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Single tooth bite forces in healthy young adults

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SUMMARY **The assessment of bite forces on healthy single tooth appears essential for a correct quantification of the actual impact of single implant oral rehabilitations. In the present study, a new single tooth strain-gauge bite transducer was used in 52 healthy young adults (36 men, 16 women) with a complete permanent dentition. The influences of tooth position along the dental arch, of side, and of sex, on maximum bite force were assessed by an ANOVA. No significant left–right differences were found. On average, in both sexes the lowest bite force was recorded on the incisors (40–48% of maximum single tooth bite force), the largest force was recorded on the first molar. Bite forces were larger in men than in women ($P < 0{\cdot}002$), and increased monotonically along the arch until the first or second permanent molar ($P < 0{\cdot}0001$). The present data can be used as reference values for the comparison of dental forces in patients.**

KEYWORDS: **isometric force, clench, single tooth, man**

Introduction

Quantitative assessments of oral function are becoming more and more requested in all fields of stomatognathic rehabilitation (1, 2, 3, 4, 5). Jaw movements, electromyographic patterns of the main masticatory muscles, chewing efficiency, patterns of occlusal contacts, bite force measurements are all performed both in healthy subjects and in patients (1–15).

In particular, the development of suitable transducers made possible the measurement of bite forces in single, well-defined positions along the dental arch (1, 2, 4–7, 10–12, 15, 16). Both theoretical models and actual *in vivo* measurements found that the bite force varies in the different regions of the oral cavity, being largest corresponding to the posterior teeth (molars and premolars), intermediate in the canine area, and least in an incisal clench (2, 4–7, 9, 11, 12, 14, 16, 17).

Currently, single tooth transducers have become available. These instruments permit the assessment of the bite force corresponding to single natural or prosthetic teeth. This approach appears to neglect oral function as a whole, but it appears essential for a correct quantification of the actual impact on single implant oral rehabilitations (18).

Healthy subjects in their twenties with a complete natural dentition should represent a reference group for good oral function (5). The effects of ageing, pathology and treatment could then be quantitatively compared with this reference.

In the present study, a new single tooth bite transducer was used in a group of healthy young adults with a complete permanent dentition. The influences of tooth position along the dental arch, and of sex, on maximum bite force were analysed.

Materials and methods

Sample

Data from 52 white northern Italian people were included in this study. The subjects were selected from a group of dental school students aged 19–29 years (36 men, mean age 20·3 years, SD 2·2; 16 women, mean age 20·1 years, SD 1·1) according to the criteria described by Ferrario *et al.* (13). Briefly, all subjects had a sound full permanent dentition (28 teeth at least), overjet and overbite ranging from 2 to 4 mm, no anterior or lateral crossbite, no cast restorations or cuspal coverage, no previous craniofacial trauma or

surgery, and no signs or symptoms of temporomandibular or cranio-cervical disorders.

All subjects gave their informed consent to the experiment. All procedures were non-invasive, the only risk being dental fracture during maximum clench. This risk was limited as detailed under 'Experimental protocol'. The study protocol was approved by the local ethic committee.

Experimental protocol

Single teeth bite forces were measured with a strain-gauge bite force transducer* made of stainless steel. The transducer had a vertical height of 4 mm, and was 5×7 mm wide (total area 33 mm^2). Calibration of the instrument was performed at room temperature between 0 and 350 N, with a $\pm 2\%$ error. When the instrument was tested with full dental protection (see below), the deviation from linearity with a load of 300 N was +7·3%, and with a load of 350 N was +9%.

The peak force measurements were displayed on the screen of a computerized interface, and recorded for further analysis.

Teeth were protected by covering both sides of the transducer with several loops of polytetrafluorethylene (PTFE†) obtained from a 25-cm-long band. The PTFE was further covered by a PTFE cap (FEP 140), and a disposable latex sheath‡ was used to exclude moisture. The mounting was repeated for each subject. The total thickness of the transducer with the complete protection for the dental cusps was 8·5 mm, which was reduced during teeth clenching. Indeed, when the instrument was positioned on the first molar, it gave an additional incisor overbite of 10 mm.

During testing, the subjects were seated upright on a stool without a backrest.

