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Experimental evaluation of occlusal forces

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The paper presents the results of measuring the occlusion forces in the group of 163 subjects being tested. In the research, the method based on the dependence of the plastic deformity and force intending the spherical penetrator upon each other in a metal sample was implemented. The results obtained allowed us to estimate the distribution of occlusion forces along the alveolar ridge and to define the dimensions of the maximum forces applied, while biting and gnawing. The biting force between the first incisors for different angles of parting mandible was also measured.

Key words: occlusion forces, alveolar ridge, distribution, occlusion, teeth, jaw separation

1. Introduction

The occlusal force provided us with a great deal of information on the mechanical condition of stomatognathic system. A correct selection of biomaterials' properties and geometrical features of structures used in order to restore the correct function of the masticatory organ, in many cases requires taking into consideration the mechanical conditions of the mandible and the jaw's work. The evaluation of equilibrium states of the mandible by means of numerical methods allows us to determine, depending on the value of the dental arch load, the response in joints as well as the forces generated in masticatory muscles. The reliability of the results obtained with the use of calculation techniques based on occlusal forces data is dependent on a correct determination, in natural conditions, of the constrictive forces. The main factors, which influence the value of the force measured and are associated with the measuring technique, can be itemized as follows: the force exerted by an instrument on the teeth at the point of contact; a change of the mandible abduction angle during measurement and the size of jaws' opening at the final stage of measurement. Invariability of these parameters is the basic condition for obtaining representative results. In the paper presented, the occlusal forces inside the oral cavity are determined by means of the instruments of our own design which make it possible to carry out measurements quickly and in a way eliminating most of the causes of mistakes.

2. Methods

Typical instruments used for force measuring are based on linear dependences of a force value upon an elastic strain of their core. In the method developed, elastic strain is used for the evaluation of forces. The basis for the solution was Mayer's dependence [1] of the force indenting a spherical penetrator in metal upon formed diameter of indentation, in this paper has been written as $F=cd^u$, where: F is the load force, d – indentation diameter, c – material constant, u – Mayer's coefficient.

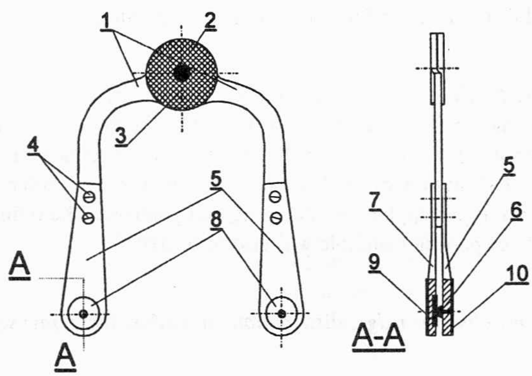

Fig. 1. Diagram of the biting force measuring instrument

A diagram of the measuring instrument is shown in figure 1. It has been originally assumed [2] that the instrument would be built in a way enabling symmetric measurements of the load on both sides of the dental arch. It consists of two arms *1*, which are connected with each other by means of an articulated joint *2*, being located at the central point of a holder *3*. At the end of each arm, two plates are fastened by means of screws *4*. In the upper plates *5*, spherical penetrators *6* are placed; in the lower plates *7*, they are cut out coaxially in relation to the nest's *8* penetrator. In these nests, specimens *9* are placed, which are made of soft metal sheet. Before starting the measurement the spacing of arms is adjusted to the occlusion conditions by rotating the arms. Then, small single polyethylene shields are put on the tips of the instrument *10*. During the measurement, the patient presses on the shield with his teeth, which brings about an indention of balls into the metal plate. In such a way, we obtain the impressions of teeth in a shape of a bowl on the specimens. The bowl diameter is closely associated with the value of the pressure exerted. The dependence of the force upon the impression's diameter is determined by calibration. In the preliminary investigations, the possibility of using copper, aluminium and lead specimens was analysed. Taking into consideration the sizes of impressions obtained at the loads corresponding to typical constrictive forces, the aluminum specimens were recognized as optimal. The copper specimens, which turned out to be too hard, were rejected. The plastic lead specimens were used for the investigation of small forces occurring in persons with a reduced efficiency of the masticatory organ.

