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Chewing efficiency and occlusal forces in PMMA, acetal and polyamide removable partial denture wearers

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Purpose: Thermoplastic materials, such as acetal (AC) and polyamide (PA), constitute an alternative to polymethyl methacrylate (PMMA) based resins as the materials for removable partial dentures. However, none of the previous studies compared chewing efficiency and occlusal forces in the wearers of dentures made of various materials. Therefore, the aim of this study was to determine and compare the chewing efficiency and occlusal forces in PMMA, PA and AC RPDs' wearers. The hypothesis was that the type of denture base material shows a significant effect on chewing efficiency (expressed as a degree of food fragmentation) and occlusal force. *Methods*: The experiment included the group of 30 patients using removable partial dentures. The dentures made of PMMA, acetal and polyamide were tested in each patient. Each denture was worn for 90 days, with a random sequence of the denture manufacturing and insertion. After 7, 30 and 90 days of each denture wear, chewing efficiency coefficient was determined with the aid of a sieving method, and occlusal force was measured with a dynamometer. *Results*: The use of dentures made of PMMA or acetal was reflected by a marked increase in chewing efficiency and occlusal force. None of these parameters changed significantly with the time of denture wear. Moreover, no significant correlation was found between chewing efficiency and occlusal forces. *Conclusions*: Denture base material exerts significant effects on the degree of food fragmentation and the level of occlusal forces. The use of dentures and clasps made of materials with lower modulus of elasticity is associated with lower chewing efficiency and lower occlusal forces.

Key words: *denture base material, removable partial denture, chewing efficiency, occlusal force, thermoplastic materials*

1. Introduction

Very often even a minor teeth loss requires reconstruction in order to restore normal occlusion conditions, physiological function of the mastication organ and esthetic appearance of the dental arch. Insertion of fixed dentures or implant dentures constitutes an optimal treatment from the viewpoint of the mastication organ function. Unfortunately, this is not always possible due to medical or economic reasons [9]. However, removable partial dentures (RPDs), the most popular type of prostheses in many countries, can be a method of choice in such cases. The removable dentures made of injection-molded thermoplastic materials, such as acetal (AC) or polyamide (PA), constitute an alternative to widely used polymethyl methacrylate (PMMA) dentures [22]. The thermoplastic materials have lower modulus of elasticity than the PMMA denture base materials [29]; furthermore, the modulus of elasticity of AC is higher than that of PA [26]. Moreover, the use of PA and AC denture bases allows tooth-colored retentive clasps to be manufactured, thus improving the esthetics of the denture [8]. Due to markedly lower modulus of elasticity than in the case of wires made of metal alloys, the dentures made of thermoplastic polymers presented with lower retentive force of the clasp [26]. Although, the results

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of previous studies suggest that the clasps made of PA do not undergo a permanent deformation and do not show resultant decrease in the retentive force with the time of denture wear, as observed in the case of wire clasps, retentive force generated by the latter is still markedly higher, even after many years of denture use. Injection-molded thermoplastic denture base materials show the tendency to color deterioration [27], but have lower sorption and solubility [18]. Polyamide resin when compared with PMMA shows also higher *Candida* spp. biofilm formation than PMMA materials [6]. In turn, the main drawbacks of PMMA denture base materials include the presence of a residual monomer in the polymerized material, which may lead to various adverse effects on oral health, such as irritation or an allergic response [16].

Although the PMMA, PA and AC have been used in clinical practice for several dozen years and were a subject of extensive multidirectional research, to the best of our knowledge, none of the previous studies compared the chewing efficiency (CE, also referred to as masticatory performance) of dentures made of these materials. Therefore, the aim of this study was to determine and compare the chewing efficiency and occlusal forces in PMMA, PA and AC RPDs' wearers. We hypothesized that the type of denture base material exerts a significant effect on chewing efficiency (expressed as a degree of food fragmentation) and occlusal force.

