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INNOVATION

Development of computerized masticatory force measurement system

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ABSTRACT

Purpose: The aim of this study was to assess the Maximum Voluntary Bite Force (MVBF) in Indian population with normal occlusion and after treatment of mandibular angle fracture.
Materials and methods: This paper discusses the development of a sensor fork with modified load cell and computer-based bite force measuring system that generates force profile on the computer. This is a powerful diagnostic tool in response to the needs of dentists seeking an accurate way to dynamically measure occlusion.
Results: This study was carried out to evaluate the maximum voluntary bite force generated by the patients after the treatment of mandibular angle fracture. The *in vivo* measurements were repeated on the following day, week and two months later. The measurements of the device were highly repeatable.
Conclusion: This development provides the cost effective and handy equipment for bite force measurement further, if again sensor thickness reduced, we will be able to get more close results of forces that are exactly generated during the mastication process. Our study shows a significant difference in mean bite force efficiency between the all the treatment weeks and increased with time at $\alpha = 0.05$ level. The gender difference was statistically significant in the male and female.

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Masticatory system; maximum voluntary bite force (MVBF); force profile; bite force device and sensor fork with load cell

1. Introduction

Nowadays, there is the demand of development of the bite force system that will help with the assessment of assorted problems associated with the orthodontist.[1] Measuring the bite force with this weighing system is the easiest way of diagnosis and treatment with a variety of diverse orthodontics abnormalities in functioning.

The prior studies have discovered the importance of the maximum voluntary bite force (MVBF) in the evaluation of temporomandibular joint (TMJ) problems and chewing function.[2–4] 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] Some investigators presumed that the symptoms due to temporomandibular diseases decreased in individuals with higher bite forces.[6] In addition, MBF was reported to be lower in patients with temporomandibular joint disorders.[7–9] It is important to note that each investigator used his/her custom-made device to measure the maximal bite force. The assorted results of different studies may originate from different sensors used in setup or varied mouthpiece materials.

Maximum human bite force and its effects have been closely studied in numerous laboratory experiments. It varies with several factors including subject gender, age, food type, jaw disorders, tooth quality, muscular strength and other factors. Incisors are located in the front of the jaw and have the least mechanical advantage, being at the front of the mouth.[10] Conversely, molars at the rear have the greatest potential for mechanical advantage. It has been reported that the average bite force of incisors is 40% that of molars and chewing force at the incisor is 47% of the force on the molars.[11]

Svensson and colleagues presumed that weakness in MBF might be an aetiological factor for the development of TMJ diseases.[12] The magnitude of MBF is related to the power of the chewing muscles and particularly the masseter muscle.[13] Genetic factors, differences in gender and sports may affect the strength of the muscles.[14,15] It was also observed that MBF would be changed in case of face height. It was shown that MBF was considerably decreased in patients with TMJ dysfunction and occlusion problems.

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Table 1. Maximum bite force in male and female subjects as reported by different articles.

Article Number	Male Max. Force (N)	Female Max. Force (N)	Measurement device	References
1	847	597	Quartz force transducer	[2]
2	909	777	N/A	[4]
3	652	553	Strain gauge mounted on mouthpiece	[23]
4	587	425	Digital dynamometer	[24]
5	505	315	Digital dynamometer	[25]
Average	700	533	–	–

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.[16] 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.[17] Typically, males generate higher MBF than females in the molar region.[2] However, no significant difference exists for the incisor MBF between the males and females.[2]

Force measurement has been conducted to assess both the force required for mastication and maximum bite force.[18] Forces on all contacting teeth during mastication range between 190 and 260 N.[19] Maximum bite force is variable between the experiments, but generally falls within the range of 500–700 N.[20] Maximum bite force as reported by several different articles for young, healthy subjects is shown in Table 1.