The results of our own investigations presented in this paper concern mainly an asymmetric load of the dental arch. Consequently, a single simplified arm of the instrument, which was modified in a way shown in figure 2, was used for the measurements [3], [4].

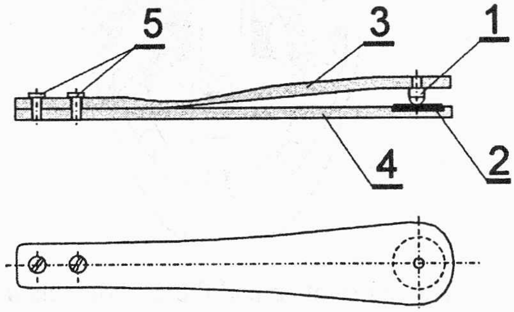

Fig. 2. Diagram of the force measuring instrument for the measurements in the individual points of the dental arch: *1* – penetrator, *2* – specimen, *3* and *4* – plates, *5* – assembling screws

The force measuring instrument consisted of two plates (*3*, *4*) put on each other and fastened down with screws (*5*). The penetrator (*1*) was placed centrally over the nest of a 10 mm diameter and a depth of 0.5 mm, in which specimens – circular plates (*2*) – were inserted.

In the instrument prepared for measurements, the penetrator slightly touches the surface of the specimen preventing it from falling out during the preparation for measurements in the oral cavity.

When we dealt with a small mandible abduction, a 7 mm thick version of the instrument was used for measurements. In order to measure the forces, which allowed us to evaluate how the degree of the mandible abduction influenced the biting efficiency, a modified versions of the instrument were used [5]. They consisted of pistons ended with a penetrator (*3*) and small cylinders, at the bottom of which lay the same specimens (*4*) as in the previous instrument. On the surfaces coming into contact with teeth, small teflon hoods (*1*), 4 mm thick, were put on. A diagram of the instrument being in the oral cavity is presented in figure 3. On the basis of the evaluation of the mandible abduction efficiency determined in adult patients, the following overall lengths *L* of measuring sets were accepted for performance: 33, 39 and 45 mm. The opening's width during the measurement was determined by choosing an appropriate length of the piston.

Depending on the expected value of the biting strength evaluated in investigation of palpable muscles, the following kinds of penetrators and specimens were used in all variants of instruments:

a) large forces – a penetrator of 3.8 mm diameter, an aluminum specimen 1.2 mm thick,

b) average forces – a penetrator of 2.9 mm diameter, an aluminum specimen 1 mm thick,

c) small forces – a penetrator of 3.8 mm diameter, a lead specimen 1.6 mm thick.

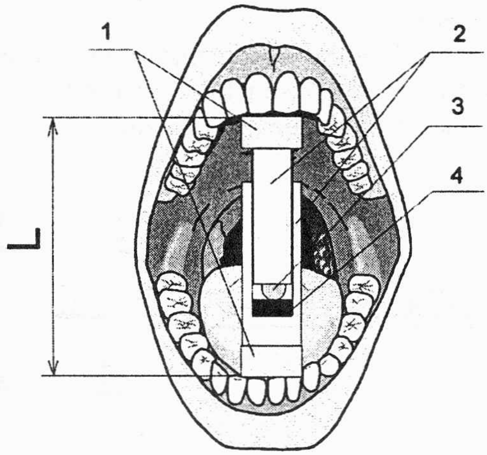

Fig. 3. Structure and way of application of the instrument measuring the occlusive force at different angles of mandible abduction in an oral cavity: *1* – teflon plate, *2* – cylinder and piston, *3* – penetrator, *4* – specimen

The constants *c* and the coefficients *u* in Mayer's formula were determined on the basis of measurements of the impressions' diameters obtained during the calibration of instruments. Diagrams presenting the changes of impressions' diameters, depending on the value of the indenting force and the penetrator's diameter, are presented in figure 4 for aluminum and lead specimens.

