

IMPLICATIONS OF CLINICAL-BIOLOGICAL FACTORS IN THE TREATMENT PLANNING OF PATIENTS WITH EXTENSIVE PARTIAL EDENTULISM: TWO-STEP CLUSTER ANALYSIS

Siminiuc Petruța¹, Agop-Forna Doriană^{*2,3}, Dascălu Cristina², Forna Norina^{2,3}

“Grigore T. Popa” University of Medicine and Pharmacy Iasi, Romania

1. Ph.D. Student

2. Faculty of Dental Medicine

3. Romanian Academy of Scientists (AOSR)

*Corresponding author. E-mail: dr.doriana.forna@gmail.com

Abstract

Aim of this study was to evaluate the differences and similarities in the characterization of systemic and clinical-biological factors in patients with extensive partial edentulism as well as the influence of clinical-biologic factors in the planning of prosthetic treatment. **Materials and method.** Clustering analysis was conducted on 194 patients (mean age 56.46 years $\pm$ 0.738 years) with extensive partial edentulism. The clinical-biological indices of systemic status and prosthetic field (dental support; periodontal support; bone support; mucous support; occlusion support; mandibulo-cranial support) were evaluated both initially and after the completion of the pre- and pro-prosthetic stages. Two-Step Clustering method related the clinical-biological indices to the fixed and removable prosthetic solutions. **Results.** According to clinical-biological indices, patients were grouped in 4 clusters (pre-treatment) and 3 clusters (secondary stage). Following pre- and pro-prosthetic stage, demographic differences emerged alongside shifts in prosthetic preferences, with notable patterns such as Cluster 1 favoring metal framework partial dentures with clasps and Cluster 2 increasing the use of composite dentures with rigid or semi-rigid RPD frameworks. **Conclusion.** The dynamic relationship between cluster profiles and prosthetic treatment choices is influenced by demographic and clinical-biologic factors across treatment stages.

Key words: clustering, extensive partial edentulism, pre-prosthetic, pro-prosthetic, rehabilitation

INTRODUCTION

Clustering analysis is a technique of data mining focused on extracting valuable insights from extensive datasets, to uncover previously unrecognized relationships within datasets [1]. Clustering focuses on identifying groups within a set of unlabeled data. It partitions data into distinct groups, ensuring that objects within the same cluster exhibit high similarity, while being distinctly different from objects in other clusters [1]. It is particularly valuable in exploratory and evaluative data analysis, where researchers aim to uncover hidden features without prior knowledge of the dataset [2]. In medicine and dentistry clustering analysis has indications in early disease detection and prediction of disease, providing fast, cost-effective, reliable

medical solutions for patients, identifying treatment methods, and even structuring effective healthcare policies [3, 4]. The selection of appropriate clustering techniques and algorithms depends on a clear understanding of the data's structure, the type of analysis required, and the dataset's size [4]. The Two-Step Clustering method is a tool that enables the identification of patterns and relevant factors influencing the quality of planning and the success of treatment. It facilitates informed and personalized medical decision-making, ensuring a more efficient prosthetic rehabilitation process. Advantages of the Two-Step Clustering Method are as follows [5, 6]:

-Handling large volumes of mixed data. Two-Step Clustering can simultaneously

analyze numerical variables (e.g., quantitative values of clinical-biological indices) and categorical variables (e.g., subjective classifications, clinical stages).

-Identifying relevant subgroups. The algorithm allows for the identification of homogeneous patient groups based on similarities in index values, revealing relevant patterns (e.g., changes of clinical-biological indices after pre- and pro-prosthetic stages) with significant clinical implications.

-Automation and objectivity in the process. Two-Step Clustering automatically selects the optimal number of clusters, minimizing the risk of subjectivity in interpretation.

-Identifying important predictors. The algorithm provides insights into the importance of each clinical-biological index in defining clusters. For instance, in evaluating the prosthetic field, it can identify critical factors for optimizing treatment planning, such as mucosal and bone tissues condition or changes in cranio-mandibular relationships.

