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Review Article

Dentistry Section

Bite Force Recording Devices - A Review

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ABSTRACT
In dental research, bite force serves as a valuable parameter to evaluate the efficacy of masticatory system. A variety of devices with different design and working principle have been used to record bite force, but no single device is capable to record all the required forces. One may find it difficult to choose a device that will fulfil the purpose of recording bite force for research. So, the present review aims to report and compare the wide range of devices and will help in describing their uses for recording bite force.

Keywords: Force transducer, Malocclusion, Masticatory muscles, Strain gauge transducer

INTRODUCTION
Bite force can be defined as the force applied by the masticatory muscles in dental occlusion [1]. It may be recorded to evaluate the function and efficacy of masticatory system. In dental research, bite force has been recorded as a variable to assess the efficacy of various dental procedures like prosthesis [2], orthodontic treatment [3]; or to study effects of deformities and pathologies on the masticatory system like malocclusion [4], temporomandibular disorders [5]. A variety of devices with a diversity of designs and working principles have been used to record bite force [6]. A researcher may find it difficult to choose a device that will fulfil the aim for recording bite force. So, the present review aimed to report and compares the wide range of devices used for recording bite force.

DEVICES FOR RECORDING BITE FORCE
The bite force devices can either be mechanical or electrical or combination of both. The earlier devices, were mechanical in built. The first such device was built by Borelli in 1681 [7]. It was called as gnathodynamometer. In this device different weights were attached to a cord that passed over molar teeth of mandible in open position. Subjects were then asked to close the jaw. Up to 200 kg weight was raised by the subjects [7]. Later, several devices were developed; some were newly invented while others were modifications and alterations of previous ones. These include the lever-spring, manometer spring and lever, and micrometered devices [8].

Nowadays, sensitive electronic devices are used in most of the bite force devices. Such devices are both accurate and precise enough for common load measuring purposes [7]. Most of the devices can record a wide range of force (50-800 N) with accuracy (10 N) and precision (80%) [9]. These devices use load cells (transducers) to convert force to electrical energy that may be based on one of the following working principles.

Types of load cells (force transducers):

1. **Strain-gauge transducers;**
2. **Piezoelectric transducers;**
3. **Pressure transducers.**

i. Strain-gauge transducers
The strain gauge transducers are devices that consist of a metal plate or fork. On loading, these metal plates undergo deformation, due to which its resistance changes, which in turn, results in a change in electric potential or voltage. This change in voltage can be calibrated with a known weight to indicate the applied load.

Strain-gauge transducers have been used to record bite force in several studies [10,11]. Several designs of these transducers have been described previously [10,12]. One such early design was described by Linderholm H and Wennström A [13]. This design consisted of bite plates made from two steel bars, joined by a steel wedge. These plates were attached with strain gauges and the assembly was connected in a Wheatstone bridge circuit. A potentiometer writer recorded the load on bite plates.

Although strain-gauge transducers have been proven to be accurate for the measurement of maximum bite force, it is still difficult to record a true maximum bite force. It has been suggested that this is mainly due to discomfort and to the fear of breaking cusps and edges of teeth and dental restorations, when biting on the hard surfaces of the transducers [9,12]. Hence, several authors have attempted to make biting to be more comfortable by covering the metal surfaces with different materials such as acrylic resin, gutta percha, gauze and polyvinyl chloride [14,15]. However, using the protective covers may reduce the discomfort to some extent, but it does not help in overcoming the fear associated with biting on the hard surfaces [9,12]. Another major disadvantage of strain gauge transducers is that there may be an unavoidable jaw separation caused by the thick metal plate or bite fork used in them. Koc D et al., found that electromyographic activity decreases with an increased jaw opening which may lead to a decreased bite force [16]. The strain gauge transducers can be used in subjects where bite force of single tooth or group of teeth needs to be recorded. These can be used wherever there is no requirement of recording bite force in maximal intercuspal occlusion.

ii. Piezoelectric transducers
When subjected to force, certain crystalline material (e.g., quartz) produce charges on their surface that is directly proportional to the rate of change of that force. These crystals are called as piezoelectric crystals [17]. The produced signals are in the form of a small electric charge and therefore need to be amplified to give a significant reading of load on the material. The whole assembly is called as piezoelectric transducer.