2. Materials and methods

The study included the group of 30 patients (18 women and 12 men) aged between 35 and 60 years (mean 49.6 years) who meet the following criteria:

- unilateral or bilateral loss of 3–6 teeth from one dental arch, corresponding to Kennedy class III, and presence of natural teeth in the opposing dental arch,
- at least 2 years elapsed between the last episode of tooth loss and the denture insertion; this criterion was based on the observation that the most enhanced degradation of the skeletal scaffold and remodeling thereof took place within initial two years after tooth extraction [24],
- lack of pain and auscultatory abnormalities in the temporomandibular joints, no spontaneous painn or enhanced tone of the masticatory muscles.

A total of 16 patients presented with bilateral teeth loss, while 14 individuals were diagnosed with a partial unilateral teeth loss. All the enrolled patients were subjected to preliminary clinical evaluation consisting in history taking and physical exam. Three dentures made of different materials: PMMA (Villacryl H Plus; Zhermack, Italy), acetal (T.S.M. Acetal Dental; Pressing Dental, San Marino) and polyamide (Valplast; Valplast, United States) were tested in each patient. The PMMA dentures were equipped with wrought wire clasps (WWCs) made of a Cr-Ni alloy wire, 0.8 mm in diameter (Dentaurum, Germany). The acetal dentures consisted of the AC-made framework and retentive clasps, with the PMMA base and teeth. The teeth of the PA dentures were made of PMMA. The sequence of the denture manufacturing and insertion varied within the group to avoid a potential confounding effect of the fixed order of prosthesis insertion on the study results. Each of the dentures was worn for 90 days, and the denture made of another material was manufactured a few days before the end of the previous 90-daywearing cycle. Chewing efficiency (CE), expressed as a degree of food fragmentation, and occlusal force were determined prior to denture insertion and after 7, 30 and 90 days of their use.

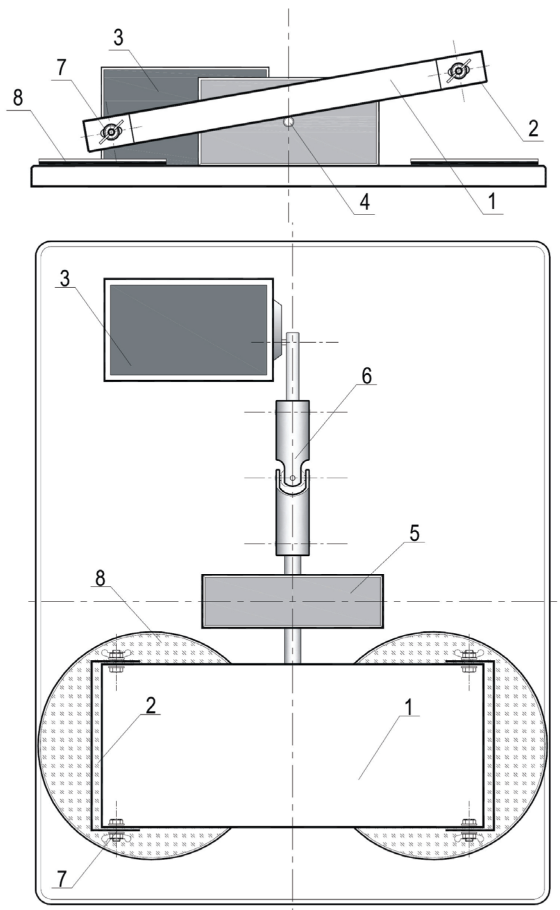

Fig. 1. Scheme of the sieving device: 1 – mini-chamber, 2 – throttles, 3 – drive, 4 – supporting bar, 5 – support for the bar, 6 – winch mechanism, 7 – fixing elements enabling movement and stabilization of the throttles, and thus adjustment of the aperture width, 8 – container for the sieved material