-Flexibility in Longitudinal Analysis. The method allows for the characterization of patients within each cluster and tracks how patients from a given cluster evolve during dental treatments (e.g., pre- and post-prosthetic procedures), offering a dynamic perspective on the oral cavity rehabilitation process.

Extensive partial edentulism complications (dental migrations, extrusions, facial and temporomandibular disorders changes) led to characterization of edentulism as a significant public health concern [7, 8]. Clustering technique was used only in a few studies related to edentulous patients either to evaluate oral cavity status in epidemiological studies related to oral conditions or to evaluate the

factors influencing edentulism. One research group conducted an epidemiological study aiming to investigate the prevalence of edentulism among adults in relation to gender, age, and education level, aiming to use baseline data to promote oral health [8]. The clustering effects of carious lesions, apical lesions, periodontal bone loss, and periodontal pocketing, assessed in clinical or radiographic examinations were determined in a sample of 175 patients. The research group reported substantial clustering effects between dental conditions and highlighted misleading estimates of epidemiological studies if clustering is present [9]. A cross-sectional study was conducted in a probabilistic, multi-stage cluster sampling framework, analyzing data of chronic diseases, mental disorders and edentulism. The research group concluded that clustering analysis leads to conclusions that are misaligned with previous reports, highlighting the need for longitudinal studies to test causal and temporal relationships between edentulism with chronic diseases [10]. One epidemiologic research regarding edentulous patients used the proportional stratified cluster sampling method, aiming to evaluate partial and complete tooth loss related to demographic factors and oral health behaviors among elderly population [11].

AIM OF STUDY

The study aimed to evaluate, using the Two-Step Clustering method, the differences and similarities in the characterization of clinical-biological factors in patients with extensive partial edentulism as well as the influence of clinical-biologic factors in the planning of prosthetic treatment.

MATERIALS AND METHOD

1. Study design

The research was conducted on study group of 194 patients (age: mean age 56.46 years $\pm$ 0.738 years, range 41-78 years; gender: 105 men, 89 women) with extensive partial edentulism addressing for fixed and removable prosthetic treatment in Clinical Base of Faculty of Dental Medicine, UMF "Grigore T. Popa" Iasi.

The prosthetic field status was assessed initially and after completion of the pre- and post-prosthetic stages by using qualitative clinical-biological indices:

- General status (GSI);
- Dental support (DSI);
- Periodontal support (PSI);
- Bone support (BSI);
- Mucous support (MSI);
- Occlusion support (OSI);
- Mandibulo-cranial support (MCSI).

The clinical-biological indices were measured using the clinical scoring scale developed within the Department of Extensive Partial Edentulism and Removable Restorations, Faculty of Dental Medicine, UMF "Grigore T. Popa" Iași:

- 1 (low),

- 2 (medium),
- 3 (good),
- 4 (very good).

Prosthetic field status was evaluated before and after pre- and pro-prosthetic stage, analyzing also the relationships between the distribution of clinical-biological indices within clusters and selected prosthetic treatment solutions. The status of the prosthetic field was evaluated during the pre-treatment stage (primary indices) and upon completion of the pre- and post-prosthetic stages (secondary indices). The assessment of the clinical-biological indices was performed during the initial stage outlines the therapeutic project framework, which serves as the basis for selecting non-specific and specific prosthetic field preparation procedures.

2. Clustering analysis

Stages of Clustering method (fig.1) are as follows: 1. extraction of data from database; 2. pre-process data to select appropriate features; 3. Configure to determine parameters to get optimal performance; 4. Apply clustering algorithm; 5. Visualization and interpretation of results.