The constant values in Mayer's formula calculated for individual specimens were as follows:

a) $u = 1.71$, $c = 276$ – for aluminum specimens of ϕ 10 mm, 1.2 mm thick, for a penetrator of a diameter of 3.8 mm,

b) $u = 1.71$, $c = 305$ – for aluminum specimens of ϕ 10 mm, 1 mm thick, and a penetrator of a diameter of 2.9 mm,

c) $u = 3.0$, $c = 22.79$ – for lead specimens of ϕ 10 mm, 1.6 mm thick, and a penetrator of a diameter of 3.8 mm.

The advantage of the method described lies in highly insignificant penetration of a penetrator into the specimen. This eliminates the possibility of changes in the position of mandible apices and joint disks during measurements associated with a decrease in the angle of mandible abduction when load is increased.

The purpose of our investigations was to determine the distribution of forces along the dental arch loaded symmetrically and asymmetrically, as well as to evaluate the maximum biting strength between molar teeth and the impact of the mandible abduction degree on the value of occlusive forces that could be generated. The values of forces, which occurred during cracking food, were evaluated as well. In our investigation 163 people took part. Their temporomandibular joints worked correctly and they had their own dentition in the zones of the force measurement. Eight women and eleven men aged from 25 to 41 with a full dentition were chosen in order to examine the changes in constrictive forces along the dental arch. In the remaining people, the biting strength was determined only in the rear zones of the dental arch. Fourteen men at the age of 17–47 and ten women at the age of 16–43 participated in the tests carried out at a wide jaws' opening. The measurement cycle was started by familiarizing the

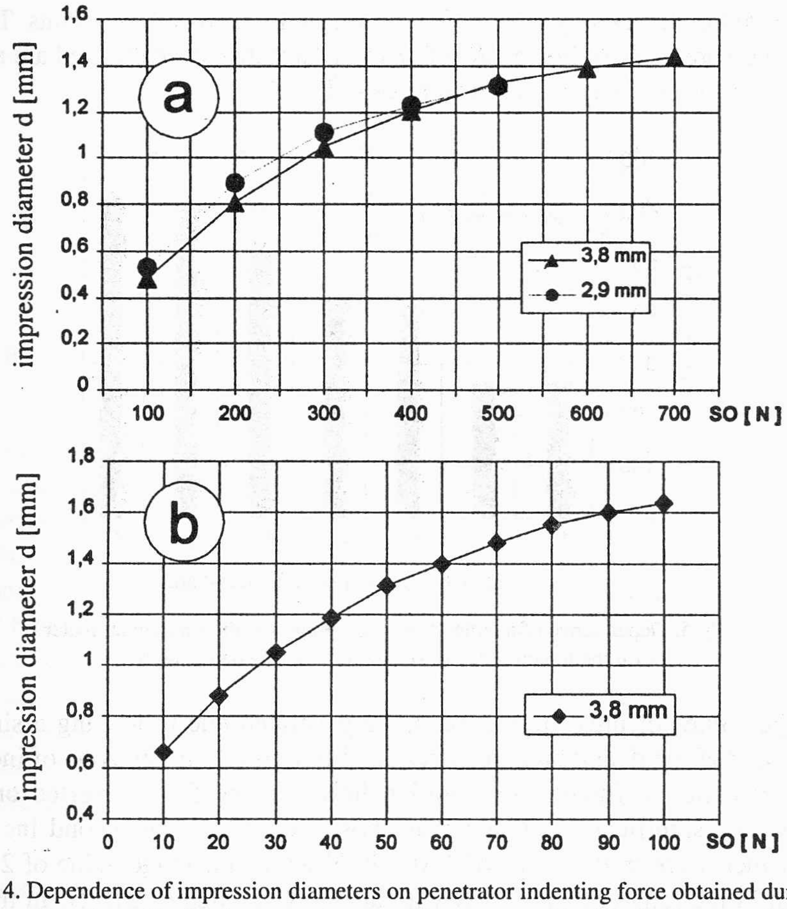

Fig. 4. Dependence of impression diameters on penetrator indenting force obtained during: a – calibration with aluminum specimens and instrument with globule diameter of 2.9 and 3.8 mm, b – calibration with leaden specimens and instrument with globule diameter of 3.8 mm

