The importance of occlusal force measurement in orthognathic surgery - A pilot study

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ABSTRACT

Purpose: This pilot investigation was designed to apply several, newly developed and more sophisticated methods of measuring muscle structure and function in a situation where adaptation of muscle is pivotal to the success of a therapeutic approach.

Materials and Methods: Patients attending the combined orthodontic/orthognathic surgery clinic at the Clitrofa – Centro Médico, Dentário e Cirúrgico, in Trofa - Portugal were tested according to the protocol of Bite force and occlusal contact area were simultaneously measured with Bite Training Machine and Occlusal Force Diagnostic System. An Experimental design used for the measurement of occlusal force. The study involved the contribution of two independent examiners that measured the bite pressure (psi) in five different FSS sensors at three different time moments. A combination of different parametric tests has been used to compare the different experimental variables.

Results: Neither the variation of examiner, nor the variations of time have shown to influence the bite pressure (psi). In contrast, the occlusal force measurement system developed has shown a high level of sensitivity due to the distribution of the five FSS sensors in the horseshoe-shaped form. A three-pressure region model fits the experimental data shown in this study, comprising a low-pressure region located in the anterior part of the dental arch, a medium-pressure region in the medial part of the dental arch and an high-pressure region located in the posterior part of the dental arch.

Conclusions: The piezoelectric sensors used in the present study have shown high reproducibility of measurement. Due to the recent miniaturization of FSS sensors, the authors are developing new occlusal force measurement systems comprising a higher number of piezoelectric sensors, with the objective of attaining even higher sensitivity of measurement throughout the different region of the dental arches.

KEYWORDS

Orthognathic surgery, massseter muscle, occlusal force measurement

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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[1-13] but few reports compared the results with those in controls with normal occlusion.[1,3,6-9,12,13] 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 regarding reproducibility and quantification. Recently, a simple method for occlusal analysis, the Dental Prescale™ system (Fuji Photo Film Co., Japan), has been developed. This is a computerized system intended to assist occlusal analysis by providing information as to the magnitude of the bite force and the distribution of occlusal contacts. The system is capable of simultaneously measuring these parameters for teeth separated by less than 10mm and has potential for research in centric occlusion. 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 colour developing chewing-gum system has already been used for analysing the masticatory function of dental implants[19] and dentures[20].

The authors decided to build their own Occlusal Force Diagnostic System and test it on a group of patients.

OCCLUSAL FORCE DIAGNOSTIC SYSTEM

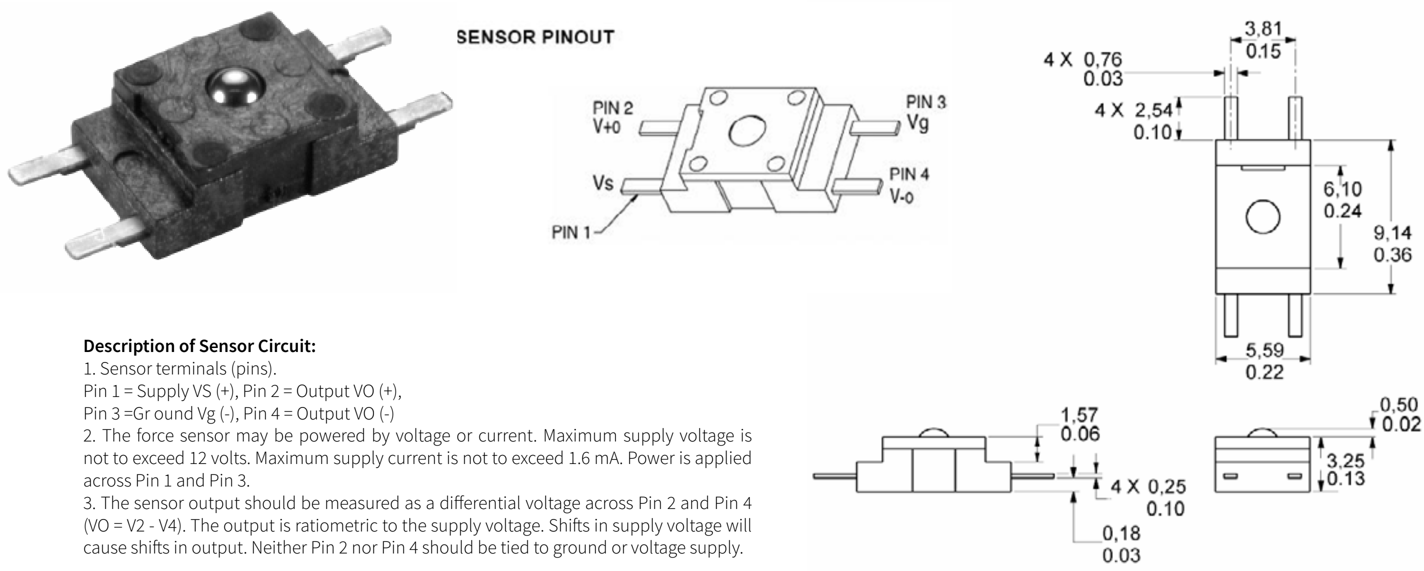
A) Sensors

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.

The typical applications of these sensors are medical infusion pumps, ambulatory non-invasive pump pressure, occlusion detection, kidney dialysis machines, load and compression sensing, variable tensions control, robotic end-effectors and wire bonding equipment.



Description of Sensor Circuit:

1. Sensor terminals (pins).
Pin 1 = Supply VS (+), Pin 2 = Output VO (+),
Pin 3 =Gr ound Vg (-), Pin 4 = Output VO (-)
2. The force sensor may be powered by voltage or current. Maximum supply voltage is not to exceed 12 volts. Maximum supply current is not to exceed 1.6 mA. Power is applied across Pin 1 and Pin 3.
3. The sensor output should be measured as a differential voltage across Pin 2 and Pin 4 (VO = V2 - V4). The output is ratiometric to the supply voltage. Shifts in supply voltage will cause shifts in output. Neither Pin 2 nor Pin 4 should be tied to ground or voltage supply.