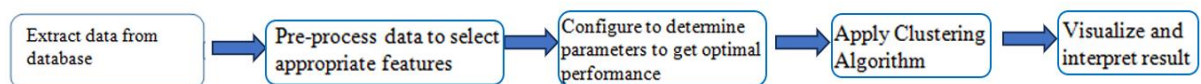


Fig.1. Stages of Clustering Method
(adapted after [12])

Working principles in Two-Clustering technique [5, 6]:

- Input characteristics:
 - Mixed variables: Two-Step Clustering can handle both continuous (numerical) and categorical variables. In this

context, the variables are the seven clinical-biological indices.

- Initial assessment: Objects are divided into subgroups using a distance-based model (for numerical

variables) or similarity-based model (for categorical variables). This step reduces the complexity of large datasets.

- Two-Step Algorithm:
 - Initial clustering: Objects are divided into subgroups using a distance-based model (for numerical variables) or similarity-based model (for categorical variables). This step reduces the complexity of large datasets.
 - Clusters modeling: The log-likelihood method is applied to refine and optimize the initially identified groups, ensuring a balance between intra-group cohesion and inter-group separability.
- Determining the optimal number of clusters:
 - Algorithm can determine optimal number of clusters based on criteria such as Schwarz Bayesian Criterion.
- Cluster interpretation:
 - Each cluster groups patients with similar values for the analyzed clinical-biological indicators. Evaluating the importance of variables in defining the clusters provides insights into significant predictors.
- Cluster quality:
 - Quality is assessed by measuring cohesion (how

similar the objects within a cluster are) and separability (the differences between clusters). In the study, the described clusters are of satisfactory quality.

Two-Step Clustering method related the clinical-biological indices to the fixed implant-supported dentures and removable prosthetic solutions (acrylic dentures, composite dentures with rigid and semi-rigid FPD framework, flexible dentures, implant-supported removable dentures).

RESULTS

Figures 2-3 exposes clusters comparison for initial evaluation scores and secondary evaluation scores of the clinical-biological indices of patients with partial extensive edentulism. In the investigated patients' cohort, the primary predictor is the initial evaluation score of cranio-mandibular relationships, while the minor predictor is the general health score of the patients. We applied the Two-Step Clustering classification technique to the seven initially evaluated scores to identify potential similarities in their progression within the patient sample. The automatic classification generated four clusters, each with satisfactory quality in terms of cohesion and separability: Cluster 1 (22 cases), Cluster 2 (43 cases), Cluster 3 (92 cases), and Cluster 4 (37 cases). The most significant predictor in defining the identified clusters was the initial evaluation score of cranio-mandibular relationships, while the least significant predictor was the general health score of the patients.