Our aim is to design and develop a local; reliable, cost effective, repeatable and easy-to-use clinical diagnostic device that senses and helps to analyse occlusal contact forces which are known to be related to dysfunction in the temporomandibular joint. There is a no appropriate, reliable measurement method. The performance of the device is first presented for measuring MBF in healthy subjects. This device will further be used for measuring MVBF in various craniomandibular disorders and can be helpful to resolve the effectiveness of the treatment of mandibular fracture.

The present study aim at evaluation of Occlusal Forces Data in graphical representation with a personal computer (PC) that would lead to wonderful clinical and teaching aid and recording and retrieving data is easy. This paper illustrates the design and development of bite force system based on analogue to digital converter (ADC) along with fully featured microcontroller system and PC based software. The system is highly accurate, fast with high resolution.

Reusable sensor fork shaped to fit the dental arch to sense pressure at teeth and converted to digital form by ADC. The data obtained from the sensor that is connected by means of USB port of PC. Evaluating occlusal forces is as simple as having a patient bite down on the sensor. The sensor sends real-time and relative occlusal contact force information to excel sheet and force profile was plotted on the screen using Windows based visual basic software and statistically analysed by dentist for further treatment. The greatest strength of this system is able to compare bilateral contacts with reasonable accuracy. Diagnostic display comprises instantly information of forces on all teeth which is available for clinicians on click of a mouse. The Force profile identifies the presence and magnitude of occlusal obstructions and alerts the clinician to any destructive contacts that damage expensive treatments such as implants and complex bridge work. The forces of the tooth contacts are shown in easily understandable colour-coded pressure profile. These allow instant diagnosis of the occlusion, as well as the instant force with a colour profile.

The paper is organised as Section 2: Materials and methods, where development of sensor fork with modified load cell and its signal conditioning is explained in detail, Section 3: Objective of the system, elaborates on the helpfulness of system for diagnosis to dentist Section 4: Details of experimental set up configuration and its capabilities are presented and discussed, Section 5: Results and discussion, experimental clinical results are summarised, Section 6: conclusion, the designed set up is cost effective, portable and repeatable for bite force measurement.

2. Materials and methods

The bite force recorder consisted of a detailed state of art device, which was carefully selected and individually crafted using technical expertise when required. The actual device was developed in combination with the superior technical knowledge in our laboratory.

It consists of following components:

1. Sensor fork with modified load cell.
2. Electronics signal conditioning circuit.
3. Battery for instrumentation amplifier and Wheatstone bridge.
4. Computer for display,
5. Disposable polypropylene cap.

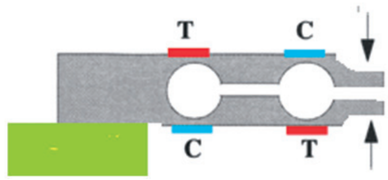

Figure 1. Used sensor fork (Modified parallel beam load cell).

A load cell was modified in the shape of fork with the help of milling machine and surface grinder. The strain gauge was the sensory element of sensor fork. The strain gauge indicating "T" in Figure 1 is under tension and "C" indicating is under compression. The total thickness of the fork at the biting end was 8.0 mm and width was 20 mm. There was a gap of 3 mm between upper and lower parts of fork with each being 2.5 mm thick, thus giving a thickness of 8.0 mm. Total length of the fork was 15 cm. Being sensor fork was made up of specialised aluminium there is no question of rusting of fork.

2.1 Electronics signal conditioning circuits

It consisted of a Wheatstone bridge assembly, an instrumentation amplifier, microcontroller and PC or Laptop for display. Signal conditioning circuits and microcontroller were supplied with battery voltage and whenever a force was applied to fork, it re-enacted a process similar to bending of a beam and caused an elongation of the strain gauge, which caused a measurable change in the resistance of one of the arms comprising the Wheatstone bridge and was ultimately transformed into a change in the measured voltage which was processed through signal conditioning circuits and displayed on computer screen display. Fork tip was covered with disposable polypropylene cap.