patients with the aim of the investigations as well as with the force measuring instrument. Later on, the instrument was placed at a selected point of the dental arch and the person being examined was asked to clench his/her teeth with such a maximum force that he/she did not feel any unpleasant sensation. After biting the instrument, the specimen was taken out and the impression formed this way was measured. For this purpose an optical meter was used with a scale of 0.02 mm built into a Briviskop hardness tester of Reichert company.

3. Values of constrictive forces along the dental arch

The first tests carried out "in vivo" were supposed to determine the forces which allowed an individual teeth to act on a teething ring under symmetrical and asymmetrical loads of the dental arch. The test began from incisors ($n = 1$), then it was gradually carried out along the dental arch to molar teeth ($n = 7$) and repeated three times. It was found that accustoming the person being examined to the instrument and informing him/her about the results obtained in the tests by others often significantly improved the results. This means that direct measurements of biting strength have a subjective character and are not closely associated with the efficiency of masticatory muscles.

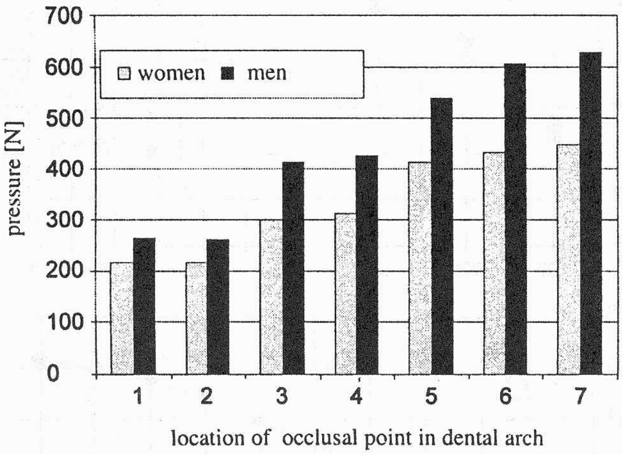

Fig. 5. Dependence of average forces exerting pressure on dynamometer on the location of measuring point in the dental arch

Average values of pressing forces, being generated due to loading a single tooth set in one side of the dental arch, are presented in figure 5. In the zone of incisors, the values of constrictive forces were similar, however, the forces exerted on the first incisors were insignificantly greater than those exerted on the second incisors. The results for men were in the range of 110–420 N with an average value of 260 N, and for women in the range of 87–378 N with an average value of 215 N. In the zone of canine teeth in men, there was observed an increase of constrictive forces to the average value of 413 N at a range of changes from 203 to 560 N. For women, the load in the zone of canine teeth amounted to 301 N at a range of changes from 205 to 480 N. For the first premolar teeth, the results were insignificantly higher than in the case of canine teeth. However, both for some of the men and women examined, an insignificant decrease of the force value was observed in the case of the canine tooth. Moving backwards along the dental arch, the average values of constrictive forces increased, reaching the following values for men: 540 N for the second premolar tooth, 606 and 628 N for the first and the second molar teeth. For women, the occlusal forces in analogical points amounted to 413, 433 and 450 N, respectively. In none of the investigated cases of people with a full dental arch, the occlusal forces in the rear dental arch zone were reduced to the value lower than 270 N, whereas the highest values in the case of women amounted to 660 N, and in the case of men, 860 N.

