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Research Article

Measurement of Occlusal Force in Orthognathic Surgery using Force Sensing Sensors

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Abstract

Purpose: This study was designed to apply alternative and innovative methods of measuring muscle area, volume, structure, function and fibre orientation to a situation where adaptation of muscle is pivotal to the success of a therapeutic approach.
Materials and Methods: Ten patients attending the combined orthodontic/orthognathic surgery clinic at the Clitrofa – Centro Médico, Dentário e Cirúrgico, in Trofa - Portugal were tested according to the following protocol:
a) Bite Training Machine: The occlusal contact area indicator was placed between the upper and lower dental arch, and the subjects were instructed to bite as forcefully as possible for about 3 seconds. The values were visualized in the dynamometer and the procedure was repeated after 10 minutes until the patient felt comfortable.
b) Occlusal Force Diagnostic System: The system was placed between the upper and lower dental arch, and the subjects were instructed to bite as forcefully as possible for about 3 seconds. The values were registered (T0) and the procedure was repeated after 10 minutes (T1), and 1 month after surgery (T2).
In this study, the bite force and occlusal pressure were measured for 10 patients twice by two different observers. These 10 patients were scheduled for a bimaxillary osteotomy involving a combination of maxillary Le Fort I impaction procedure coupled with a sagittal split advancement of the mandible.
Conclusions: When comparing pre-op (Times 0 and 1) and post-op (Time 2) data, significant statistical differences have been found in the mean bite pressure measured by FSS sensor Q3/P3 located in the anterior region of the maxilla/ mandible ($p < 0,05$), those differences being absent in the remaining FSS sensors Q1/P1, Q2/P2, Q4/P4 and Q5/P5 ($p > 0,05$). Significant differences ($p < 0,05$) have been identified between certain pairs of FSS sensors, allowing the definition of a three-pressure region model where the key-factor seems to be the relative distance of the sensors to the occlusion region: the higher the distance to the occlusion region, the lower is the mean bite pressure (psi).

Keywords
Orthognathic Surgery; Masseter Muscle; Occlusal Force Measurement

Declaration of Conflicting Interest

The authors declare that they have no conflict of interest.

Introduction:

One of the main purposes of orthognathic treatment in patients with a dentofacial deformity is to improve masticatory function as well as aesthetics. Numerous studies have documented masticatory function for example: including bite force, occlusal contact and masticatory efficiency, in patients with mandibular prognathism before and after orthognathic surgery[1,2,3,4,5,6,7,8,9,10,11,12,13] but few reports compared the results with those in controls with normal occlusion[1,3,6,7,8,9,12,13]. There have also been few studies that involved evaluation of these parameters at the initial medical consultation for patients undergoing orthognathic surgery[14,15]. No reports were found that simultaneously evaluated the relationships between bite force, occlusal contact and masticatory efficiency in patients with mandibular prognathism and in controls with normal occlusion.

Previously, changes in bite force and occlusal contact before and after orthognathic surgery were investigated and presented using the T-Scan system™ (Tekscan, USA)[3]. This system is convenient and simple but is poor in regard to reproducibility and quantification. Another method for occlusal analysis, the Dental Prescale™ system (Fuji Photo Film Co., Japan), has been developed. It is a horseshoe-shaped thin film that consists of two layers: a layer of microcapsules containing colour-forming materials and a layer of colour-developing materials. The colour-developing materials, producing a red colour in the contact area when a force is generated, absorb the released colour-forming materials. The Dental Prescale™ system has already been used for analysing occlusion in dentures[16,17], dental implants[18] and orthognathic surgery[7,8].

Many methods for the quantitative measurement of masticatory efficiency have been introduced, but none stands out as ideal. Spectrophotometric methods for the evaluation of masticatory efficiency have been reported, involving measurement of the absorbance of adenosine triphosphate (ATP) granules[6,7,12]. This technique shows accuracy and reproducibility but is complicated. A new chewing-gum system has been developed for the estimation of masticatory function by the Meiji Chewing Gum Corporation. It utilizes a phloxine–sodium bicarbonate reaction and measures a chromatic coordinate as an indicator. This low-adhesive colourdeveloping chewing-gum system has already been used for analyzing the masticatory function of dental implants[19] and dentures[20].

Force Sensing Sensors:

The FS Series sensors provide precise reliable force sensing performance in a compact commercial grade package. The sensor features a proven sensing technology that uses a specialized piezoresistive micromachined silicon sensing element. The low power, unamplified, uncompensated wheatstone bridge circuit design provides inherently stable mV outputs over the force range.

Force sensors operate on the principle that the resistance of silicon-implanted piezoresistors will increase when the resistors flex under any applied force. The sensor concentrates force from the applications, through the stainless steel ball, directly to the silicon-sensing element. The amount of resistance changes in proportion to the amount of force being applied. This change in circuit resistance results in a corresponding mV output level change.

The stainless steel ball provides mechanical stability and is adaptable to a variety of applications. The FSS sensor delivered 20 million operations in Mean Cycles to Failure (MCTF) reliability testing at 50°C [122°F]. This test determines the number of possible sensor operations at full scale until failure. Various electric interconnects can accept prewired connectors, printed circuit board mounting, and surface mountings. The sensor design also provides a variety of mounting options that include mounting brackets, as well as application specific mounting requirements.

Figure 1: Schematic illustration of the FSS sensor

Materials and Methods:

Ten patients attending the combined orthodontic/orthognathic surgery clinic at the Clitrofa – Centro Médico, Dentário e Cirúrgico, in Trofa - Portugal were tested according to the following protocol:
a) Bite Training Machine: In order to provide adequate training to the patients and teach how to bite in the same way during the study a bite training machine was developed. The major components of this new machine were: a dynamometer, a force indicator and an occlusal contact area indicator. The occlusal contact area was built in an hard photosensitive resin with a similar strength of the occlusal force diagnostic system, and two springs were placed to allow movement return. The dynamometer was order from Mitutoyo™ (Mitutoyo Corporation, USA) and ensure that patient was biting hard enough to see the reading.