Figure 1. Schematic illustration of the FSS Sensor, sensor circuit and mounting

B) Distribution

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. The first idea was to place seven sensors distributed by the dental arch in a horseshoe-shaped form designated by bite force, but because of the sensors dimensions was decided to place only five. 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 sensor’s 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.

During the process of development was felt interesting to have the five sensors reading at the same time. To achieve this several changes were introduced, namely the inclusion of five digital screens, each one corresponding to one sensor, the construction of a portable suitcase able to accommodate all the occlusal diagnostic system and an on-off bottom. Each digital screen works with its own battery placed in the suitcase under a metal foil that cover all the electrical connections.

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

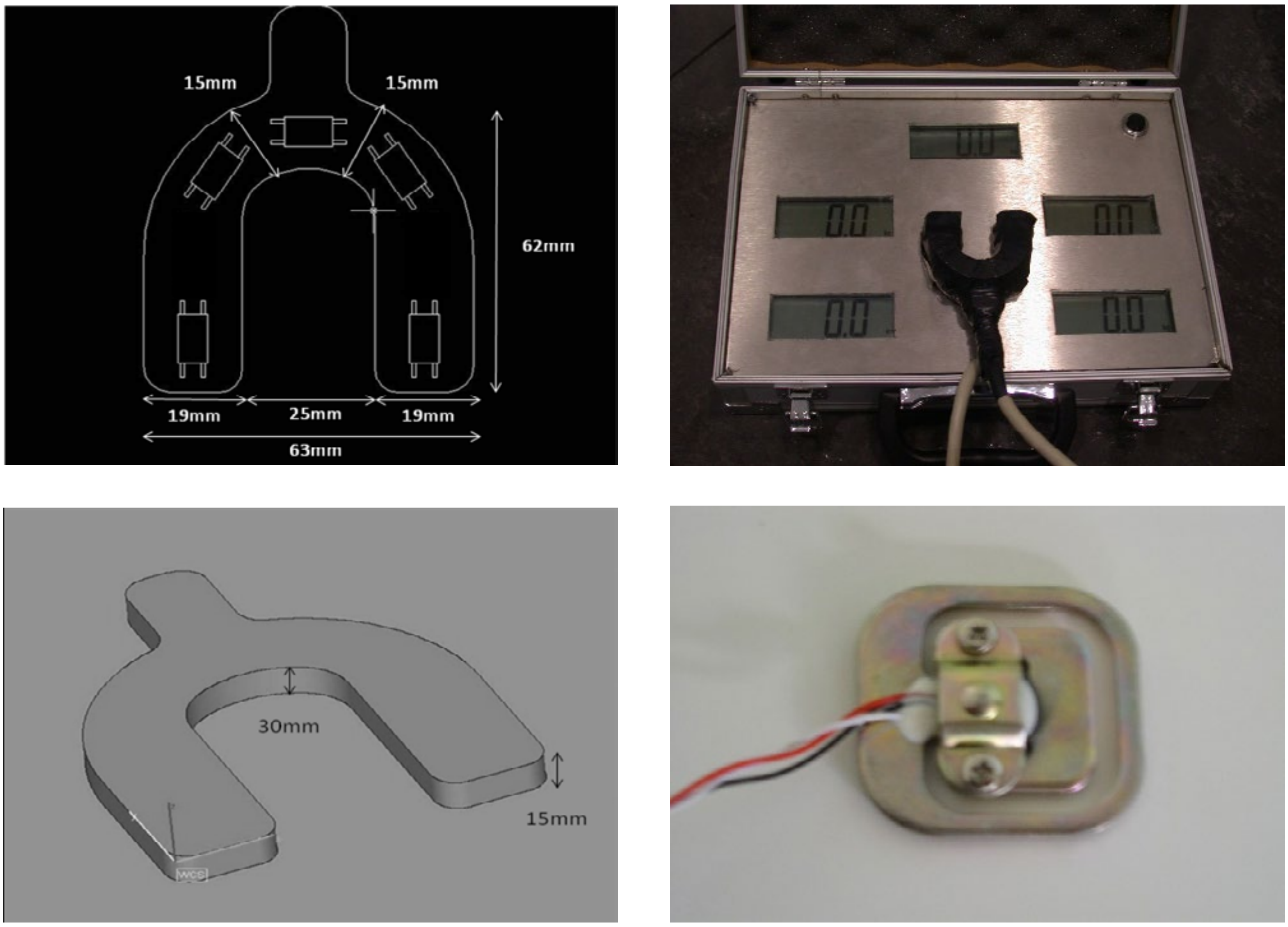


Figure 2. Components of the Occlusal Force Diagnostic System: FSS sensor, Sensors distribution, Occlusal platform dimensions and Digital screens

C) Compatibility

It is very important to ensure compatibility between the pressure or force sensor and the application in which it is used. The following should be considered before a sensor selection is made: (1) material; (2) chemicals; (3) concentration; (4) temperature; (5) exposure time; (6) type of exposure; (7) criteria for failure; and (8) general information such as application environment, protection of the device, and other foreign substances in the area.

D) Repeatability Test

The occlusal force diagnostic 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 after 1 month (T2). In the proposed repeatability test, the bite force and occlusal pressure were measured in 30 consecutive patients twice by two different observers.

