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A validation study of a new instrument for low cost bite force measurement

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ABSTRACT

Quantitative assessment of force in masticatory muscles is not a routine clinical test, probably due to the lack of an "easy-to-use" device. Aim of this study is (1) to present a low cost bite force instrument located in a custom-made housing, designed to guarantee a comfortable and effective bite action, (2) to evaluate its mechanical characteristics, in order to implement it in clinical settings and in experimental setups.

Linearity, repeatability and adaptation over time were assessed on a set of four different sensors in bare and housed condition. Application of the housing to the transducer may appreciably alter the transducer's response. Calibration of the housed transducer is thus necessary in order to correctly record real bite force. This solution may represent a low cost and reliable option for biting force measurement and objective assessment of individual force control in the scientific and clinical setting.

1. Introduction

Bite force is a biological variable that has been frequently used to assess the function of the masticatory system. Variations of maximum voluntary bite force and precision seem related to different conditions as acutely provoked pain (Wang et al., 2010), chronic orofacial pain (Pereira et al., 2009) and temporomandibular disorders (Bakke and Hansdottir, 2008; Kogawa et al., 2006), occlusal factors (Koc et al., 2011; Trawitzki et al., 2011), wearing dentures (Caloss et al., 2011) or prosthetic implants (Rismanchian et al., 2009) and can be considered as useful indicator in diagnosing the functional status of the masticatory system and monitoring the effectiveness of a therapy.

The first experimental attempt to measure bite force was conducted by Giovanni Alfonso Borrelli and described in his book De Motu Animalium in 1680 (Ortug, 2002). Since then, depending on the available technologies, bite force was measured in different ways. As examples, Castroflorio et al. (2008) used intraoral load cells embedded in customized acrylic splint, Hoyuela et al. (2015) measured jaw elevator muscles force in rheumatoid arthritis women by a bite fork mounted with strain gauge and complex extra oral devices were used to assess bite force and oral reflexes (Turker et al., 2004). The bite force in clinical setting is not yet used as routine outcome measure, while it is extensively measured in research by study-customized devices. Indeed, only few commercial devices for measuring bite force are available and were tested for their reliability. Tscan III (Tekscan Inc, South Boston, USA), a widely used system for assessing forces on dental surfaces, did not show an adequate level of validity in measuring the absolute bite force value, due to individual response behaviour of the pressure sensors utilized by the system (Cerna et al., 2015).

GM10 occlusal force-meter (Nagano Keiki Japan) is a portable bite force gauge that demonstrated a good accuracy and reliability in clinical setting but was found to be uncomfortable due to excessive hardness of the bite (Serra and Manns, 2013). Major practical and technical problems related to measuring the force of bite are:

(1) thickness of the intraoral sensor: excessive interocclusal distance alters the physiological posture of the mandible and affects the developed force. On the other hand miniature load cells are delicate, expensive and not adequate for routine clinical use;
(2) positioning of the sensor: when a single force transducer is placed between the incisors it requires a protrusion of the mandible, which affects the biting force, while placement of the sensor in the premolar or molar region makes the precise repositioning of the sensors more difficult, thus affecting repeatability;

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(3) costs: extra oral apparatuses have been developed, connected with servo controlled motors, adequate to investigate motor function and reflexes (Turker et al., 2004; van der Bilt et al., 2006) however, due to their cost and complexity, these systems are more suited for research purposes than for routine clinical examination. Some authors have used load cells mounted on a customized dental (Castroflorio et al., 2008) device to evaluate bite force, but also this approach results in a complex and costly technical procedure.

Aim of this study is to present a much simpler and practical solution, based on a low cost and versatile piezo-resistive force sensor, adequate to measure bite force in a clinical setting. A thin commercial transducer is accommodated within a protective rubberized housing and characterized from the electro-mechanical point of view.

2. Material and methods

2.1. Sensor housing description

Force measurement was based on the piezoresistive force transducer Flexiforce A201 (Tekscan, Boston, MA, USA), featuring a load range of 100 lb, equivalent to 440 N, and a sensitivity of 0.01 V/N. The *FlexiForce* force sensor is a flexible printed circuit with at one end an active sensing area made of pressure-sensitive ink of 1 cm of diameter. The circuit is embedded within two polyester film layers with a final thickness of 0.2 mm (Fig. 1A).