CE was evaluated on the basis of the degree of standardized food sample fragmentation. The degree of fragmentation was determined with a prototype device for sieve analysis, constructed by the authors [3]. The device is presented schematically in Fig. 1. Each patient received a 3 ± 1 g serving of peanuts (Felix Intersnack, Poland), portioned with the aid of an analytical scale (Radwag, AS 110/C/2, Poland), and packed in sealed disposable polyethylene foil bags (40 × 60 × 0.4 mm; BRB, Poland). The participant was instructed to chew the sample for 40 cycles [19], [28], with a single cycle corresponding to one complete sequence of abduction and adduction of the mandible, along with laterotrusive and mediotrusive movements resulting in crushing and rubbing of the food bolus. After chewing, the material was transferred to the mini-chamber of the sieving device. Both ends of the mini-chamber were equipped with adjustable throttles, used to adjust the width of an aperture between the chamber's bottom and the throttle. In order to obtain repeatable results, the width of the aperture was calibrated with 1.8 ± 0.02 mm and 2.4 ± 0.02 mm thick cuboid standards. Such adjustment of the aperture enabled us to obtain three fractions of granular material during the gradation test: particles smaller than 1.8 mm, between 1.8 and 2.4 mm, and larger than 2.4 mm. During sieving, the trough was placed at a 20° angle with respect to the device's bottom and exposed to vibrations in order to enforce passage of the fragmented material and separation of particles or their aggregates of different sizes, starting from the smallest ones. Subsequently, each fraction was weighted with an analytical scale (Radwag, AS 110/C/2) to the nearest 0.001 g. The results were used to calculate the chewing efficiency (CE)

$$CE = \frac{1.5 \times m_1 + m_2 + 0.5 \times m_3}{m} \tag{1}$$

where: CE – chewing efficiency coefficient, m_1 – mass of the particles smaller than 1.8 mm, m_2 – mass of the particles between 1.8 and 2.4 mm, and m_3 – mass of the particles larger than 2.4 mm; m – initial mass of the sample, 1.5 and 0.5 – coefficients assigned to m_1 and m_3 masses, respectively.

As we assumed that higher chewing efficiency results in better fragmentation of the sample, 1.5 and 0.5 coefficients were assigned to the CE indices for the particles smaller than 1.8 mm and particles larger than 2.4 mm, respectively. Therefore, the theoretical values of the CE coefficient could range between 1.5 ($m_3 = m$) and 4.5 ($m_1 = m$).

Moreover, occlusal force was determined during the course of the *in vivo* study, with a device presented schematically in Fig. 2. The dynamometer was placed on the chewing surface of the denture teeth, at the central point of the edentulous ridge. The place of the measurement was identical for all the tests and for the dentures made of different materials. The patient was asked to bite the device placed between the natural antagonistic teeth for 5 ± 1 s in order to push a penetrator (a steel ball, 3.8 mm in diameter) into a lead plate with 1-mm thickness and 10-mm diameter. The occlusal force was measured 3 times, with 1-min intervals between the consecutive measurements, and the minimum and maximum values were not considered during statistical analysis. Subsequently, the diameters of the ball's imprints on the lead plate were measured to the nearest 0.01 mm with a metallographic optical microscope (Axio Observer, Zeiss, Germany), and the occlusal force was calculated from Meyer's equation

$$P = Cd^n \tag{2}$$

where P – occlusal force, d – diameter of indentation (mm), Meyers coefficients, $C = 307$, $n = 1.71$.

The results were subjected to statistical analysis with a Statistica 10 software. As the distributions of the residuals were not normal and/or the variances were not equal, the non-parametric Kruskal–Wallis test ($\alpha = 0.05$) was used. The following null hypo-

(a) (b)

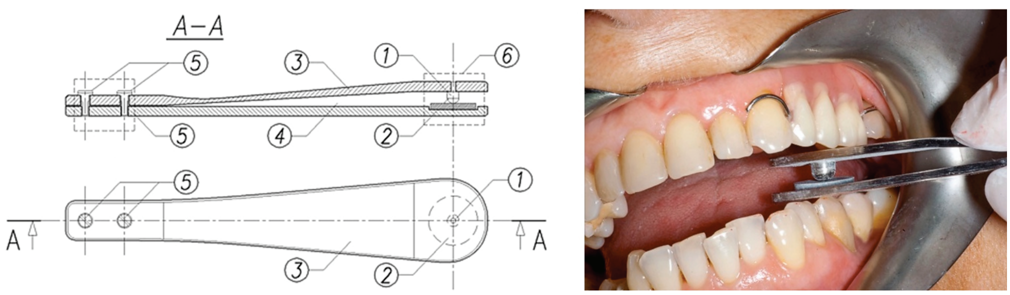

Fig. 2. Scheme of the device for occlusal force determination: 1 – penetrator, 2 – sample (Pb plate) in a nest, 3 and 4 – arms, 5 – joining screws, 5 – handle, 6 – zone of force application (a), and the device in situ during the measurement of occlusal forces (b)

