DEVICES TO MEASURE TONGUE FORCE - A CRITICAL ANALYSIS

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Abstract. Introduction: *For several years, researchers have been looking for methods to quantify the force or pressure exerted by the tongue. A lot of devices were constructed for this purpose. However, on Speech-Language Pathology clinical practice, tongue force is still evaluated by qualitative methods in which only perception and practical experience are used to classify this force. Quantitative evaluation is accomplished using instruments that show the numerical value of the force or pressure exerted by the individual, which makes the diagnosis of the tongue more accurate. The purpose of this study is to present a critical literature review about the devices to quantify tongue force.* ***Methods:*** *Through a bibliographic search in libraries and databases such as Medline, Lilacs, Bireme, Capes, and patent's databanks, 120 studies on tongue force were reviewed. They cover the period until 2010 without initial period limitation. Thirty six different devices were described.* ***Results:*** *The devices were grouped into categories according to their technology: mouthpiece containing strain gauges (N=9), load cells (N=1) or force sensing resistors (N=2), pressure sensors attached on teeth or on palatal plates (N=7), dynamometers (N=3), bulbs filled with some fluid and connected to a pressure sensor (N=7) and other technologies (N=7). Some of them have shortcomes such as not being sensitive enough to small changes in force (dynamometers), difficulties in positioning reproducibility (bulbs and sensors attached to teeth), force direction different from clinical evaluation (sensors on palatal plates) and other specific points for each device. A critical analysis of the technologies is presented. Some studies describe the use of electromyography to estimate muscle force and were also discussed. Methodological differences made it difficult to compare the forces measured in different studies, as they depend of the degree of protrusion, the direction of the movement, the distance between mandible and maxilla, the tongue region in contact with the sensor, the area in which the pressure is exerted. A lack of reproducibility in any of these parameters might lead to significant variation in the obtained results.* ***Conclusion:*** *Several instruments to measure tongue force were found. All these methods can potentially help the professional in the evaluation of orofacial myology, making the diagnosis of tongue force more reliable. According to their specific design, devices are more indicated to different assessments of tongue force, as 15 different muscles are involved in tongue movements. Other advantages of the quantitative evaluation are the possibility to follow the evolution of the therapy, to facilitate the communication among professionals involved in the treatment of the patients and to make the prognosis of the treatment more accurate.*

Keywords: *tongue, muscle strength, pressure, instrumentation, biomechanics*

1. INTRODUCTION

For several years, researchers have been looking for methods to quantify the force or pressure exerted by the tongue. An adequate strength is essential for the tongue to perform appropriately the functions of mastication, swallowing, suction, breathing and speech articulation, and to keep proper teeth position, as the force exerted by the tongue on teeth balances the force exerted by lips and cheeks.

Tongue force can be evaluated by qualitative or quantitative methods. Qualitative evaluation is more routinely used in Speech-Language clinical practice. This kind of evaluation is subjective, depends of the experience of the professional and is not free from controversies. In this procedure, tongue strength is usually tested by having the patient to protrude the tongue against the finger of the professional or against a tongue depressor while the professional applies resistance. Quantitative evaluation is accomplished using instruments that show the force value exerted by the subject, which makes the diagnosis of tongue force more accurate. The purpose of this study was to present a critical literature review about the devices to quantify tongue strength

2. METHODS

A critical bibliographic state of the art review about the devices designed to quantify tongue strength was carried out in libraries and databases such as Medline, Lilacs, Bireme, Capes' periodicals, and patent`s bank. Articles considered were written in Portuguese and English, dated up to 2010 and without initial period limitation. The terms used in the search were "tongue", "force", "strength", "pressure", or, in portuguese, "língua", "força", "pressão". An additional search was also made in the bibliographic references of the selected articles. The bibliographical analysis was made in three steps. During the first phase, those articles in which the content did not correspond with the objective settled were excluded; during the second phase, the references duplicated in the databases were deleted; and in the third phase, the references that described the same instrument were deleted. A brief description of each instrument was provided, and information about sample and force values was shown by table 1. For patents documents, only the instrument and method were described.

3. RESULTS

It was obtained 120 references corresponding to the objectives settled. After the third phase, 36 studies remained. The devices were grouped into seven categories according to their technology: mouthpiece containing strain gauges (N=9), load cells (N=1) or force sensing resistors (N=2); pressure sensors attached on teeth or on palatal plates (N=7); dynamometers (N=3); bulbs filled with some fluid and connected to a pressure sensor (N=7) and other technologies (N=7). Some studies describe the use of electromyography to estimate muscle force and were also discussed.