2.2 Disposable polypropylene caps

In order to reduce metallic impact on the teeth and to prevent cross contamination, the biting end of the fork was covered with disposable caps, made up of polypropylene possessing excellent elasticity for ease of placement and removal as well as adequate strength to withstand large biting force without fracture. The thickness of each cap was very small than 0.8 mm. Hence, total thickness and size of fork tip was 9.6 mm along with the cap.

The subjects were comfortably seated in the dental chair with natural unsupported posture, looking straight, and the procedure was explained to them. The MVBF was measured with a bite force system. The bite force was recorded in the right and left permanent first premolars and molars bilaterally for male and in the right and left permanent first molars bilaterally for female. The measurements were taken with the probe tip placed against the occlusal surface of the lower teeth and the patient being asked to close onto the gauge in a natural closing arc. The subjects were asked to bite onto the gauge as hard as possible and the value was recorded as the maximum voluntary bite force of that tooth. The procedure was made three times, with an interval of two minutes and the final value was determined as the average of the measurements and recorded in an excel sheet.

Data collected by the investigators were recorded by the system to an Excel spreadsheet. All the data were visually screened for any missing data or outliers and for validity of distribution assumptions. Data were then summarised by finding means and standard deviations. Statistical analysis was carried out using statistical package of social sciences. The values in excel sheet use to generate force profile using a programme written in visual basics 6 (VB 6) software (Redmond, WA).

3. Objective of system

3.1. Easy to use and easy to interpret

The system plugs right into the USB port of a Windows based PC or laptop. Stunning graphics make seeing the balance of the perfect bite easy to determine and adjust. Data can be printed to provide valuable documentation for patient data base files, patient education or insurance claim documentation. This software can incorporate many easy to use ideas gathered from the experience with the users, streamline data collection and improve data presentation, so doctors will require to spend less time in collecting and analysing data and more time applying the information and discussing the results with their patients.

In future more applications may be possible for this system in numerous craniomandibular diseases like fixed prosthesis, occlusion equilibrium, etc., and identity premature contact, increase implant longevity, enhanced patient comfort, etc.

In order to know the effectiveness of the treatment of mandibular fracture bite force measurement is an important parameter. It will also help in evaluating the duration required to achieve maximum bite force.

This system can be integrated into an existing dental workstation for diagnostic and treatment management, helping to make dentist; practise more efficient and productive than recent days.

3.2. Occlusal analysis

By this system, we can measure dental occlusal forces and force profile allows examine balanced occlusion of the patient.

The experts can provide diagnosis and improvement status of the treatment to the patient. After recording a dental occlusion the data can store in computer and retrieve it as needed. This vivid, full-colour graphics can be transferred into other documents for a patient's records or insurance claim reports. The images can be used to educate the patient.

The graphic representations produced by design system will not only ease the understanding for treating to clinicians, but also a beneficial tool for the patient to help them visualise and understand the nature and degree of their occlusal disharmony.

4. Details of experimental set up

The system is as shown in Figure 2 and includes ADC0809, AT89S51; Max232 & NE555N receive 5V supply. While the sensor fork is modified load cell and the instrumentation amplifier has a dual power supply of ±12V.

To calibrate the sensor fork 0–3 kg range, we have applied various loads on the fork. The output voltage of sensor fork is very low in millivolt which is difficult for measurement. Thus, the output is amplified by instrumentation amplifier. The loads vary from 0 kg to 3 kg at the interval of 1 kg respectively. We get corresponding output as 0 ± 0.046 V, 2.34 ± 0.08 V, 4.74 ± 0.08 V and 7.50 ± 0.08V. The relationship between applied load and output voltage is linear. The output of Instrumentation amplifier is given to the input channel of ADC. The ADC receives clock from the timer. The ADC then converts the analogue data to Digital form and sends it to the microcontroller for serial communication with the PC. The job of the microcontroller is to read data from ADC and send it to the PC. For transmission of data we use the RS 232. Thus, for serial communication, we use the Max 232 IC to convert the microcontroller voltage levels to RS232 Standards.