theses were tested: median values of CE coefficient determined prior to the denture insertion and 7 days after the PMMA, PA or AC denture insertion are equal (n = 30 in each group), median values of CE determined during a 3-month use of the denture made of a given material are equal (n = 30 in each group), median occlusal forces determined during a 3-month use of the denture made of a given material are equal (n = 30 in each group), median occlusal forces are equal irrespective of the denture base material used (n = 90 in each group). Whenever the null hypothesis was rejected, multiple comparisons of mean ranks for all groups were conducted with the aid of a post-hoc test (α = 0.05). Spearman's rank correlation coefficients were used to analyze associations between occlusal forces and CE coefficient values (α = 0.05).

3. Results

Median values of CE coefficient are presented in Table 1. Median CE after 7 days of denture use differed significantly (P < 0.001) from the respective parameter determined prior to the denture insertion (WT). The results of post-hoc test are presented in Table 2. Median CE coefficient for PMMA and AC dentures was significantly higher than median CE determined prior to the denture insertion (WT) or median CE coefficient for PA dentures. Moreover, median CE coefficient for PMMA dentures turned out to be significantly higher than the respective parameter for AC dentures. Median CE coefficient determined after 7 days of PA denture use did not differ

Table 1. Medians, interquartile ranges, minimum and maximum values of chewing efficiency coefficient

Denture base material, days after insertion	Chewing efficiency coefficient			
	Median	Interquartile range	Minimum	Maximum
WT	0.77	0.12	0.63	0.97
PMMA, 7 days	1.02	0.13	0.90	1.29
PMMA, 30 days	1.07	0.17	0.93	1.32
PMMA, 90 days	1.10	0.17	0.87	1.34
AC, 7 days	0.89	0.06	0.81	1.09
AC, 30 days	0.94	0.11	0.82	1.15
AC, 90 days	0.93	0.13	0.77	1.16
PA, 7 days	0.79	0.06	0.69	0.95
PA, 30 days	0.81	0.09	0.73	0.96
PA, 90 days	0.80	0.11	0.68	0.96

WT – without denture, PMMA – polymethyl methacrylate, AC – acetal, PA – polyamide.

Table 2. Comparison of chewing efficiency indices determined prior to the denture insertion and after 7 days of the PMMA, PA or AC denture wear; multiple comparisons of mean ranks for all groups conducted with the aid of a post-hoc test, α = 0.05

Denture base material, days after insertion (I) group	Denture base material, days after insertion (J) group	Significance
WT	PMMA, 7 days	<0.001
	AC, 7 days	<0.001
	PA, 7 days	1.000
PMMA, 7 days	AC, 7 days	0.005
	PA, 7 days	<0.001
AC, 7 days	PA, 7 days	<0.001

WT – without denture, PMMA – polymethyl methacrylate, AC – acetal, PA – polyamide.

Table 3. Medians, interquartile ranges, minimum and maximum values of occlusal forces

Denture base material, days after insertion	Occlusal force, N			
	Median	Interquartile range	Minimum	Maximum
PMMA	100	71	38	272
AC	81	59	29	263
PA	48	44	10	220
PMMA, 7 days	90	83	38	250
PMMA, 30 days	106	71	50	269
PMMA, 90 days	99	64	45	272
AC, 7 days	81	64	30	260
AC, 30 days	85	59	34	263
AC, 90 days	71	41	29	250
PA, 7 days	50	47	10	208
PA, 30 days	48	50	10	220
PA, 90 days	39	42	14	178

WT – without denture, PMMA – polymethyl methacrylate, AC – acetal, PA – polyamide.

significantly from median CE measured prior to the denture insertion (WT). Median values of CE coefficient for the PMMA ($P = 0.066$), AC ($P = 0.128$) and PA dentures ($P = 0.456$) did not change significantly in the course of the denture wear.