Piezoelectric force transducers using quartz crystals as the active element are readily available commercially. Recently, manufacturing of piezoelectric material in the form of thin foil sheets have been made possible. Using these foils as the active element, an occlusal force transducer can be fabricated that is less than 2 mm in thickness. It helps to measure occlusal forces with lesser jaw separation than in bite force devices using strain gauge transducers. These foils can be cut into any desired shape and size [18]. Some piezoelectric devices have been reported for giving incorrect readings [19,20]. These devices can be used in subjects where bite force have to be recorded in subjects with minimal jaw opening. Devices using piezoelectric transducers have been used for measuring bite force in several studies [21,22].

iii. Pressure transducers

The pressure transducers consist of a chamber filled with a fluid or air. When subjected to force, the pressure within the chamber increases. This increase in pressure can be transmitted to pressure gauge for measurement. Based on the contents of chamber, the pressure transducers can be of two types: pneumatic (air is the medium) and hydraulic (liquid is the medium).

One such device was developed by Braun S et al., [23]. The device consisted of a fibre-reinforced, sterilizable, rubber tube connected to a pressure sensor (Omega Model No. PX300 – 1KGV, Omega Engineering, Inc, Stamford, Conn). Pressure change was converted to an electrical signal and transferred to a digital strain indicator (Vishay/Ellis – 20, Measurements Group, Inc, Raleigh, NC). In their study, the mean maximum bite force in second premolar/first molar region was found to be 738 N. The authors explained these high values may be due to following reasons: 1) The tube was relatively comfortable so the subjects were less reluctant to record true maximal forces; 2) During biting, the tube deformed elastically, conforming to the occlusal anatomy of teeth, and thereby providing more uniform force distribution. This deformation is important because it gives the subjects a degree of psychological security to exert their true maximum bite force; 3) The subjects were all dental students and this may have been a contributory factor for the higher maximum voluntary bite force values. However, in this study, there are no details mentioned about the pressure range created by bite forces, the length and the diameter of the tube, the degree of rigidity of the tube and the type and viscosity of the fluid used to fill the tube.

In a study, Winocur E et al., used a pressure recording device which consisted of a flexible rubber tube (Wing Foot 300, Good year, Akron, Ohio) which was 20 cm long and 9.5 mm in diameter and filled with water [3]. On one end, the tube was sealed to a manometer (Armaturenbau GmbH, Wesel – Ginderich, Germany, 63' RKG 300 psi). In order to measure the maximum bite force, subjects were instructed to bite as hard as possible at the molar or incisor region, and the peak biting pressure was preserved by a special handle on the manometer dial. The measured pressure was then converted to a force value (N) according to a predefined calibration curve. In the authors' opinion, this system was safe, comfortable, and accurate in measuring maximum bite force [3].

Recently, some advanced devices have been developed. One such system uses magnetic near field communication for bite force sensing and monitoring. The design consists of a force sensor placed within a splint. The device uses a wireless connection between a passive force sensor, and an active external unit. The external unit energizes the sensor and records all force measurements permanently. The design have been patented but the authors do not intend to develop it commercially [24].

SOME COMMERCIALLY AVAILABLE BITE FORCE RECORDING DEVICES

1. Dentoforce 2 (ITL AB, Sollentuna, Sweden)

It is a device which has a metal fork provided with strain gauge transducer. The fork is coated with a soft rubber which can be placed in the interocclusal region and on which the subjects can bite. The bite fork is connected to a recorder and the force (in Newtons) is displayed on a digital display device (Multimeter 4055. ITL AB, Solientuna. Sweden) [25]. The device can display the minimum and maximum values during the measurement as well as it can also display an instantaneous reading during biting. The device also consists of filters which increase the quality of the output signal. It can measure forces up to 1000 N [25]. The thickness (vertical height) of the fork is 11 mm. After positioning, subjects are asked to bite as hard as possible for 3 to 4 seconds. This can be repeated with a relaxation period of 30 seconds interval [26]. The device has been successfully used for research purpose [25,26].