The occlusal contact area indicator was placed between the upper and lower dental arch, and the subjects were instructed to bite as forcefully as possible for about 3 seconds. The values were visualized in the dynamometer and the procedure was repeated after 10 minutes until the patient felt comfortable.
b) Occlusal Force Diagnostic System: The system was placed between the upper and lower dental arch, and the subjects were instructed to bite as forcefully as possible for about 3 seconds. The values were registered (T0) and the procedure was repeated after 10 minutes (T1), and 1 month after surgery (T2).
The occlusal force diagnostic system has been developed between CEiiA - Centre of Engineering and Product Development in Oporto and the UCL, Eastman Dental Institute in London. One sensor was for the anterior teeth (central and lateral incisors), two sensors for the canine and first pre-molar and another two sensors for the second pre-molar and first molar. The objective of this sensors distribution was to make measurements of occlusal contact areas and occlusal pressures individually and in total. The sensors were connected between them, and the cables connected to a transducer that shows the digital reading in kilograms.

The five sensors were distributed in the following order, the readings were in kilograms:
Sensor A: right maxillary second pre-molar and right maxillary first molar between 1st and 4th quadrants;
Sensor B: right maxillary canine and right maxillary first pre-molar between 1st and 4th quadrants;
Sensor C: right and left maxillary central incisors and right and left maxillary lateral incisors area;
Sensor D: left maxillary second pre-molar and left maxillary first molar between 2nd and 3rd quadrants, and finally
Sensor E: left maxillary canine and left maxillary first pre-molar between 2nd and 3rd quadrants.

In this study, the bite force and occlusal pressure were measured for 10 patients twice by two different observers. These 10 patients were scheduled for a bimaxillary osteotomy involving a combination of maxillary Le Fort I impaction procedure coupled with a sagittal split advancement of the mandible.

The dental arch in a horseshoe-shaped form was built by a superior and an inferior 3mm height metal foil covered by an hard resin, with the following intra-oral measures: 63mm total width, 62mm total length, 15mm width in anterior occlusal contact area, 19mm width in posterior occlusal contact area, 30mm anterior height and 15mm posterior height. The dental arch dimensions were based on the majority of the dental arches studied during the improvement process.

The experimental design devised for this study is depicted in Figure 2, comprising a combination of different examiners, sensors and times of measurement.

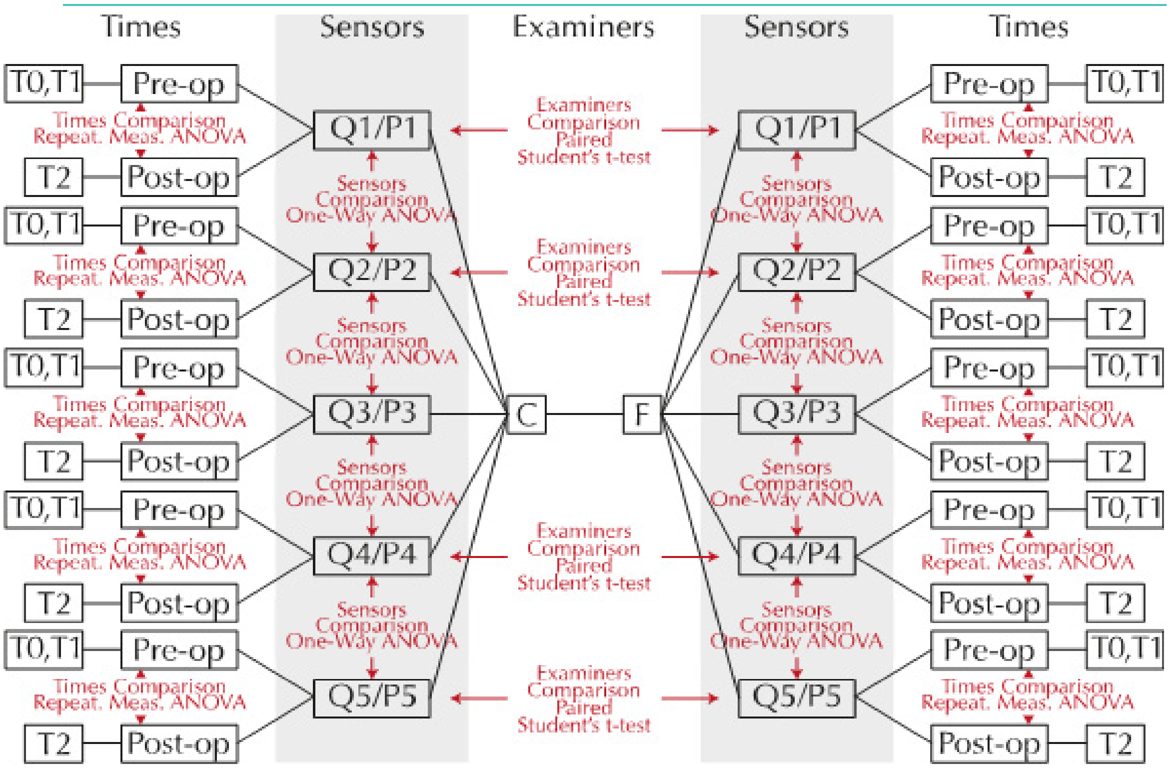

Figure 2: Experimental design used for the measurement of occlusal force. The study involved the contribution of two independent examiners (F and C), that measured the bite pressure (psi) in five different FSS sensors (Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5) at three different time moments (Time 0, Time 1 and Time 2).

IBM® SPSS® version 25 was used to analyze the data obtained. The data were first tested to ensure they conformed to a normal distribution by using the Kolmogorov-Smirnov test, the Shapiro-Wilks test or by determining the values of skewness (acceptable values for normality between -2 and +2) and kurtosis (acceptable values for normality between -2 and +2). Descriptive statistics included the arithmetic mean ($\bar{x}$), standard deviation (SD), and standard error of the mean (SE), as well as the 95% confidence interval (95% CI). Where the data were not normally distributed, the median and the inter-quartile range (IQR) were noted.

In those situations where the data were normally distributed and the variances were constant, comparative analysis involved either the unpaired or paired two-tailed Student's t test. Multiple comparisons were made using the One-Way Analysis of Variance (ANOVA) or Repeated Measure Analysis of Variance (ANOVA) depending if the data were, respectively, unpaired or paired.

Post-Hoc Gabriel test and post-hoc Bonferroni test were used, respectively for One-Way ANOVA and Repeated Measures ANOVA, to identify the pairs where the significant statistical differences were located.