The five sensors were distributed in the following order, the readings were in kilograms:

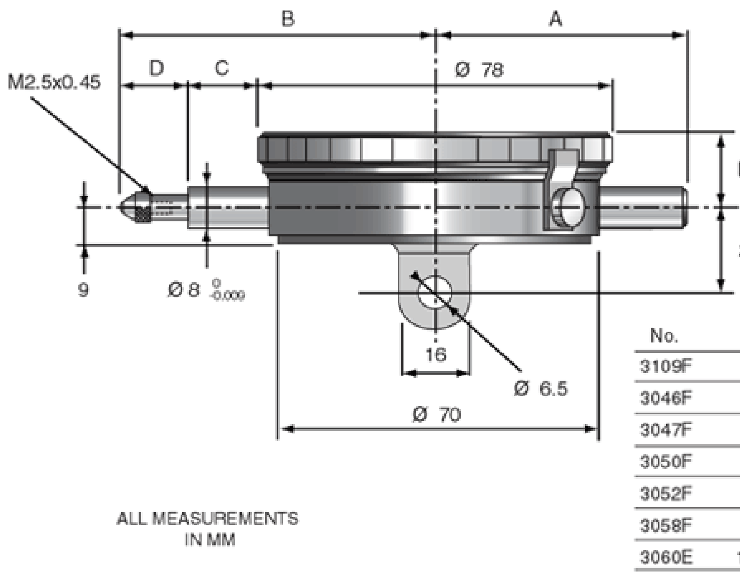
- Sensor A: right maxillary second pre-molar and right maxillary first molar between 1st and 4th quadrants,
- Sensor B: right maxillary canine and right maxillary first pre-molar between 1st and 4th quadrants,
- Sensor C: right and left maxillary central incisors and right and left maxillary lateral incisors area,
- Sensor D: left maxillary second pre-molar and left maxillary first molar between 2nd and 3rd quadrants,
- Sensor E: left maxillary canine and left maxillary first pre-molar between 2nd and 3rd quadrants,

E) 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 a 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 ordered from Mitutoyo™ (Mitutoyo Corporation, USA) and ensure that the 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.



No.	A	B	C	D	E
3109F	56	79	25	15	17
3046F	56	75.5	15.5	21	16.5
3047F	56	75.5	15.5	21	16.5
3050F	49	93	25	29	16.5
3052F	73	104	25	40	17
3058F	82	142	43	60	17
3060E	112	203	73	91	17
3062E	132	243	94	110	17

Figure 3. Major components of the Bite Training Machine: dynamometer, force indicator and occlusal area

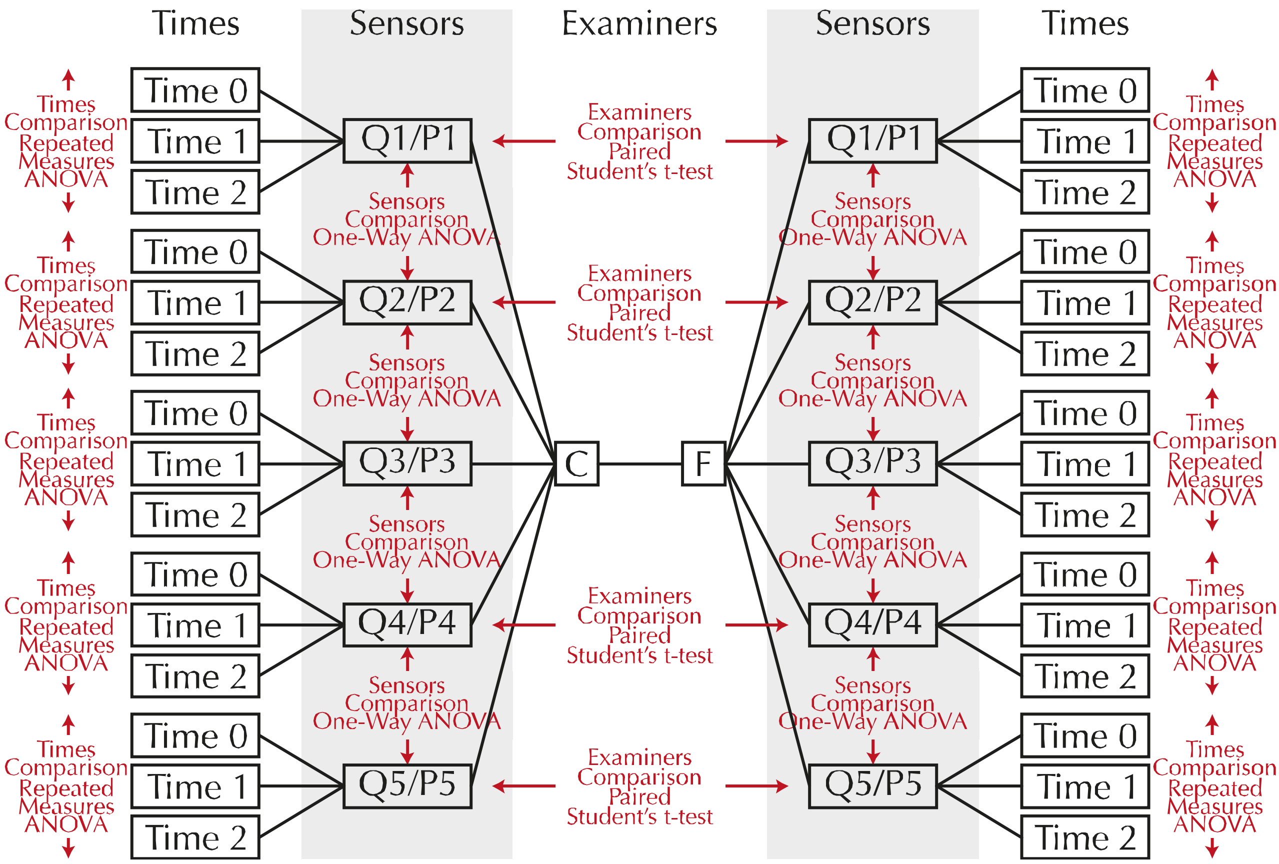


Figure 4. Experimental design used for the measurement of occlusal force. The study involved the contribution of two independent examiners (F and C), that measured the bite pressure (psi) in five different FSS sensors (Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5) at three different time moments (Time 0, Time 1 and Time 2).

MATERIALS AND METHODS

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 after 1 month (T2). In the proposed repeatability test, the bite force and occlusal pressure were measured in 30 consecutive patients twice by two different observers.

A combination of different parametric tests has been used to compare the different experimental variables. The experimental design devised for this study is depicted in Figure 4, comprising a combination of different examiners, sensors and times of measurement.