The sensor fork developed for the measurement of bite force applied on the patient's incisor teeth is as shown in Figure 3. This sensor is having four strain gauges to measure force applied by teeth. Sensor fork is used for the measurement of very high compressive and tensile force and high pressures. A sensor fork cell is generally comprised of three parts: a mechanical system, a strain gauge, and an electronic signal conditioning system. The measurement of a force is done by the use of these three parts in the order they are listed. It should be noted that sensor fork (modified load cell) can be configured with multiple strain gauges. Every time across each tooth measurement is made and the result stored in spreadsheets on new row and afterward the data from the spreadsheet for performance evaluation and testing is plotted on the screen using software developed in Visual Basics (VB) software which would be obtained as force profile indicates the force on an individual tooth in the dental arch form as shown in Figure 4.

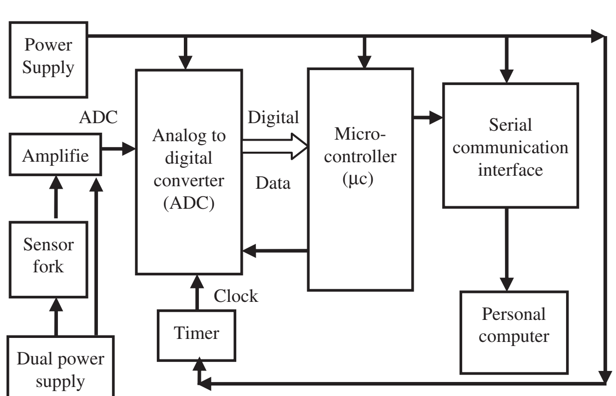

Figure 2. Block diagram of the experimental set up.

5. Results and discussion

The bite force values are shown on the right hand side in the Figure 5 that indicates the force on an individual tooth in the dental arch style. These force values are stored in the excel sheet. The graph on the

Figure 3. Patient bites on sensor fork.

left hand side is a simple histogram graph indicating force of each tooth. This graph can be used by the dentist for diagnosing purposes.

Overall average bite force efficiency of control group (normal group) and study group (under treatment) were recorded as shown in Table 2. The overall bite force efficiency of control group is as shown in Figure 6(a).

The study group consists of patients who fulfilled the selection criteria. Out of 22 patients, seven cases were of isolated angle fracture, eleven were angle fracture with parasymphysis, 2 were angled with opposite side body fracture, 2 were angle fracture with symphysis fracture and one was angle fracture with subcondylar fracture of same side. Out of 22 patients, 20 were males (90.91%) and two were females (9.09%).

Out of 22 patients 14(63.64%) patients fall in the age group of 20 to 30 years, 3 patients(13.64%) in 30 to 40 years and 5(22.73%) in 40 to 60 years.

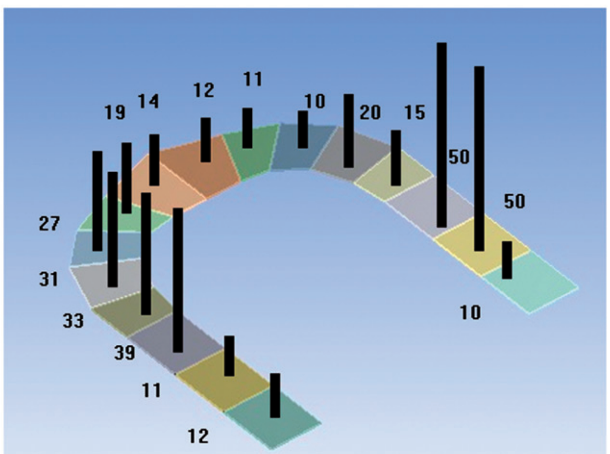

Figure 4. Sample bite force profile indicates the force on an individual tooth in the dental arch form.