Where the requirements for parametric statistical analysis were not met, the data were analyzed using either the Wilcoxon Signed Rank (U) test for paired data or the Mann-Whitney (U) test for unpaired data as appropriate. Comparison between three or more groups were made using the Kruskal-Wallis (H) or the Friedman (H) test depending if the data were, respectively, unpaired or paired.

The minimum level of significance (α level) accepted throughout the development studies was 0.05 (*), considered to be "moderately significant". Levels of 0.01 (**) were considered as "significant" and 0.001 (***) designated as "highly significant". A lack of statistical significance was designated as (ns).

Comparison A – Testing the Differences between Examiners (F versus C)

Research question: Are there any significant statistical differences in the mean bite pressure (psi) measured by Examiner F and Examiner C in the same experimental conditions?

H0: There are no significant statistical differences in the mean bite pressure (psi) measured by Examiner F and Examiner C in the same experimental conditions.

H1: There are significant statistical differences in the mean bite pressure (psi) measured by Examiner F and Examiner C in the same experimental conditions.

Comparison B – Testing the Differences between Times (T0 versus T1 versus T2)

Research question: Are there any significant statistical differences in the mean bite pressure (psi) measured between moments Time 0 (before surgery), Time 1 (10 minutes after T1) and Time 2 (1 month after surgery) in the same experimental conditions?

H0: There are no significant statistical differences in the mean bite pressure (psi) measured at moments

Time 0, Time 1 and Time 2 in the same experimental conditions.
H1: There are significant statistical differences in the mean bite pressure (psi) measured at moments Time 0, Time 1 and Time 2 in the same experimental conditions.

Comparison C – Testing the Differences between Sensors (Q1/P1 versus Q2/P2 versus Q3/P3 versus Q4/P4 versus Q5/P5)

Research question: Are there any significant statistical differences in the mean bite pressure (psi) measured by sensors Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5 in the same experimental conditions?
H0: There are no significant statistical differences in the mean bite pressure (psi) measured by sensors Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5 in the same experimental conditions.
H1: There are significant statistical differences in the mean bite pressure (psi) measured by sensors Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5 in the same experimental conditions.

Results:

Table 1 presents the experimental data for the measurement of mean bite pressure (psi), as well as its SD and variance values.

Variable	Mean (psi)	SD (psi)	Variance
P1_F_T0	87,400	22,775	518,711
P1_F_T1	89,111	23,793	566,111
P1_F_T2	92,600	29,364	862,267
P1_C_T0	87,100	23,202	538,322
P1_C_T1	87,200	23,275	541,733
P1_C_T2	92,600	28,737	825,822
P2_F_T0	66,800	39,197	1536,400
P2_F_T1	66,800	39,194	1536,178
P2_F_T2	71,200	29,005	841,289
P2_C_T0	66,600	39,036	1523,822
P2_C_T1	66,400	40,153	1612,267
P2_C_T2	71,200	29,192	852,178
P3_F_T0	5,200	7,757	60,178
P3_F_T1	5,200	7,757	60,178
P3_F_T2	34,600	14,653	214,711
P3_C_T0	5,200	7,685	59,067
P3_C_T1	5,100	7,622	58,100
P3_C_T2	34,100	14,693	215,878
P4_F_T0	65,200	36,820	1355,733
P4_F_T1	65,500	36,782	1352,944
P4_F_T2	70,600	26,391	696,489
P4_C_T0	66,800	35,010	1225,733
P4_C_T1	66,200	35,661	1271,733
P4_C_T2	68,600	29,636	878,267
P5_F_T0	86,200	24,091	580,400
P5_F_T1	85,900	23,914	571,878
P5_F_T2	89,500	29,114	847,611
P5_C_T0	86,600	23,782	565,600
P5_C_T1	86,700	23,655	559,567
P5_C_T2	90,100	29,464	868,100

Table 1: Values of bite pressure (psi) measured at the different experimental conditions shown in Figure 1.

Comparison A – Testing the Differences between Examiners (F versus C)

The statistical comparison between examiners F and C regarding the measurement of mean bite pressure (psi) was performed using a Paired Student's t-test for the five different FSS sensors (Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5) at the three different time moments (Time 0, Time 1 and Time 2) (Figure 3 and Table 2).

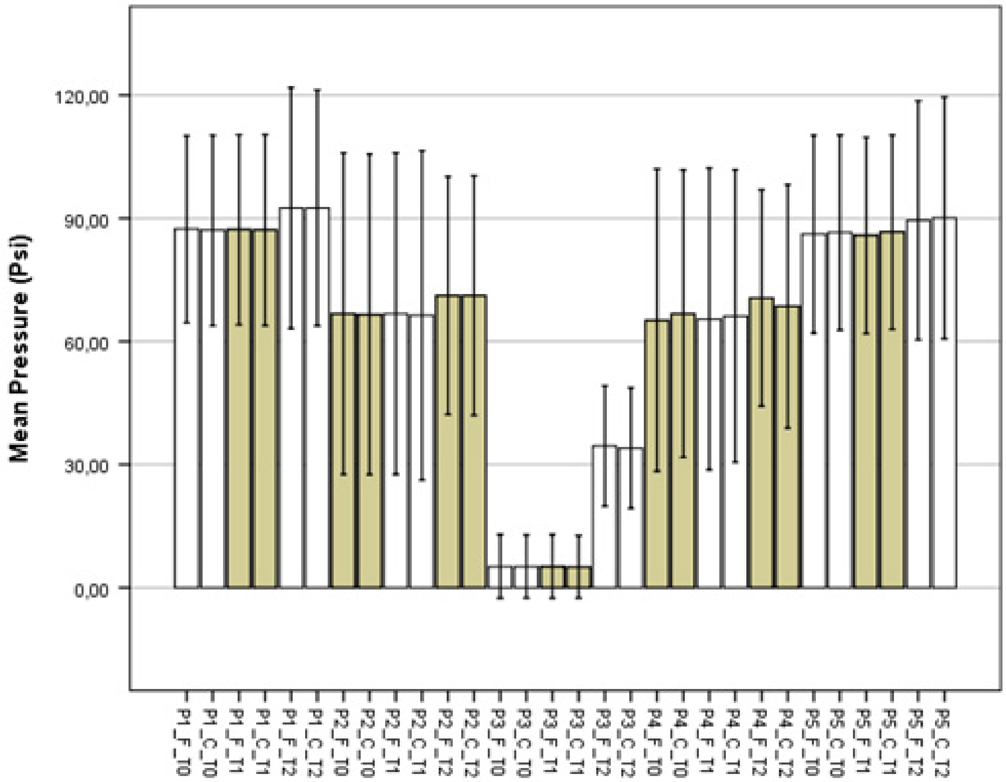

Figure 3: Mean bite pressure (psi) measured by Examiner F and Examiner C in five different FSS sensors (Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5) at three different time moments (Time 0, Time 1 and Time 2). Error bars represent standard deviation values.