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

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

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

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

H0: There are no 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 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 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 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 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.

Table 1. Values of bite pressure (psi) measured at the different experimental conditions shown in Figure 4.

Variable	Mean (psi)	SD (psi)	Variance
P1_F_T0	52,567	38,264	1464,116
P1_F_T1	53,067	38,224	1461,099
P1_F_T2	54,033	39,063	1525,895
P1_C_T0	53,300	39,034	1523,666
P1_C_T1	53,800	39,284	1543,269
P1_C_T2	53,733	39,559	1564,892
P2_F_T0	36,567	28,877	833,909
P2_F_T1	36,500	28,567	816,052
P2_F_T2	36,967	28,823	830,792
P2_C_T0	36,833	28,666	821,730
P2_C_T1	36,833	28,680	822,557
P2_C_T2	37,133	29,180	851,499
P3_F_T0	0,700	2,667	7,114
P3_F_T1	0,700	2,667	7,114
P3_F_T2	0,667	2,537	6,437
P3_C_T0	0,700	2,667	7,114
P3_C_T1	0,700	2,667	7,114
P3_C_T2	0,667	2,537	6,437
P4_F_T0	28,933	24,996	624,823
P4_F_T1	29,567	25,117	630,875
P4_F_T2	29,433	24,897	619,840
P4_C_T0	29,400	25,125	631,283
P4_C_T1	29,867	24,926	621,283
P4_C_T2	29,600	24,926	619,913
P5_F_T0	67,933	37,300	1391,306
P5_F_T1	65,533	35,586	1266,395
P5_F_T2	66,700	36,174	1308,562
P5_C_T0	66,633	36,480	1330,792
P5_C_T1	66,400	35,953	1292,593
P5_C_T2	66,867	35,509	1260,878

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).

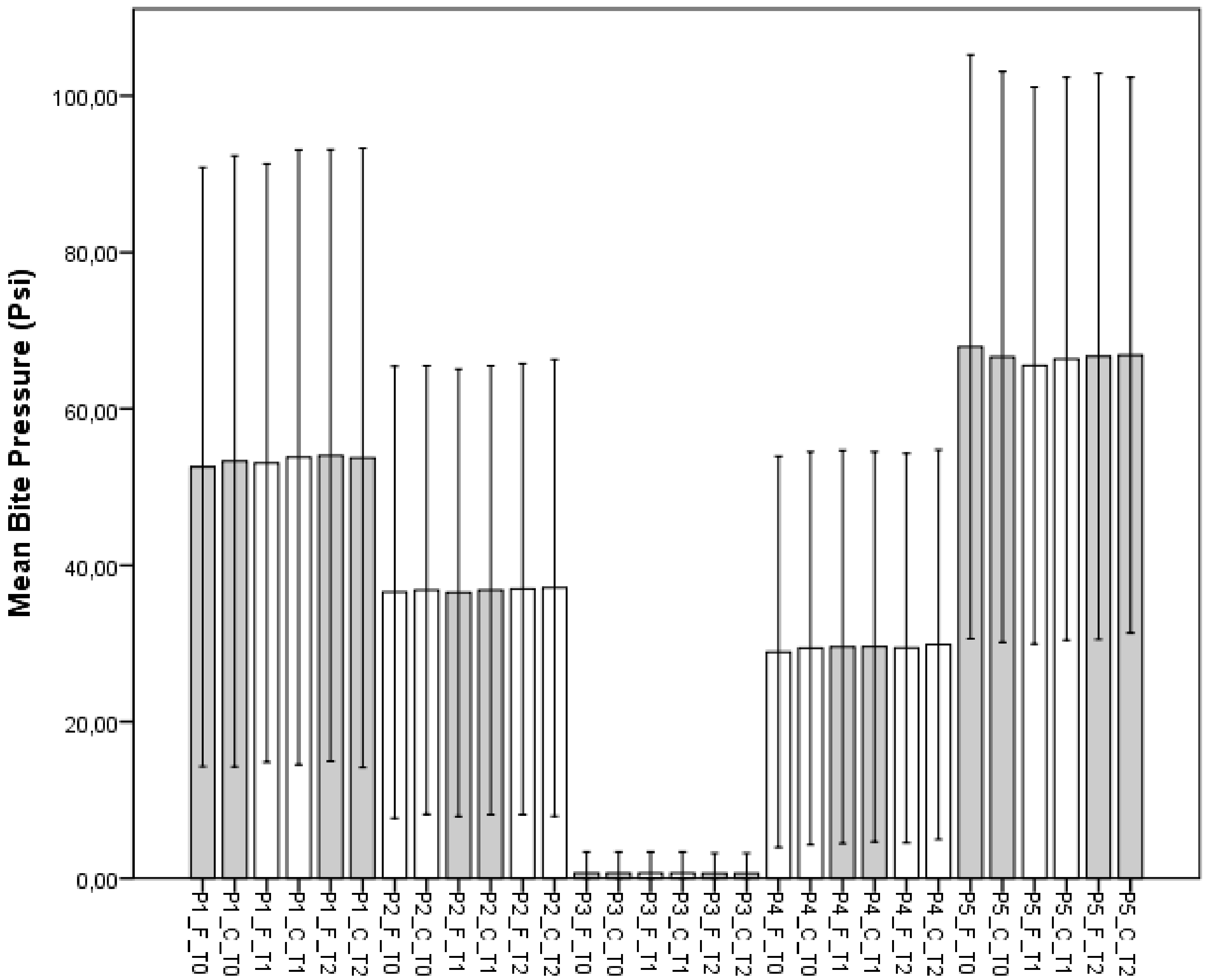


Figure 5. Mean bite pressure (psi) measured by Examiner F and Examiner C in five different FSS sensors (Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5) at three different time moments (Time 0, Time 1 and Time 2). Error bars represent standard deviation values.