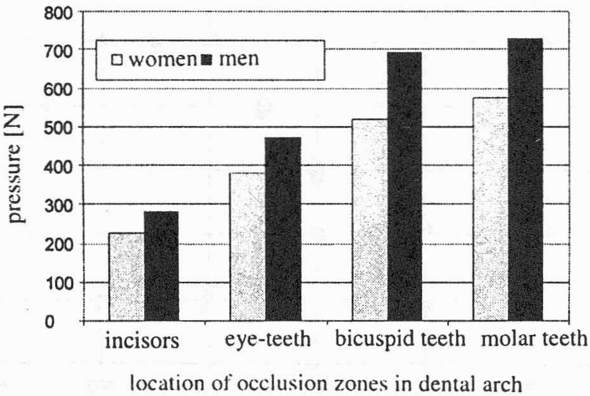

Fig. 6. Average biting forces obtained due to symmetrical loading of dental arch in the regions of incisor teeth, eye teeth, bicuspid teeth and molar teeth

When investigating symmetrical values of the dental arch load, we deal with some difficulties in a precise simultaneous placing of the instrument between single pairs of lateral teeth. Therefore, the point of measurement was defined by designating the following zones: incisive, canine, premolar and molar teeth. The average values of total biting strengths obtained in the given zones are presented in figure 6. A symmetrical distribution of the load brought about an increase in the pressure force which did not exceed 30% in relation to the asymmetrical load obtained by the same people. It is worth emphasizing that in lateral parts of the dental arch, the differences in values of simultaneously measured forces, which occur on the left and right sides, are in the range of 23–41%. This means that the determination of total load of the stomatognathic system by summing up the load of individual teeth, which is described in some papers, is rather questionable.

4. Maximum values of constrictive forces at an asymmetrical load

Molar teeth have been considered as the most convenient for extensive measurements of the biting strength maximum values obtained at an asymmetrical load. The occlusal forces differ in this case insignificantly, which facilitates both the selection of people with their own dentition, who can participate in the experiment, as well as a comparison of the results obtained. During the tests, the examined persons clenched their teeth on a teething ring with a force they recognized as the upper limit of their abilities. Thus, the results express a fully subjective character of individual features of the masticatory organ efficiency, connected both with the psyche and the functioning of mechanoreceptors [6], [7] situated in teeth and the paradontium.

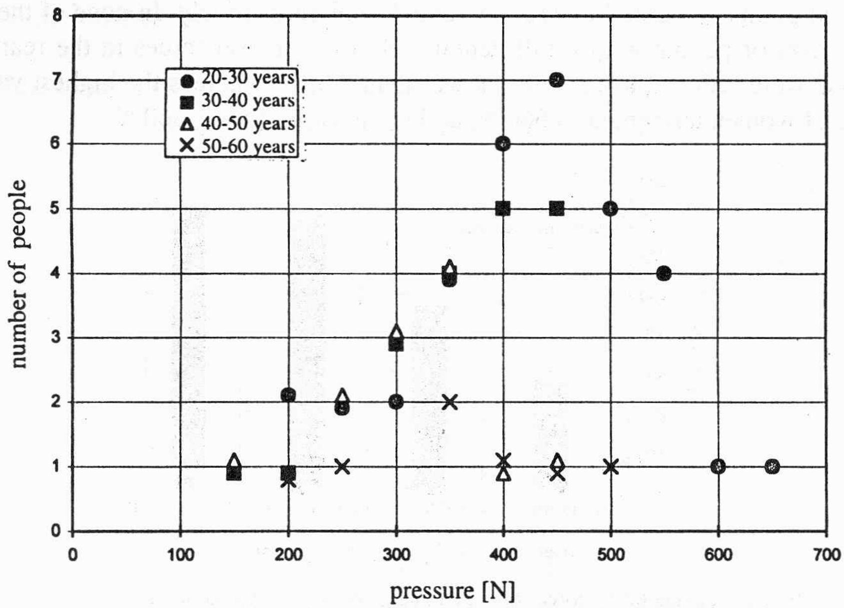

Fig. 7. Influence of age on the number of women, whose individual biting force values between molar teeth are measured

