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MAXIMAL BITE FORCE MEASUREMENT BY THE "ISTANBUL BITE FORCE RECORDER"

"İSTANBUL KUVVET ÖLÇERİ" İLE MAKSİMAL ISIRMA KUVVETİ ÖLÇÜMÜ

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ABSTRACT

There is currently no standardized method and device for measuring the maximal bite force (MBF). Many researchers used diverse methods to measure MBF, nevertheless variant results were encountered. The aim of this study was to develop a novel computer-assisted, portable device which is easy to use, reliable and repeatable for long-term monitoring. The device was tested for objectively measuring the MBF.

The device was designed as an analog signal processing unit which measured bite forces by using a strain gage and a computer-controlled recording unit. First, as an in vitro test a calibration was performed in the laboratory to assess the repeatability of the device. To study the in vivo performance, the incisor-region MBF measurements with the Istanbul bite force recorder of twenty-eight healthy subjects were obtained. The in vivo measurements were repeated on the following day and two months later.

The measurements by the device were highly repeatable and the output of the device was linear in the range of 1-223 Newton. When Bland Altman plot was surveyed, the distribution remained mainly at ±2 standart deviation. Intraclass correlation (ICC) values state that the concordance of measurments was very high and the variance between measurements was low ($p<0.001$).

The newly designed Istanbul bite force recorder is a reliable tool for measuring the incisor MBF. Its main advantages are portability with battery operation, small sensor size, and standard USB port-to-computer connection. Future studies will be performed to evaluate the use of the device in various cranio-mandibular diseases.

ÖZET

Maksimal ısırma kuvveti (MIK) ölçümünde standardize olmuş bir metod ya da cihaz yoktur. Pek çok araştırmacı MIK ölçümünde farklı düzenekler kullanmışlardır ve araştırmalardan elde edilen sonuçlar birbirinden oldukça farklıdır. Bu çalışmanın amacı MIK'in objektif olarak değerlendirilmesini sağlayacak, kullanımı kolay, tekrarlanan ölçümlerde güvenilir sonuçlar veren, bilgisayar destekli yeni bir ölçüm aleti geliştirmektir.

Cihaz ısırma kuvveti kaydı elde etmek amacıyla analog sinyal işleyici ünite, gerilme ölçer (strain gage) ve bilgisayar kontrollü kayıt ünitesi kullanan portatif bir alet olarak tasarlandı. Önce in vitro olarak cihazın tekrarlanabilirliğinin değerlendirilmesi için laboratuar ortamında kalibrasyon testi yapıldı. İn vivo testte 28 sağlıklı kişi alındı ve İstanbul kuvvet ölçeri ile insisör bölge MIK değerleri ölçüldü. In vivo ölçümler bir gün sonra ve 2 ay sonra tekrarlandı.

Cihazın yüksek oranda tekrarlanabilir olduğu ve cihaz çıktısının 1-223 Newton aralığında lineer olduğu görüldü. Bland Altman plotu dağılımların çok büyük oranda ± 2 standart deviasyon içinde kaldığını göstermekteydi. Sınıfiçi korelasyon (ICC) değerlerinden ölçümler arasındaki uyumun çok yüksek olduğunu ve ölçümler arası varyansın düşük olduğunu saptandı ($p<0.001$).

Yeni tasarlanan İstanbul kuvvet ölçeri insisör bölge MIK ölçümünde kullanılabilecek güvenilir bir alettir. Ana avantajları pilli ve taşınabilir olması, küçük sensör boyutu ve standart USB portu ile bilgisayara bağlanabilmesidir. Cihazın çeşitli kraniomandibuler hastalardaki kullanımının değerlendirilmesi için daha fazla çalışmaya ihtiyaç bulunmaktadır.

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INTRODUCTION

Stomatognothic system is a complex structure that is made up of the temporomandibular joint, the chewing muscles, the teeth, the gum, the tongue and the pharynx. Many conditions like various joint and muscle problems, occlusion disorders, dentures, age, gender, orthognathic surgery, psychological problems and trauma may affect the function of the stomatognothic system (1). Bite forces, which may greatly differ in magnitude and direction, result from the different action combinations of the masticator and the cooperative muscles (2). Maximal bite force (MBF) is the maximal force which can be obtained in the mouth with the help of the masticator muscles.