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

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	-0,733	4,185	29,000	-0,960	,345
Examiner F versus Examiner C, P1, Time 1	-0,733	2,993	29,000	-1,342	,190
Examiner F versus Examiner C, P1, Time 2	0,300	2,200	29,000	0,747	,461
Examiner F versus Examiner C, P2, Time 0	-0,267	1,437	29,000	-1,017	,318
Examiner F versus Examiner C, P2, Time 1	-0,333	2,040	29,000	-0,895	,378
Examiner F versus Examiner C, P2, Time 2	-0,167	3,302	29,000	-0,276	,784
Examiner F versus Examiner C, P3, Time 0	-0,467	1,961	29,000	-1,304	,203
Examiner F versus Examiner C, P3, Time 1	-0,033	1,426	29,000	-0,128	,899
Examiner F versus Examiner C, P3, Time 2	-0,433	2,944	29,000	-0,806	,427
Examiner F versus Examiner C, P4, Time 0	1,300	3,164	29,000	2,251	,032
Examiner F versus Examiner C, P4, Time 1	-0,867	2,623	29,000	-1,810	,081
Examiner F versus Examiner C, P4, Time 2	-0,167	3,687	29,000	-0,248	,806
Examiner F versus Examiner C, P5, Time 0	-0,733	4,185	29,000	-0,960	,345
Examiner F versus Examiner C, P5, Time 1	-0,733	2,993	29,000	-1,342	,190
Examiner F versus Examiner C, P5, Time 2	0,300	2,200	29,000	0,747	,461

There are no significant differences in the mean bite pressure (psi) measured by Examiner F and Examiner C, when the measurement is made in the same experimental conditions (Figure 5). Almost all experiments reveal p-values above the cut-off value of 0,05 ($p > 0,05$), which means that H0 proposition is valid (Table 2). The results obtained for sensor Q4/P4 at time 0 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 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.

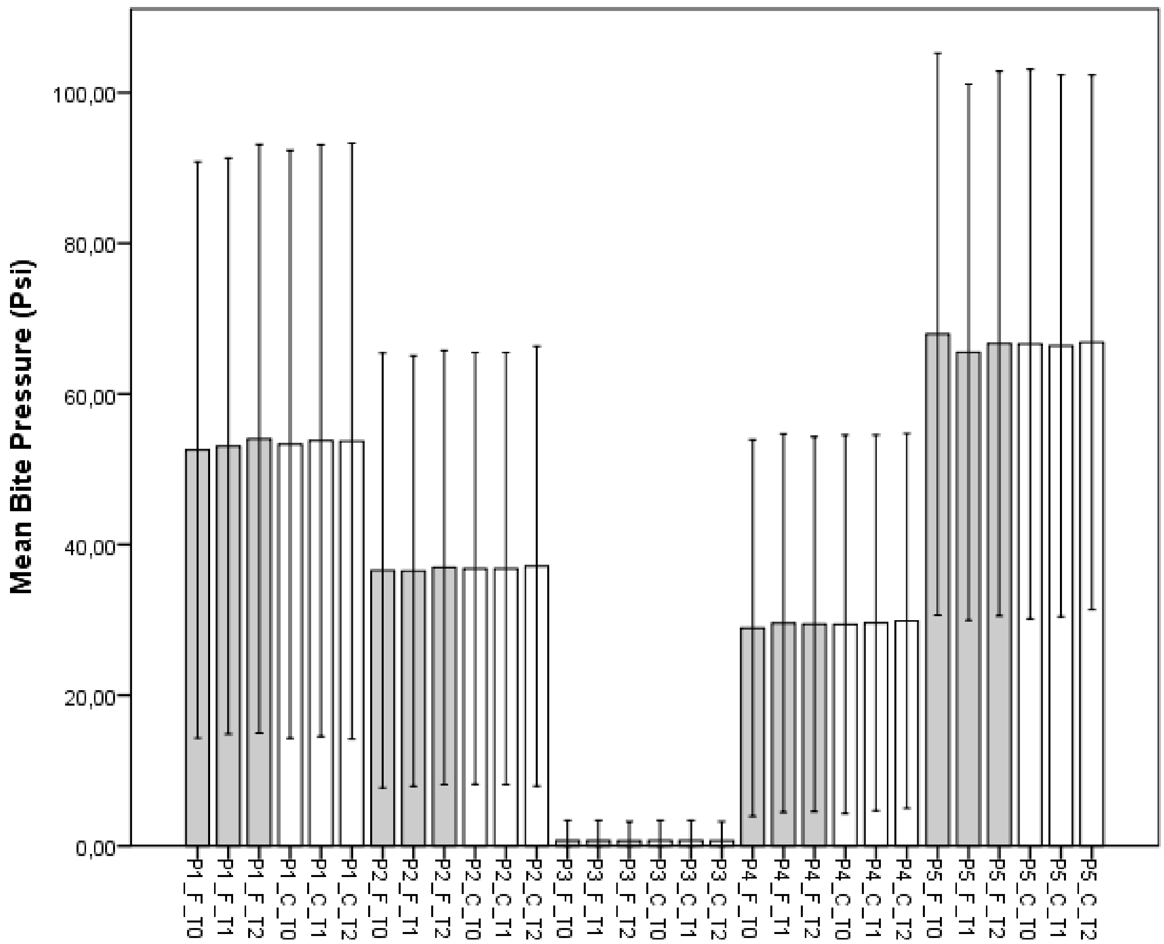


Figure 6. Mean bite pressure (psi) measured in three time moments (Time 0, Time 1 and Time 2) by Examiner F and Examiner C in five different FSS sensors (Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5). Error bars represent standard deviation values.

Table 3. Statistical parameters obtained in the Repeated Measures ANOVA for the comparison of time moments (Time 0, Time 1 and Time 2) when measuring the mean bite pressure (psi) in different experimental conditions.