The transducer was positioned corresponding to the maxillary right second permanent molar, and the subjects were asked to clench maximally. The peak value was recorded by the instrument, the transducer was positioned corresponding to the next maxillary tooth (right first permanent molar), and the clench was repeated. The sequence was continued along the dental arch toward the left second permanent molar, a minute of rest was allowed, and the entire sequence was repeated once again. The first sequence of measurements was discarded, and only the second sequence was recorded by the computer for further quantitative analysis.

Statistical calculations

Descriptive statistics were computed separately for each tooth, and for men and women. A three-way factorial ANOVA with repeated measures was performed. Factor 1 was sex (two levels, men, women), factor 2 was side (two levels, right, left), and factor 3 was tooth (seven levels, central and lateral incisor, canine, first and second premolar, first and second molar). The interactions between the three factors were also computed. *Post-hoc* tests were performed when significant differences were found in the main effects. The statistical package STATISTICA§ was used for all calculations, with a 5% level of significance.

Method error

Both the immediate (2 h) and the short-term (2 weeks) repeatability of bite force measurements were performed in five subjects. A first series of measurement was performed in each subject as detailed before. After a 2-h rest, the same subjects performed a second series of assessments. The same subjects returned in the laboratory 2 weeks later, and a third and fourth series of measurements with a 2-h interval were performed. In no occasion the subjects were allowed to see the actual value of their bite force.

Paired measurements were analysed to identify both systematic and random errors. No systematic differences between the first and second (immediate repeatability), and the first and third (short-term repeatability) series were found. Random errors were assessed by computing Dahlberg statistics, that is, from the differences between the two assessments as: Error $= \sqrt{[\Sigma(\text{first measurement} - \text{second measurement})^2/(2 \times \text{number of couples of repeated measurements})]}$.

The resulting random errors for the immediate repeatability were 2·47 (molars), 1·96 (premolars), 1·51 (canine) and 0·97 (incisors). The errors for the short-term repeatability were 5·59 (molars), 1·66 (premolars), 0·84 (canine) and 1·25 (incisors).

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†Teflon; Loctite 55, Brugherio, Milan, Italy.

‡Omnitex; Omni, Fidenza, Parma, Italy.

§Statsoft Inc., Groningen, The Netherlands.

Results

The three-way factorial ANOVA found no significant differences in the factor 'side' (left and right, $F = 0{\cdot}993$, d.f. = 1, 25; $P > 0{\cdot}05$), and left–right pooled bite forces were computed (Table 1).

On average, in both sexes the lowest value of bite force corresponded to the incisors (central incisor in women, lateral incisor in men, *c.* 40–48% of maximum single tooth bite force), while the largest value corresponded to the first permanent molar.

Bite forces were larger in men than in women (factor 'sex', $F = 11{\cdot}792$; d.f. = 1, 25; $P < 0{\cdot}002$), and increased monotonically along the arch until the first or second permanent molar (factor 'tooth', $F = 70{\cdot}261$, d.f. = 6, 150; $P < 0{\cdot}0001$). No significant interactions were found ($P > 0{\cdot}05$ in all cases).

Post-hoc tests were performed for the factors 'sex' and 'tooth'. Overall, within each sex, bite forces recorded over the posterior teeth (premolars and molars) were significantly larger than forces measured over incisors and canines (Table 2). Moreover, in men the bite force recorded over the canine was significantly larger than the corresponding incisal force.

Table 1. Descriptive statistics of the single tooth bite forces (left and right average) in healthy young adults (36 men and 16 women)

Tooth	1	2	3	4	5	6	7
Women							
Mean	93·88	95·75	119·68	178·54	206·01	234·46	221·71
SD	38·16	36·59	42·58	77·20	86·52	70·53	73·08
Men							
Mean	146·17	139·30	190·31	254·08	291·36	306·07	294·30
SD	44·44	51·40	79·36	72·20	57·29	41·99	55·92

All values are Newton.

Table 2. *Post-hoc* tests: 'tooth' (left and right pooled) within each sex. The significant ($P < 0{\cdot}05$) differences in men (M) and women (F) are indicated

Tooth	1	2	3	4	5	6	7
1				F	F	F	F
2				F	F	F	F
3	M	M			F	F	F
4	M	M	M				
5	M	M	M	M			
6	M	M	M	M			
7	M	M	M	M			

Table 3. *Post-hoc* tests: 'sex' (men versus women) within each 'tooth' (left and right pooled). The significant differences ($P < 0{\cdot}05$) are indicated

	Men						
Women	1	2	3	4	5	6	7
1			*	*	*	*	*
2			*	*	*	*	*
3			*	*	*	*	*
4				*	*	*	*
5		*			*	*	*
6	*	*				*	*
7	*	*			*	*	*

The rows indicate the female teeth, the columns indicate the male teeth.