3.1. Mouthpiece containing strain gauges

Kydd (1956) used a device composed by a denture base made of methyl methacrylate, which vertical dimensions were maintained between the bases by four vertical rods imbedded in the lower denture base. Between the rods there were three blocks of methyl methacrylate positioned to approximate the lingual surface of the lower incisor area, right and left second premolar and first molar areas. Electric resistance strain gauges were attached to these blocks. Pressure exerted by tongue on the block produced a deformation on the gauge, modifying its resistance. An alternating current amplifier and a multichannel pen recorder were used to give dynamic as well as static recordings.

This author and co-workers developed another pressure transducer composed of a stainless-steel cantilever beam that bended on its free end as pressure was applied. Within its proportional limit, the amount of deflection of the tapered steel and epoxy-resin cantilever beam was nearly proportional to the stress exerted on it. Strain gauges were bonded to both sides of the cantilever beam by an amine-hardened epoxy resin. As the cantilever beam was stressed in both directions, the strain-gauge wire was also deformed, with an accompanying alteration in the resistance. The transducers were positioned as close to the lingual surface of the maxillary central incisors as possible (Kydd et al., 1963).

Proffit et al. (1964) also used a stainless steel deflection beam with two strain gauges, one on each side, which was secured to a piece of stainless steel that served as a mounting plate and was insulated with a thin covering of epoxy resin. Three intraoral transducers were placed on upper central incisor and first upper molar by a resin.

Sanders (1968) described a device that consisted of a force-displacement transducer connected to a single channel direct writing portable recording system, a specially designed tongue pressure disk and a head stabilizer. The transducer consisted of four strain gauges bonded to a beam and forming a bridge connection which measured strain produced on the beam by force applied to lugs attached to the beam. The subject was requested to press the disk with his/her tongue as hard as he/she could. Subjects were tested for maximum tongue pressure on two different occasions. There was no difference in the amount of pressure produced on the two tests.

Dworkin (1980) measured tongue strength using just one semiconductor strain gauge welded to a tubular stem for easy insertion into the mouth and a single channel pen-writing portable recording system. The force transducer could be positioned anteriorly, between upper and lower incisor teeth, or laterally, between the canine and first bicuspid teeth, and the subject was requested to bite down on the stem and apply tongue pressure against the transducer with the tongue tip.

Durkee (1987) suggested a device to measure tongue force in three directions along the axes X, Y and Z. The device was within a cylindrical container closed on the sides and on the back and opened in the anterior part, from where emerged a smaller tubular structure containing an individual dental plate, made of dental impression material for teeth positioning and maintenance of apparatus to the mouth. Inside the device, next to the posterior wall, there was a diaphragm. There was a stem all over the apparatus. The stem was connected to a receptacle for the tongue at the anterior end of this stem, and to a diaphragm at the posterior end, and thus had the function of transmitting the force from the tongue to the diaphragm. Two strain gauges positioned 90 degrees relative to each other were assembled over the stem, to detect and measure tongue forces in directions X and Y (horizontal and vertical). When the stem was moving in these directions, the sensors were pressed onto the unit wall. A third strain gauge was located in contact with the diaphragm and detected the tongue force in the Z axis (anterior) direction. During the measurements, the subject positioned the plate between teeth and tongue in the receptacle. During speech, the movement of the tongue produced a force in the receptacle in different directions, leading to a displacement of the stem, with consequent diaphragm movement and sensors pressing. The signals from the strain gauges were directed to an amplifier and then to an oscilloscope or a computer screen.

A device named TOMS consisted of an aluminum cantilever beam with two strain gauges mounted on opposite sides at the base of the beam and arranged with two passive dummy resistors in a Wheatstone bridge configuration. The beam could be oriented to take reading of upward tong thrust, or it may be rotated 90º to acquire values of right and left lateral tongue thrust. The transducer was housed in a polypropylene mouth clamp that could be adjusted to accommodate a range of mouth sizes. Dental impression putty was used to custom fit the mouth clamp to each subject. The signal from the gauges was amplified and transmitted to an analog-to-digital converter. A rubber tongue cup was placed over the end of the beam (Robinovitch et al., 1991).

Scardella et al. (1993) measured tongue force using a force transducer that translates direct compression forces generated by the tongue to an active arm outside of the mouth connected to a strain gauge with linear response for forces between 50 and 100 gf, which was incorporated into a two arm active bridge circuit. Blumen et al. (2002) used a device very similar to that used by Scardella et al. (1993). The instrument was composed by an U-shaped plastic plate mouthpiece. Dental impression material was used to secure the mouthpiece to the lower teeth. The contact arm carried a slight indentation to indicate where to place the tip of the tongue and was connected to a strain gauge located outside the mouth. The response signal was linear from 0.49 to 9.81 N. The strain gauge was connected to amplifiers. The signals were recorded in a microcomputer using an analogue-digital system.

