



Development trends of mucous-borne dentures in the aspect of elastomers applications

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ABSTRACT

Purpose: The aim of this study is to foresee the influence of elastomers on the development of mucous-borne dentures in the aspect of bio-compatible use of prosthetic foundation tissue load bearing capacity.

Design/methodology/approach: Multi-criteria comparative analysis based on the dendrological matrix of attractiveness and potential was used for the studies of denture solution and materials. There were differentiated seven groups of conventional dentures without an implantological stabilisation - the so-called hard dentures (CD) and those with a soft relining (CD-P), stabilized on one implant (SID) or on two implants (TID), that were differentiated as far as the denture attachment to implant was concerned. The first group was marked as „hard” (K) due to the used materials and inconsiderable lateral compliance. The elastomeric attachments (S) constituted the second group of attachments.

Findings: In case of conventional dentures a significant influence of the relining on attractiveness was observed. In case of dentures retained on elastomeric attachments – they decided not only on the attractiveness, but they have also significantly increased dentures' potential.

Research limitations/implications: Throughout the studies the variation of denture bearing structure materials were not taken into account, based on the assumption that acrylates are the most commonly used.

Practical implications: The similar level of attractiveness of dentures retained on implants significantly varying as far as their construction is concerned shows that the focus should be mainly put on material design of elastomers' wearing characteristics.

Originality/value: Multi-criteria heuristic analysis proved to be an effective tool for examination of dentures in the aspect evaluation of dentures material and construction that show perspectives of the broadest use due to exploitation of the tissue bearing capability.

Keywords: Biomaterials; Complete Denture; Heuristic forecasting; Denture attachment

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MATERIALS

1. Introduction

The development of prosthetics is inseparably connected with the development of the science of materials and the resulting new denture construction possibilities. Edentulism afflicts more than 70% of elderly people in a part of European countries, whereas in the North America it afflicts 25-30% [1] of that part of the population.

The most affordable “mucous-borne” dentures are also the most commonly used in the treatment of the edentulism. It is due to the use of the mucous membrane support. Most of the characteristics determining the selection and formation of dentures functionality has been already defined between the years 1950-1960, when the prosthetics was developed by the use of polymethacrylates [2]. The development and improvement of the materials and manufacturing technology [3,4], as well as the occlusal contact registering methods [5] lasts for almost a hundred of years. Unfortunately, a significant improvement of the successful treatment by means of the mucous-borne dentures (CD) without the implantological stabilisation has not been achieved yet. The basic root-cause of failures are the functional characteristics described as functional insufficiency. It is defined as a total resultant of all biological, technical and material factors of the system [6,7]. The chewing insufficiency and insufficient denture retention on the foundation during oral cavity function are usually related to the lower denture, which is dictated by the anatomical aspects. Because of the problems with dentures retention that the patients encounter, they commonly use the advertised adhesives, which seem to have some side effects. The stabilisation of the lower denture by means of attaching it to two implants (two-implant retained dentures: TIDs) is an effective method of improving the functional efficiency. Experiments conducted during the past two decades showed that this type of dentures however, does not have the required reliability. Although, due to the low risk of implant loss from the front section of the mandibular bone they are treated as a standard solution in case of the edentulism of the mandible [8]. The cost is still the basic factor influencing the choice of a given treatment method. The example here can be the comfortable and aesthetic implant-dentures fixed on a larger number of implants that are affordable only for the most wealthy patients. The realisation cost of the mucous-borne conventional dentures is incomparably lower. The direct wearing cost is not too high either. Although, it has to be mentioned that this type of dentures solution is socially expensive. A significant part of the wearers is early professionally and socially excluded. Hence, similarly to the classic model of a technical object, also in case of dentures a compromise solution might be searched for.

The aspects of the denture material design in relation to a biocompatible use of the tissue bearing capabilities are especially important in case of the single-implant retained dentures (SIDs). Reduction of the number of implants to the single implant creates an additional possibility to reduce the costs of the implantological treatment.

The aim of this study was to foresee, on the basis of the current status the influence of elastomer use on the development of mucous-borne dentures in the aspect of the biocompatible use of the bearing capabilities of the denture foundation tissue. The study was conducted by means of a comparative analysis, whereas the material was selected on the basis of the branch literature.