Examiners Comparison	Mean Difference	Standard Deviation of Differences	Degrees of Freedom (df)	Test statistic from Paired t-test	P-value from Paired t-test
Examiner F versus Examiner C, P1, Time 0	0,300	0,823	9	1,152	0,279
Examiner F versus Examiner C, P1, Time 1	0,100	0,876	9	0,361	0,726
Examiner F versus Examiner C, P1, Time 2	0,000	1,054	9	0,000	1,000
Examiner F versus Examiner C, P2, Time 0	0,200	0,919	9	0,688	0,509
Examiner F versus Examiner C, P2, Time 1	0,400	1,647	9	0,768	0,462
Examiner F versus Examiner C, P2, Time 2	0,000	0,471	9	0,000	1,000
Examiner F versus Examiner C, P3, Time 0	0,000	0,471	9	0,000	1,000
Examiner F versus Examiner C, P3, Time 1	0,100	0,316	9	1,000	0,343
Examiner F versus Examiner C, P3, Time 2	0,500	0,850	9	1,861	0,096
Examiner F versus Examiner C, P4, Time 0	-1,600	4,061	9	-1,246	0,244
Examiner F versus Examiner C, P4, Time 1	-0,700	2,263	9	-0,978	0,354
Examiner F versus Examiner C, P4, Time 2	2,000	7,055	9	0,896	0,393
Examiner F versus Examiner C, P5, Time 0	-0,400	1,075	9	-1,177	0,269
Examiner F versus Examiner C, P5, Time 1	-0,800	1,033	9	-2,449	0,037*
Examiner F versus Examiner C, P5, Time 2	-0,600	1,506	9	-1,260	0,239

Table 2: Statistical parameters obtained in the Paired Student's t-test for the comparison of examiners F and C when measuring the mean bite pressure (psi) in different experimental conditions.
* moderately significant to 0.05 level; ** significant to 0.01 level; *** highly significant to 0.001 level.

Comparison B – Testing the Differences between Times (T0 versus T1 versus T2)

The statistical comparison between the three-time moments (Time 0, Time 1 and Time 2) regarding the measurement of mean bite pressure (psi) was performed using a Repeated Measures ANOVA for the five FSS sensors (Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5) and the different examiners F and C (Figure 4 and Table 3).

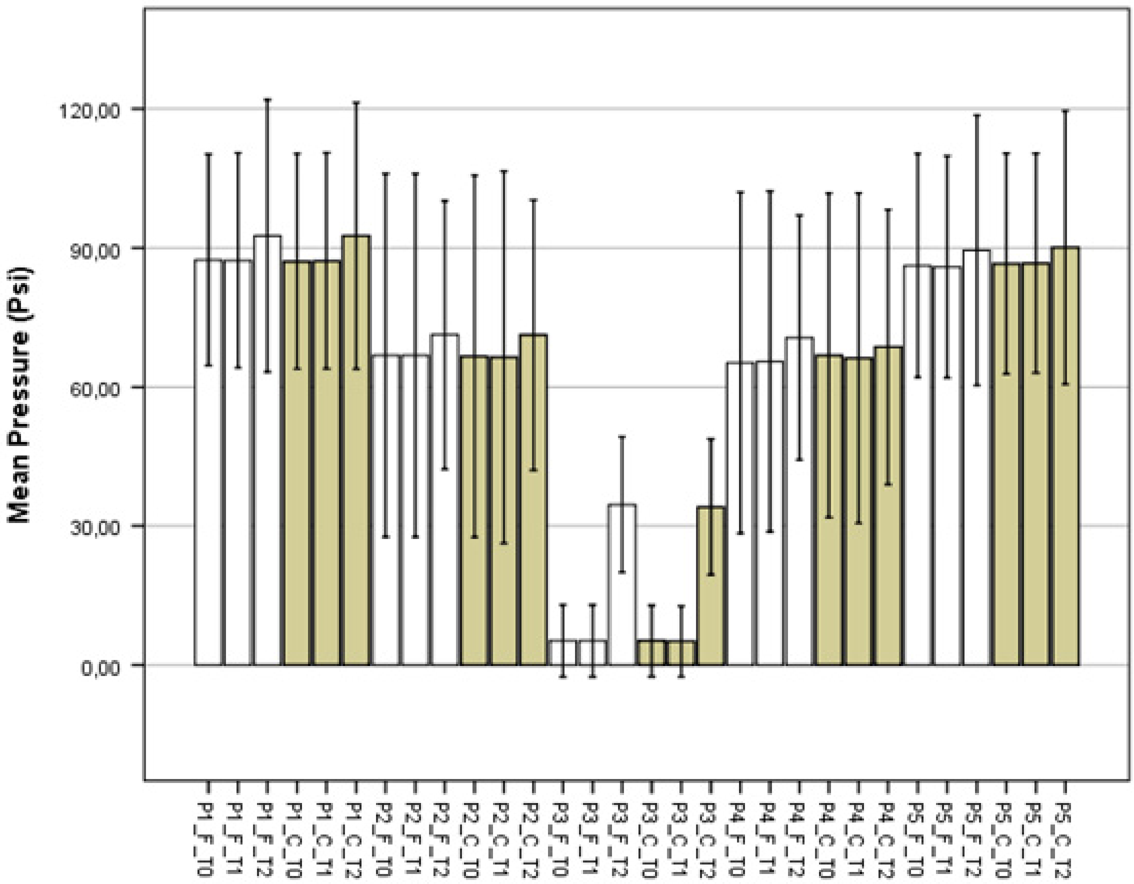

Figure 4: Mean bite pressure (psi) measured in three-time moments (Time 0, Time 1 and Time 2) by Examiner F and Examiner C in five different FSS sensors (Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5). Error bars represent standard deviation values.