3.2. Mouthpiece containing load cells

Mortimore et al. (1999) used a transducer consisting of a machined nylon hand grip and a mouthpiece. The mouthpiece consisted of a 1 cm diameter nylon plate behind which was positioned a 0±6 kgf button load cell. Behind the plate, the mouthpiece consisted of a groove of approximately 2 mm deep and 2 mm wide. Subjects were asked to rest their upper and lower incisor teeth in the groove in order to the transducer to reach steady state. Force could then be exerted on the plate by the subject`s tongue. The transducer was connected to a linear visual scale displaying force in Newton or as a percentage of the subject’s maximum force (measured during a previous trial).

3.3. Mouthpiece containing force sensing resistors

Miller et al. (2008) developed an instrument to measure tongue force. The force receptor element consisted in a metal plate covered by a disposable element and attached to an adjustable length beam which made the coupling of the plate to the electrical resistive strain gauge force sensor. This plate-stem-sensor set was fixed to a vertically positioned disk, to which other sensors could be fixed. As the disk was rotated, it modified the direction of plate positioning and the direction of the force necessary to push it. Thus, it allowed tongue force measurements in different directions. The instrument base housed the transducer and the electronic system. The signal generated by the transducer was electronically processed an output signal that was the force magnitude profile exerted by the tongue over time. During the measurement, the patient was positioned in front of the machine, with the chin on a support and he/she should exert tongue force over the force receptor element, the plate.

An instrument consisting of two mouthpieces, one superior and one inferior, with three force sensing resistors in each, was proposed by Sangave et al. (2008). The sensors were piezoresistive, Flexiforce A201 (Tekscan, Boston, MA) with measuring range from 0 to 110 N and were distributed in a way that allowed to measure tongue force in horizontal direction, either forward, to the right or left. Each sensor was fixed in a stainless steel plate attached to the mouthpiece. Over the sensor, there was a piece made of silicone which consists of two 1.58 mm thick each layers but with different areas. The bigger one (13 mm x 8 mm) was pressed by the tongue during measurements while the smaller one (8 mm x 8 mm) was in contact with the sensor and thus maximized the force transfer from the bigger to the smaller area. The system had an interface built in Labview that shown the forced exerted by the tongue in each sensor separately, allowing comparison with previously collected data.

3.4. Pressure sensors attached on teeth or on palatal plates

Staehlin et al. (1999) developed a palatal plate equipped with one or more pressure sensors to measure tongue force during function. When contacted by tongue, the sensors produced an electrical output that was proportional to the applied pressure. The electrical signal was then applied to a control and display device which provided a visual feedback to the person being evaluated.

Wakumoto et al. (2003) proposed a palatal plate with the shape of the user's palate in which ten pressure sensors were secured to its lower surface.

Robbins et al. (2004) developed an instrument to measure tongue pressure on the hard palate. The device consisted on a base adjacent to the hard palate made of dental acrylic molded in anatomical shape with two resistive pressure sensors in the inferior part of the base arrayed along a sagittal plane to provide two pressure measuring points: one next to the alveolar area and the other next to the palate. A double mouth piece, the same as the one used to protect athletes teeth during physical activity, was connected to the sensor base. The mouthpiece consisted in a C shape interdental plate with the sensor base attached to the central point of the plate. It rested on the patient teeth and it was intended to make the position of the sensors in the oral cavity reproducible. It could be adapted to many types of dental arches, since it was heat moldable. The instrument allowed the patients to close their mouths, likely what happens in a normal deglutition. It also provided visual feedback to encourage the patient to increase the applied force. The feedback system was composed by a lamp, a sound generator and a digital display which provided information about pressure peaks, average pressure or the force percentage related to a predetermined peak. The instrument could also be used as a training device, as it indicated, by visual and auditory stimuli, the pressure that exceeded a threshold established according to the needs of the patient.

Hori et al. (2006) measured tongue pressure during mastication and swallowing using seven pressure sensors (capacity of 200 kPa) installed in a palatal plate and recorded on a computer through an interface board. Each sensor was fixed in an Au-Pd-Ag alloy disk to avoid the effect of strain in the resin from appearing in the experimental data. Cables from each sensor were passed through a vinyl tube (1 mm diameter) to exit the oral cavity *via* the oral vestibule. Later the authors modified the device, using only five sensors, three placed along the median line and two in the posterior-lateral part of the hard palate. No palatal plate was used. The sensors were attached to the palate using an adhesive resin (Hori et al., 2009).