The importance of MBF in the evaluation of temporomandibular joint problems and chewing function have been shown in previous studies (2,3,4). It was reported that abnormal mechanical stress originating especially from the muscles and the consequent inflammation influenced the feeling of pain in the temporomandibular joint (5). However, previous studies on this topic revealed contradictory results. While some investigators presumed that the symptoms due to temporomandibular diseases decreased in individuals with higher bite forces (6), others reported that there was no such correlation (7). In addition, MBF was reported to be lower in patients with temporomandibular joint disorders (8,9,10). It is important to note that each investigator used his/her custom-made device to measure the maximal bite force. Consequently, the results of previous studies widely varied from each other. The diverse results of different studies may originate from different sensors (eg: EMG or different types of gages) used in setup or varied mouth piece materials.

The aim of this study is to develop a novel computer-assisted measurement device which is easy to use, reliable and repeatable to objectively determine bite forces, which are known to be related with dysfunction in the temporomandibular joint. There is a lack of standardized measurement method which is also easy to use and reliable. Since the device can monitor bite forces over long durations, it can be carried along by the patient for taking measurements at various times during day and night. The performance of the device is first presented for measuring MBF in healthy subjects. This device will further be used for measuring MBF in various craniomandibular disorders and can be helpful to resolve current conflicts in the literature. For example, the device may be used during sleep to monitor bruxism.

MATERIALS and METHODS

Istanbul Bite Force Recorder

The flow diagram of the study was given in the Figure-1. The device was housed in a portable (14 × 8 cm) box (Figure 2A) and it recorded bite forces by using a strain gage (11). The cylindrical strain gage (model 13; Honeywell Sensotec, Columbus, OH) with a diameter of 9.7 mm and a height of 3.3 mm was placed between two small C-shaped stainless steel panels (316L) which were 0.85 mm thick (Figure 2B). The