Within each tooth, the forces measured on all male molar and premolars were larger than the forces measured on all female teeth (Table 1). The difference was statistically significant in all occasions for both molars, while second premolar force in men was significantly larger than the force recorded on all female teeth excluding the first molar (Table 3). Male canine and first premolar were submitted to significantly larger bite forces than female canine and incisors. The first premolar in men was clenched on significantly and more powerfully than the equivalent female tooth. In women, molar bite force was larger than male incisal bite force, a difference significant at the 5% level (Table 3).

Discussion

In the current study, a new bite force transducer for the assessment of single teeth was used in a group of healthy young adults with complete permanent dentitions. The instrument and the measurement protocol had a good reproducibility, both on an immediate (2 h) and a short-term (2 weeks) basis, similar to that reported in previous investigations (7). The instrument, with the dental protection *in situ*, gave a total incisal opening of 10 mm, well inside the range reported by Paphangkorakit and Osborn(19).

The only possible risk of the current study was dental fracture. Dental cusps were protected by using PTFE coatings. This material can be deformed by occlusal load, and can be easily applied without the need of individual preparations, such as those necessary when

acrylic appliances are used (10, 11, 16, 19). Indeed, several previous investigations used plastic materials (1, 2, 5, 9, 14, 15).

In all subjects two actual measurements of bite force were performed for each tooth, but only the second value was recorded for further analysis. Indeed, almost all investigated men and women had a second bite force assessment larger than the first assessment performed on the same tooth (7, 12). Probably the subjects became accustomed with the device and dared to clench more powerfully (10, 12).

The measurements were performed for all 14 teeth of the maxillary arch, neglecting the third molars. Indeed, not only these teeth were not present in all investigated subjects, but their actual contribution to the total bite force appears to be negligible (only 4%, when measured with a pressure sensitive film, 14).

In the present study, men had a larger bite force than women for all teeth, with sex ratios ranging from 63 (canine) to 77% (first molar). Most male bite forces were larger than female bite forces, with several statistically significant differences (Tables 1 and 3). This finding is in accord with most literature reports performed on young healthy adults (2, 3, 4, 9, 12), even if some investigations found a non-significant sex effect (1).

On average, males possess a larger body mass than females, and, in particular, significantly larger facial structures (20, 21). Moreover, their muscular mass is more developed, producing a larger force in almost all body districts (22). A significant sex difference is found also for the sovramandibular muscles. A further factor to be considered to explain sexual dimorphism may be dental size. Indeed, human teeth have been reported to be larger in males than in females (23–27), thus presenting a larger area of periodontal ligament.

All the present values of bite force were symmetric in both sexes, as already reported by previous investigations (1, 4, 6, 9, 12). It has to be mentioned that a dental arch asymmetry could also be an artefact provoked by the measurement protocol. As already reported, in almost all subjects the second bite force assessment produced larger forces than the first assessment performed on the same tooth. The sampling sequence being constant along the arch (always right to left), a larger left-side force might be theoretically expected (12).

The present maximum bite forces were not comparable with literature reports, being in most cases lower than previous values collected on healthy subjects of the same sex, age and race, with differences ranging between 40 and 80% (1, 2, 5–7, 10, 16). Nevertheless, the present increment of bite force along the arch (from incisors to molars) was similar to those previously found.

Among the factors that can explain these differences, at least in part, there is the vertical height of the transducer, the maxillomandibular relationships during clenching, and, mostly, the actual number of teeth involved in the bite effort. Indeed, in the present investigation the clenching effort was measured on single maxillary teeth.

In conclusion, the force transducer used in the present investigation allowed quantifying the bite forces on each tooth of the dental arch. In young healthy adults, significantly larger forces were found on the molar and premolar teeth, with a symmetric distribution between the left and right side of the arch. Men had larger bite forces than women. The current data can be used as reference values for the comparison of dental forces in patients.

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