The Madison Oral Strengthening Therapeutic (MOST) consisted of an adult-sized polymer athletic mouthguard in with a palatal plate made of dental putty was attached and embedded with a conductive elastomer force sensor. Pressure readings were obtained by connecting the MOST mouthpiece to a simple electronic circuit. The voltage was recorded directly at 500 Hz to an electronic text file using data acquisition cards and LabVIEW (Hewitt et al., 2008).

The palatal plate developed by Kieser et al. (2008) was designed to provide simultaneous measurement of pressure at diverse locations in the mouth and was constructed from a chrome-cobalt alloy. To measure pressure during swallowing, an anterior pair of gauges measured lingual and labial contact against the left central incisor tooth; two pairs of gauges measured pressure contributions of the lateral tongue margin and cheeks on the canine and first molar teeth. Finally, lingual pressure on the midline of the palate was measured by two gauges, one at the position of the premolars and one on the posterior boundary of the hard palate. The 8-channel output was gathered simultaneously on an ML785 Power Lab via an 8-channel bridge amplifier and 8-channel Bioamp, then recorded and displayed on a computer.

3.5. Dynamometers

Posen (1972) measured maximum tongue force in subjects with and without problems in occlusion. The instrument was made of a gauge to give reading up to 50 N when pushing a spring that is attached in the gauge. In the other end of the spring, a concave piece was the place that tongue exerted force.

McWilliams, Kent (1973) constructed a device to measure maximum protrusive tongue forces consisting of an amplifier, used with a differential transformer that measured the displacement of a calibrated coil spring. The position in which patients held the device was standardized with use of an acrylic adapter. Measurements were recorded on a zero to ten scale.

Rumburg (1986) created a device that comprised a base that supported a stem in which there was a blade in vertical position. This blade was the place that the subjects exerted force by protruding their tongue. The horizontal displacement of the blade moved a spring and the force exerted was shown in a dial indicator by a scale created by the inventor. The device had also a rest chin place that determined the patient position related to the device.

3.6. Bulbs filled with some fluid and connected to a pressure sensor

Robin et al. (1992) developed a portable pressure detecting device employing a water-filled bulb of a suitable size to fit within the mouth. The bulb was connected to a transducer in order to convert the pressure sensed by the bulb to an electrical signal representing the sensed pressure. The bulb was resilient to deform under the pressure generated by the tongue and to thereafter return to original shape when pressure was removed. An output display provided the sensed pressure. The Iowa Oral Performance Instrument (IOPI) is a second version of the instrument used by Robin et al., (1992). The difference is that the IOPI's bulb is filled with air. IOPI is commercially available and it was used by several authors in tongue pressure investigations (Clark et al., 2003). IOPI has a holder to measure laterally tongue pressure and protrusive tongue pressure.

Bu Sha et al. (2000) measured tongue force using a custom-designed lingual force transducer housed in a piece of polyvinyl chloride tubing. The tube was bisected lengthwise, and a latex balloon catheter was mounted between the two halves of tubing and secured in place with dental impression material. The balloon was positioned so that, when it was inflated with 4 mL of saline, it protruded 1.0 cm beyond the end of the tube. A rubber sheath, 2 mm in thickness, covered the end of the tube, providing the subject a soft, stable surface to bite when producing protrusion efforts. The sheath was marked at 0.5 cm intervals from the balloon end of the tube to a length of 4.0 cm. The balloon catheter was connected to a pressure transducer and the output was amplified and recorded and reconverted into force. The subject held the transducer in the mouth and bit down on the tube. With the tip of the tongue on the balloon, increasing or decreasing the depth of the transducer in the oral cavity increased or decreased the length of the tongue muscle fibers. Most of subjects had maximum force at a transducer position of 2.5 cm.

Hayashi et al. (2002) used an air filled bulb made from rubber connected by a tube to a pressure transducer, an amplifier and a record system. McAuliffe et al. (2005) used a similar device composed by a rubber air filled bulb connected to a pressure transducer to measure tongue pressure against palate.

Ball et al. (2006) described another tongue pressure measurement device using bulbs, the Kay Swallowing Workstation. It was composed by a three-silicon-bulb array integrated to a computer based system capable to simultaneously collect pressure exerted by tongue in three palatal points.