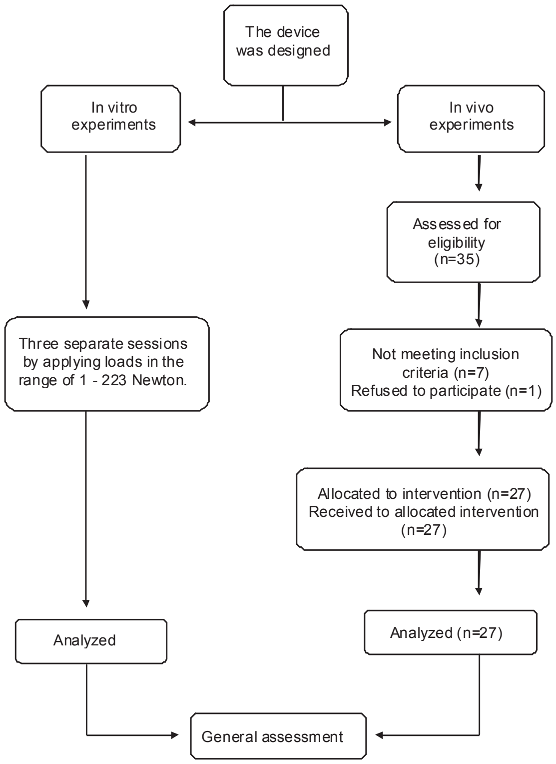

Figure 1. Consort flow diagram of the study

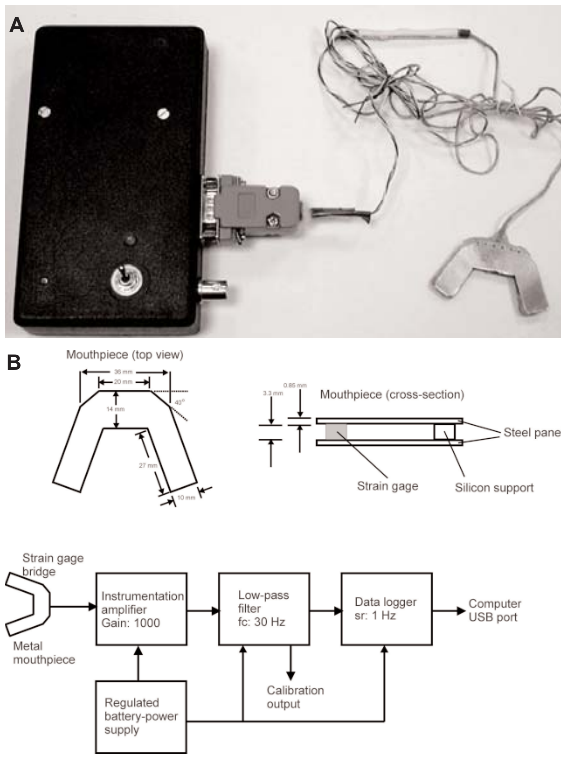

Figure 2. Bite force recorder. (A) Picture of the recorder unit and the mouthpiece (B) Mouthpiece dimensions and cross-section. Functional block diagram of the device. fc: cut-off frequency, sr: sampling rate.

Table I

Exclusion criteria for the study:

1- Patients with any of the following diagnoses:
   a. Patients with reductible and non-reductible TMJ disc displacement
   b. Patients with TMJ degeneration
   c. Patients with TMJ subluxation
   d. Patients with myofacial trigger point that affects TMJ muscles
   e. Patients receiving radiotherapy at TMJ region
   f. Patients who had surgery or arthroscopy at TMJ region
2- Patients who do not have continuous dental arches (loss of more than six teeth).
3- Patients with major occlusion disorders.
4- Patients with previous diagnoses of rheumatic diseases.
5- Patients with previous diagnoses of major psychiatric disorders.

panels were connected to each other so that the mouthpiece of the device was 5 mm high. The dimensions of the mouthpiece and the block diagram of the device are given in Figure 2B.

The strain gage was already packaged as a strain-gage bridge by the manufacturer, and its output was amplified (gain: 1000) by an instrumentation amplifier (AD627; Analog Devices, Norwood, MA). The output of the amplifier was further processed with a low-pass filter which had a cut-off frequency of 30 Hertz (12) to obtain the calibration output of the device. During clinical tests, the filter output was recorded by a data logger (U12-013; Onset Computer, Bourne, MA) at a sampling rate of 1 s. Since bite-force fluctuations are very slow, this sampling rate was adequate for the purpose of this study. On the other hand, the separate calibration output enabled faster response times to obtain the dynamic calibration of the device. The device was powered by a regulated-battery supply (±3 V), and the sensor in the mouthpiece was hermetically sealed. The device was connected to external equipment (i.e., computer) by the clinician only while the mouthpiece was outside the patient; therefore, there was no need for extra power-supply isolation.

The output voltage was proportional to the bite force and the relative measurement error was 2 %. The output readings could be recorded over months by using the 64-kbyte memory in the data logger. The programmable settings (e.g. recording duration) in the data logger could be adjusted by connecting the device to a personal computer via the USB port. At the end of an experiment, the bite force values were transferred to a personal computer to be analyzed by the clinician. The software (HOBOware Ver.2; Onset Computer, Bourne, MA) enabled data transfer as text (ASCII) or spreadsheet (e.g. MS Excel) files. The subject had only access to an on/off switch on the device and could not alter the settings.

Subjects

Fifteen male (mean age: 29.5±8.7) and thirteen female (mean age: 28.8±8.1) healthy individuals who complied with the exclusion criteria defined in Table 1 participated in the study. Following interviews, all subjects were also clinically examined. The experiments do not pose any harm to the subjects and they adhere to the U.S. NIH ethical guidelines for testing human subjects. Before participation, each subject was informed about the experimental details and their written consents were obtained in compliance with the Declaration of Helsinki.

Experimental procedure

First, in vitro calibration tests were performed to assess the repeatability of the new bite force recorder. The calibration of the device was tested at three separate sessions by applying loads in the range of 1-223 Newton. During calibration, the loads were applied perpendicularly on the anterior part of the mouthpiece by using a small hand press. This contact point for loading mimicked the clinical application. Then, incisor-region MBF values of the subjects were measured with the bite force recorder. The sensor part of the device was placed in the mouth at the interincisor position between the central incisors. Sterile plastic covers were used for each subject and the mouthpiece of the device was cleaned with a disinfectant solution after each use. The in vivo measurements were repeated on the following day and two months later.