Times Comparison	Degrees of Freedom *(df)*	Test statistic (F)	P-value (Sig)
Time 0 vs Time 1 vs Time 2, Examiner F, P1	2,58	3,225(a)	0,047(a)
Time 0 vs Time 1 vs Time 2, Examiner C, P1	2,58	0,714	0,494
Time 0 vs Time 1 vs Time 2, Examiner F, P2	2,58	0,695	0,503
Time 0 vs Time 1 vs Time 2, Examiner C, P2	2,58	0,352	0,705
Time 0 vs Time 1 vs Time 2, Examiner F, P3	2,58	1,000	0,374
Time 0 vs Time 1 vs Time 2, Examiner C, P3	2,58	1,000	0,374
Time 0 vs Time 1 vs Time 2, Examiner F, P4	2,58	1,854	0,166
Time 0 vs Time 1 vs Time 2, Examiner C, P4	2,58	0,488	0,616
Time 0 vs Time 1 vs Time 2, Examiner F, P5	2,58	8,715(a)	0,000(a)
Time 0 vs Time 1 vs Time 2, Examiner C, P5	2,58	0,423	0,657

a) Mauchly's Test of Sphericity ($p < 0{,}05$) reveals violation of sphericity principle, indicating distortion in the calculation of variance, F-ratio and p-value obtained in these results for the Repeated Measures ANOVA.

There are no significant differences in the mean bite pressure (psi) measured at Time 0, Time 1 or Time 2, for the same Examiner (C or F) and the same Sensor (Q1/P1, Q2/P2, Q3/P3, Q4/P4 or Q5/P5) (p > 0,05) (Figure 6). Almost all experiments reveal p-values above the cut-off value of 0,05 (p > 0,05), which means that H0 proposition is valid. The results obtained from Examiner F, sensors Q1/P1 and Q5/P5, were not considered significant, as sphericity principle was not verified (Table 3). Thus, it is concluded the mean bite pressure (psi) measured at different time frames is consistently the same, showing the high reproducibility of the measurements.

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).

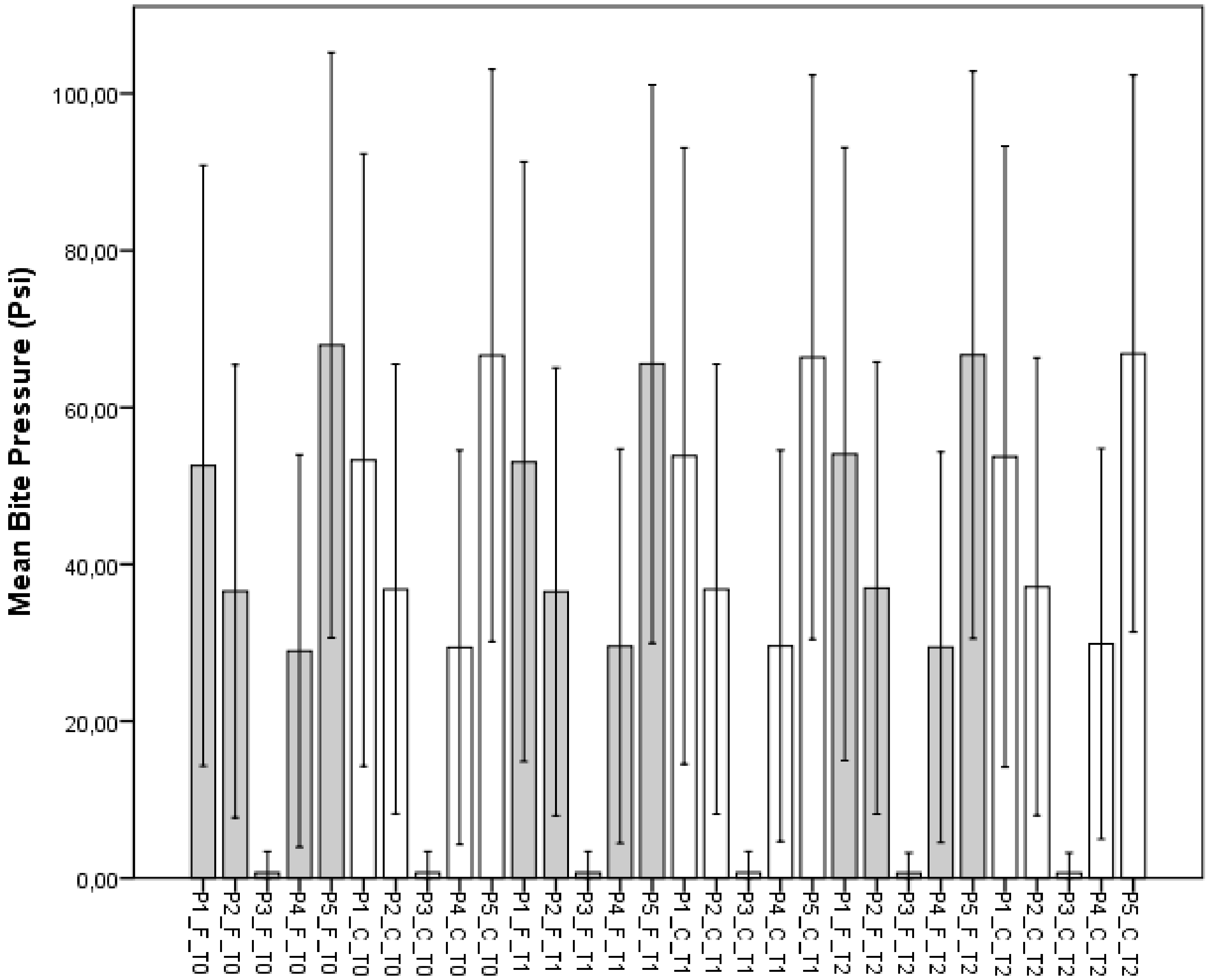


Figure 7. Mean bite pressure (psi) measured in five FSS sensors (Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5) by Examiner F and Examiner C at three different time moments (Time 0, Time 1 and Time 2). Error bars represent standard deviation values.

Table 4. 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.