Utanohara et al. (2008) used a tongue pressure measurement device consisting of a disposable oral probe, an infusion tube as a connector, and a recording device. The probe was assembled with a small, partially inflated bulb made from medical grade latex, a plastic pipe as a connector and a syringe cylinder for the patient to hold on. A recording device with a manual autopressurization system was used. By pushing the pressurization button, the probe was inflated with air at an initial pressure of 19.6 kPa. This pressure was taken as the standard and measurement was performed after zero calibration. The subjects were asked to place the bulb in their mouth, holding the plastic pipe at the midpoint of their central incisors with closed lips, to raise the tongue and compress the bulb onto the palate with maximum voluntary effort, and the maximum value was recorded.

3.7. Other technologies

Margolis, Prakash, (1954) developed an instrument to measure oral pressures named “The Photoelectric Myodynagraph”, which contains an horizontal tube with an enclosed column of gas at atmospheric pressure connected to a photoelectric recording mechanism. Pressure exerted by the tongue on the compressible mouthpiece located at one end of the tube raised the pressure of the air column. At the other end of the tube a rubber diaphragm was placed, which, by distention, indicated variations of pressure on the system. A small metal arm cemented on the rubber diaphragm rested against the lateral extension of a mirror mount. Distension of the diaphragm caused deflection of the mirror. A watch spring on the mirror mount caused the mirror to return to its original position when the diaphragm was deflected on removal of pressure on the mouthpiece. The shaft of the recording mechanism also carried a small mirror which was on the same vertical line as the first mirror. When the horizontal axes of these mirrors were parallel, the light from the incandescent lamps of the photoelectric recorder was equally divided between two phototubes, hence there was no flow of current through the recording coil. When the mirror was deflected by distention of the diaphragm, there was a shift of light from one phototube to the other, resulting in a flow of current through the recording coil which in turn moved the recording pen to a position where the two mirrors were again parallel. Recording were made on a record roll and converted to force/area.

Wallen (1974) proposed a transducer system capable of measuring pressure in various planes. It could be rotated to any angle, relative to fixed landmarks. The transducer design features a spherical tongue contact surface so that its rotation would not be distorted by changes in shape of the pressure receiving area. The transducers were mounted in acrylic base attached to the surface of incisors teeth. In order to allow rotation, a piece of stainless steel wire was embedded into the acrylic and the fixed end of the wire projected into the socket of the transducer base. Shielded wires connected the transducers to the input of a dynography. With the transducer plate in place, subjects swallowed water and saliva at different angulations. Subjects with normal occlusion exerted maximum lingual pressure when transducer was at 22.5 degrees to the oclusal plane.

A device to measure tongue force based on suction was developed by Price, Darvell (1981). A detachable mouthpiece made from the shortened barrel of a 2.5 mL disposable plastic syringe into which a cottonwool was inserted as a saliva trap and attached to a mechanical vacuum gauge of the Bourdon type. The cotton was secured by compressing the heat softened open end of the mouthpiece to prevent accidental aspiration. The subject had to suck it as forcefully as possible so that pressure reductions could be recorded from the dial gauge.

Frohlic et al. (1990) used an open cannula (internal diameter 0.7 mm) embedded in a small customized acrylic shield which was bonded to the teeth. The cannula projected 2 to 3 mm from the tooth surface. The open end of the cannula was flush with the acrylic surface, the other end extended along the lingual surface of the teeth, passing the most distal tooth of the dental arch along the buccal surface of the posterior teeth. The cannula was connected to a pressure measuring system by a tube passing between lips. The extra-oral system consisted of a bottle containing water and compressed air, a pressure transducer and a flow limiting valve. The pressure caused a constant stream of water to escape to the open end of the cannula. When it was covered by the tongue, a resistance was offered to the escape of the water and the pressure built up in the water system was recorded by the pressure transducer which reflected the pressure from the tongue. Water escaped through the cannula was swallowed by the patient.

Other research group measured tongue protrusion force using a force transducer (Grass FT10 Force Displacement Transducer) trapped in a vertical surface. The instrument had a piece to be housed in the oral cavity. This piece had a cushion for teeth positioning, which the subjects had to bite and press the tongue against a round button of 20 mm diameter connected to the force transducer by a cylindrical steel beam of 5 mm diameter and 50 mm length. The button protruded 25 mm from the cushion inside the oral cavity. The percentage of the force related to maximum force was shown in an oscilloscope to provide visual feedback (O'Connor et al., 2007).

A device developed by the Biomechanical Engineering Group at UFMG was composed of a piston-cylinder assembly attached to a double silicon protector and to a head that connected it to the cylinder. The oral protector was inserted and fitted in the mouth of the patient which was required to push the cylinder head with the tongue with the maximum force he could exert. The cylinder head hydraulically transmitted the produced force to a pressure sensor. The pressure sensor measurements were transmitted through a data acquisition device to a personal computer (Barroso et al., 2009).

