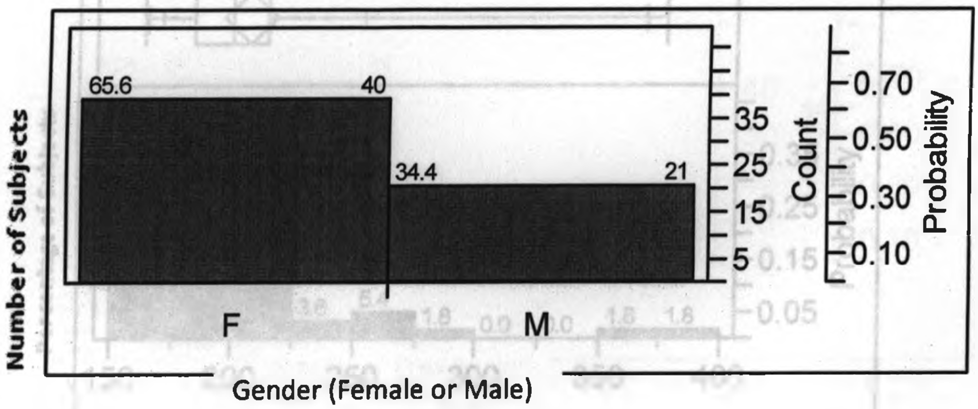


Figure 5. Gender distribution of the sample

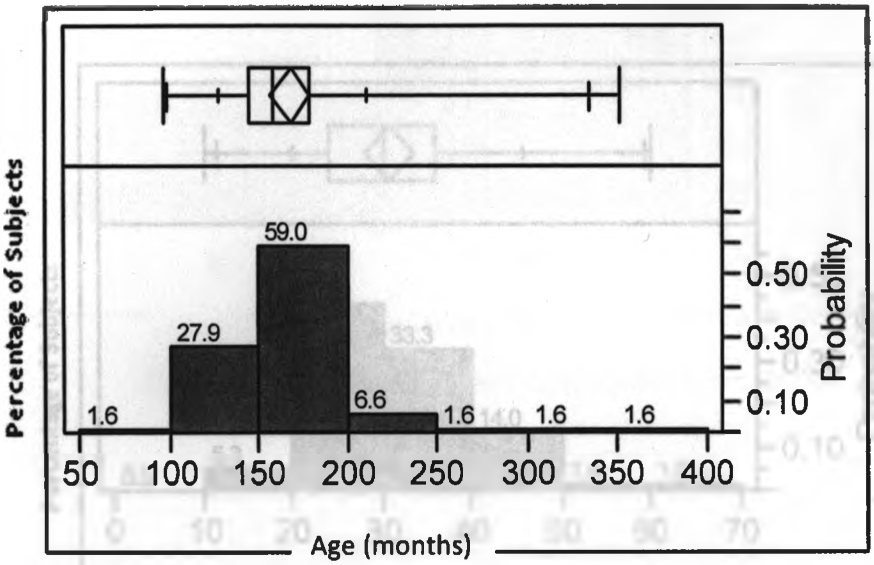


Figure 6. Age distribution of the sample at initiation of treatment

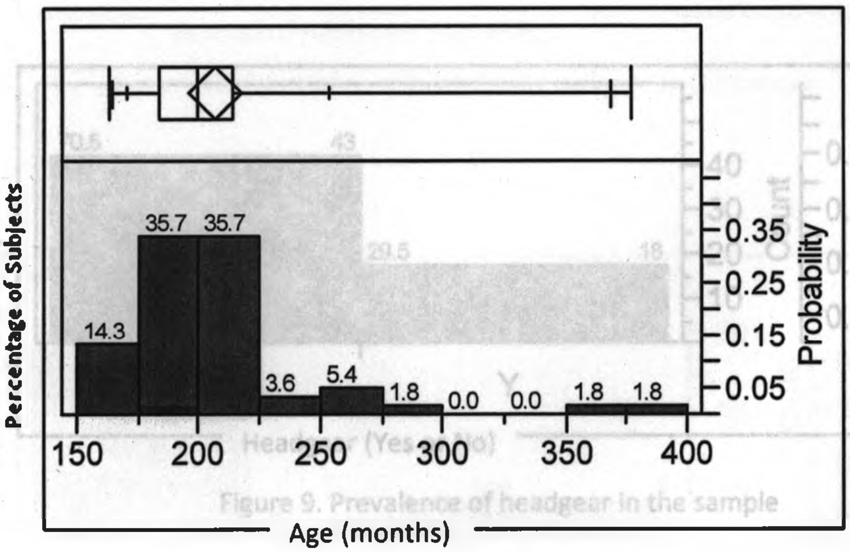


Figure 7. Age distribution of the sample at termination of treatment (deband)