Statistical Analysis

The raw voltage data obtained from the bite force recorder were converted to force units in Newtons by using the calibration coefficient obtained from the in vitro experiment. Statistical tests were performed on force values. Paired t-test and Bland-Altman plot were used to find the statistical differences between the first vs. second, the second vs. third and the first vs. third measurements. Pearson correlation coefficient and intra-class correlation coefficient were calculated for the pairs of the first, the second and the third measurements. Variation coefficient for each measurement was presented. Statistical significance level was set at = 0.05 (two-tailed).

Local ethic committee agreement was taken for the study.

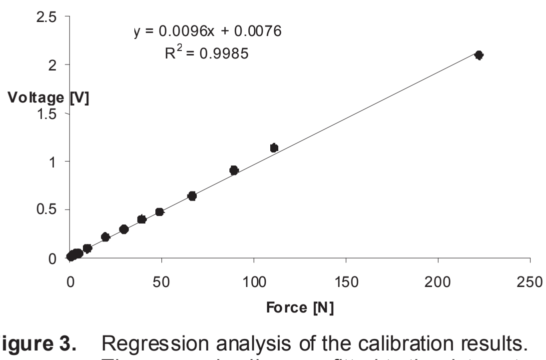

Figure 3. Regression analysis of the calibration results. The regression line was fitted to the data set consisting of the averages of three calibration measurements.

Table II

Calibration results of bite force recorder (in vitro measurements)

	Mean	Variance	t-test	p	Pearson Correlation
1st measurement	0.457	0.330	-0.256	0.802	0.990
2nd measurement	0.465	0.431			
1st measurement	0.457	0.330	0.297	0.771	0.992
3rd measurement	0.451	0.345			
2nd measurement	0.465	0.431	0.568	0.580	0.995
3rd measurement	0.451	0.345			

Table III

Descriptive statistics of the in vivo measurements (N: Newton).

	Minimum (N)	Maximum (N)	Mean (N)	Standard Deviation	Variation Coefficients
1st measurement	53.25	146.67	101.01	34.65	34.30
2nd measurement	47.58	139.16	98.98	32.87	33.20
3rd measurement	51.18	140.47	97.57	32.33	33.13

Table IV

The results of variance analyzes at repeating measurements.

Source	factor	Type III Sum of Squares	df	Mean Square	F	P
factor	Level 1 vs. Level 3	330,913	1	330,913	2,503	0,125
	Level 2 vs. Level 3	55,491	1	55,491	0,351	0,558
Error (factor)	Level 1 vs. Level 3	3569,781	27	132,214		
	Level 2 vs. Level 3	4268,466	27	158,091		

factor	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	101,01	6,549	87,573	114,447
2	98,98	6,212	86,234	111,726
3	97,572	6,111	85,033	110,111

RESULTS

Calibration

The calibration results are given in Table 2. There was no significant change in the calibration (n = 10; paired t-tests between sessions: first-second, p = 0.802; second-third, p = 0.580; third-first, p = 0.771). Therefore, the calibration results were highly repeatable. The average calibration data are shown in Figure 3, in which the

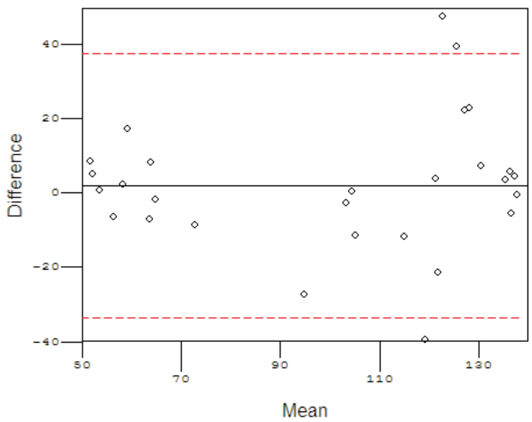

Figure 4. Differences between the mean values of first and second measurements according to Bland-Altman plots (mean: 2.04±17.87 Newton)