The Myometer 160 contained a probe, which consisted of two plates that were screwed together on one side. On the other side (probe tip), the two plates could be pushed towards each other. The applied force was measured by an electronic device installed between the plates and shown on a bar graph. To measure tongue force, the patient placed the lips around the opening of the plate and protruded the tongue as hard as possible against the probe tip (Lambrechts et al., 2010).

Table 1 shows information about sample and results for the researches made using each instrument described above.

Table 1. Devices to measure lingual force and main results

Reference	**Method**	**Sample**	**Results**
Margolis, Prakash, (1954)	The Photoelectric Myodynagraph	-	-
Kydd (1956)	Mouthpiece containing three strain gauges	One edentulous 30 years old man	Maximum force exerted anteriorly 23.13 N. Maximum force exerted laterally to the right: 11.56 N. Maximum force exerted laterally to the left: 10.23 N
Kydd et al. (1963)	Mouthpiece containing two strain gauges	Subjects aged between 14 and 20 years old, with and without anterior open bite	Average pressure during swallowing was 27.95 kPa in subjects with anterior open bite and 12.06 kPa in normal subjects
Proffit et al. (1964)	Mouthpiece containing two strain gauges	19 men aged between 22 and 32 years old	Average of maximum pressure during saliva deglutition was 4 kPa on anterior teeth and 4.20 kPa on lateral teeth
Sanders (1968)	Mouthpiece containing four strain gauges	17 adults	-
Posen (1972)	Dynamometer	Subjects with normal occlusion	Maximum force: 6 N to 25 N.
McWilliams, Kent (1973)	Dynamometer	Seven subjects with tongue thrust and open bite	Maximum force: 4.83 (Measurements were recorded on a zero to ten scale)
Wallen (1974)	Pressure sensors mounted in acrylic base attached to the surface of incisors teeth	-	-
Dworkin (1980)	Mouthpiece containing a strain gauge	67 men and 58 women aged between 20 and 72 years old	Maximum force exerted anteriorly: 32.9 N for men and 27.5 N for women. Maximum force exerted laterally to the right: 31.7 N for men and 28.7 N. Maximum force exerted laterally to the left: 29.3 N for men and 23.7 N for women
Price, Darvell (1981)	A device to measure suction force	139 subjects	-
Rumburg (1986)	Dynamometer	- -	- -
Durkee (1987)	Mouthpiece containing strain gauges	- -	- -
Frohlic et al. (1990)	A cannula, to provide water scape, connected to a pressure measuring system.	25 young adults with normal dental occlusion	Average pressures in rest position were -0.17 kPa, -0.001 kPa, -0.03 kPa and 0.48 kPa, during chewing were 5.08 kPa, 9.41 kPa, 9.34 kPa e 14.33 kPa and during swallowing were 19.65 kPa, 32.65 kPa, 30.45 kPa e 27.56 kPa at upper incisor, lower incisor, upper molar and lower molar respectively.
Robinovitch et al. (1991)	Mouthpiece containing two strain gauges	One normal subject	Maximum force exerted laterally: 14.1 N Average force exerted laterally: 3.03 N
Robin et al. (1992)	Bulb filled with water and connected to a pressure sensor	- -	- -
Scardella et al. (1993)	Mouthpiece containing a strain gauge	Five normal male subjects aged between 21 and 36 years old	Maximum force ranged between 9.50 N and 16.33 N, average maximum force was 12.67