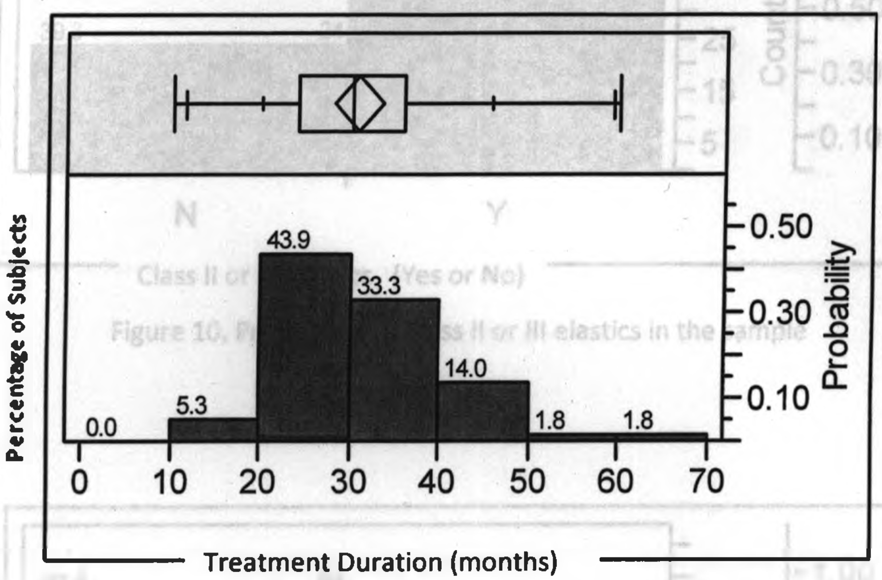


Figure 8. Treatment duration of the sample

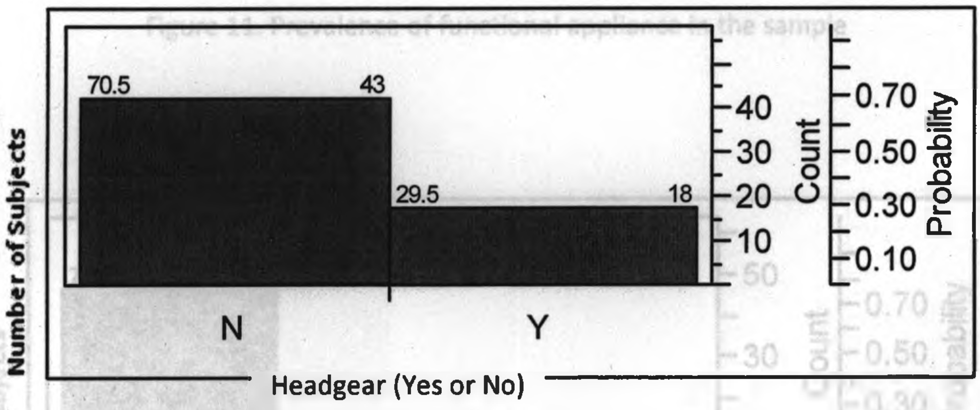


Figure 9. Prevalence of headgear in the sample

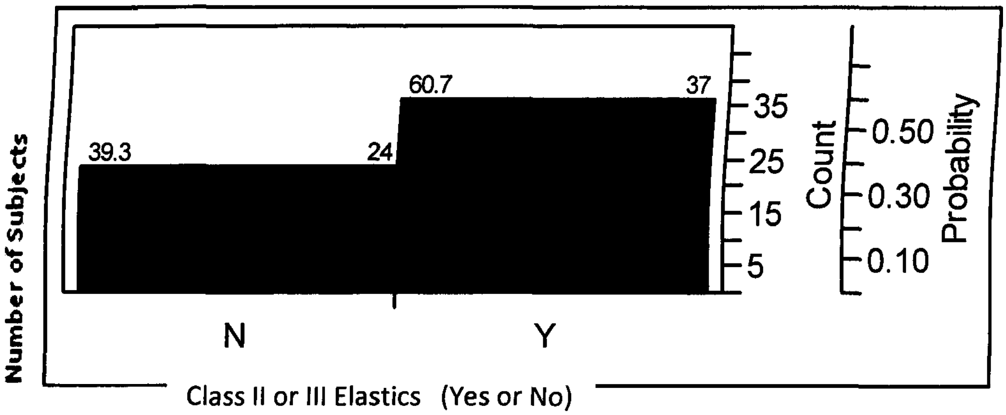


Figure 10. Prevalence of Class II or III elastics in the sample

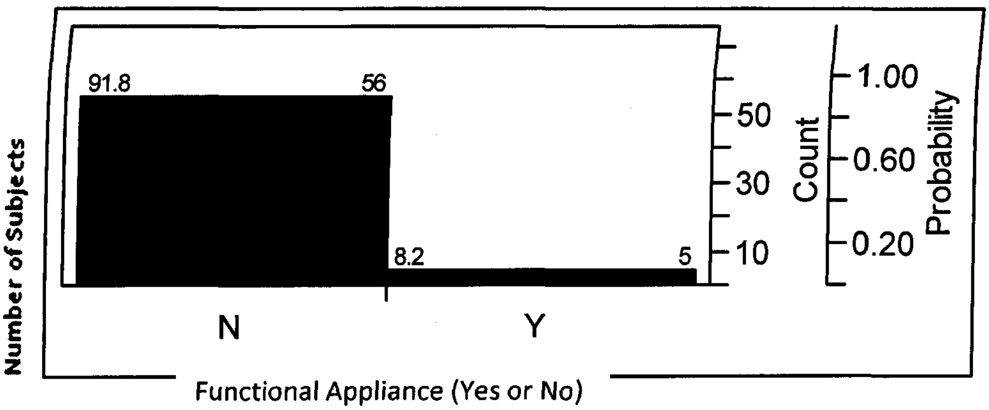


Figure 11. Prevalence of functional appliance in the sample

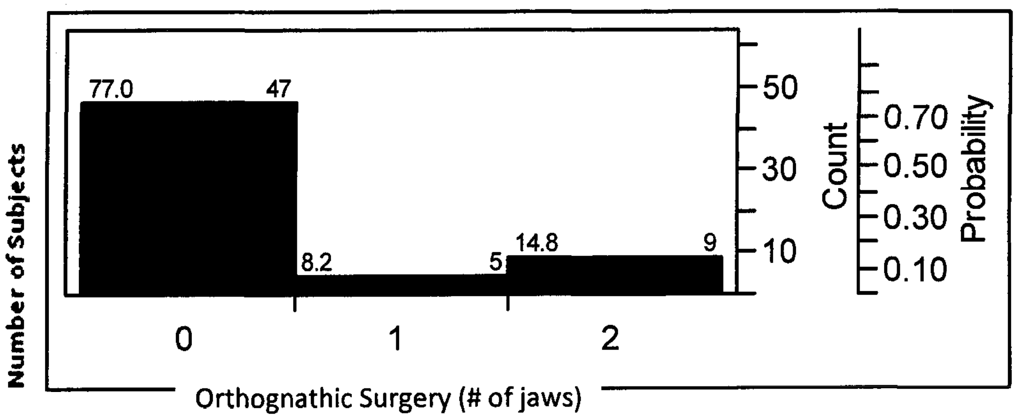


Figure 12. Prevalence of orthognathic surgery in the sample

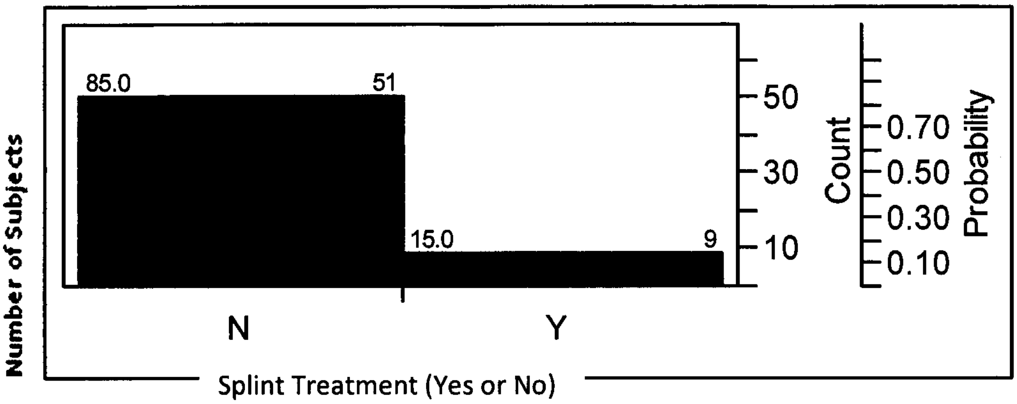


Figure 13. Prevalence of splint treatment in the sample