Times Comparison	Degrees of Freedom (df)	Test statistic (F)	P-value (Sig)
Time 0 vs Time 1 vs Time 2, Examiner F, P1	2, 18	2,711	0,094
Time 0 vs Time 1 vs Time 2, Examiner C, P1	2, 18	3,372	0,057
Time 0 vs Time 1 vs Time 2, Examiner F, P2	2, 18	0,599	0,560
Time 0 vs Time 1 vs Time 2, Examiner C, P2	2, 18	0,665	0,527
Time 0 vs Time 1 vs Time 2, Examiner F, P3	2, 18	52,762	0,000**
Time 0 vs Time 1 vs Time 2, Examiner C, P3	2, 18	49,924	0,000**
Time 0 vs Time 1 vs Time 2, Examiner F, P4	2, 18	1,042	0,373
Time 0 vs Time 1 vs Time 2, Examiner C, P4	2, 18	0,232	0,796
Time 0 vs Time 1 vs Time 2, Examiner F, P5	2, 18	0,832	0,451
Time 0 vs Time 1 vs Time 2, Examiner C, P5	2, 18	0,808	0,461

Table 3: Statistical parameters obtained in the Repeated Measures ANOVA for the comparison of time moments (Time 0, Time 1 and Time 3) when measuring the mean bite pressure (psi) in different experimental conditions.
* moderately significant to 0.05 level; ** significant to 0.01 level; *** highly significant to 0.001 level.

Because Repeated Measures ANOVA only gives information about the presence of differences, not specifying where these differences are located, a Post-Hoc Bonferroni test was used to perform pairwise comparisons between the times, and these results are represented in Table 4.

Independent Variable			Mean Difference (I-J)	Std. Error	Sig.
F_Q3/P3	T0	T1	0,000	0,000	-
		T2	-29,400	4,047	0,000***
	T1	T0	0,000	0,000	-
		T2	-29,400	4,047	0,000***
	T2	T0	29,400	4,047	0,000***
		T1	29,400	4,047	0,000***
C_Q3/P3	T0	T1	0,100	0,233	1,000
		T2	-28,900	4,140	0,000***
	T1	T0	-0,100	0,233	1,000
		T2	-29,000	4,047	0,000***
	T2	T0	28,900	4,140	0,000***
		T1	29,000	4,047	0,000***

Table 4: Statistical parameters obtained in the Post-Hoc Bonferroni test for the comparison of Times (Time 0, Time 1 and Time 2) when measuring the mean bite pressure (psi) in different experimental conditions.
* moderately significant to 0.05 level; ** significant to 0.01 level; *** highly significant to 0.001 level.

Comparison C – Testing the Differences between Sensors (Q1/P1 versus Q2/P2 versus Q3/P3 versus Q4/P4 versus Q5/P5)

The statistical comparison between the five FSS sensors (Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5) regarding the measurement of mean bite pressure (psi) was performed using a One-Way ANOVA for the different examiners F and C at the three different time moments (Time 0, Time 1 and Time 2) (Figure 5 and Table 5).

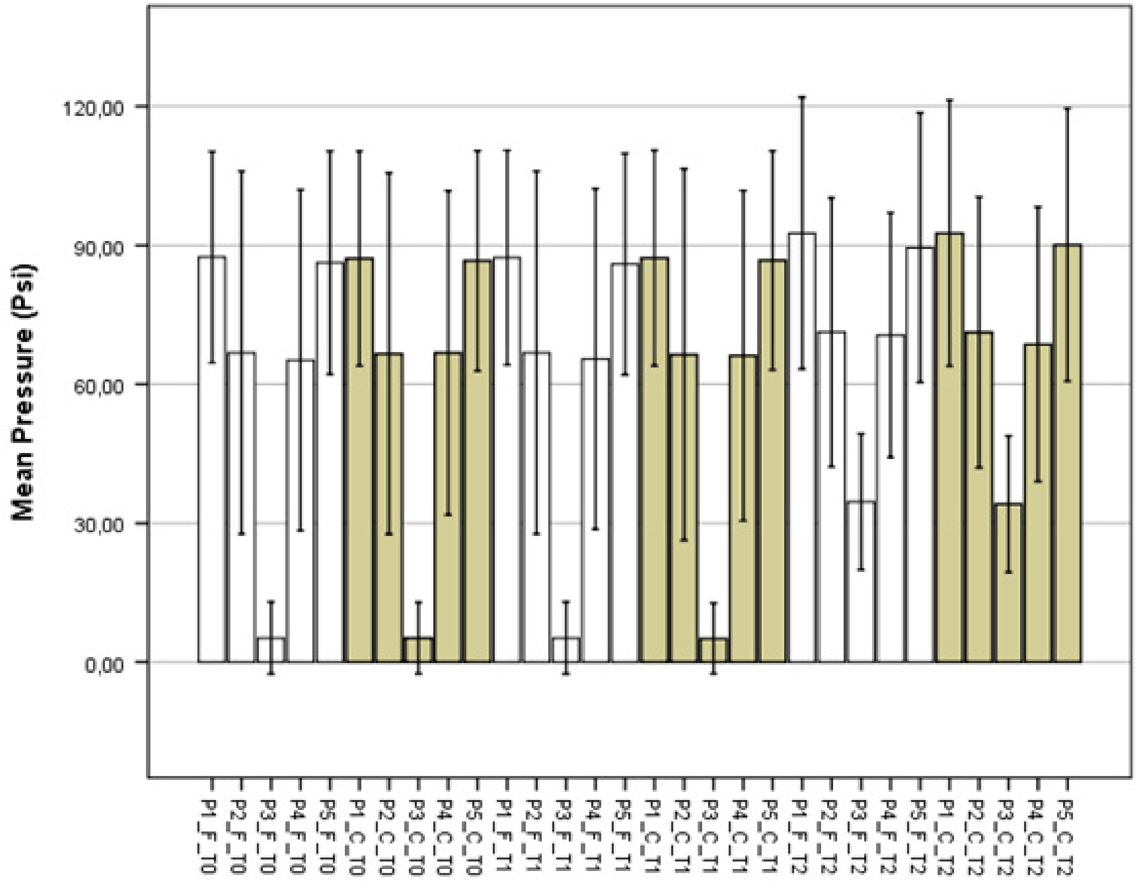

Figure 5: Mean bite pressure (psi) measured in five FSS sensors (Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5) by Examiner F and Examiner C at three different time moments (Time 0, Time 1 and Time 2). Error bars represent standard deviation values.