			N±1.25 N
Staehlin et al. (1999)	Pressure sensors attached on palatal plate	- -	- -
Mortimore et al. (1999)	Mouthpiece containing load cell	86 women and 81 men aged between 42 and 62 years old	Maximum force for men: 26±8 N Maximum force for women: 20±7 N
Bu Sha et al. (2000)	Bulbs filled with saline and connected to a pressure sensor	11 men between 19 and 41 years old	Maximum force: 28.0±2.0 N
Blumen et al. (2002)	Mouthpiece containing a strain gauge	Eight healthy men aged between 25 and 60 years old.	Maximum force: 5.44±1.52 N
Hayashi et al. (2002)	Bulbs filled with air and connected to a pressure sensor	41 subjects between 24 and 85 years old	Average pressure: 27 kPa
Wakumoto et al. (2003)	Ten pressure sensors attached on palatal plate	- -	- -
Clark et al. (2003)	Bulbs filled with air and connected to a pressure sensor	63 subjects aged 19 to 95 years old	Maximum pressure: 40 kPa Average pressure: 35 kPa
Robbins et al. (2004)	Two pressure sensors attached on palatal plate	- -	- -
McAuliffe et al. (2005)	Bulbs filled with air and connected to a pressure sensor	15 subjects between 20 and 31 years old	Average pressure: 36,92±6,44 kPa
Hori et al. (2006)	Seven pressure sensors attached on a palatal plate	10 healthy subjects (8 men and 2 women) between 24 and 30 years old	Pressure during swallowing ranged between 0.8 and 17.1 kPa
Ball et al. (2006)	Three Bulbs filled with air and connected to a pressure sensor	21 subjects (average age of 63,6 years old)	Pressure during swallowing: between 7,76 kPa and 20,56 kPa
O'Connor et al. (2007)	A mouthpiece containing a round button connected to the force sensor by a cylindrical steel beam	12 male subjects with average age of 23 years old	Maximum force: 24.3±6.7 N
Miller et al. (2008)	Mouthpiece containing a force sensing resistor	- -	- -
Sangave et al. (2008)	Mouthpiece containing six force sensing resistors	- -	- -
Hewitt et al. (2008)	Pressure sensors attached on palatal plate	36 healthy subjects (18 men e 18 women) between 19 e 71 years old.	-
Kieser et al. (2008)	Eight pressure sensors attached on palatal plate	five adult volunteers	Pressure during swallowing of 10 mL of water ranged from 13.05 to 289.75 kPa
Utanohara et al. (2008)	Bulbs filled with air and connected to a pressure sensor	843 subjects between 20 and 79 years old	Maximum pressure was 41.7±9.7 kPa between 20 and 29 years old; 41.9±9.9 kPa (30 to 39); 40.4±9.8 kPa (40 to 49); 40.7±9.8 kPa (50 to 59); 37.6±8.8 kPa (60 to 69); and 31.9±8.9 kPa (70 to 79).
Hori et al. (2009)	Five pressure sensors attached to the palate	30 healthy subjects (20 men and 10 women) between 24 and 35 years old	Pressure during swallowing ranged between 1.0 and 14.5 kPa
Barroso et al. (2009)	A piston-cylinder assembly attached hydraulically to a pressure sensor.	10 subject aged between 14 and 80 years old	Average force: between 3.55 N and 13.24 N Maximum force: between 4.97 N and 19.96 N
Lambrechts et al. (2010)	The Myometer 160	107 subjects between 7 and 45 years old	Average pressure: 1.66 N

- No information was provided. **- -** Patent document.

3.8. Relationship between eletromiographic activity and force

Some studies describe the use of electromyography as an indirect tool to estimate muscle force. Non invasive intraoral electrodes were used by Scardella et al. (1993) and Blumen et al. (2002) while intramuscular electrodes were used by Hiyama et al. (2000) and Eastwood at al. (2003). Surface electrode have some advantages in relation to intramuscular electrode because the first is non invasive, easier to apply and more acceptable by the patients (Staudenmann et al., 2007). However, to measure intrinsic muscles electromyography activity, intramuscular electrode is essential (Pittman, Bailey, 2008).

4. DISCUSSION

Several researchers developed methods to quantify force/pressure exerted by the tongue, using different technologies. A trend of using strain gauges was observed in the first devices developed. Recently, the number of researches using bulbs and palatal plates with pressure sensors increased.

Each category has good and bad points. The disadvantage of using dynamometers (Posen, 1972; McWilliams, Kent, 1973; Rumburg, 1986) is that they are not sensitive to small changes in force and, in some cases, the measures are not reliable, as an amount of force could be generated by the patient's or the therapist's hand pushing the transducer toward the patient's mouth (Mcwilliams et al., 1973). The problem of the bulbs (Robin et al., 1992; Bu Sha et al., 2000; Hayashi et al., 2002; Clark et al., 2003; McAuliffe et al., 2005; Ball et al., 2006; Utanohara et al., 2008) is the difficulty in positioning reproducibility inside the oral cavity. Air-filled bulbs positions are difficult to adjust because it slides too easily on the tongue surface and the connected tube is not scaled to show the position of the bulb after lips closure. This kind of instrumentation should contain a pressurization system like that of the instrument proposed by Utanohara et al. (2008), to maintain the bulb inflated with air at the same pressure before each measurement. Palatal plates (Staehlin et al., 1999; Wakumoto et al., 2003; Robbins et al., 2004; Hori et al., 2006; Hewitt et al., 2008; Kieser et al., 2008) need to be customized as each person has his/her palate size and they evaluate tongue force only in cranial direction, which is incompatible to the subjective evaluation made by speech pathologists, not allowing comparisons between quantitative and qualitative evaluations. However they are efficient to measure tongue force during the functions, as they allow the patient to close his mouth and perform the functions (speech, mastication, swallowing) almost normally. Another alternative method is to attach the sensors directly on palate or on teeth (Hori et al., 2009). This method has two disadvantages. First, it is the difficulty to accommodate the sensors at the established points to make comparative revaluation possible, for example, before and after myofunctional therapy. The second disadvantage is that the sensors are difficult to sterilize and disinfect properly, so they cannot be used in different patients. This method is better to measure tongue during functions than the palatal plates because the palatal plates are comparatively more bulky. The instruments that used strain gauges (Kydd, 1956; Kydd et al., 1963; Proffit et al., 1964; Sanders, 1968; Dworkin, 1980; Durkee, 1987; Robinovitch et al., 1991; Scardella et al., 1993) generally have a cumbersome mechanical structure required for their function and the hard inflexible structure of the gauges can cause intraoral lacerations or discomfort to the patient. A specific problem occurred with the instrument of Dworkin, (1980). He did not interface the tongue and the transducer with a small tongue cup, therefore, he measured tongue contact pressure rather than total tongue force.