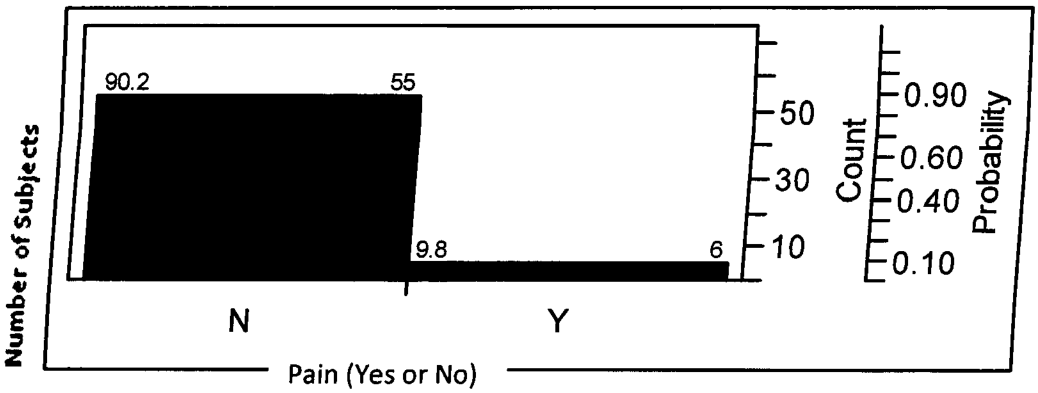


Figure 14. Prevalence of pain in the sample

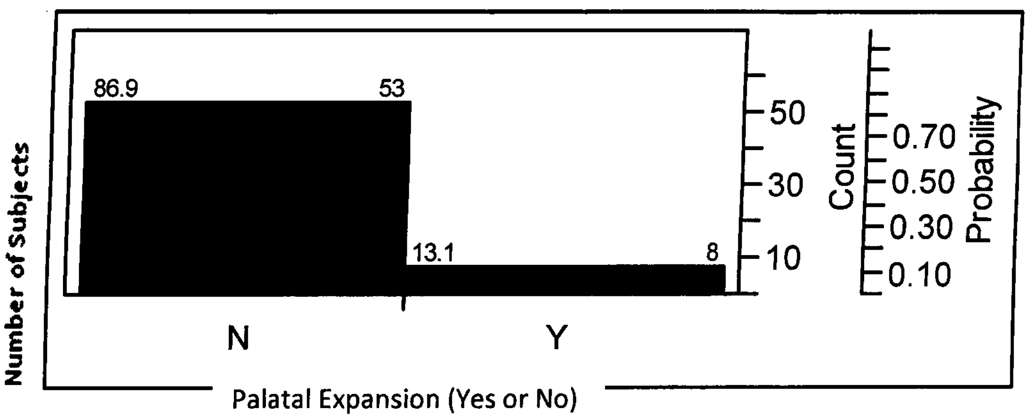


Figure 15. Prevalence of palatal expansion in the sample

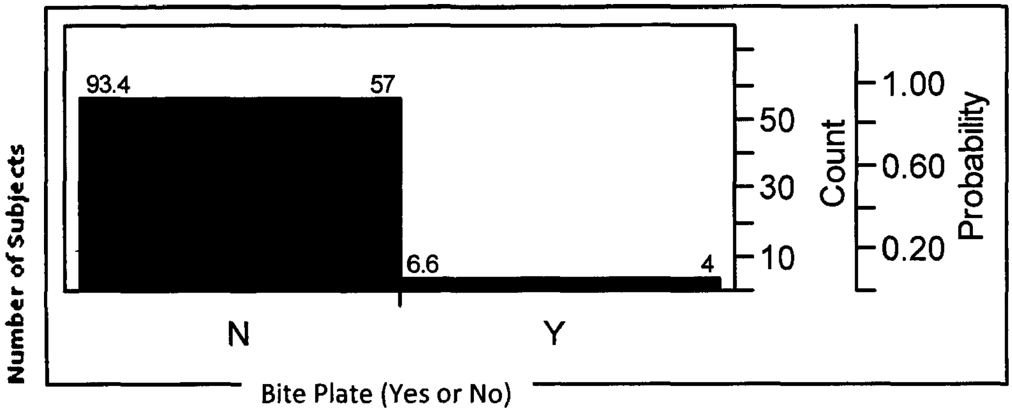


Figure 16. Prevalence of bite plate in the sample

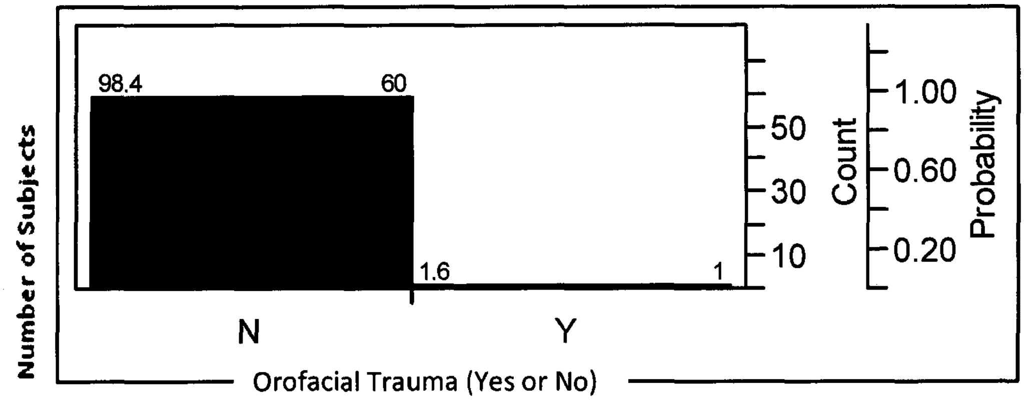


Figure 17. Prevalence of history of orofacial trauma in the sample

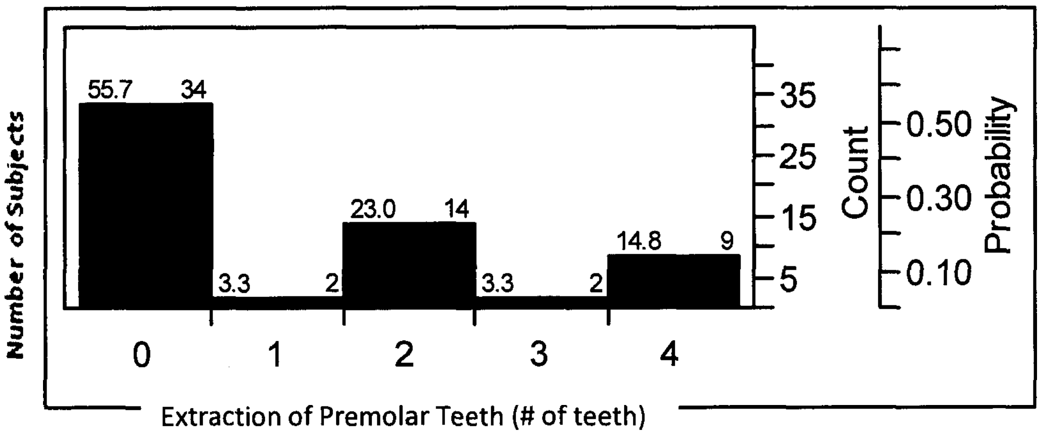


Figure 18. Prevalence of extraction of premolar teeth in the sample

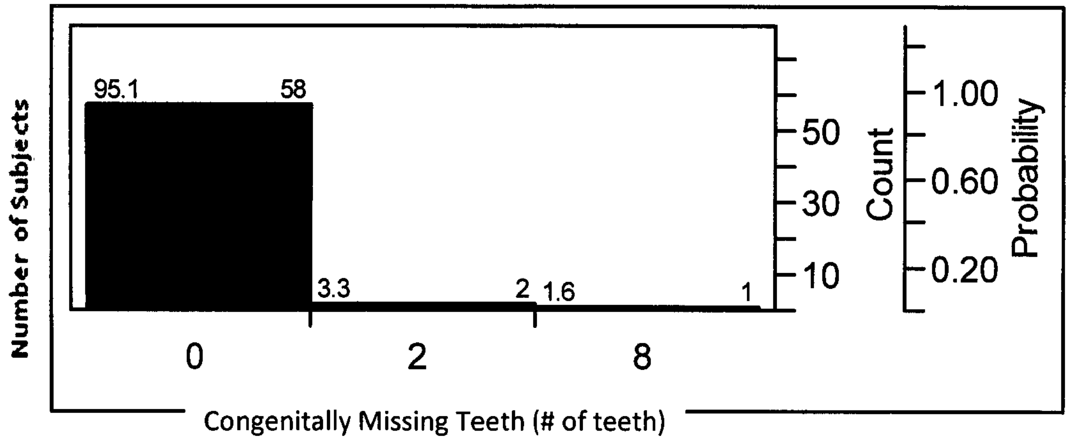


Figure 19. Prevalence of congenitally missing teeth in the sample