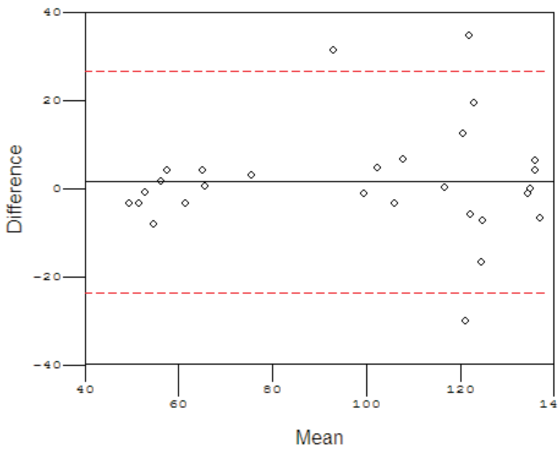

Figure 5. Differences between the mean values of secon and third measurements according to Bland-Altman plots (mean: 1.40 ± 12.57 Newton)

Table V

Reliability analysis of the in vivo measurements (sICC: Single Measure Intraclass Correlation; aICC: Average Measure Intraclass Correlation).

	sICC	aICC
1st and 2nd measurements	0.8601 (lower: 0.7204, upper: 0.9327) F=13.39, DF=27; p<0.001	0.9248 (lower: 0.8375, upper: 0.9652) F=13.39, DF=27; p<0.001
2nd and 3rd measurements	0.9256 (lower: 0.8460, upper: 0.9649) F=25.89, DF=27; p<0.001	0.9614 (lower: 0.9166, upper: 0.9821) F=25.89, DF=27; p<0.001
1st and 3rd measurements	0.9411 (lower: 0.8770, upper: 0.9723) F=32.98, DF=27; p<0.001	0.9697 (lower: 0.9345, upper: 0.9860) F=32.98, DF=27; p<0.001

Table VI

Pearson correlation values of the in vivo measurements (* Correlation is significant at the 0.01 level (2-tailed)).

	1st measurement	2nd measurement	3rd measurement
1st measurement	1	0.861*	0.943*
2nd measurement	0.861*	1	0.926*
3rd measurement	0.943*	0.926*	1

voltage output of the device is plotted as a function of the applied force (data points). The straight line is the best-fit line obtained by linear regression. There is a very high correlation between the voltage output and the force input ($r = 0.999$), and this correlation is highly significant ($p<0.001$). The straight line can be represented as the function: $V = 0.0096 \times F + 0.0076$, where F is the force input and V is the voltage output. The calibration coefficient is 0.0096 V/N (or ~104 N/V). The zero error of the device is +7.6 mV.

In vivo experiment

Mean value of three MBF measurements was 96.90±36.6 N in females and 101.16±29.1 N in males. There was no significant difference between the MBF values of male and female subjects ($p = 0.730$). When three measurements (first day, the day after and two months later) of each subject were compared with each other, there were no statistically significant differences (Tables 3-6). The measurements were also significantly correlated ($p<0.01$).

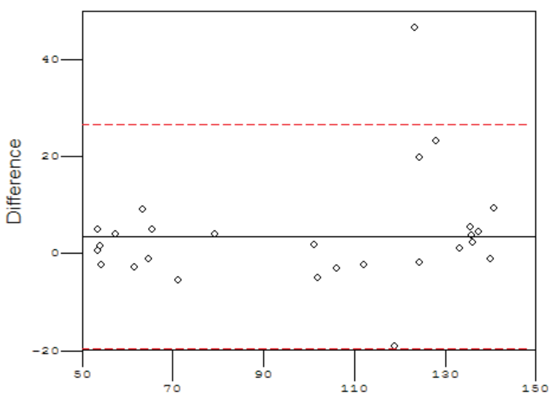

Figure 6. Differences between the mean values of first and third measurements according to Bland Altman plots (mean: 3.43 ± 11.5 Newton)

When Bland Altman plot was surveyed, the distribution remained mainly at ±2 standart deviation (Figure 4-6). Intraclass correlation (ICC) values state that the concordance of measurments was very high and the variance between measurements was low (Table-5). The results of variance analyzes at repeating measurements was given in Table-4.