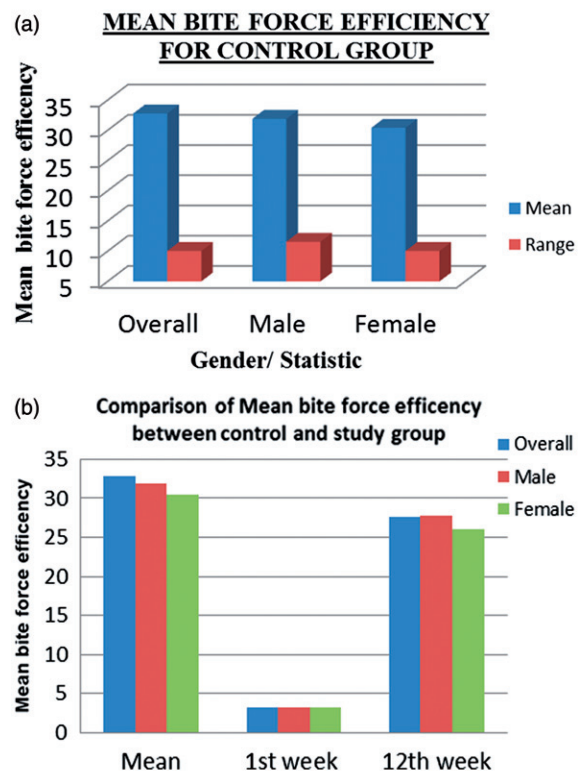

Figure 6. (a) Gender wise efficiency of control group. (b) Gender wise comparison of bite force efficiency between normal and treated group of patients.

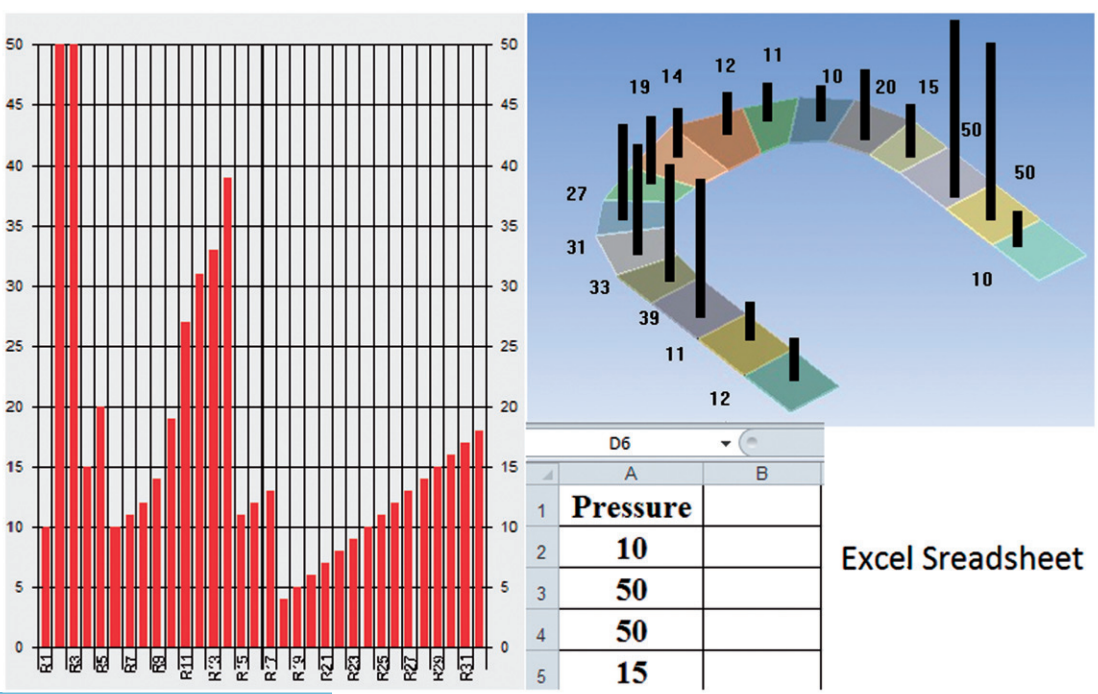

Figure 5. Force profile generated on screen for excel sheet created during force measurement of all teeth.