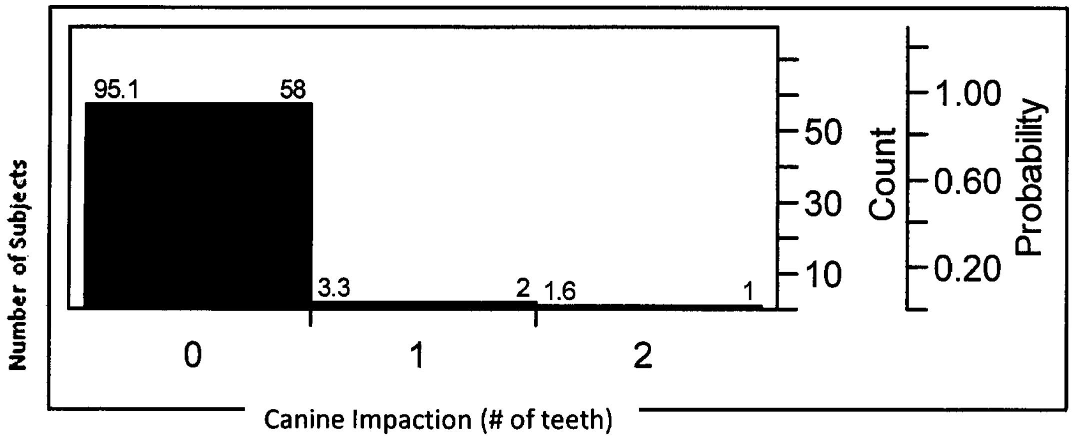


Figure 20. Prevalence of canine impaction in the sample

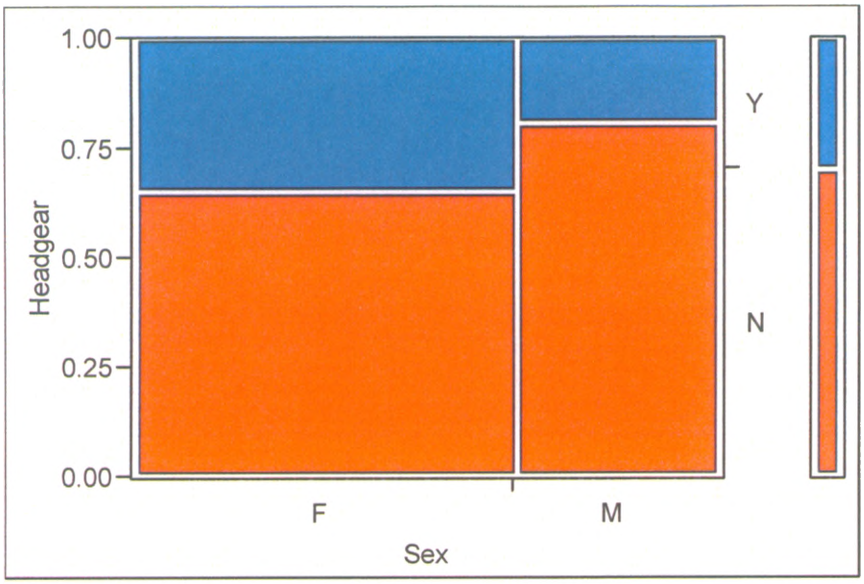


Figure 21. Association of headgear treatment by sex

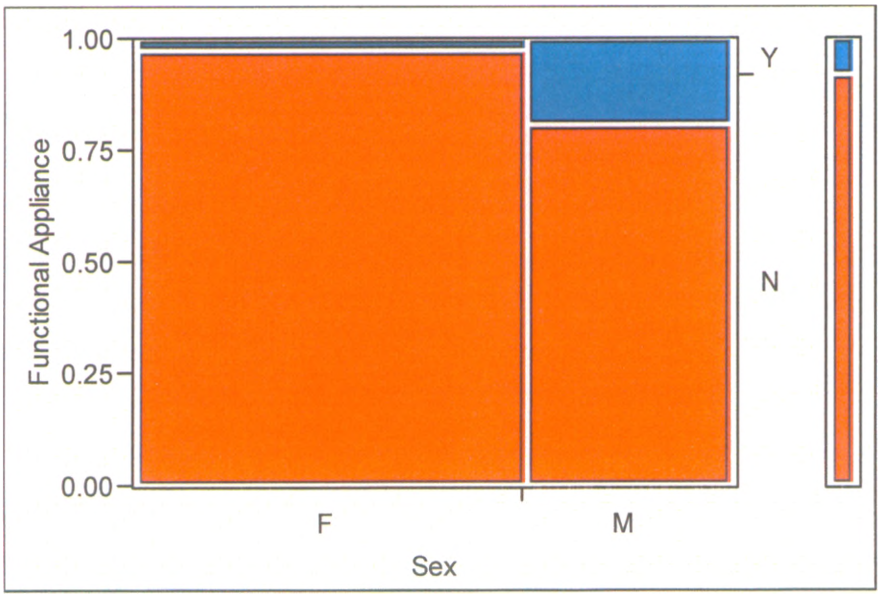


Figure 22. Association of functional appliance treatment by sex

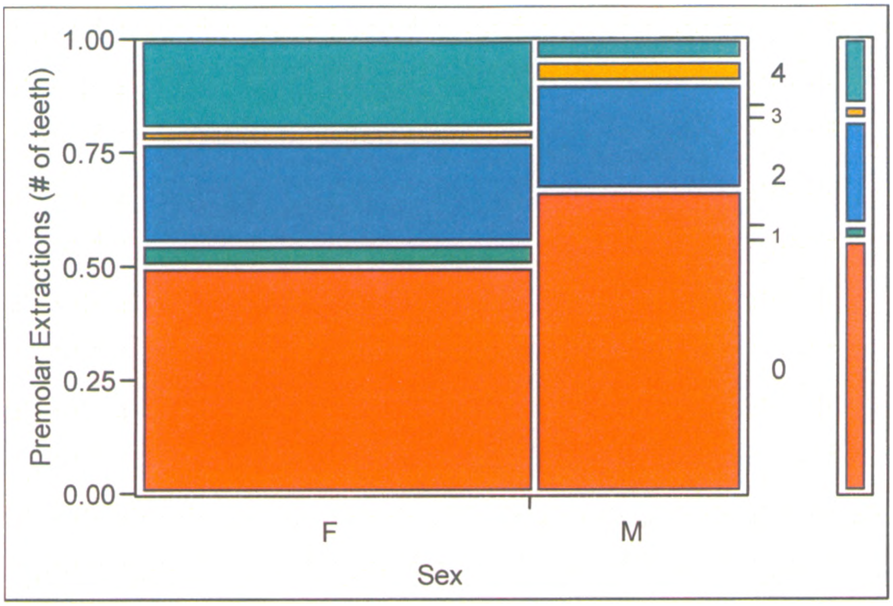


Figure 23. Association of premolar extraction treatment by sex

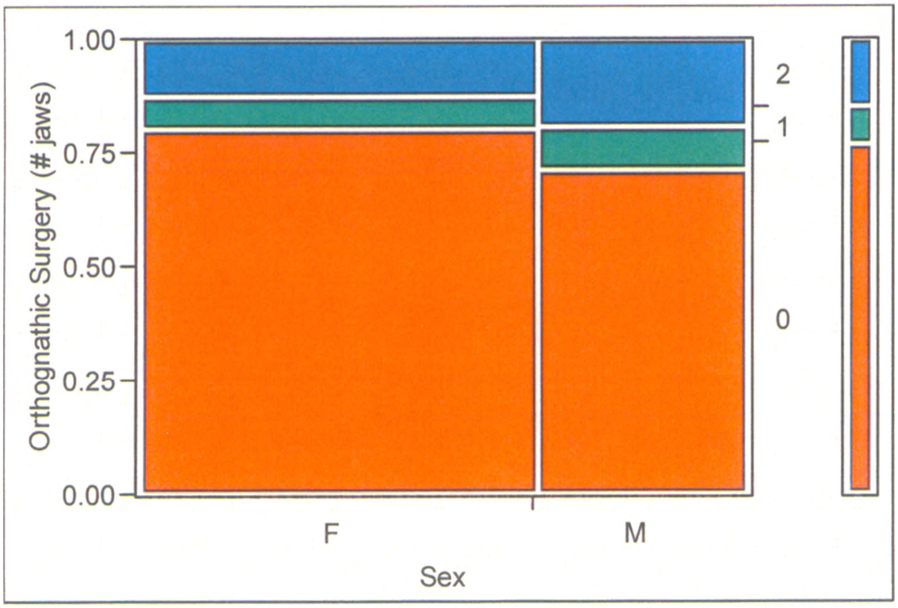


Figure 24. Association of orthognathic surgery treatment by sex

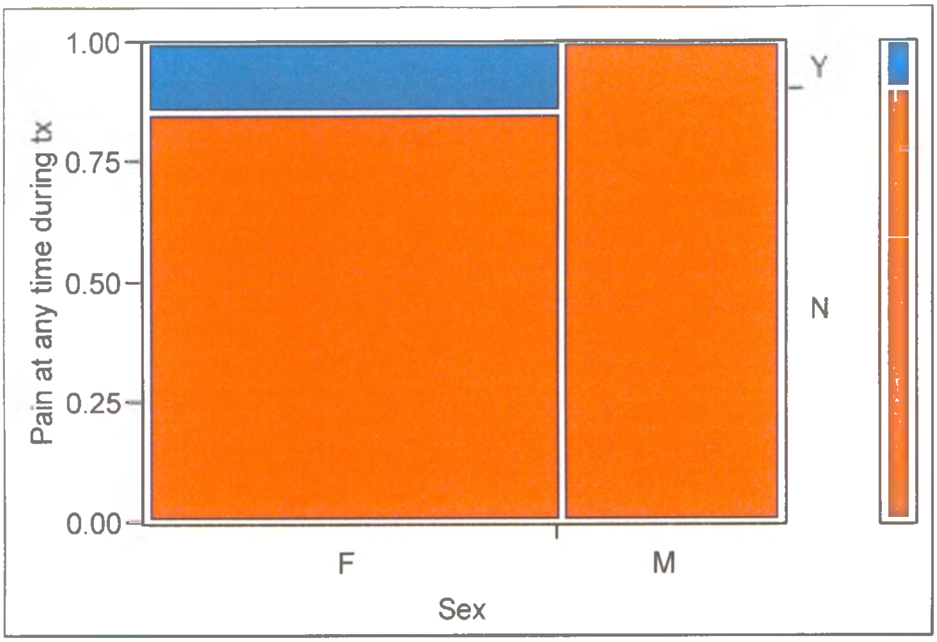