2. Methods

2.1. Indices of the functional efficiency

Dentures functional characteristics depend on biological and technical factors [6]. These factors can be also divided into material and mechanical ones. Among the purely mechanical factors there are muscle efficiency and the kinematics of the mandible resulting from the anatomical construction of the masticatory organ (including the temporo-mandibular joints). The occlusal force and chewing efficiency in case of patients with natural teeth belong to the mechanical factors that have a weak correlation to occlusal surfaces geometrical characteristics [9]. In case of the material interferences, such as prosthetic restoration, especially those functioning with the support of the mucous membrane, the occlusal force and chewing efficiency no longer depend on the muscles potential efficiency. Both, the shape of the resistance surface defined by slopes of edentulous processes and the shape of the occlusal surface belong to the mechanical factors for the mucous-borne dentures. First of the individual foundation factors does not depend on external interference. The second factor depends on the shape of the artificial teeth and their position on the dental arc in relation to the opposite teeth and, at the first place it depends on the individual neuronal-muscle coordination that decreases along with age in case of patients afflicted with edentulism. Hence, in case of an edentulism that afflicts especially the elderly people, a successful treatment depends, to a significant extent, on factors related to materials.

The symptoms of an undesirable reaction of complete mucous-borne dentures on tissue are:

- mucous membrane injuries,
- pain discomfort,
- alveolar processes atrophy caused by overloading,
- lack of sufficient functional stabilisation,
- effects of implants and attachments overloading, including osseous atrophy around the implant neck.

Functional efficiency evaluation on the prosthetic restoration requires determination to what extent the analyzed solution restores the lost oral cavity functions and if the solution is free from undesirable reactions on tissue, which equals to a biocompatible use of tissue load-bearing capability.

2.2. Dentures selection for investigations and the development evaluation method

The research method i.e. multi-criteria comparative analysis based on the procedural benchmarking technique enables transformation of the hidden or inaccurate knowledge available only to experts into an open quantitative knowledge that makes it possible to conduct the multi-criteria class evaluation using a range scale [10-15]. Solutions of the mucous-borne dentures were divided into 5 groups, differentiated by the used materials and / or the number of implants. In the first place there were distinguished conventional acrylic „hard” dentures (CD) and then the conventional dentures relined with soft elastomer material layers (CD-P). The soft layers relining hard denture saddles constitute a method of increasing CD wearing comfort in case of pain sensations and mucous membrane injuries. The influence of the

soft relining on the improvement of denture wearing comfort is shown on Fig. 1 [16-19]. Soft relining for the long-term applications are usually made of silicones. Acrylates relatively quickly lose the plasticizers in the oral cavity environment, which results in a loss of their elasticity. Hence, for the long-term applications silicones are preferred.

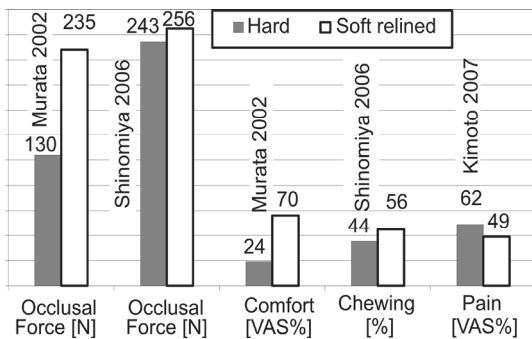


Fig. 1. The influence of the denture relining on the functional efficiency [16-19]

The remaining groups were constituted by the dentures retained on a single implant (SID) and those retained on two implants (TID). Generally, the comparison of functional efficiency between CD and TID was shown on Fig. 2 [20-23]. The SID solutions are not worse than TID [24]. The most important component of the implant-retained denture is the way, in which they are attached to the implants (attachment). An attachment creates a problematic constructional constraint. Material problems related to the attachments wear and failure, as well as the osseous atrophy resulting from overloading in the zone of the implant neck show that the choice of materials for attachments is incorrect. In case of dentures retained on implants there always arises a fundamental question about the influence of attachments

characteristics on the distribution of mastication forces. Examinations that attempt to answer that question are numerous, although most of them are not free from methodological errors [25-32]. In few studies of implant-retained dentures there are mapped oblique occlusal forces [33-36]. Fig. 3 shows the most crucial influence of the oblique mastication force on the most dangerous lateral implant loads (the torque has to be divided by the moment arm, unfortunately the authors did not give the arm, which should be app. 5-7 mm). In case of the applied vertical force, the mucous membrane foundation is evenly loaded. Hence, forces on the implant are insignificant. In practice, the lack of possible denture settlement oblique to the implant axis is the root cause of the overloading effects. Most of the studies are focused on the wear and failure observations, on the basis of which it is very hard to formulate general conclusions regarding material design. Exceptional are the studies, in which there is proposed use of silicone materials [37,38] for attachments, for which the loading of the denture stabilizing implants is much lower [39,40] (Fig. 4). The primary clinical examinations show significant effectiveness of silicone attachments in TID [41].