Table 4. Comparison of occlusal forces for various denture base materials; multiple comparisons of mean ranks for all groups conducted with the aid of a post-hoc test, $\alpha = 0.05$

Denture base material (I) group	Denture base material (J) group	Significance
PMMA	AC	<0.048
	PA	<0.001
AC	PA	<0.001

WT – without denture, PMMA – polymethyl methacrylate, AC – acetal, PA – polyamide

Table 5. Correlations between occlusal forces and chewing efficiency coefficient values, $\alpha = 0.05$

Denture base material, days after insertion	*N*	Spearman R-coefficient	Significance
PMMA (total)	90	–0.096	0.3760
AC (total)	90	0.012	0.914
PA (total)	90	0.108	0.311
PMMA, 7 days	30	–0.170	0.377
PMMA, 30 days	30	–0.108	0.571
PMMA, 90 days	30	–0.038	0.844
AC, 7 days	30	–0.008	0.965
AC, 30 days	30	–0.018	0.925
AC, 90 days	30	0.056	0.769
PA, 7 days	30	0.229	0.224
PA, 30 days	30	0.014	0.9391
PA, 90 days	30	0.120	0.529

Medians, interquartile ranges, minimum and maximum values of occlusal force are presented in Table 3. Denture base material exerted a significant ($P < 0.001$) effect on median occlusal force. Occlusal force for the PMMA dentures was significantly higher than occlusal forces for the AC and PA dentures. Moreover, occlusal force for the AC dentures turned out to be significantly higher than occlusal force for the PA dentures (Table 4). Denture wearing time did not exert a significant effect on occlusal forces for the PMMA ($P = 0.537$), AC ($P = 0.655$) and PA ($P = 0.05$) dentures.

No significant ($P < 0.05$) correlations were found between occlusal forces and CEcoefficient values (Table 5).

4. Discussion

Removable partial dentures are widely used in clinical practice and despite a decrease in the mean number of missing teeth observed in past decades [12], the demand for this type of dentures is still projected to grow due to an increase in human population and its longevity [5]. However, despite the high prevalence of partial edentulism [12] and widespread use of RPDs, the *in vivo* studies of chewing efficiency and occlusal forces in RPD wearers are extremely rare.