Table 2. Bite forces for control group.

Category	Statistics/Gender	Overall	Male	Female
Control group (Normal)	Mean ± S.D	32.77 ± 10.52	31.89 ± 11.39	30.41 ± 7.47
	Range	10.03–51.64	11.57–51.64	10.03–34.67
Study group (Under treatment)	1st week	3.21	3.22	3.13
	12th week	27.63	27.79	26.00
	t value	−2.08	0.04	−1.41
	p values	0.048	0.49	0.08

Overall bite forces of the patients (study group) were recorded post operatively over the duration of twelve weeks. Overall bite force efficiency of patients for first, second, fourth, sixth, eighth, tenth, twelfth weeks were compared with each other using paired *t* test as shown in Figure 6(b).

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 and standard USB port-to-computer connection. The device provides force data that are transferred to a personal computer and stored in digital media. This sensor fork provides comfort during biting. The small sensor size would also minimise 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 which affect the MBF are the age, gender, body mass index (BMI), occlusion state, vertical separation of jaws, the 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. There are inter-individual differences between MBF measurements of healthy individuals and various diseases may also affect MBF. Different investigators obtained various results from MBF measurements in the incisor region, which was the location studied here. Maximum mean values varied between 108–293 N.[21,22] Mean values in our study were relatively higher 22.2–43.2 kgf (222–432 N). There may be several possible causes for these relatively higher 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 on the anterior part of the sensor to conform to the clinical application. The output would change if the load was applied at the other place than that of standardised point. In our future studies, we would like to improve the device by placing specific designed sensors with reduced thickness for the premolar, molars and incisor teeth at a time.

6. Conclusion

The system makes easy to see interferences, their locations and their force levels. This takes the guesswork out of adjusting. Record again to verify if and when proper anterior guidance has been achieved. There are various inventions going on bite force measurement, also there are several machines available for bite force measurement, but these machines are very costly and not easily available in India, so treatment is carried out by visual observation. Hence, we developed the portable and low-cost equipment.

In our study all the comparisons show that there is a significant difference in mean bite force efficiency between the all the treatment weeks. This difference is increasing as the time (in terms of week) increases. The mean difference is significant at $\alpha = 0.05$ level. Overall bite force efficiency of male and female patients for first and twelfth weeks were compared with each other using paired *t* test. In both the cases, i.e. in males as well as females, significant difference in mean bite force efficiency was observed between the first and twelfth weeks.

Subsequently, we are working forward to develop competitive software that can help us in further analysis. The aim of the study was to evaluate the maximum voluntary bite force generated by the patients. Thus, this system makes easy to see their bite forces. Record again to verify if and when proper guidance has been achieved. Documentation and retrieving data for future implementation is advantageous.

Here, we developed, the cost effective and handy equipment for bite force measurement using microcontroller and sensor fork. This device can be used in dental applications for the treatment of mandibular fracture and bite force measurement. Additionally, we are now working on the development of new thin sensor. If again sensor thickness is reduced, we will be able to get more close results of forces that are exactly generated during the mastication process.

Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

References

[1] Gutkin VI, Osipovich LA. Devices for measuring the force of dental bite (gnathodynamometers). Biomed Eng. 1990;24:65–71.

[2] Waltimo A, Könönen M. A novel bite force recorder and maximal isometric bite force values for healthy young adults. Eur J Oral Sci. 1993;101:171–175.

[3] Ahlberg JP, Kovero OA, Hurmerinta KA, et al. Maximal bite force and its association with signs and symptoms of TMD, occlusion, and body mass index in a cohort of young adults. Cranio. 2003;21:248–252.