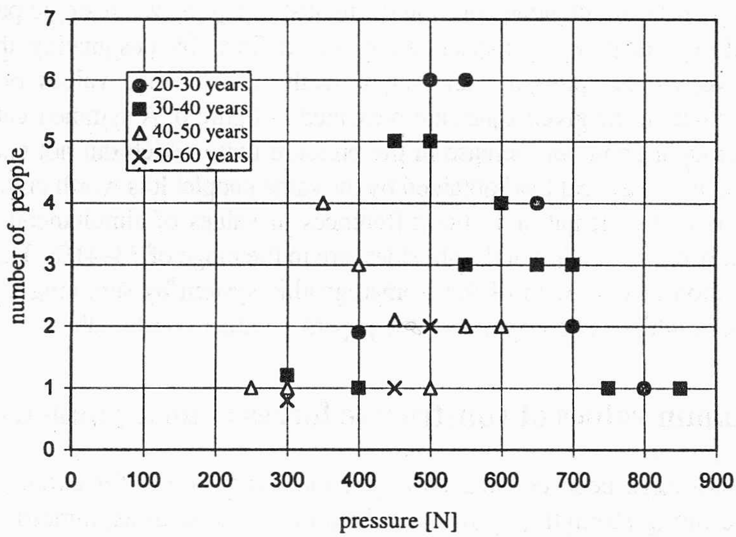

Fig. 8. Influence of age on the number of men, whose individual biting force values between molar teeth are measured

We failed in our attempt to arrange the results of the investigations according to the job and education criteria in order to find regularities. However, positive results were obtained by dividing the population examined into sex and age groups. The population was divided into four age groups: 20–30 years, 30–40 years, 40–50 years and 50–60 years. The results are presented in figures 7 and 8.

In the group of men, the force of 300 N was not exceed by only four persons from two oldest age ranges. The force within the limit of 300–500 N was achieved by thirty-two people from different groups, and the force of 500–700 N was achieved by twenty-nine persons, none of whom belonged to the oldest group. The force above 700 N was achieved by three persons from two youngest groups. Assessing the results presented one has to bear in mind that the size of individual age groups was diverse. In the case of women: the 1st group – 34 persons, the 2nd group – 18 persons, the 3rd group – 12 persons, the 4th group – 7 persons. In the case of men: the 1st group – 21 persons, the 2nd group – 27 persons, the 3rd group – 16 persons, the 4th group – 4 persons. The size of the oldest group was drastically limited by the requirement of having one's own dentition in the measurement zone. The data presented prove that only a few people are able to generate the constrictive forces of maximum values given in the above-quoted literary sources. The forces, which occur most frequently, are in the range of 350–500 N for women and 450–700 N for men.

5. Impact of the width of jaws' opening on the values of constrictive forces

The impact of the mandible abduction angle on the biting strength between incisors was measured for the opening that changed gradually from a maximum to minimum. In order to obtain a full picture of patient's muscles' efficiency, additional measurements of constrictive forces were performed (by means of a 7 mm thick in-

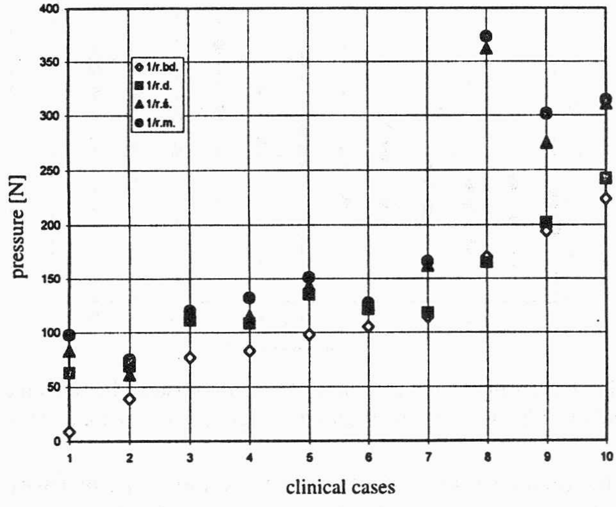

Fig. 9. Biting force values (in the group of 10 women) measured between incisor teeth for the following mandible dilation: very large (1/r.bd.), large (1/r.d.), medium (1/r.ś.) and small (1/r.m)

strument) between the canine teeth and the first molar teeth. In order to obtain similar conditions of a teeth contact with the surface of the instrument, the polyethylene overlays used during measurements in a standard instrument were replaced with the