2. IDDK (Kratos, Cotia, São Paulo, Brazil)

IDDK is a digital dynamometer with a capacity of 1000 N [27] or 100 kg force [5]. The device can be adapted to the human oral cavity for bite force recording. It comprises of a bite fork made up of two metal rods with plastic disks as an outer covering, connected to a digital display with a cord. The thickness (vertical height) of the fork is 14.6 mm. The fork has to be placed in between the teeth and subjects have to bite on the plastic disk to record the bite force. When force is applied, the metal rods will undergo a deviation, generating an electrical signal which is transmitted to the display unit. The operator can hold the display unit in his hand while recording the bite force. The device has a “set-zero” key which helps in exact control of the values obtained. It also registers the peak value that helps in recoding the maximum value obtained even after removal of the load. The appliance also has a switch to select between traction or compression functions. The operator can choose the scale to be in N or Kgf. It has a load cell along with the electronic circuit to provide readings of bite force on the digital LCD screen [5]. The device has been successfully used in several studies to record the bite force [5,28].

3. GM10 (Nagano Keiki, Japan)

The GM10 force gauge consists of a hydraulic pressure gauge with a biting element made of a vinyl material, encased in a polyethylene tube called disposable occlusal cap. It is 17 mm in width, 5.4 mm in height and 63.5 mm in length [29]. The bite force (N) is calculated by the device and displayed digitally [30]. The accuracy and repeatability of this occlusal force gauge has been previously confirmed [6,29].

The specifications of this device are [4]:

a- Force range: 0 – 1000 N.

b- Accuracy: ±1 N.

c- Weight: About 70 g.

d- Size: 195 (L) × 29 (W) × 18(H) mm.

The device has been successfully used in several studies for recording bite force in human dentition [29,31]. No discomfort or pain was experienced by subjects while biting on the instrument [29].

The main advantages of the GM10 occlusal force-meter are: a) portable; b) easy to use; c) soft biting element that enables safe, accurate, and comfortable bite force recording; d) instantaneous digital measurement of bite force – as bite force is calculated and displayed digitally in Newtons; and e) bite force could be measured unilaterally or bilaterally.

4. T Scan system (Tekscan, Inc., South Boston, MA)

The T scan system is a computerized occlusal analysis system which was invented and patented by Maness WL et al., and developed by the Tekscan Company to assist in occlusal analysis [32]. It was developed for utilization in prosthodontics as an adjunct for correction of occlusal problems [33]. The first generation sensor (G1) comprised of a mylar laminated pressure sensitive ink grid, which had a shape of dental arch. When it is placed intraorally and a load is applied, the sensor relayed real-time occlusal contact sequences and relative force information to computer software. The resultant data is displayed as a force snapshot, or as a continuous force movie of the entire occlusal contact event in two or three dimensions [33].

Newer model, (i.e., T-scan III) utilizes an ultra-thin (0.004 inch, 0.1 mm), reusable sensor that is shaped to fit the dental arch, which inserts into data acquisition electronics. This system is portable and also plugs into the USB port of Windows-based PC or laptop.

Major advantage of T scan is its thin sensor so it can evaluate the bite force and the occlusal contact area in the intercuspal position. Lyons MF et al., evaluated the T Scan system and tested the accuracy of the system in measuring bite force [34]. The authors concluded that the system did not measure bite force accurately, but the device was still useful as a clinical tool in the determination of the position of contact points. The T-scan system has occasionally given misleading reproductions of occlusal contacts and hence has been criticized since it gives only a narrow range of measurements for occlusal force. Due to inadequate flexibility of the foil, uncontrolled shift in mandible have been seen, which results in incorrect data. The sensitivity and planar resolution capacities of the device are also inadequate leading to incorrect data [20]. The device has been used in several studies for occlusal analysis and bite force estimation [35,36].