Figure 25. Association of pain by sex

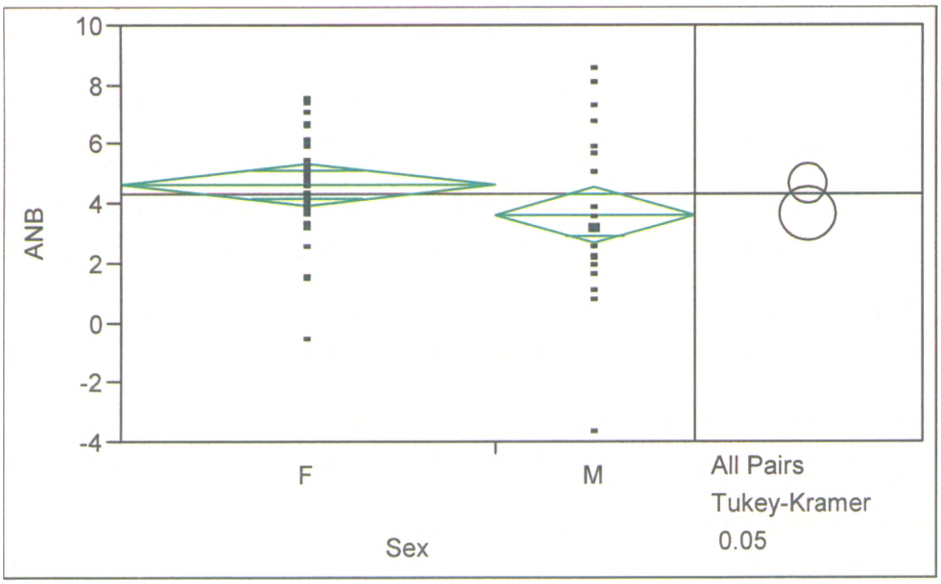


Figure 26. Association of the cephalometric measurement of ANB by sex

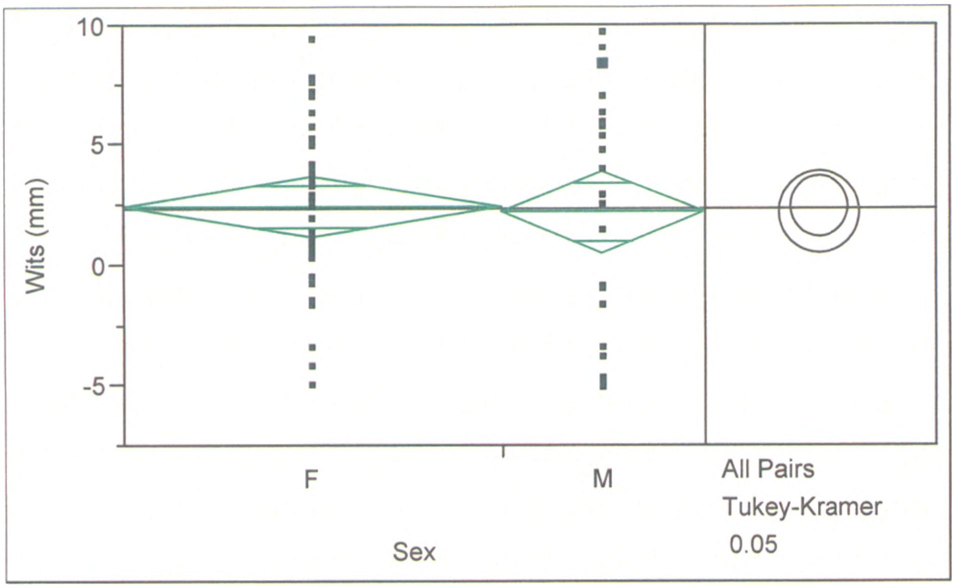


Figure 27. Association of the cephalometric measurement of Wits by sex

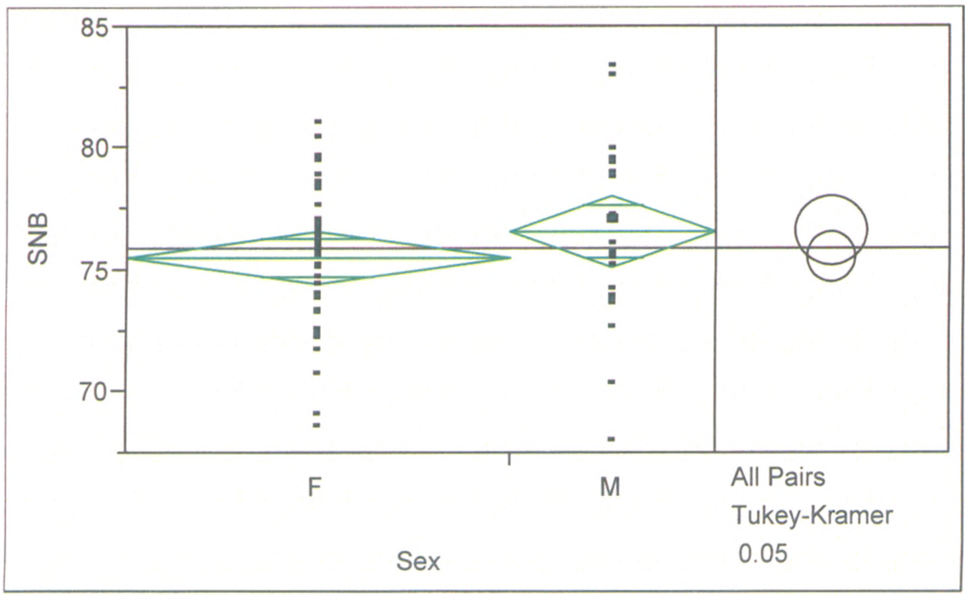


Figure 28. Association of the cephalometric measurement of SNB by sex

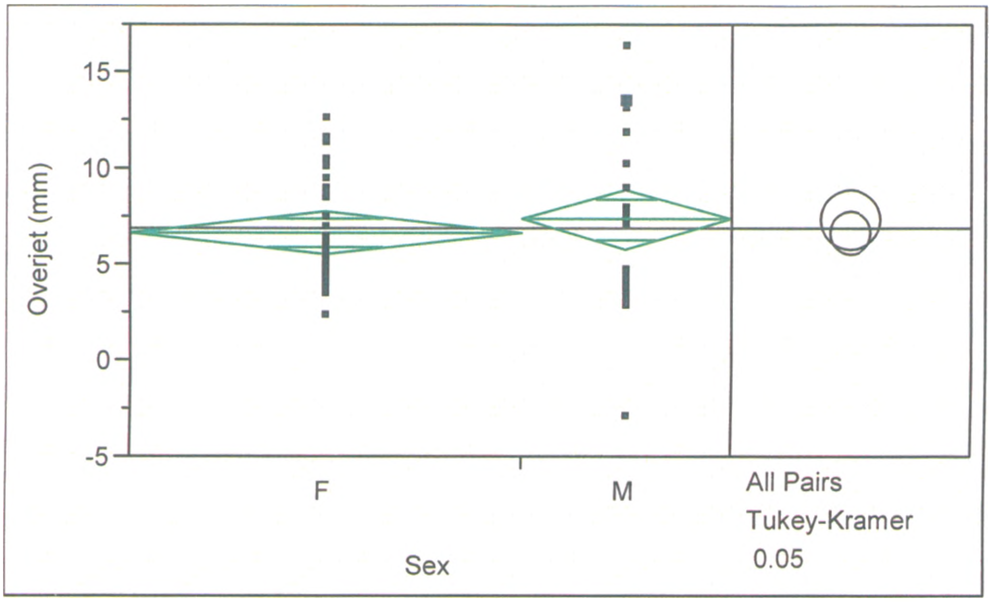


Figure 29. Association of the cephalometric measurement of overjet by sex

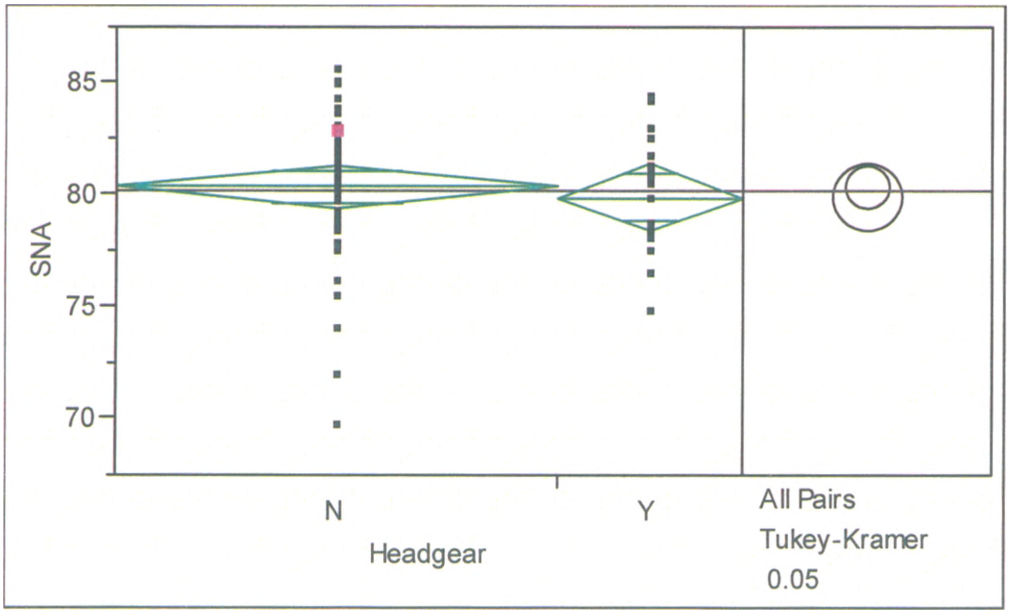


Figure 30. Association of headgear treatment by the cephalometric measurement of SNA