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	77446,893	4,000	19361,723	22,403	0,000*
	Within Groups	125316,767	145,000	864,254		
	Total	202763,660	149,000	-		
P1 vs P2 vs P3 vs P4 vs P5, Examiner F, Time 1	Between Groups	73363,693	4,000	18340,923	21,931	0,000*
	Within Groups	121264,500	145,000	836,307		
	Total	194628,193	149,000	-		
P1 vs P2 vs P3 vs P4 vs P5, Examiner F, Time 2	Between Groups	76440,693	4,000	19110,173	22,265	0,000*
	Within Groups	124454,267	145,000	858,305		
	Total	200894,960	149,000	-		
P1 vs P2 vs P3 vs P4 vs P5, Examiner C, Time 1	Between Groups	75558,160	4,000	18889,540	21,890	0,000*
	Within Groups	125122,933	145,000	862,917		
	Total	200681,093	149,000	-		
P1 vs P2 vs P3 vs P4 vs P5, Examiner C, Time 2	Between Groups	75539,667	4,000	18884,917	22,027	0,000*
	Within Groups	124317,667	145,000	857,363		
	Total	199857,333	149,000	-		
P1 vs P2 vs P3 vs P4 vs P5, Examiner C, Time 3	Between Groups	76227,040	4,000	19056,760	22,140	0,000*
	Within Groups	124804,933	145,000	860,724		
	Total	201031,973	149,000	-		

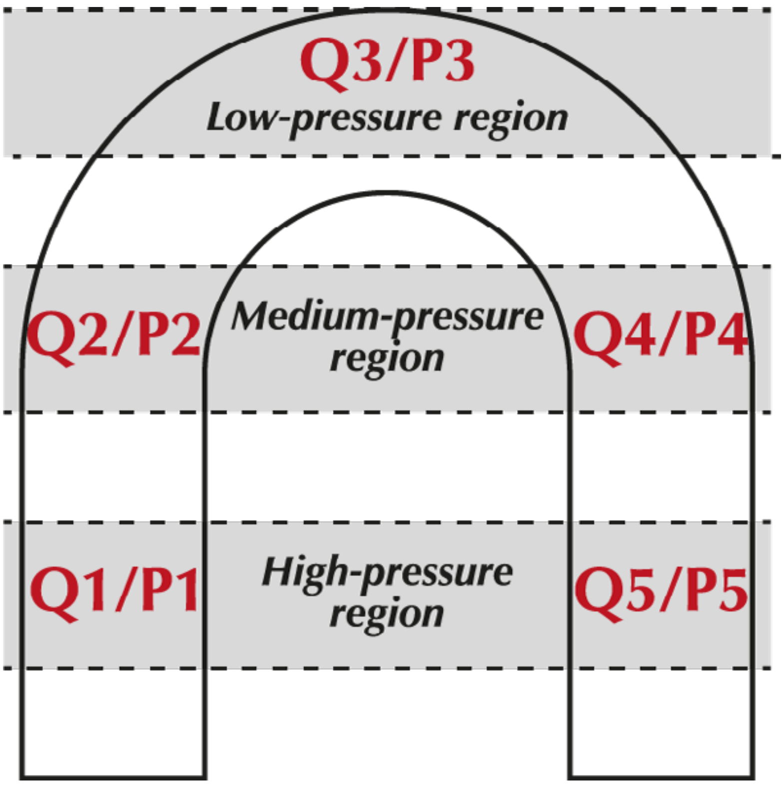


Figure 8. Three-pressure region model for dental occlusion.

Table 5. 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.

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.
F_T0	Q1/P1	Q2/P2	16,000	7,591	0,308
		Q3/P3	51,867*	7,591	0,000
		Q4/P4	23,633*	7,591	0,022
		Q5/P5	-15,367	7,591	0,363
	Q2/P2	Q1/P1	-16,000	7,591	0,308
		Q3/P3	35,867*	7,591	0,000
		Q4/P4	7,633	7,591	0,976
		Q5/P5	-31,367*	7,591	0,001
	Q3/P3	Q1/P1	-51,867*	7,591	0,000
		Q2/P2	-35,867*	7,591	0,000
		Q4/P4	-28,233*	7,591	0,003
		Q5/P5	-67,233*	7,591	0,000
	Q4/P4	Q1/P1	-23,633*	7,591	0,022
		Q2/P2	-7,633	7,591	0,976
		Q3/P3	28,233*	7,591	0,003
		Q5/P5	-39,000*	7,591	0,000
	Q5/P5	Q1/P1	15,367	7,591	0,363
		Q2/P2	31,367*	7,591	0,001
		Q3/P3	67,233*	7,591	0,000
		Q4/P4	39,000*	7,591	0,000
F_T1	Q1/P1	Q2/P2	16,567	7,467	0,245
		Q3/P3	52,367*	7,467	0,000
		Q4/P4	23,500*	7,467	0,020
		Q5/P5	-12,467	7,467	0,633
	Q2/P2	Q1/P1	-16,567	7,467	0,245
		Q3/P3	35,800*	7,467	0,000
		Q4/P4	6,933	7,467	0,986
		Q5/P5	-29,033*	7,467	0,002
	Q3/P3	Q1/P1	-52,367*	7,467	0,000
		Q2/P2	-35,800*	7,467	0,000
		Q4/P4	-28,867*	7,467	0,002
		Q5/P5	-64,833*	7,467	0,000
	Q4/P4	Q1/P1	-23,500*	7,467	0,020
		Q2/P2	-6,933	7,467	0,986
		Q3/P3	28,867*	7,467	0,002
		Q5/P5	-35,967*	7,467	0,000
	Q5/P5	Q1/P1	12,467	7,467	0,633
		Q2/P2	29,033*	7,467	0,002
		Q3/P3	64,833*	7,467	0,000
		Q4/P4	35,967*	7,467	0,000