Sensors Comparison		Sum of Squares	Degrees of Freedom (df)	Mean Square	Test statistic (F)	P-value (Sig)
P1 vs P2 vs P3 vs P4 vs P5, Examiner F, Time 0	Between Groups	44901,920	4	11225,480	13,854	0,000***
	Within Groups	36462,800	45	810,284		
	Total	81364,720	49	-		
P1 vs P2 vs P3 vs P4 vs P5, Examiner F, Time 1	Between Groups	44727,320	4	11181,830	13,780	0,000***
	Within Groups	36514,700	45	811,438		
	Total	81242,020	49	-		
P1 vs P2 vs P3 vs P4 vs P5, Examiner F, Time 2	Between Groups	21315,200	4	5328,800	7,695	0,000***
	Within Groups	31161,300	45	692,473		
	Total	52476,500	49	-		
P1 vs P2 vs P3 vs P4 vs P5, Examiner C, Time 1	Between Groups	45045,520	4	11261,380	14,391	0,000***
	Within Groups	35212,900	45	782,509		
	Total	80258,420	49	-		
P1 vs P2 vs P3 vs P4 vs P5, Examiner C, Time 2	Between Groups	45192,280	4	11298,070	13,971	0,000***
	Within Groups	36390,600	45	808,680		
	Total	81582,880	49	-		
P1 vs P2 vs P3 vs P4 vs P5, Examiner C, Time 2	Between Groups	21982,680	4	5495,670	7,548	0,000***
	Within Groups	32762,200	45	728,049		
	Total	54744,880	49	-		

Table 5: Statistical parameters obtained in the One-Way ANOVA for the comparison of FSS sensors (Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5) when measuring the mean bite pressure (psi) in different experimental conditions.
* moderately significant to 0.05 level; ** significant to 0.01 level; *** highly significant to 0.001 level.

Because One-Way ANOVA only gives information about the presence of differences, not specifying where these differences are located, a Post-Hoc Gabriel test was used to perform pairwise comparisons between the FSS sensors, and these results are represented in Table 6.

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.
F_T0	Q1/P1	Q2/P2	20,600	12,730	0,673
		Q3/P3	82,200	12,730	0,000***
		Q4/P4	22,200	12,730	0,579
		Q5/P5	1,200	12,730	1,000
	Q2/P2	Q1/P1	-20,600	12,730	0,673
		Q3/P3	61,600	12,730	0,000***
		Q4/P4	1,600	12,730	1,000
		Q5/P5	-19,400	12,730	0,741
	Q3/P3	Q1/P1	-82,200	12,730	0,000***
		Q2/P2	-61,600	12,730	0,000***
		Q4/P4	-60,000	12,730	0,000***
		Q5/P5	-81,000	12,730	0,000***
	Q4/P4	Q1/P1	-22,200	12,730	0,579
		Q2/P2	-1,600	12,730	1,000
		Q3/P3	60,000	12,730	0,000***
		Q5/P5	-21,000	12,730	0,650
	Q5/P5	Q1/P1	-1,200	12,730	1,000
		Q2/P2	19,400	12,730	0,741
		Q3/P3	81,000	12,730	0,000***
		Q4/P4	21,000	12,730	0,650
F_T1	Q1/P1	Q2/P2	20,500	12,739	0,680
		Q3/P3	82,100	12,739	0,000***
		Q4/P4	21,800	12,739	0,603
		Q5/P5	1,400	12,739	1,000
	Q2/P2	Q1/P1	-20,500	12,739	0,680
		Q3/P3	61,600	12,739	0,000***
		Q4/P4	1,300	12,739	1,000
		Q5/P5	-19,100	12,739	0,758
	Q3/P3	Q1/P1	-82,100	12,739	0,000***
		Q2/P2	-61,600	12,739	0,000***
		Q4/P4	-60,300	12,739	0,000***
		Q5/P5	-80,700	12,739	0,000***
	Q4/P4	Q1/P1	-21,800	12,739	0,603
		Q2/P2	-1,300	12,739	1,000
		Q3/P3	60,300	12,739	0,000***
		Q5/P5	-20,400	12,739	0,686
	Q5/P5	Q1/P1	-1,400	12,739	1,000
		Q2/P2	19,100	12,739	0,758
		Q3/P3	80,700	12,739	0,000***
		Q4/P4	20,400	12,739	0,686

F_T2	Q1/P1	Q2/P2	21,400	11,768	0,523
		Q3/P3	58,000	11,768	0,000***
		Q4/P4	22,000	11,768	0,485
		Q5/P5	3,100	11,768	1,000
	Q2/P2	Q1/P1	-21,400	11,768	0,523
		Q3/P3	36,600	11,768	0,031*
		Q4/P4	0,600	11,768	1,000
		Q5/P5	-18,300	11,768	0,719
	Q3/P3	Q1/P1	-58,000	11,768	0,000***
		Q2/P2	-36,600	11,768	0,031*
		Q4/P4	-36,000	11,768	0,036*
		Q5/P5	-54,900	11,768	0,000***
	Q4/P4	Q1/P1	-22,000	11,768	0,485
		Q2/P2	-0,600	11,768	1,000
		Q3/P3	36,000	11,768	0,036*
		Q5/P5	-18,900	11,768	0,682
	Q5/P5	Q1/P1	-3,100	11,768	1,000
		Q2/P2	18,300	11,768	0,719
		Q3/P3	54,900	11,768	0,000***
		Q4/P4	18,900	11,768	0,682

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.
C_T0	Q1/P1	Q2/P2	20,500	12,510	0,658
		Q3/P3	81,900	12,510	0,000***
		Q4/P4	20,300	12,510	0,670
		Q5/P5	,500	12,510	1,000
	Q2/P2	Q1/P1	-20,500	12,510	0,658
		Q3/P3	61,400	12,510	0,000***
		Q4/P4	-,200	12,510	1,000
		Q5/P5	-20,000	12,510	0,688
	Q3/P3	Q1/P1	-81,900	12,510	0,000***
		Q2/P2	-61,400	12,510	0,000***
		Q4/P4	-61,600	12,510	0,000***
		Q5/P5	-81,400	12,510	0,000***
	Q4/P4	Q1/P1	-20,300	12,510	0,670
		Q2/P2	,200	12,510	1,000
		Q3/P3	61,600	12,510	0,000***
		Q5/P5	-19,800	12,510	0,699
	Q5/P5	Q1/P1	-,500	12,510	1,000
		Q2/P2	20,000	12,510	0,688
		Q3/P3	81,400	12,510	0,000***
		Q4/P4	19,800	12,510	0,699