Appendix I

TMJ Condylar Assessment Score

TMJ condylar scoring was based on a system outlined and utilized by Helenius et al. Examples of gradings are demonstrated in the diagram below as per Helenius et al. They designated grade 0 as no erosion of the condylar head, grade 1 as very slight erosion (Figure 1 A), grade 2 as erosion of the top of the condyle (Figure 1 B), grade 3 as erosion of half of the condyle (Figure 1 C), and grade 4 as complete erosion of condyle (Figure 1 D).

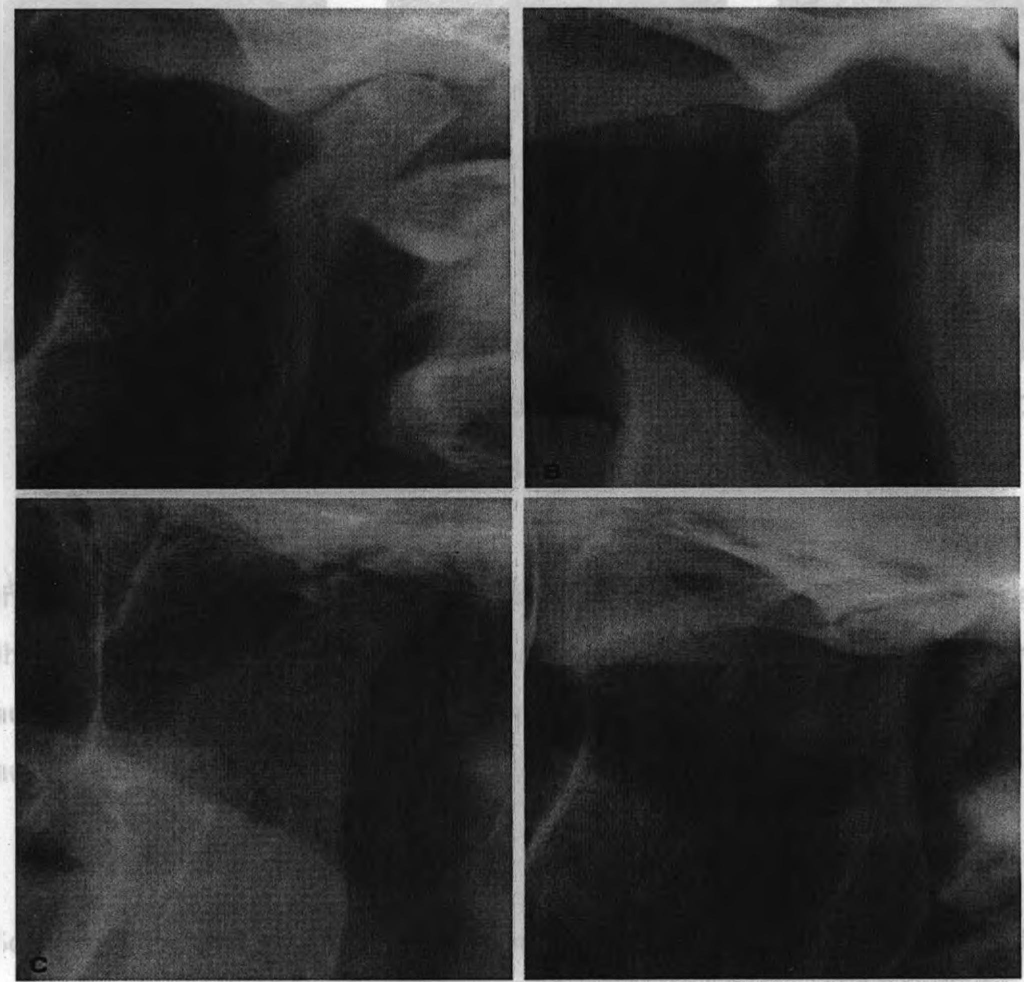
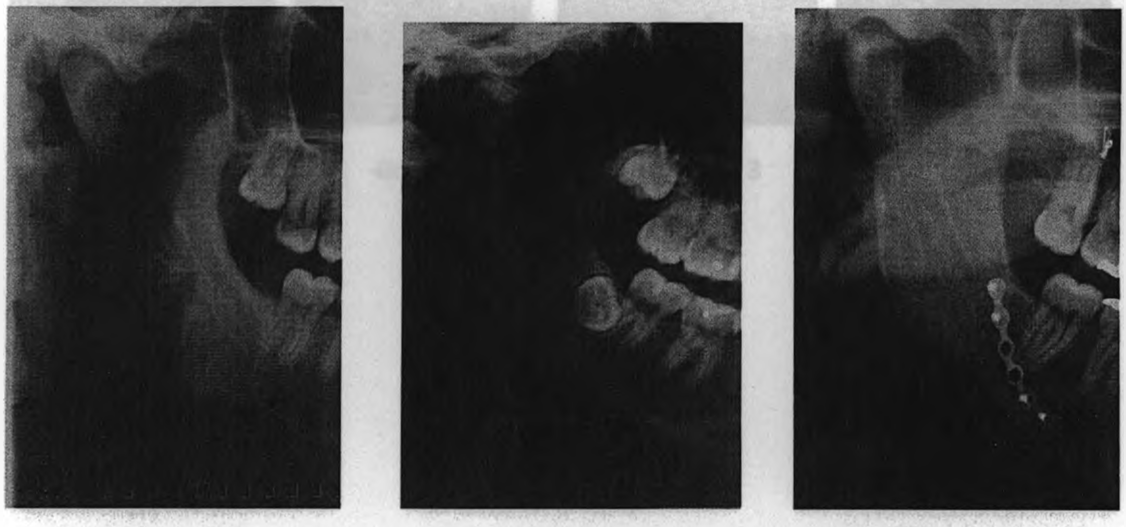