DISCUSSION

There is currently no standardized method and device for measuring MBF. Investigators have tested sensors with different operation principles and various devices. Strain gages at different thicknesses and quantities, piezoelectric crystals, other transducers or electromyography (EMG) were used in these devices. For example, Castroflorio and colleagues used an intra-oral compressive force sensor in combination with superficial EMG in order to evaluate the masticator muscle power (13). Kalachev measured the distribution of the occlusal load in two halves of a dentition with a T-scan system, which was an occlusal analysis device for determining the functional masticator equilibrium (14). Maurer and colleagues evaluated the chewing power in patients with mandibular resection by using a computer assisted measurement device (15). Rottner and colleagues reported that the bite force could be measured independently from the occlusal morphology of the teeth with thin-film transducer foils (16). Ferrario and colleagues showed that the submaximal bite forces and the surface EMG potentials of mandibular elevator muscles, which were simultaneously recorded with the help of a transducer, had a linear relationship (17). Stegenga and colleagues employed two strain gauges and two parallel stainless steel beams to measure the bite force in their equipment (8). They could measure torques with strain gauges attached to the upper beam.

This article describes a device with a novel approach. The bite force recorder presented here is capable of monitoring bite forces over a long period of time, and can be worn during day and night. Since there is no established standard for measuring bite forces, it is critical to determine the bite force periodically to study cranio-mandibular diseases. For example, the device may be used to monitor bruxism during sleep. We are currently working to improve the mouthpiece for long-term monitoring and to establish a wireless link. Although we did not test the drift in this study (not relevant for MBF measurements), we expect it to be negligible because the sensor was hermetically sealed. However, we will test the drift before using the device for a long-term measurement.

The first use of the device was demonstrated for measuring the incisor MBF in healthy subjects. We hypothesize that Istanbul bite force recorder may be used in follow-up of patients with bruxism, evaluation of dental interventions, results of masseter hypertrophy treatment and also in follow-up of the diseases of TMJ and disorders affecting muscles of TMJ.

The statistical analyses showed that the bite force measurements were repeatable and the recorder device was reliable. The main advantages of the device are its portability with battery operation, small sensor size, and standard USB port-to-computer connection. The device provides force data that may be transferred to a personal computer and stored in digital media. The overall thickness of the sensor mouthpiece is 5 mm in the bite force recorder described above. This thickness is lower than those reported in the literature and provides comfort during biting. The interincisal distance was 15 mm in the study by Stegenga and colleagues (8), 22 mm in the study by Waltimo and Könönen (2), and 10 mm in the study by Ferrario and colleagues (17). The small sensor size would also minimize distress during the long-term use of the mouthpiece. The sensor structure can be easily disinfected and placed between the teeth in the current design.

Numerous factors are effective on the MBF. Those factors are the age, gender, BMI, occlusion state, vertical separation of jaws, position of the mandible, load per periodontal ligament area, thickness of the sensor, the oral region where the measurement is performed, and the exact placement of the sensor (2). There are inter-individual differences between MBF measurements of healthy individuals and various diseases may also affect MBF. The effect of the temporomandibular joint (TMJ) diseases on MBF is still not clear. Although some authors reported negative effects, others showed that there was no change (18,19). Svensson and colleagues presumed that weakness in MBF might be an etiological factor for the development of TMJ diseases (20). The magnitude of MBF is related to the power of the chewing muscles and particularly the masseter muscle (21). Genetic factors, differences in gender and sports may effect the strength of the muscles (22,23). It was shown that MBF was considerably decreased in patients with TMJ dysfunction and occlusion problems, but no relation between the Helkimo's index, BMI and MBF was found (3).

Different investigators obtained various results from MBF measurements at the incisor region, which was the location studied here. Maximum mean values varied between 108-293 N (24,25). Mean values in our study were relatively lower (97-101 N). There may be several possible causes for these relatively lower measurements. The differences between the measurement devices (e.g. the direction of the forces), anatomy, psychological conditions, mean age, and inability to bite maximally due to various causes may have contributed to that slight discrepancy. The calibration of the device was performed at the anterior part of the sensor to conform with the clinical application. The output would change if the load was applied at the posterior ends. In our future studies, we would like to improve the device by placing specific sensors for the molars.

The forces generated in the molar region would be expected to be higher. MBF values over 700 N were reported in the previous articles which studied that region (26). The greatest power is typically obtained in the first molar area and it may reach to four times as much as generated in the incisor region (27). Typically, males generate higher MBF than females in the molar region (2). However, no significant difference exists for the incisor MBF between males and females (2). Our results were consistent with that finding. Large scale investigations, however, must be performed in order to determine reference values for MBF according to age and gender.

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