Some devices have single characteristics that did not allow grouping them in any of the defined categories (Margolis, Prakash, 1954; Wallen, 1974; Price, Darvell, 1981; Frohlic et al., 1990; O'Connor et al., 2007; Barroso et al., 2009; Lambrechts et al., 2010). The device described by Frolich et al. (1999) has an important limitation. It can not be used with patients with swallowing disorders due to the risk of water aspiration.

The device created by The Biomechanical Engineering Group from UFMG (Barroso et al., 2009) is the first device to measure tongue strength developed in Brazil. The main identified limitation in the device is the difficulty to seal the tubes, which caused some leakage that influenced the measurements and created air bubbles inside the system. Because of the leakage, the water contained inside the device had to be replaced after each test, which made the measurements laborious. The instrument was bulky, making its transportation difficult. Besides, some components made of glass made the system fragile with consequent risk of fracture. And finally the sensor was capable to measure forces between 0 and 40 N. Some patients can exert more than 40 N in protrusion tasks and in this case there was saturation of the system.

Some studies describe the use of electromyography to estimate muscle force (Staudenmann et al., 2007), as the electromyography signal amplitude generally increases as the force of the muscle increases providing a qualitative indication of a relationship between the variables. However, it is not possible to quantify the force (De Luca 1997). The evaluation of lingual electromyography activity is questioned mainly because of the use of surface electrodes and the interference of adjacent muscles, as tongue muscles have small size and they are interconnected (Pittman, Bailey, 2008).

In an overall view, most of the devices measure force in only one direction. However tongue activity during the functions involves a combination of dynamic and static forces as the tongue is oriented in a variety of different positions. The measurement generally occurs while the individual is performing a voluntary task, requiring a high level of cognition while functions are more instinctive than cognitive, and it may be coordinated in the cerebrum at a different level (Robinovicth et al., 1991). The large size of some devices make difficult their transportation (Miller et al., 2008) and the lack of position reproducibility of the sensor inside the oral cavity make difficult the comparisons in subsequent evaluations.

The wide variation in maximum and average strength and pressure values found were related to the great diversity of devices. Methodological differences made it difficult to compare tongue force measured in different studies, as it depends on a number of factors such as the degree of protrusion, the direction of the movement, the distance between mandible and maxilla, the tongue region in contact with the sensor, the area in which the pressure is exerted. A lack of reproducibility in any of these parameters might lead to significant variation in the obtained results (Robinovicth et al., 1991).

The use of quantitative methods to measure tongue force help the professional in the evaluation of orofacial myology, making the diagnosis of tongue force more reliable, especially in those subjects with a slight strength deficit which are difficult to be noted by clinical evaluation. Other advantages of the quantitative evaluation are the possibility to follow the evolution of the therapy and to make easier the communication among professionals involved in the treatment of the patients, improving the comprehension during the discussion of the clinical reports. The prognosis of the treatment can be more accurately defined based on the values of obtained forces. However it is important to highlight that the quantitative assessment should not be used to substitute the qualitative, but to complement it, since professional experience is essential to perceive the pathology of the patient.

5. CONCLUSION

Several instruments to measure tongue force were found. All these methods can potentially help the professional in the evaluation of orofacial myology, making the diagnosis of tongue force more reliable. According to their specific design, devices are more indicated to different assessments of tongue force, as 15 different muscles are involved in tongue movements. Other advantages of the quantitative evaluation are the possibility to follow the evolution of the therapy, to make easier the communication among professionals involved in the treatment of the patients and to make the prognosis of the treatment more accurate.

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