Figure 1. Condylar assessment score guide

Subdivisions were also added mainly for condylar surfaces with irregularities. These included: osteophyte (a) defined as a marginal bony outgrowth, sclerosis (b) defined as a local area with increased density of the cortical bony joint surface extending into the subcortical bone, and irregular border or concavity (c) defined as a hollowed out area on the bony contour with a well-defined cortical outline of the joint surface.



OSTEOPHYTE (a) SCLEROSIS (b) IRREGULAR BORDER (c)

Figure 2, 3, and 4. Condylar assessment score subdivisions

If a subject was assigned a grade of 2 with a subdivision (a, b, or c), grade 3, or grade 4, there were to be included in the sample. Scoring of all sample subjects was done by one author (DZB). When a subject had a score that was borderline between 2 or 3, a second author was consulted (AHM).

Scores of 0 to 2 were considered to be mild, scores of 2a, b, or c and scores of 3 were considered to be moderate, and scores of 4 were considered to be severe bony condylar changes.

Examples of condyle assessment score of subjects from our study:

Grade 1

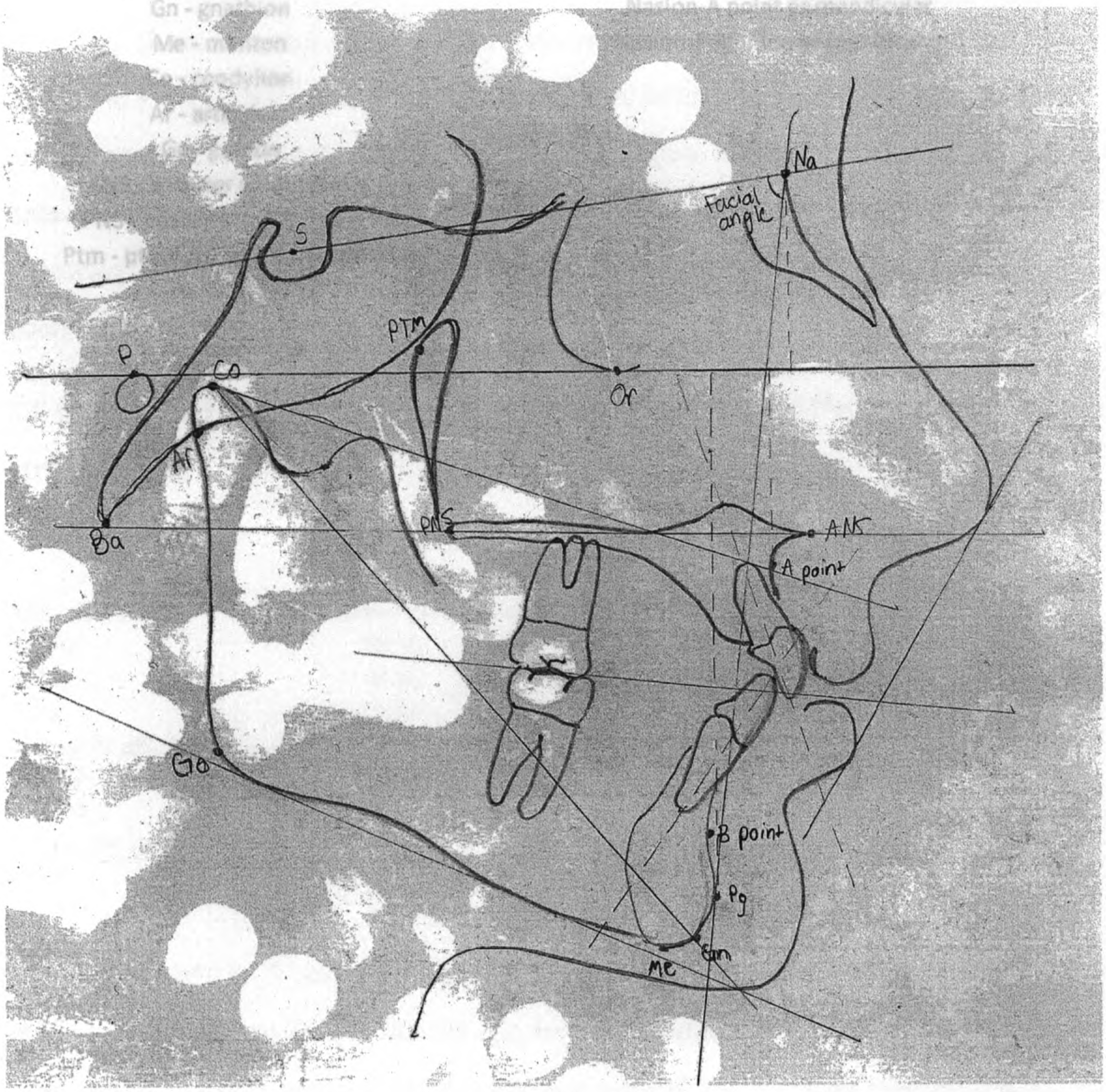
Grade 2

Grade 3

Grade 4

Appendix II

Cephalometric Study



Cephalometric Points Used

Na - nasion
S - sella
Ba - basion
Or - orbitale
P - porion
A - A point
B - B point
Pg/Po - pogonion
Gn - gnathion
Me - menton
Co - condylion
Ar - articulare
Go - gonion
ANS - anterior nasal spine
PNS - posterior nasal spine
Ptm - pterygomaxillary fissure