Forces exerted on the active sensing area cause a roughly proportional change of the sensor's conductance. A special housing was developed in order to protect the sensor from mechanical damage and to reduce discomfort for the subject during clenching. The force transducer was inserted in a home made "sandwich structure" composed of different plastic foils and a steel disc, stuck together by bi-adhesive film. The multi-layer "L" shaped housing was developed as shown in Fig. 1B and C. The external layer is made of a silicone rubber material, commonly used in preparing dental orthotics (Bioplast – Scheudental - Germany). This layer provides the possibility of small yielding of the surface under the teeth, thereby generating a wider contact surface, thus lowering local pressure. It also provides improved comfort during clenching, as compared to a hard surface. An internal thinner layer is made of two hard plastic foils, which provide a flexible support as well as a graduated handle for the housed sensor. The force transducer is inserted in-between the two plastic foils, coupled with a metal disc (diameter = 10 mm, thickness 0.8 mm) located exactly below the sensory area of the transducer and fixed by bi-adhesive film to the plastic foil and the transducer. The steel disc ensures that virtually all the force lines between upper and lower teeth are conveyed through that area, according to recommendation given by the manufacturer in the flexiforce user manual (https://www.tekscan.com/support/faqs/flexiforce-user-manual). The lateral, short arm of the "L" structure can be shortened by simply cutting the excess with scissors in order to adapt to the latero-lateral dimension of the subject's mouth.

Since the sensor does not tolerate heat or immersion sterilization, it should be inserted into a disposable latex or nitrile glove in order to prevent contact with saliva and thus exclude the need for sterilization. Final thickness of the housed sensor is about 7 mm and decreases to (5–6) mm after some pressure is exerted by the teeth, slightly accommodating in the superficial layer. This allows jaw-elevator muscles fibers to work at optimal length, therefore permitting an adequate expression of force (Fernandes et al., 2003; Manns et al., 1979).

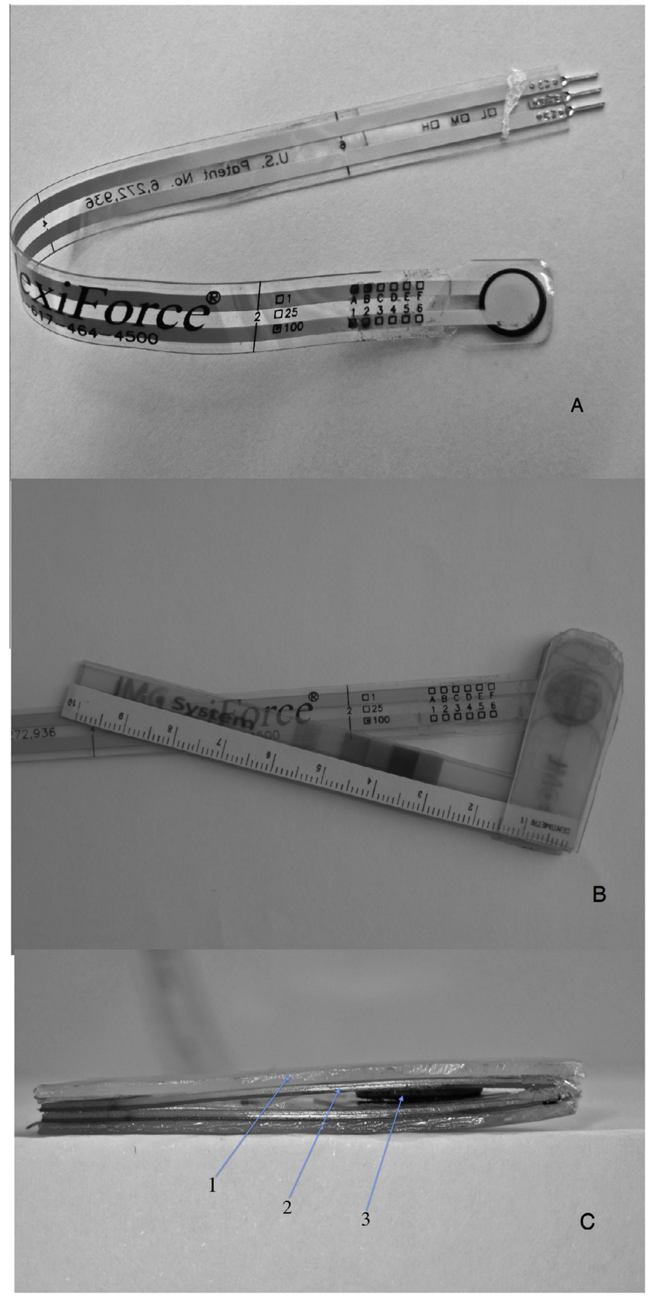

Fig. 1. (A) – The piezoresistive film sensor. (B) – Housed transducer, top view. (C) – Housed transducer, lateral view: (1) external silicone layer, (2) internal hard plastic layer, (3) metal disc.

A graduated handle allows for accurate repositioning along the antero-posterior direction, in different experimental sessions. Moreover, the "L" shape of the housing allows both the sensor and the graduated handle to exit the mouth through the inter-incisal opening, thus preventing damage by canine teeth.

2.2. Device characterization

Force-output measurements of bare and housed transducer have been performed on a set of four A 201 Flexiforce devices. The sensor under test was first preconditioned according to the manufacturer recommendations (https://www.tekscan.com/support/faqs/flexiforce-user-manual). The preconditioning consisted of loading the sensor up to 490 N for 30 s for three times. This treatment was actually repeated few more times to improve