C_T1	Q1/P1	Q2/P2	20,800	12,718	0,660
		Q3/P3	82,100	12,718	0,000***
		Q4/P4	21,000	12,718	0,649
		Q5/P5	,500	12,718	1,000
	Q2/P2	Q1/P1	-20,800	12,718	0,660
		Q3/P3	61,300	12,718	0,000***
		Q4/P4	,200	12,718	1,000
		Q5/P5	-20,300	12,718	0,689
	Q3/P3	Q1/P1	-82,100	12,718	0,000***
		Q2/P2	-61,300	12,718	0,000***
		Q4/P4	-61,100	12,718	0,000***
		Q5/P5	-81,600	12,718	0,000***
	Q4/P4	Q1/P1	-21,000	12,718	0,649
		Q2/P2	-,200	12,718	1,000
		Q3/P3	61,100	12,718	0,000***
		Q5/P5	-20,500	12,718	0,678
	Q5/P5	Q1/P1	-,500	12,718	1,000
		Q2/P2	20,300	12,718	0,689
		Q3/P3	81,600	12,718	0,000***
		Q4/P4	20,500	12,718	0,678
C_T2	Q1/P1	Q2/P2	21,400	12,067	0,556
		Q3/P3	58,500	12,067	0,000***
		Q4/P4	24,000	12,067	0,401
		Q5/P5	2,500	12,067	1,000
	Q2/P2	Q1/P1	-21,400	12,067	0,556
		Q3/P3	37,100	12,067	0,035*
		Q4/P4	2,600	12,067	1,000
		Q5/P5	-18,900	12,067	0,711
	Q3/P3	Q1/P1	-58,500	12,067	0,000***
		Q2/P2	-37,100	12,067	0,035*
		Q4/P4	-34,500	12,067	0,061
		Q5/P5	-56,000	12,067	0,000***
	Q4/P4	Q1/P1	-24,000	12,067	0,401
		Q2/P2	-2,600	12,067	1,000
		Q3/P3	34,500	12,067	0,061
		Q5/P5	-21,500	12,067	0,550
	Q5/P5	Q1/P1	-2,500	12,067	1,000
		Q2/P2	18,900	12,067	0,711
		Q3/P3	56,000	12,067	0,000***
		Q4/P4	21,500	12,067	0,550

Table 6: Statistical parameters obtained in the Post-Hoc Gabriel test for the comparison of FSS sensors (Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5) when measuring the mean bite pressure (psi) in different experimental conditions.
* moderately significant to 0.05 level; ** significant to 0.01 level; *** highly significant to 0.001 level.

Discussion:

Comparison A – Testing the Differences between Examiners (F vs C)

No significant statistical differences in the mean bite pressure (psi) measured have been identified between Examiner F and Examiner C, when the measurement was made in the same experimental conditions. Almost all experiments revealed p-values above the cut-off value of 0,05 (p > 0,05), which means that H0 proposition is valid. The results obtained for sensor Q5/P5 at time 1 were not considered significant, as the general trend of data is the absence of statistical differences between examiners. Thus, it is concluded that the choice of examiner is not a variable that affects the mean bite pressure (psi) measured in any of the experimental conditions tested.

Comparison B – Testing the Differences between Times (T0 vs T1 vs T2)

No significant statistical differences in the mean bite pressure (psi) measured have been identified between Time 0, Time 1 and Time 2, when the measurement was made in the same experimental conditions, with exception to sensor FSS Q3/P3.

Significant statistical differences (p < 0,05) have been identified between Time 2 (1 month after surgery) and Times 0 and 1 (prior to surgery) in the FSS sensor P3/Q3 located in the anterior region of the maxillae/mandibulae. Given the nature of the surgical procedure performed in the 10 patients – a bimaxillary osteotomy involving a combination of maxillary Le Fort I impaction procedure coupled with a sagittal split advancement of the mandible – it was expected that it would reflect in the mean pressure (psi) measured in the anterior region of the maxillae/mandibulae, as now it is statistically demonstrated.

Comparison C – Testing the Differences between Sensors (Q1/P1 vs Q2/P2 vs Q3/P3 vs Q4/P4 vs Q5/P5)

Significant statistical differences in the mean bite pressure (psi) have been identified between different FSS sensors (Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5), when the measurement if made in the same experimental conditions. All experiments revealed p-values below the cut-off value of 0,05 (p < 0,05), meaning that H0 proposition is invalid. These differences have been identified between certain pairs of FSS sensors (Table 6 and Fig. 5), allowing the definition of a three-pressure region model where the key-factor seems to be the relative distance of the sensors to the occlusion region: the higher the distance to the occlusion region, the lower is the mean bite pressure (psi).

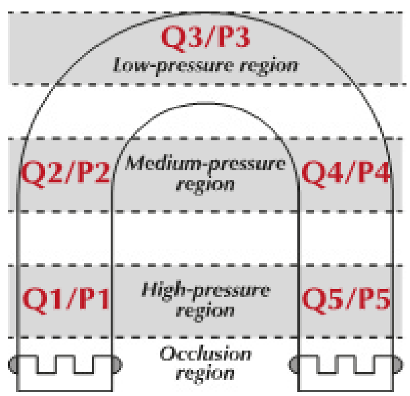

Figure 6: Three-pressure region model for dental occlusion

Another interesting observation is that, when two FSS sensors are located in the same pressure region (i.e., Q1/P1+Q5/P5 and Q2/P2+Q4/P4), no statistical differences are recognisable within the pairs of FSS sensors, meaning that the pressures detected are statistically identical to one another (p > 0,05).

On the opposite side, whenever two FSS sensors are located in different pressure regions, statistically significant differences (p < 0,05) have been found between the measured pressures (Table 5), showing the high sensibility of measurement of the experimental device.