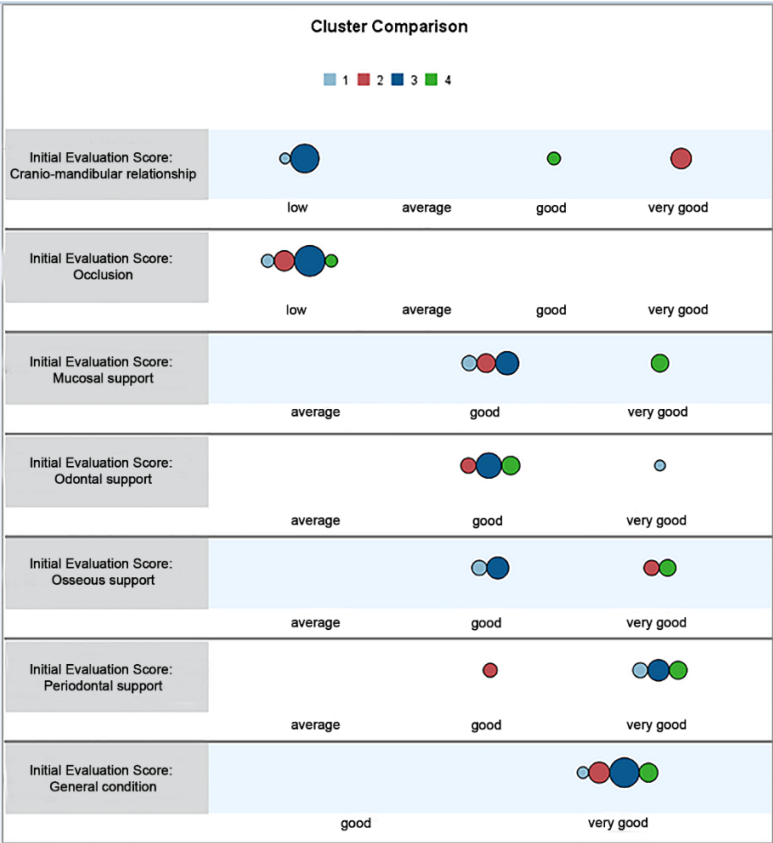


Fig.2. Cluster comparison- initial evaluation scores



Fig.3. Cluster comparison- secondary evaluation scores

Clusters grouped according to the initial evaluation scores are exposed in fig.2. The first cluster, with 22 cases, encompasses extremes: half of the patients have a very high score for mandibular-cranial relationships, while the other half have a low score in this area. Other characteristics of patients in this cluster include the fact that 3/4 of them have a low occlusion score (72.7%). The second cluster, with 43 patients, is characterized by the fact that almost all have a very high score for mandibular-cranial relationships (95.3%). Bone and mucosal support is good or very good in over 90% of cases, and periodontal support is good or very good in 76.8%. Dental support is good in 69.8% of cases. The third cluster, the largest, includes 92 patients, of whom 87% have a low score for mandibular-cranial relationships. All patients in this cluster also have a low occlusion score, although bone support is good or very good in over 3/4 of cases (78.3%), as is mucosal support (76.1% of cases). Periodontal support is good or very good in almost all patients (96.7%). Dental support is good in 68.5% of patients and moderate in nearly 1/3 (29.3%). The fourth cluster includes 37 patients, 3/4 of whom have good or very good scores for mandibular-cranial relationships (75.6%), while the rest have average or low scores. Occlusion scores are improved compared to patients in the other clusters, with 59.4% having average or good evaluations. Again, bone and mucosal support scores are good or very good in all patients, and periodontal support scores are very good in the vast majority (83.8% of cases).

Clusters grouped according to secondary clinical-biological indices are exposed in fig.3. The first cluster includes 80 patients, making it the largest of the

three recorded clusters. The patients in this group have an excellent bone support score in almost all cases (96.3%). The occlusion score ranges from low to very good, while the mandibular-cranial relationship score is very good for the vast majority of patients (70.0%). Additionally, the mucosal support score is good or very good for all patients, as are the scores for periodontal, dental, and general health support. The overall score is very good for half of the patients (51.2%) and good for the remaining 48%. The second cluster includes 50 patients, where bone support is good in most cases (72.0%) and very good for the rest. All patients in this category have a low occlusion score, and 3/4 of them (70.0%) also have a low score for mandibular-cranial relationships. The mucosal support score is good for all patients, and the periodontal support score is very good for 88.0% of them. The dental support score is moderate for 30.0% of patients, good for 54.0%, while 14% of patients in this cluster have a general health score that is good rather than very good. Consequently, none of the patients in this cluster have a very good overall score; it is good for 3/4 of them (72.0%) and moderate for the remaining 28%. The third cluster includes 64 patients, for whom bone support is also good in most cases (73.4%), though it is moderate for the rest. The vast majority of patients in this group (92.2%) have a good or very good occlusion score, as well as a good or very good mandibular-cranial relationship score (87.5%). Similarly, the mucosal, periodontal, and dental support scores are good or very good for nearly all patients, as is the general health score. The overall score is very good for 3/4 of the patients in this cluster (73.4%) and good for the rest.

The comparative study of therapeutic options (Table 2) for each of the demographic characteristics (Table 1) and identified clusters are presented below.