5. Prescale system (GC Co. Ltd, Japan)

The Dental Prescale system (Dental Prescale, Fuji Film Co., Tokyo, Japan) is a computerized system for occlusal analysis and is used for the measurement and analysis of bite force (N), occlusal contact area (mm^2), and bite pressure (MPa). It was first developed in 1981 and since then successfully used in several studies on fully dentate, partially dentate, and edentulous patients [37,38]. The film is a pressure-sensitive horse shoe shaped sheet designed to record the bite force of complete dentition at once [7].

Prescale system consists of pressure sensitive sheets (Dental Prescale; Fujifilm Co., Tokyo, Japan) and an analytical equipment (Occluzer FPD703; GC Corp., Tokyo, Japan) [37]. Two types of sheets are available: Type W (about 800 μm thick) and Type R (97 μm thick). Both types of sheets are further divided into two sub-types: 30 H and 50 H. The 30 H sheet is used to record a range of 30 to 130 kgf/cm^2, and the 50 H sheet for a range of 50 to 1200 kgf/cm^2 [7]. Each pressure-sensitive sheet consists of two polyethylene terephthalate films and numerous microcapsules containing a colour-forming material between them. When biting force is applied, the microcapsules get collapsed and the colour former contained in the capsules leak out to react with a developer and chemically form a red colour. According to the magnitude of the pressure applied, different densities of colour are formed. With increasing pressure, the red colour becomes more intense [39].

After recording, the film has to be immediately kept in a light-resistant container and transported for analysis at room temperature. To maintain reliability of the measurement, data then has to be entered using the Occluzer FPD705 (FujiFilm GC) on the same day. The magnitude of area of contact and occlusal pressure can be determined by measuring the area and density data through the colour image scanner of the Occluzer. The occlusal force (N) has to be determined as the sum of the degree of colouration and the area at each contact point [40]. The area discoloured by biting is recorded as the occlusal contact area (mm^2) [41]. The biting pressure (MPa) is the biting force per 1 mm^2 of the occlusal contact area.

The subjects have to be seated with their heads upright and in an unsupported natural head position. The sheet should be carefully placed into the patient's mouth so that the midline of the arch coincided with the midline of the sheet. Care has to be taken to include all of the teeth in the mouth. The buccal mucosa should be retracted so as not to deform the sheet [42]. The participant is required to practice biting in cusp to fossa occlusion, followed by maximal clenching in the intercuspal position with a sheet placed between the maxillary and mandibular dental arches with maximum force for 3 seconds [43], 5 seconds [41] or 10 seconds [44].

Ikebe K et al., also assessed the accuracy of the device and found it to be accurate [45]. The device was also found to be reliable [38]. The main advantages of the Dental Prescale system are: a) the ability to measure bite force close to the intercuspal position; b) the ability to calculate bite force from every tooth in recordings with trivial disturbance to occlusion; c) the ability to measure the occlusal contact area; d) it is more convenient and comfortable for subjects than strain gauge transducers; e) it's good reproducibility; f) it is an easy procedure; g) it is unaffected by temperature and humidity; and h) it is reported to be reliable for measurement of bite forces [7,46].

The main disadvantages are: a) it is time consuming; b) continuous measurements cannot be carried out; and c) overestimation of the bite force due to some technical limitations in the computerized scanning system [14].

6. MPX 5700 (Motorola, SPS, Austin, TX, USA)

In this system, a tube (7 mm diameter) and the sensor are connected to an analogue to digital converter. The system is connected to a computer where software for reading the pressure changes had been installed. This tube has to be placed interocclusally and then subject is asked to bite on it. According to the manufacturer's instructions, the MPX 5700 pressure sensor is suitable only for the measurement of air pressure. They also state that any pressure media other than dry air might have adverse effects on sensor performance and long-term reliability. However, since air is compressible, there would be bounce and a lag time which is likely to be problematic in bite force measurements. There would also be a significant effect of changes in temperature. Several studies have successfully used the device to record the bite force of subjects [47,48].