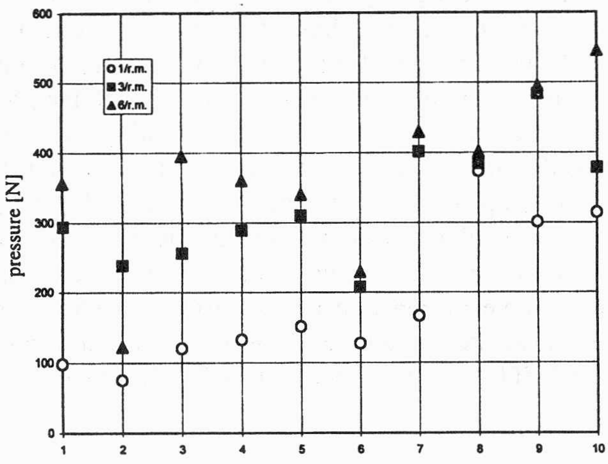

Fig. 10. Biting force values (in the group of 10 women) at small mandible dilation: for incisor teeth (1/r.m.), for eye teeth (3/r.m.), for molar teeth (6/r.m.)

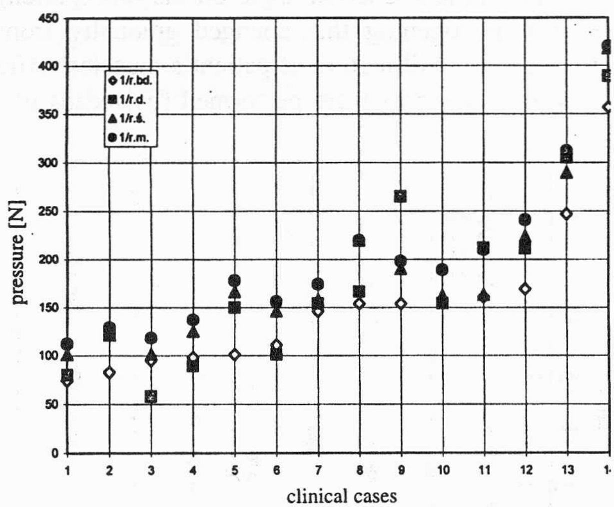

Fig. 11. Biting force values (in the group of 14 men) measured between incisor teeth for the following mandible dilation: very large (1/r.bd.), large (1/r.d.), medium (1/r.ś.) and small (1/r.m)

teflon overlays. The measurement results are presented in the form of diagrams for a group of men and women separately. The determined values of constrictive forces are shown on the vertical axis, and the numbers of clinical cases are shown on the horizontal axis in diagrams. Numbering of the clinical cases is arranged in an ascending order, assuming the forces at a maximum opening of the mandible as criterion values. The diagrams in figures 9 and 11 show the values of constrictive forces measured at a different degree of the mandible abduction between incisors. The values of forces generated between the incisors, the canine teeth and the first molar teeth and measured in the same patients at a small opening are shown in figures 11 and 12.