Table 1. Initial stage patients' clusters related to socio-demographic features

		Two-Step Cluster Number								Pearson Chi-squared test
		1		2		3		4		
		N	%	N	%	N	%	N	%	
Gender	Male	8	36.4%	28	65.1%	48	52.2%	21	56.8%	Chi2 = 5.132
	Female	14	63.6%	15	34.9%	44	47.8%	16	43.2%	p = 0.162
Age group	40-60 yrs.	11	50.0%	31	72.1%	54	58.7%	28	75.7%	Chi2 = 6.400
	>60 yrs.	11	50.0%	12	27.9%	38	41.3%	9	24.3%	p = 0.094
Environment	urban	20	90.9%	28	65.1%	69	75.0%	31	83.8%	Chi2 = 6.800
	rural	2	9.1%	15	34.9%	23	25.0%	6	16.2%	p = 0.079
Total		22	100.0%	43	100.0%	92	100.0%	37	100.0%	

In Table 2 clusters of patients (initial stage) are exposed in relation to the distribution of the selected prosthetic treatment solutions. While there were no statistically significant differences in the demographic characteristics of patients across the four clusters (Table 1), significant differences were observed in the chosen prosthetic therapy. The highest percentage of composite prostheses with rigid RPD frameworks was applied to patients in the first cluster (18.2% of them), as well as the highest percentage of flexible dentures (54.5%). For patients in the second cluster, the majority of cases were treated by metal framework partial dentures with acrylic saddles and clasps (51.2%) or fixed implant-prosthetic rehabilitation (27.9%). Patients in the third cluster received all types of treatment solutions, with metal framework partial dentures with acrylic saddles and clasps being the most common (38.0% of cases). In contrast, patients in the

fourth cluster most frequently were treated with metal framework partial dentures with acrylic saddles and clasps (35.1% of cases), flexible dentures (24.3%), or fixed implant-prosthetic rehabilitation (24.3%). The comparative study of demographic characteristics for each of the identified clusters after the completion of the pre- and pro-prosthetic stages (secondary stage) is presented in Table 3. Significant differences between genders are observed, with the first cluster predominantly grouping male patients (66.3%), while the other two clusters exhibit a balanced gender distribution, with a slight predominance of female patients. Additionally, the first cluster includes the highest percentage of patients aged 40 to 60 years (77.5%), who are also predominantly represented, albeit to a lesser extent, in the third cluster (60.9%). In the second cluster, the age group distribution is balanced, although

older patients slightly predominate,
comprising 54.0% of the cases.

Table 2. Initial stage patients' clusters related to prosthetic therapy

		Two-Step Cluster Number								Pearson Chi-squared test
		1		2		3		4		
		N	%	N	%	N	%	N	%	
Prosthetic therapy	Prosthetic Acrylic dentures					2	2.2%			Chi2 = 46.312
	Composite dentures with rigid FPD framework	4	18.2%	6	14.0%	13	14.1%	3	8.1%	p < 0.001**
	Composite dentures with semi-rigid FPD framework					9	9.8%			
	Flexible dentures	12	54.5%	3	7.0%	12	13.0%	9	24.3%	
	Metal framework partial dentures with acrylic saddles and clasps	3	13.6%	22	51.2%	35	38.0%	13	35.1%	
	Fixed implant-prosthetic rehabilitation	3	13.6%	12	27.9%	18	19.6%	9	24.3%	
	Implant-supported removable prosthetic rehabilitation					3	3.3%	3	8.1%	
Total		22	100.0%	43	100.0%	92	100.0%	37	100.0%	

Table 3. Secondary stage patients' clusters related to socio-demographic features