[4] Waltimo A, Könönen M. Maximal bite force and its association with signs and symptoms of craniomandibular disorders in young Finnish non-patients. Acta Odontol Scand. 1995;53:254–258.

[5] Wyke B, TnotjarogpCoRD. The neurology of joints-a review of general-principles. Clin Rheum Dis. 1981;7:223–239.

[6] Helkimo E, Carlsson G, Carmeli Y. Bite force in patients with functional disturbances of the masticatory system. J Oral Rehabil. 1975;2:397–406.

[7] Stegenga B, Broekhuijsen ML, De Bont LG, Van Willigen JD. Bite-force endurance in patients with temporomandibular joint osteoarthrosis and internal derangement. J Oral Rehabil. 1992;19:639–647.

[8] Larheim TA, Flöystrand F. Temporomandibular joint abnormalities and bite force in a group of adults with rheumatoid arthritis. J Oral Rehabil. 1985;12:477–482.

[9] Sato S, Ohta M, Sawatari M, et al. Occlusal contact area, occlusal pressure, bite force, and masticatory efficiency in patients with anterior disc displacement of the temporomandibular joint. J Oral Rehabil. 1999;26:906–911.

[10] Osborn JW. Features of human jaw design which maximize the bite force. J Biomech. 1996;29:589–595.

[11] Helkimo E, Ingervall B. Bite force and functional state of the masticatory system in young men. Swedish Dental J. 1978;2:167.

[12] Svensson P, Thomas G-N. Craniofacial muscle pain: review of mechanisms and clinical manifestations. J Orofacial Pain. 2001;15:2.

[13] Raadsheer MC, van Eijden TM, van Ginkel FC, Prahl-Andersen B. Contribution of jaw muscle size and craniofacial morphology to human bite force magnitude. J Dental Res. 1999;78:31–42.

[14] Bakke M. Mandibular elevator muscles: physiology, action, and effect of dental occlusion. Scand J Dent Res. 1993;101:314–331.

[15] Kuwano T, Takada H, Washino K, et al. [An evaluation of the biting force, the body composition and the amount of masticatory action in young females]. Nihon eiseigaku zasshi. Japan J Hygiene. 1998;52: 624–630.

[16] Osborn JW, Baragar FA. Predicted pattern of human muscle activity during clenching derived from a computer assisted model: symmetric vertical bite forces. J Biomech. 1985;18:599–612.

[17] Carlsson GE. Bite force and chewing efficiency. Front Oral Physiol. 1974;1:265–292.

[18] Anderson DJ. Measurement of stress in mastication. I. J Dental Res. 1956;35:664–670.

[19] Gibbs CH, Mahan PE, Lundeen HC, et al. Occlusal forces during chewing-influences of biting strength and food consistency. J Prosthetic Dentist. 1981;46: 561–567.

[20] Wood GD, Williams JE. Gnathodynamometers: measuring opening and closing forces. Dental Update. 1981;8:239–241.

[21] Hellsing G. On the regulation of interincisor bite force in man. J Oral Rehabil. 1980;7:403–411.

[22] Helkimo E, Carlsson GE, Helkimo M. Bite force and state of dentition. Acta Odontol Scand. 1977;35:297–303.

[23] Van Der Bilt A, Tekamp A, Van Der Glas H, Abbink J. Bite force and electromyograpy during maximum unilateral and bilateral clenching. Eur J Oral Sci. 2008;116:217–222.

[24] Kogawa EM, Calderon PS, Lauris JRP, et al. Evaluation of maximal bite force in temporomandibular disorders patients. J Oral Rehabil. 2006;33:559–565.

[25] Regalo SCH, Santos CM, Vitti M,et al. Evaluation of molar and incisor bite force in indigenous compared with white population in Brazil. Arch Oral Biol. 2008;53:282–286.