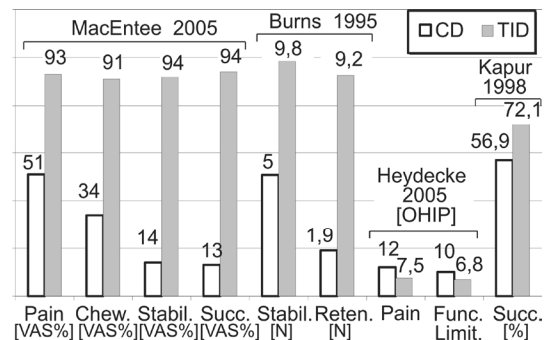


Fig. 2. Influence of CD stabilisation with two implants TID on factors of functional efficiency [20-23]

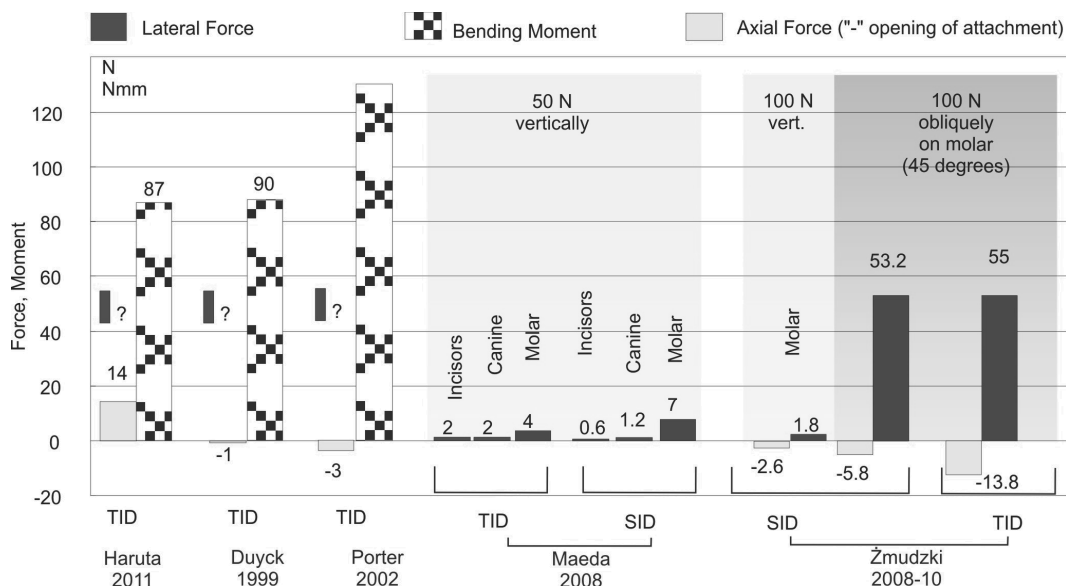


Fig. 3. Documentation of implants and attachments loading. TID - two implants [25,27,28,30]; SID - single implant [30,35,36]