		TwoStep Cluster Number						Pearson Chi-squared test
		1		2		3		
		N	%	N	%	N	%	
Gender	masculin	53	66.3%	22	44.0%	30	46.9%	Chi2 = 8.156
	feminin	27	33.8%	28	56.0%	34	53.1%	p = 0.017*
Age group	40-60 yrs.	62	77.5%	23	46.0%	39	60.9%	Chi2 = 13.606
	>60 yrs.	18	22.5%	27	54.0%	25	39.1%	p = 0.001**
Environment	urban	59	73.8%	39	78.0%	50	78.1%	Chi2 = 0.485
	rural	21	26.3%	11	22.0%	14	21.9%	p = 0.785

Total	80	100.0%	50	100.0%	64	100.0%	
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The comparative study of therapeutic options for each of the identified clusters after the completion of the pre- and pro-prosthetic stages (secondary stage) is presented in Table 4. In this case, statistically significant differences were also observed regarding the applied prosthetic therapy. In the first cluster, the highest percentage was recorded for metal framework partial dentures with clasps (42.5%), with other common therapeutic solutions including flexible dentures (22.5%) and fixed implant-prosthetic rehabilitations (22.5%). In the second cluster, the percentage of

flexible dentures increased slightly compared to the first cluster (24.0%), along with a significantly higher percentage of composite dentures with rigid or semi-rigid RPD frameworks (32.0%). Another 32.0% of cases also involved metal framework partial dentures with clasps. In the third cluster, the most frequently chosen solutions were similarly metal framework partial dentures with clasps (35.9%) and fixed implant-prosthetic rehabilitations (28.1%), with another significant percentage represented by composite dentures with rigid RPD frameworks (14.1%).

Table 4. Secondary stage patients' clusters related to prosthetic therapy

		TwoStep Cluster Number						Pearson Chi-squared test
		1		2		3		
		N	%	N	%	N	%	
Terapie protetica	Acrylic dentures					2	3.1%	Chi2 = 27.502
	Composite dentures with rigid FPD framework	7	8.8%	10	20.0%	9	14.1%	p = 0.007**
	Composite dentures with semi-rigid FPD framework			6	12.0%	3	4.7%	
	Flexible dentures	18	22.5%	12	24.0%	6	9.4%	
	Metal framework partial dentures with acrylic saddles and clasps	34	42.5%	16	32.0%	23	35.9%	
	Fixed implant-prosthetic rehabilitation	18	22.5%	6	12.0%	18	28.1%	

Implant-supported removable prosthetic rehabilitation	3	3.8%			3	4.7%	
Total	80	100.0%	50	100.0%	64	100.0%	

DISCUSSIONS

Successful prosthetic treatment must aim to address all components of the stomatognathic system, particularly mucosseous structures, to manage common complications of extensive partial edentulism, including malocclusion, mandibular latero-deviations, TMJ pain, muscular dysfunction, and abnormal cranio-mandibular relationships [13, 14]. The pre- and pro-prosthetic phases are crucial for correcting unfavorable clinical-biological indices in the prosthetic field, given the interdependent nature of stomatognathic system components [15, 16]. Achieving optimal biomechanical stability in prosthetic restorations requires favorable clinical-biological conditions of the prosthetic field. Pre-prosthetic and pro-prosthetic interventions should comprehensively address potential etiologies from various perspectives [17]. Dental practitioners must thoroughly assess the status of prosthetic field components, including remaining teeth, periodontal health, mucosal and osseous support, occlusion, and cranio-mandibular relationships [18]. Alveolar bone resorption and irregular residual ridges are among the most critical complications of extensive partial edentulism. Additionally, complications such as TMD pathology directly influence occlusion and cranio-mandibular relationships [19]. Systemic factors, including neuromuscular control, psychological state, and overall health resilience [20], alongside local factors like

the number and position of missing teeth, mandibular movement patterns, financial considerations, and patient preferences, must be carefully evaluated during prosthetic treatment planning [21].