Conclusions:

The innovation in this study resides in the construction of a prototype device called the Occlusal Force Diagnostic System accompanied by a second prototype device called the Bite Training Machine to measure patients' occlusal force.

No significant statistical differences in the mean bite pressure (psi) were detected between examiners when the measurement was made in the same experimental conditions (p > 0,05).

When comparing pre-op (Times 0 and 1) and post-op (Time 2) data, significant statistical differences have been found in the mean bite pressure measured by FSS sensor Q3/P3 located in the anterior region of the maxilla/ mandible (p < 0,05), those differences being absent in the remaining FSS sensors Q1/P1, Q2/P2, Q4/P4 and Q5/P5 (p > 0,05).

Given the nature of the surgical procedure performed in the 10 patients – a bimaxillary osteotomy involving a combination of maxillary Le Fort I impaction procedure coupled with a sagittal split advancement of the mandible – it was expected that the major changes in the patients would be concentrated in the anterior region of the maxilla/mandible, as it was statistically demonstrated.

Significant differences ($p < 0,05$) have been identified between certain pairs of FSS sensors, allowing the definition of a three-pressure region model where the key-factor seems to be the relative distance of the sensors to the occlusion region: the higher the distance to the occlusion region, the lower is the mean bite pressure (psi).

Another interesting observation is that, when two FSS sensors are located in the same pressure region (i.e., Q1/P1+Q5/P5 and Q2/P2+Q4/P4), no statistical differences are recognisable within the pairs of FSS sensors, meaning that the pressures detected are statistically identical to one another ($p > 0,05$). On the opposite side, whenever two FSS sensors are located in different pressure regions, statistically significant differences ($p < 0,05$) have been found between the measured pressures, showing the high sensibility of measurement of the experimental device.

References:

[1] Ellis, E.III., Throckmorton, G.S., Sinn, D.P. (1996) Bite force before and after surgical correction of mandibular prognathism. J.Oral.Maxillofac.Surg. 54:176-181

[2] Harada, K., Watanabe, M., Ohkura, K., Enomoto, S. (2000) Measure of bite force and occlusal contact area before and after bilateral sagittal split ramus osteotomy of the mandible using a new pressure-sensitive device: A preliminary report. J.Oral.Maxillofac.Surg. 58:370-373

[3] Iwase, M., Sugimori, M., Kurachi, Y., Nagumo, M. (1998) Changes in bite force and occlusal contacts in patients treated for mandibular prognathism by orthognathic surgery. J.Oral.Maxillofac.Surg. 56:850–855

[4] Kikuta, T., Hara, I., Seto, T., Yoshioka, I., Nakashima, T., Yasumitsu, C. (1994) Evaluation of masticatory function after sagittal split ramus osteotomy for patients with mandibular prognathism. Int.J.Adult.Orthodon. Orthognath.Surg. 9:9-17

[5] Kim, Y.G., Oh, S.H. (1997) Effect of mandibular setback surgery on occlusal force. J.Oral.Maxillofac.Surg. 55:121-126

[6] Kobayashi, T., Honma, K., Nakajima, T., Hanada, K. (1993) Masticatory function in patients with mandibular prognathism before and after orthognathic surgery. J.Oral.Maxillofac.Surg. 51:997-1001

[7] Kobayashi, T., Honma, K., Shingaki, S., Nakajima, T. (2001) Changes in masticatory function after orthognathic treatment in patients with mandibular prognathism. Br.J.Oral.Maxillofac.Surg. 39:260-265

[8] Nagai, I., Tanaka, N., Noguchi, M., et al. (2001) Changes in occlusal state of patients with mandibular prognathism after orthognathic surgery: a pilot study. Br J Oral Maxillofac Surg 39:429-433

[9] Ohkura, K., Harada, K., Morishima, S., Enomoto, S. (2001) Changes in bite force and occlusal contact area after orthognathic surgery for correction of mandibular prognathism. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 91:141– 145

[10] Proffit, W.R., Turvey, T.A., Fields, H.W., Phillips, C. (1989) The effect of orthognathic surgery on occlusal force. J Oral Maxillofac Surg 47:457-463

[11] Raustia, A.M., Oikarinen, K.S. (1994) Changes in electric activity of masseter and temporal muscles after mandibular sagittal split osteotomy. Int J Oral Maxillofac Surg 23:180–184

[12] Shiratsuchi, Y., Kouno, K., Tashiro, H. (1991) Evaluation of masticatory function following orthognathic surgical correction of mandibular prognathism. J Craniomaxillofac Surg 19:299–303

[13] Throckmorton, G.S., Buschang, P.H., Ellis III, E. (1996) Improvement of maximum occlusal forces after orthognathic surgery. J Oral Maxillofac Surg 54:1080–1086

[14] Tate, G.S., Throckmorton, G.S., Ellis, E., Sinn, D.P. (1994) Masticatory performance, muscle activity, and occlusal force in pre-orthognathic surgery patients. J Oral Maxillofac Surg 52:476-481

[15] Thomas, G.P., Throckmorton, G.S., Ellis III, E., Sinn, D.P. (1995) The effects of orthodontic treatment on isometric bite forces and mandibular motion inpatients before orthognathic surgery. J Oral Maxillofac Surg 53:673–678

[16] Matsui, Y., Ohno, K., Michi, K., Suzuki, Y., Yamagata, K. (1996) A computerized method for evaluating balance of occlusal load. J Oral Rehabil 23:530–535

[17] Suzuki, T., Kumagai, H., Watanabe, T., Uchida, T., Nagao, M. (1997) Evaluation of complete denture occlusal contacts using pressure-sensitive sheets. Int J Prosthodont 10:386–391

[18] Matsui, Y., Neukam, F.W., Wichmann, M., Ohno, K. (1996) A computerized method for evaluating distribution of occlusal load on implant-supported fixed cantilever prostheses. Int J Oral Maxillofac Implants 11:67–72

[19] Matsui, Y., Neukam, F.W., Schmelzeisen, R., Ohno, K. (1996) Masticatory function of postoperative tumor patients rehabilitated with osseointegrated implants. J Oral Maxillofac Surg 54:441–447

[20] Hayakawa, I., Watanabe, I., Hirano, S., Nagao, M., Seki, T. (1998) A simple method for evaluating masticatory performance using a color-changeable chewing gum. Int.J.Prosthodont. 11:173–176