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.
C_T0	Q1/P1	Q2/P2	16,467	7,585	0,271
		Q3/P3	52,600*	7,585	0,000
		Q4/P4	23,900*	7,585	0,020
		Q5/P5	-13,333	7,585	0,563
	Q2/P2	Q1/P1	-16,467	7,585	0,271
		Q3/P3	36,133*	7,585	0,000
		Q4/P4	7,433	7,585	0,980
		Q5/P5	-29,800*	7,585	0,001
	Q3/P3	Q1/P1	-52,600*	7,585	0,000
		Q2/P2	-36,133*	7,585	0,000
		Q4/P4	-28,700*	7,585	0,002
		Q5/P5	-65,933*	7,585	0,000
	Q4/P4	Q1/P1	-23,900*	7,585	0,020
		Q2/P2	-7,433	7,585	0,980
		Q3/P3	28,700*	7,585	0,002
		Q5/P5	-37,233*	7,585	0,000
	Q5/P5	Q1/P1	13,333	7,585	0,563
		Q2/P2	29,800*	7,585	0,001
		Q3/P3	65,933*	7,585	0,000
		Q4/P4	37,233*	7,585	0,000
C_T1	Q1/P1	Q2/P2	16,967	7,560	0,231
		Q3/P3	53,100*	7,560	0,000
		Q4/P4	24,200*	7,560	0,017
		Q5/P5	-12,600	7,560	0,635
	Q2/P2	Q1/P1	-16,967	7,560	0,231
		Q3/P3	36,133*	7,560	0,000
		Q4/P4	7,233	7,560	0,983
		Q5/P5	-29,567*	7,560	0,001
	Q3/P3	Q1/P1	-53,100*	7,560	0,000
		Q2/P2	-36,133*	7,560	0,000
		Q4/P4	-28,900*	7,560	0,002
		Q5/P5	-65,700*	7,560	0,000
	Q4/P4	Q1/P1	-24,200*	7,560	0,017
		Q2/P2	-7,233	7,560	0,983
		Q3/P3	28,900*	7,560	0,002
		Q5/P5	-36,800*	7,560	0,000
	Q5/P5	Q1/P1	12,600	7,560	0,635
		Q2/P2	29,567*	7,560	0,001
		Q3/P3	65,700*	7,560	0,000
		Q4/P4	36,800*	7,560	0,000

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.
F_T2	Q1/P1	Q2/P2	17,067	7,564	0,225
		Q3/P3	53,367*	7,564	0,000
		Q4/P4	24,600*	7,564	0,014
		Q5/P5	-12,667	7,564	0,629
	Q2/P2	Q1/P1	-17,067	7,564	0,225
		Q3/P3	36,300*	7,564	0,000
		Q4/P4	7,533	7,564	0,977
		Q5/P5	-29,733*	7,564	0,001
	Q3/P3	Q1/P1	-53,367*	7,564	0,000
		Q2/P2	-36,300*	7,564	0,000
		Q4/P4	-28,767*	7,564	0,002
		Q5/P5	-66,033*	7,564	0,000
	Q4/P4	Q1/P1	-24,600*	7,564	0,014
		Q2/P2	-7,533	7,564	0,977
		Q3/P3	28,76667*	7,564	0,002
		Q5/P5	-37,26667*	7,564	0,000
	Q5/P5	Q1/P1	12,667	7,564	0,629
		Q2/P2	29,73333*	7,564	0,001
		Q3/P3	66,03333*	7,564	0,000
		Q4/P4	37,26667*	7,564	0,000

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.
C_T2	Q1/P1	Q2/P2	16,600	7,575	0,259
		Q3/P3	53,067*	7,575	0,000
		Q4/P4	23,867*	7,575	0,020
		Q5/P5	-13,133	7,575	0,582
	Q2/P2	Q1/P1	-16,600	7,575	0,259
		Q3/P3	36,467*	7,575	0,000
		Q4/P4	7,267	7,575	0,983
		Q5/P5	-29,733*	7,575	0,001
	Q3/P3	Q1/P1	-53,067*	7,575	0,000
		Q2/P2	-36,467*	7,575	0,000
		Q4/P4	-29,200*	7,575	0,002
		Q5/P5	-66,200*	7,575	0,000
	Q4/P4	Q1/P1	-23,867*	7,575	0,020
		Q2/P2	-7,267	7,575	0,983
		Q3/P3	29,20000*	7,575	0,002
		Q5/P5	-37,00000*	7,575	0,000
	Q5/P5	Q1/P1	13,133	7,575	0,582
		Q2/P2	29,73333*	7,575	0,001
		Q3/P3	66,20000*	7,575	0,000
		Q4/P4	37,00000*	7,575	0,000

There are significant differences in the mean bite pressure (psi) measured by the different FSS sensors (Q1/P1, Q2/P2, Q3/P3, Q4/P4 and Q5/P5), when the measurement is made in the same experimental conditions (Figure 7 and Table 4). All experiments reveal p-values below the cut-off value of 0,05 ($p < 0,05$), which means that H0 proposition is invalid. Thus, it is concluded that the five FSS sensors detect different mean bite pressures (psi) for the same Examiner (F or C) at the same time moment (Time 0, Time 1 or Time 2).

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 5.

Significant differences ($p < 0,05$) have been identified between certain pairs of FSS sensors (Table 5), allowing the definition of a three-pressure region model (Figure 8): 1) low-pressure region located in the anterior part of the dental arch; 2) medium-pressure region in the intermediate part of the dental arch; and 3) high-pressure region located in the posterior part of the dental arch.

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 (Figure 8 and Table 5), showing the high sensibility of measurement of the experimental device.

CONCLUSIONS

The piezoelectric sensors used in the present study have shown high reproducibility of measurement. Neither the variation of examiner, nor the variation of time have shown to influence the bite pressure (psi).

In contrast, the occlusal force measurement system developed has shown a high level of sensitivity due to the distribution of the five FSS sensors in the horseshoe-shaped form.

A three-pressure region model fits the experimental data shown in this study, comprising a low-pressure region located in the anterior part of the dental arch, a medium-pressure region in the medial part of the dental arch and an high-pressure region located in the posterior part of the dental arch.

Due to the recent miniaturization of FSS sensors, the authors are developing new occlusal force measurement systems comprising a higher number of piezoelectric sensors, with the objective of attaining even higher sensitivity of measurement throughout the different region of the dental arches.

CONFLICT OF INTEREST

The authors declared that there is no conflict of interest.

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