In our study, two-step clustering analysis grouped patients in 4 clusters according to initially clinical -biological indices and 3 clusters according to secondary clinical-biological indices. While enhancements in mucosal and bone support indices was achieved through mucosal grafting techniques and bone augmentation procedures [22-24], cranio-mandibular relationships indices were found the most accurate predictors of clusters. Accurate diagnosis of occlusal and cranio-mandibular relationship disorders is critical for effective prosthetic treatment planning and achieving a favorable prognosis for future restorations. When misalignment between the mandible and cranium occurs, stomatognathic system dysfunctions are amplified, significantly limiting therapeutic options [25]. Addressing occlusal indices is essential to prevent instability, aesthetic deficiencies, and suboptimal contours in subsequent prosthetic restorations [26]. The relationships between the four initial clusters and the three clusters formed after pre- and pro-prosthetic stage (reveal distinct patterns in prosthetic solution preferences and demographic characteristics. In the initial stage (pre-treatment), significant differences in prosthetic therapy were observed despite no demographic differences among clusters.

Cluster 1 (half of the patients with very high score for mandibular-cranial relationships, while the other half have a low score in this area; most of them have a low occlusion score) predominantly featured composite dentures with rigid RPD frameworks and flexible dentures. In Cluster 2 (95,3% of patients with very high score for mandibular-cranial relationships; bone and mucosal support is good or very good in over 90% of cases; dental support good in 69.8% of cases), metal framework partial dentures with acrylic saddles and clasps and fixed implant-prosthetic rehabilitation were most common. Cluster 3 (most patients with low score for mandibular-cranial relationships, and occlusion score, good or very good muco-osseous support) included a wide variety of treatments, with the highest use of metal framework partial dentures with acrylic saddles and clasps. Cluster 4 (3/4 of them with good or very good scores for mandibular-cranial relationships, while the rest have average or low scores; occlusion scores improved compared to patients in the other clusters; bone and mucosal support scores are good or very good in all patients) similarly showed a preference for these dentures, flexible dentures, and fixed implant-prosthetic rehabilitation. In the secondary stage, prosthetic solutions in the secondary stage revealed shifts: Cluster 1 (excellent bone support score in almost all cases; occlusion score ranges from low to very good; the mandibular-cranial relationship score is very good for the vast majority of patients; overall score very good for 51,2% of patients and good for the remaining 48%) show the highest use of metal framework partial dentures with clasps, while Cluster 2 (bone support good in 72.0% of cases and very good for the rest; all patients with low occlusion score, and 70.0% of patients with low score for

mandibular-cranial relationships; good overall score 72.0% of patients and moderate for the remaining 28%) had a notable increase in composite dentures with rigid or semi-rigid RPD frameworks. Cluster 3 (good bone support for 73.4% of patients, moderate for the rest; good or very good occlusion score for 92% of patients; good or very good mandibular-cranial relationship score for 87.5% of patients; overall score very good for 3/4 of the patients, good for rest) maintained its preference for metal framework partial dentures with clasps and fixed implant-prosthetic rehabilitation. Our results prove the role of clinical-biological indices as valuable tools for planning prosthetic treatment in patients with extensive partial edentulism, emphasized also in research by algorithms-based applications [27-29].

The effects of clustering need to be considered when calculating the sample size required to detect a difference in treatment effect, obtaining consent for participation in the trial and finally the analysis of the data [30]. A limitation of clustering analysis is related to the cluster randomized trials (CRTs) that are commonly analyzed using mixed-effects models or generalized estimating equations, analyses that do not always perform effectively with the small number of clusters typical of most CRTs, and can lead to increased risk of finding a statistically significant treatment effect when it does not exist) if appropriate corrections are not used [31, 32].

CONCLUSIONS

According to the analyzed initially values of the clinical-biological indices, patients were grouped in 4 clusters. According to secondary values of the clinical-biological indices, number of clusters decreased to 3 after completion of pre- and pro-prosthetic

stages, due to changes of the clinical-biological indices. Cranio-mandibular relationships index was the most important predictor. The dynamic relationship

between cluster profiles and prosthetic treatment choices is influenced by both demographic and clinical factors across treatment stages.

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