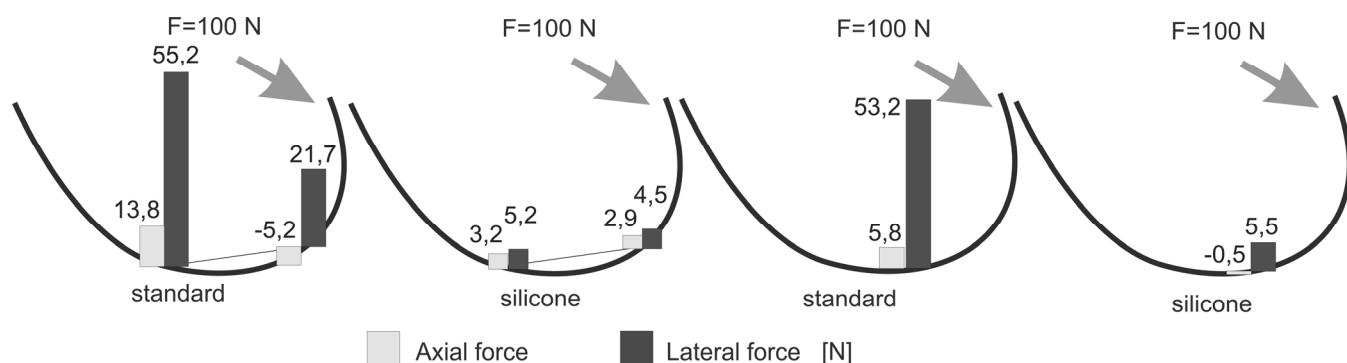


Fig. 4. Implants loading comparison for standard attachments and silicone attachments during the transmission of 100 N oblique mastication force in TID [39] and SID [35]

Dentures were divided into groups differentiated by the type of used attachments, on the basis of the conducted review of the current implant-retained dentures status. The standard commercial attachments (K) were assigned to the first group. These attachments, due to the used materials and the lack of lateral resilience are described as „hard”. The second group contained elastomer attachments (S) allowing for denture settlement in directions oblique to implant axis. Solutions, in which implants are joined together by a metal bar (TID-D), were also included in the analysis.

The detailed criteria of attractiveness and potential evaluation adopted during the dendrological matrix creation for particular dentures groups are shown in Table 1. Weight/(importance) was assigned to each criterion, and weighted values were calculated for particular criteria. After summing together, the values created a basis for dentures solutions comparative analysis - Table 2. Among the potential evaluation criteria - “prosthetic treatment” (criterion 1) was assigned to weight 0.5, although in practice this criterion seems to be even more important. “Foundation conditions” - criterion 2 covers the level of the foreseen clinical success for a given type of dentures in relation to the individual conditions resulting from the atrophied alveolar processes. “Dentures reliability” - criterion 3 evaluates solutions’ durability. A significant weight was assigned to criterion 4 i.e. “technology”, which covers activities and materials necessary during prosthetic treatment. This criterion evaluates given solutions by the denture manufacturer in the aspect of denture realisation complexity. Criterion 5 - evaluates denture maintenance and elimination of inefficiency.

Among the attractiveness criteria the highest weight was assigned to factors perceived as the most important for treatment effects, such as: comfort related to lack of injuries and pain sensations (criterion 1), then those related to the awaited effects of denture stabilisation on the foundation (criterion 3). Treatment interference was also taken into consideration (criterion 2), which in practice is very important, as most of the patients fear implantation, especially in case of an extensive

surgical interference. A lower weight was assigned to the chewing efficiency (criterion 4) based on the assumption that a patient afflicted by edentulism is not able to evaluate the denture in this respect at the stage of treatment planning. Criterion no. 5 evaluates the solution in the aspect of patients expectations related to the denture-to-foundation retention technology. Results of this analysis were shown in a graphic form in Fig. 5.

Table 1. Potential and attractiveness evaluation criteria for particular dentures groups assessed in the aspect of a broad use

	Potential	Weight
Criterion 1	Cost	0.50
Criterion 2	Foundation conditions	0.15
Criterion 3	Reliability	0.10
Criterion 4	Material and technology	0.20
Criterion 5	Susceptibility of maintenance	0.05
	Attractiveness	Weight
Criterion 1	Wearing comfort w/o injuries or pain sensation	0.30
Criterion 2	Treatment interference	0.15
Criterion 3	Stabilisation	0.20
Criterion 4	Chewing efficiency	0.15
Criterion 5	Denture-to-foundation retention technology	0.20

Table 2.
Potential and attractiveness evaluation criteria for groups of dentures assessed in the aspect of the most broaden application

Signature	Group of Dentures	Abbreviation	Potential					Attractiveness						
			Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Weighted average	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Weighted average
D	Conventional „hard”	CD	5.00	0.30	1.00	2.00	0.50	8.80	0.30	1.50	0.20	0.15	0.20	2.35
E	Conventional with soft lining layer	CD-P	4.50	1.50	0.90	1.80	0.50	9.20	1.20	1.50	0.40	0.45	0.60	4.15
B	„Hard” on 2 implants	TID-K	1.00	0.90	0.20	0.60	0.05	2.75	2.40	0.75	1.20	1.50	1.00	6.85
A	„Hard” on metal bar	TID-D	0.50	1.05	0.20	0.60	0.05	2.40	2.40	0.75	1.20	1.50	1.00	6.85
C	„Hard” on 1 implant	SID-K	1.50	1.05	0.10	0.80	0.10	3.55	2.40	1.20	1.20	1.50	0.60	6.90
F	Elastic on 2 implants	TID-S	2.50	1.20	0.90	1.40	0.50	6.50	2.40	0.75	2.00	1.50	2.00	8.65
G	Elastic on 1 implant	SID-S	3.50	1.35	0.90	1.60	0.50	7.85	2.40	1.20	1.80	1.50	1.80	8.70