Cephalometric Lines used

Frankfurt Horizontal (FH) P-Or
Sella-Nasion (SN)
Occlusal Plane (OP)
Mandibular Plane (MP) - line tangent to lower border of mandible
Palatal Plane (PP) - ANS to PNS
Upper incisor angulation (U1)
Lower incisor angulation (L1)
E Plane - line tangent to tip of nose and lower lip
Nasion-A point perpendicular
Nasion-Pogonion perpendicular

Appendix III

Error Study

The cephalometric radiographs of 16 subjects were randomly selected from the sample and retraced about one year after the initial tracing on Dolphin Imaging 10.0. Eight cephalometric measurements were selected to include as many landmarks as possible. These included U1-PP, IMPA, ANB, ramus height, PP-MP, OP-FH, Y-axis (SN-SGn), and FMA. Differences were then calculated between the original and retraced measurements. The measurement error of the original measurements and difference between the original and the retraced measurements was then calculated. The following formula was then used to calculate the intra-class correlation coefficient for each of the eight measurements:

ICC (R) = measurement error (original) – measurement error (difference)/measurement error (original)

Measurement	Original measurement error	Difference measurement error	ICC
U1-PP	83.49	1.34	0.98
IMPA	44.45	0.69	0.98
ANB	332.98	0.07	1
ramus height	30.1	3.32	0.89
PP-MP	12.55	0.67	0.95
OP-FH	33.35	1.2	0.96
Y-axis (SN-SGn)	8.04	1.53	0.81
FMA	11.04	1.16	0.9

The eight ICC's were then added together and divided by eight to achieve the mean ICC. The mean ICC or R for this study was calculated to be 0.934. This can be interpreted as a 93% agreement between the original and retraced measurements. For orthodontic cephalometric studies, and R of at least 0.9 is considered desirable.

Appendix IV

Condylar Grading by Subject

	Condylar Assessment Score					
	Initial		*Deband*		*2 Year Retention*	
Subject	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**
1	Grade 1	Grade 1	Grade 1	Grade 1	Grade 3	Grade 3
2	Grade 1	Grade 2	Grade 1	Grade 2	Grade 1	Grade 3
3	Grade 2	Grade 2	Grade 2	Grade 2	Grade 3	Grade 3
4	Grade 1	Grade 3	Grade 1	Grade 4	Grade 2	Grade 4
5	Grade 2	Grade 0	Grade 2	Grade 0	Grade 3	Grade 1
6	Grade 2	Grade 1	Grade 2	Grade 1	Grade 3	Grade 1
7	Grade 0	Grade 2	Grade 1	Grade 2	Grade 1	Grade 2c
8	Grade 1	Grade 3	Grade 1	Grade 3	n/a	n/a
9	Grade 2	Grade 1	Grade 3	Grade 1	Grade 3	Grade 1
10	Grade 2	Grade 1	Grade 2	Grade 1	Grade 3	Grade 1
11	Grade 0	Grade 2	Grade 0	Grade 3	n/a	n/a
12	Grade 0	Grade 2	Grade 1	Grade 2	Grade 1	Grade 2c
13	Grade 2	Grade 0	Grade 3	Grade 0	n/a	n/a
14	Grade 2	Grade 2	Grade 2a	Grade 2a	Grade 2a	Grade 2a
15	Grade 2	Grade 0	Grade 2	Grade 1	Grade 3	Grade 1
16	Grade 2	Grade 1	Grade 2	Grade 2	Grade 3	Grade 2
17	Grade 0	Grade 1	Grade 0	Grade 1	Grade 1	Grade 3
18	Grade 2	Grade 0	Grade 2	Grade 0	Grade 3	Grade 1
19	Grade 2	Grade 0	Grade 2c	Grade 1	Grade 2c	Grade 1
20	Grade 2	Grade 2	Grade 2	Grade 2	Grade 3	Grade 2
21	Grade 1	Grade 1	Grade 1	Grade 2	Grade 1	Grade 3
22	Grade 3	Grade 1	n/a	n/a	n/a	n/a
23	Grade 2	Grade 1	Grade 2	Grade 2	Grade 3	Grade 3
24	Grade 1	Grade 2	Grade 1	Grade 2	Grade 1	Grade 3
25	Grade 1	Grade 0	Grade 1	Grade 1	Grade 3	Grade 3
26	Grade 2	Grade 1	Grade 2	Grade 1	Grade 3	Grade 1
27	Grade 0	Grade 2	Grade 1	Grade 2a	n/a	n/a
28	Grade 2	Grade 1	Grade 2	Grade 1	Grade 3	Grade 1
29	Grade 2	Grade 2	Grade 3	Grade 3	n/a	n/a
30	Grade 2	Grade 1	Grade 3	Grade 1	Grade 3	Grade 1

31	Grade 3	Grade 3	Grade 3	Grade 3	Grade 3	Grade 3
32	Grade 2	Grade 1	Grade 2	Grade 1	Grade 3	Grade 0
33	Grade 2	Grade 2	Grade 2	Grade 2	Grade 3	Grade 3
34	Grade 2	Grade 1	Grade 2	Grade 3	n/a	n/a
35	Grade 2	Grade 0	Grade 2	Grade 0	Grade 3	Grade 1
36	Grade 2	Grade 1	Grade 2	Grade 1	Grade 3	Grade 2
37	Grade 2	Grade 0	Grade 2	Grade 1	Grade 3	Grade 1
38	Grade 1	Grade 2	Grade 2	Grade 2	Grade 3	Grade 2
39	Grade 2	Grade 0	Grade 2	Grade 1	Grade 3	Grade 1
40	Grade 2	Grade 0	Grade 3	Grade 1	Grade 3	Grade 1
41	Grade 0	Grade 2	Grade 1	Grade 3	Grade 1	Grade 3
42	Grade 1	Grade 2	Grade 1	Grade 3	n/a	n/a
43	Grade 0	Grade 2	Grade 0	Grade 2a	Grade 1	Grade 2a
44	Grade 0	Grade 1	Grade 1	Grade 2a	n/a	n/a
45	Grade 2	Grade 3	n/a	n/a	n/a	n/a
46	Grade 2	Grade 0	Grade 2	Grade 1	Grade 3	Grade 1
47	Grade 2	Grade 2	Grade 3	Grade 3	n/a	n/a
48	Grade 2	Grade 2	Grade 3	Grade 1	n/a	n/a
49	Grade 2	Grade 0	Grade 3	Grade 1	n/a	n/a
50	Grade 0	Grade 2	Grade 1	Grade 2	Grade 2	Grade 3
51	Grade 2	Grade 3	Grade 3	Grade 3	Grade 3	Grade 4
52	Grade 2	Grade 1	Grade 2	Grade 1	Grade 3	Grade 1
53	Grade 2	Grade 0	Grade 2	Grade 2	Grade 3	Grade 3
54	Grade 1	Grade 2	Grade 1	Grade 2	Grade 1	Grade 3
55	Grade 2	Grade 1	Grade 2	Grade 2	Grade 3	Grade 3
56	Grade 2	Grade 0	Grade 2	Grade 2	Grade 3	Grade 2
57	Grade 3	Grade 1	n/a	n/a	n/a	n/a
58	Grade 1	Grade 2	Grade 1	Grade 3	n/a	n/a
59	Grade 2	Grade 3	n/a	n/a	n/a	n/a
60	Grade 3	Grade 2	Grade 3	Grade 2	Grade 3	Grade 2
61	Grade 1	Grade 2	Grade 2	Grade 2	Grade 3	Grade 3

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