Chewing efficiency is determined by the number of missing teeth, number of opposing teeth pairs and, according to some authors, also by occlusal force[15], [23]. Paphangkorakit et al. [15] showed that CE correlates with muscle work, but not with muscle effort and masticatory effectiveness (the ratio of masticatory performance, also referred to as chewing efficiency, to muscle work). Therefore, individuals who present with good conventional CE are not necessarily effective chewers since they use more muscle work during the chewing. Sarita et al. [17] demonstrated that reduced dental arches with intact premolar regions and at least one occluding pair of molars are sufficient for satisfactory chewing ability. In contrast, the arches with 3–4 pairs of occluding premolars and the asymmetric arches result in the weakening of chewing efficiency, and the arches with 0–2 occluding premolars present with seriously reduced chewing ability, especially with respect to hard foods. The use of removable dentures results in marked improvement of chewing efficiency of hard foods in such cases [11], [21], and the degree of improvement depends on the number of natural opposing teeth pairs [21]. We showed that the use of RPD is reflected by a marked improvement of CE, expressed as a degree of food fragmentation, which is consistent with the results of previous studies [1]. CE turned out to be the highest in the case of dentures made of PMMA equipped with WWCs. The lower the modulus of elasticity of the denture base materials and clasps was, the lower the CE in their wearers. The effects of various denture base and clasp materials on the chewing efficiency in partially edentulous patients have not been analyzed to date. Osada et al. [14] conducted an *in vitro* study of various polymeric clasps; they showed that the clasps made of materials with lower modulus of elasticity produced lower retentive forces that further decreased with the time of denture wear. Arda et al. [2] demonstrated that cobalt-chromium alloy clasps required higher force for insertion and removal than the acetal clasps. These findings correspond with the results of our study, in which both the CE coefficient values and occlusal forces turned out to be the highest in the case of the most rigid WWCs, and were the lowest in the case of clasps made of the material with the lowest modulus of elasticity. However, our findings did note quivocally explain if and to what extent the use of denture base materials with lower modulus of elasticity influenced the level of CE. Nevertheless, Wadachi et al. [26] showed that the dentures made of materials with modulus of elasticity lower than that of PMMA, such as PA, can be deformed easily and as a result, a larger load is transmitted onto the mucosa under the denture. In view of these findings, it can be supposed that the use of materials with lower modulus of elasticity may result in pain due to greater mobility of the denture and its worse stabilization, both leading to a decrease in CE. This can be changed due to the use of soft denture lining materials which evenly distribute the loads transferred onto the mucosa during chewing and thus relieve the soft tissues from mechanical stress [4], which, in turn, promotes an increase in both chewing efficiency and occlusal force [10], [13], [20]. Therefore, the analysis of CE in the wearers of dentures made of the same material but equipped with clasps made of materials with different modulus of elasticity seems to be a reasonable direction of future research, as well as the analysis of CE in individuals using dentures made of materials with different modulus of elasticity equipped with clasps made of the same material.

Our observation that CE did not change significantly with the time of denture wear is consistent with the results published by Aras et al. [1]. During a one-year follow-up, these authors did not demonstrate significant changes in the chewing efficiency of RPD wearers subjected to a chewing test with standard two-colored wax cubes. None of the previous studies analyzed the CE in RPD wearers during a longer, several-year follow-up; also the time of observation in our study was limited in order to minimize the effects of changes in the alveolar ridge [24], decrease in the retentive force with the time of denture wear caused by tribological deterioration of the clasps [14] or alterations in the number of functional teeth [25] on CE.

We showed that occlusal forces decreased with the modulus of elasticity of the denture base materials and remained unchanged throughout the follow-up period. Occlusal forces for PMMA RPDs were similar to those reported by Aras et al. [1]; however, these authors used different method of measurement and did not analyze the effect of the time of denture wear on occlusal forces. Although a longer study, lasting for a few years, would likely produce different results due to time-related changes in the material properties and status of the tissues, these changes might be partially compensated while the patients got accustomed to their dentures; this issue needs to be addressed during future research.

The lack of significant correlation between the occlusal force and CE coefficient values can be explained by the fact that the former is measured as the maximum vertical force; however, it should be remembered that food is also pounded during chewing, which points to more important role of the denture retention, stabilization and quality of denture-supporting tissues in this process [25], [30]. For example, complete denture wearers with a low residual ridge exhibited occlusal force comparable to those with high residual ridges, but showed lower chewing efficiency [7]. This may be associated with the phenomenon demonstrated previously during the FEM studies, namely a marked decrease in the area of mechanical stress transmission onto mucosal membrane resulting from the relatively greater influence of lateral masticatory forces than the vertical force, as well as from an increase in sliding associated with the destabilization of a complete denture and over denture retained with one or two implants [31]. Similar phenomenon may also take place in the case of RPDs, and its extent is likely determined by the rigidity of the clasps and denture material. However, this hypothesis needs to be verified during further simulation studies, laboratory and clinical research involving a larger group of patients. Also the use of standardized test foods of various types seems to be justified, as the results of chewing tests with standard two-colored wax cubes point to a correlation between maximum bite force and chewing efficiency [25].

5. Conclusions

This study showed that denture base material exerts significant effects on chewing efficiency and occlusal forces. The use of dentures and clasps made of materials with lower modulus of elasticity was associated with lower chewing efficiency and lower occlusal forces. No significant correlations were demonstrated between the occlusal forces and CE coefficient values for prostheses and clasps made of different materials.

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