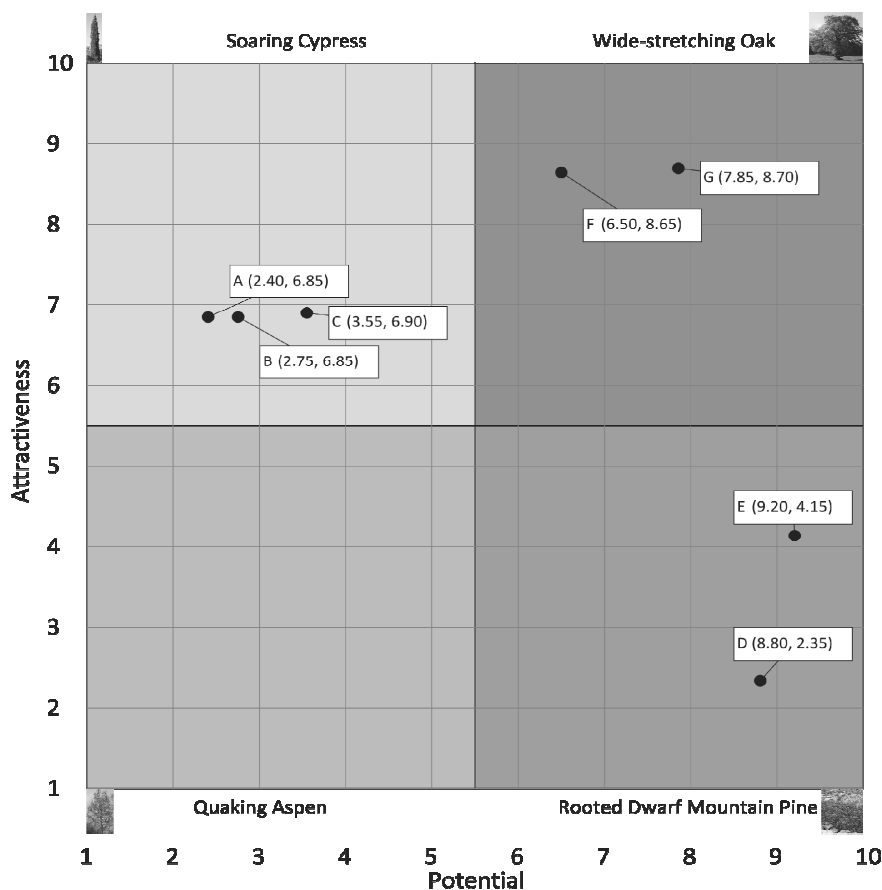


Fig. 5. Graphical presentation of multi-criteria analysis results

3. Description of the obtained results

The conducted multi-criteria analysis showed that the best perspectives for a broad use are connected with the elastomers. Especially, when they are used for attachments that retain denture on a single implant. It was observed that in case of conventional dentures relining has a significant influence on the increase of the dentures attractiveness. For dentures retained on implants, elastomer attachments caused not only an increase of the attractiveness, but they also remarkably increased the dentures potential. A similar level of attractiveness for dentures retained on implants that have significantly different structure resulting from the number of retaining implants or a metal bar clearly shows that the focus should be, in the first place put on the material aspect, especially material design of elastomer wearing characteristics.

The basic functional characteristic of the soft elastomer relining is the ability to relieve loading in mucous membrane tissue. Patients better evaluate wearing comfort of the relined dentures - [42,43]. Generally, there was observed a decreased frequency of injuries [42], although it is not a rule. Relining increases chewing efficiency [44]. Changes of the maximal occlusal force or the muscle activity are less important [43,45,46]. In case of the conventional dentures it is proven that [42] relining should be treated as a standard in prosthetic treatment. There were pointed out [42] numerous advantages resulting from a better adaptation to the soft relining dentures, both medical and economical, as these dentures do not require corrections that are so often necessary in case of CD.