7. FSR No. 151 (Interlink Electronics Inc., Camarillo, CA, USA)

FSR No. 151 is a force sensing resistor from Interlink Electronics Inc. The sensor is a circular conductive polymer pressure-sensing resistor. It consists of two thermoplastic sheets; the bottom sheet is deposited with two conducting interdigitated electrodes, and the top sheet is coated with a semi-conductive Polyetherimide ink. The basic feature of this sensor it that it is piezoresistive, i.e., its resistance decreases with increasing applied pressure. The main function of the thermoplastic sheets is to protect and insulate the sensor from moisture and temperature changes. The diameter of this circular sensor is 12 mm and the thickness is 0.25 mm. The device have been used in many bite force studies [49,50].

8. MPM -3000 (Nihon, Koudenshi Co, Tokyo)

The device include a digital multimeter MPM -3000 (Nihon Koudenshi Co, Tokyo) and an occlusal force transducer. It has a plate 17 mm in diameter at the end and a block 1 mm high and 3 mm in a diameter located at the centre. The block has to be placed on the occlusal surface of teeth and the subject is then asked to bite on the block, while maximum digital readouts will be measured and displayed in kg [51]. The device have been successfully used in several studies [51,52].

9. Flexiforce (Tekscan, South Boston, MA, USA)

Freeman PW and Lemen CA [53] developed a device, Flexiforce (Tekscan, Inc., South Boston, USA), for measuring bite force in small mammals. Their apparatus consisted of two parts; a piezoresistive load cell and an electronic device for detecting the changes in the resistance of the sensor. The piezoresistive sensor was a strip of thin plastic 10 mm wide, 150 mm long, and 0.2 mm thick.

The piezoresistive material is the circular part at the tip of the sensor. It functions as a variable resistor, i.e., its resistance decreases when the force applied increases. The second part, which is the electronic device used for measuring the changes in the resistance of the sensor, was an electric circuit connected to a B2pe microcontroller (Parallax, Inc., Rocklin, California). Flexiforce sensors can measure force up to 4500 N. Freeman PW and Lemen CA concluded that Flexiforce sensors are inexpensive and easy to use [53]. However, they found that these sensors are less accurate than other types of load cells. The device have been used successfully in several studies [53,54].

General considerations for recording bite force in human subjects

It is suggested by some authors [6,55] that while recording bite force in human subjects, they should be seated upright without head support and with the Frankfort plane nearly parallel to the floor and feet resting on the floor.

According to Hellsing E and Hagberg C, there is a direct correlation between head posture and bite force [56]. When compared to bite force in natural head posture, there is a temporary rise in bite force during extension of head. Although, Sonnesen L and Bakke M found no correlation between bite force and head posture [57].

The position of the transducer also affects the bite force measurements. Posterior teeth have higher bite force when compared to anterior teeth [58]. Higher bite force is present when measured bilaterally in comparison to bite force when measured unilaterally [58]. Although Jian C et al., found that there is no significant difference in bite force measurement of single tooth in comparison with bite force measurement of multi-paired teeth [59].

Before the recording, all subjects should be trained to perform their highest possible bite force. They should be instructed to bite as hard as possible on the device without moving the head for 3-4 seconds [26,60]. Some researchers instruct them to bite for 15 seconds [61]. The highest value of multiple bite force measurements per side should be recorded as the maximum bite force for that side [6,62]. It is suggested to give a rest period between multiple recordings to avoid fatigue of masticatory muscles [6,62]. There should be an interval of minimum of 30 seconds after each biting [26,60], few authors suggest this interval should be 2-3 minutes [4,29]. To avoid methodological errors Dahlberg G suggested recording the bite force in two different session with seven days interval [63].

CONCLUSION

A variety of devices and methods have been used in dentistry for recording the bite force, but there is a lack of systematic comparison of different devices to record bite force. Taking its advantages and disadvantages in consideration, a researcher may choose a device that suits the purpose of his study.

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