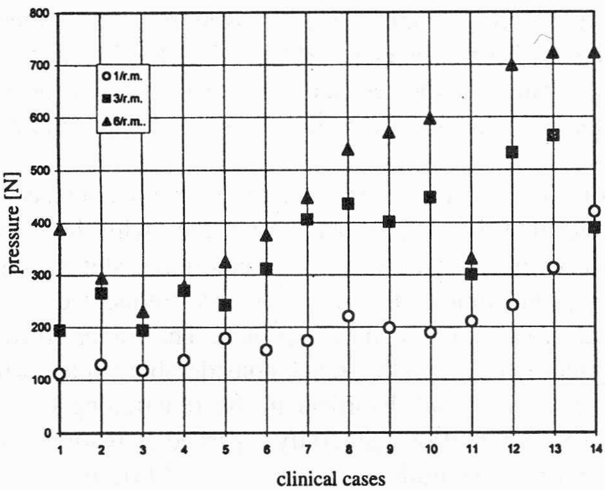

Fig. 12. Biting force values (in the group of 14 men) at small mandible dilation: for incisor teeth (1/r.m.), for eye teeth (3/r.m.), for molar teeth (6/r.m.)

As one can see, the lowest values of constrictive forces occur in most cases at wide and very wide openings. Such results were achieved by nine women and ten men. In five cases, the lowest values were achieved at a wide opening, in four of which the difference between the forces at a wide and very wide openings was minimal. The values of forces for a group of women, at a very wide opening, were in the range of 9–224 N; a woman pressing with a force of 9 N during the measurement of biting strength between molar teeth achieved a result of 356 N, which was similar to an average result for the whole population. A maximum value of the force measured between molar teeth in the group of women was 545 N. In the group of men, the range of forces measured between incisors by means of a 45 mm long instrument was in the range from 74 to 357 N, whereas the forces between incisors measured at a narrow opening were in the range of 389–722 N. A change in the hardness of an overlay being in contact with teeth brought about a noticeable decrease in the occlusal force within the zone of incisors. It was characteristic that in patient No. 14, who achieved definitely higher values of forces between incisors than the others, pathological attrition of front teeth was found.

Forces generated during food consumption were estimated by replacing the polyethylene overlays in the instrument consisting of a single arm first with slices of hard cheese, and then with smoked meat. The slices were about 3 mm thick. It was assumed that the force necessary to crumble food was associated with the mechanical properties of a food, not with the efficiency of the stomatognathic system. Thus, the number of people participating in the experiment was reduced to two. An estimated evaluation of the forces was made on the basis of a repeated activity of cracking the food which surrounded the force measuring instrument. The test was stopped at the moment when the participant of the experiment felt the contact with the metal surface of the instrument. In the case of cheese, the impressions left on the specimens were practically invisible, whereas in the case of smoked meat, the forces recorded were in the range of 60–100 N for the incisors' zone and of 80–130 N for the premolar and molar teeth zones. It can be suspected that the measured forces necessary for multiple crushing and grinding a bite of food will suffice to crumble most of the food being eaten.

When evaluating the forces occurring in interdental contacts, it is important to bear in mind the fact that they are assosiated not only with the chewing activity. Cyclic muscular contractions can be caused by emotional states (anger, fear, pain) or chilling of the body. In clinical practice, there are frequent cases of a pathological parafunctional load of the stomatognathic system. The forces freed during a habitual behaviour, e.g. "grinding one's teeth", reach considerable values, which leads to a fast destruction of tooth crowns and disorders in the functioning of temporomandibular joints [8]–[10]. Also, in conditions generally regarded as resting, masticatory muscles are active and maintain the mandible in a state of equilibrium.

6. Conclusions

The tests carried out allow us to draw the following conclusions:

1. The constrictive forces in a group of men are higher than in the group of women. There is also a tendency towards a decline in the biting efficiency with age. Despite a considerable individual diversity of biting strength there are areas common for all classified populations.

2. Obtaining a symmetrical load of specimens used for a simultaneous measurement of occlusal forces on opposite sides of the dental arch turned out to be impossible.

3. An increase in the biting strength as the occlusal point moves backwards along the dental arch and a decrease in the force at a large mandible abduction occur as a rule.

4. Detailed values of forces obtained may constitute a basis for assuming an appropriate load in model tests of the mechanical states of a stomatognathic system.

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