Although, in practice, there are still missing the material design criteria for the relining materials, one of the unsolved issues is the choice of material elasticity characteristics in the aspect of the expected effect of the mucous membrane loading. Elasticity of all plasticized acrylates, polysiloxanes and their copolymers can be controlled by the level of cross-linking, as well as the plastic material content including nano-filler additives. In the evaluation of wearing characteristics of the relining materials there are used quite complex visco-elastic models describing strain-stress characteristics in a similar way to the mucous membrane tissue [43]. Nevertheless, treating the relining as an isolator absorbing vibrations and defining dynamical energy loss characteristic in the material did not lead to the solution of the problem of determining favorable material characteristics. On the basis of evaluated hysteresis loop, it was defined that strain recovery during single chewing cycle is an advantageous characteristic [43,47,48]. The advantages resulting from the material ability to cumulate and to diffuse energy in a single chewing cycle can be observed even without the complex studies, which at the end do not bring to much light to the issue of foreseeing relining layers characteristics in the aspect of the denture functional efficiency.

Few prevailing attempts to evaluate the characteristics of the soft liners on the basis of examinations in simulated conditions of exploitation loadings have to be perceived as partially successful. The in-vitro [49] examinations were conducted on a remarkably simplified model, geometry of which only to some extent reflects the real object, whereas it is hard to transfer the results of the FEM analysis conducted in the study [50] to the reality, as simulations are done on flat models. A better mapping of the real object was achieved in studies on spatial models [51-53]. On the

basis of the defined criteria of mucous membrane stress state evaluation, which are in accordance with the knowledge used in bed sore prevention, observed are both advantageous and disadvantageous influence of the relining. A distortional deformation in deep tissue and shear at the sides of the alveolar ridge increase together with the increased resilience of the relining layer. In these areas it results in an increased risk of the so-called deep sore, developing subsurface from the bone towards the surface of the soft tissue.

Dentists are not very eager to use relining layers due to the de-bonding of the denture basis in the warranty period. Bond strength on the level of 440 kPa is perceived as sufficient [54]. Although, the ISO standard [55] gives higher requirements related to the bond strength. The minimum required bond strength in case of soft and super-soft materials is, as provided by the norm respectively 1 MPa and 0.5 MPa. The issue of silicones bond to the denture basis was to a great extent solved by an appropriate choice of primers and following the rules of manufacturing the relining layer [56]. Achieving a good bond strength requires however the choice of material that is appropriate for the individual conditions and cooperation with technician as adherence of hot cured materials is usually higher than that of those polymerized directly in oral cavity. The relining materials are not willingly used due to the remarkable susceptibility to fungal infections either. Resistance of the relining materials to fungal and bacterial colonisation is significantly lower than this of the denture basis due to the excessive porosity and water sorption. The inner surface of the relining remains unavailable from the outside for the hygienic agents. The longer the use is, the more it becomes a habitat for bacteria that infect the mucous membrane. There have been done some developments in this respect recently thanks to the used binary silicones with silver nano-particles [57]. The material issues related to prevention against the loss of relining exploitation characteristics in the environment of the oral cavity are discussed in paper [58].

Currently, the evaluation of functional characteristics of the relining materials becomes especially important due to the fact that the implant retained dentures are more and more popular. For these dentures there are observed numerous injuries of the mucous membrane. Relining is here used as standard preventive measures [59-61].

4. Summary

Multi-criteria comparative analysis based on the dendrological matrix of attractiveness and potential was used for the studies of denture solution and materials. There were differentiated seven groups of conventional dentures without an implantological stabilisation - the so-called hard dentures (CD) and those with a soft relining (CD-P), stabilized on one implant (SID) or on two implants (TID), that were differentiated as far as the denture attachment to implant was concerned. The first group was marked as „hard” (K) due to the used materials and inconsiderable lateral compliance. The elastomeric attachments (S) constituted the second group of attachments. In case of conventional dentures a significant influence of the relining on attractiveness was observed. In case of dentures retained on elastomeric attachments - they decided not only on the

attractiveness, but they have also significantly increased dentures' potential. The similar level of attractiveness of dentures retained on implants significantly varying as far as their construction is concerned shows that the focus should be mainly put on material design of elastomers' wearing characteristics.

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