

## ORIGINAL ARTICLE / ОРИГИНАЛНИ РАД

# Microcomputed tomography cortical bone evaluation for craniofacial implantology

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**SUMMARY**

**Introduction** Good implant stability is one of the most important factors for successful implant therapy. This precondition is important for all kinds of implants, oral and extra-oral, i.e. craniofacial implants as well. One of the most important factors for satisfactory implant stability is the bone quality, particularly of the cortical bone, which is determined by its microarchitectural parameters.

The aim of this paper was to assess cortical bone microarchitectural parameters in the targeted regions for craniofacial implant placement.

**Methods** Bone quality on targeted locations was determined by the micro-CT method on a cadaver model. The target places for implant placement were the periorbital, the perinasal, and the periauricular region. Microarchitectural parameters included cortical thickness (Ct.Th.), cortical porosity (Ct.Po.), pore diameter (Po.Dm.), and pore separation (Po.Sp.).

**Results** The smallest Ct.Po. (4.1%) and the largest Po.Sp. (0.5 mm) were determined in glabella. The maximum Ct.Th. (2.7 mm) as well as Po.Dm. (0.2 mm) were found in the zygomatic region. The mastoid part of the temporal bone showed the smallest Ct.Th. (1.2 mm) and Po.Sp. (0.3 mm). The highest Ct.Po. was in the perinasal region (8.5%).

**Conclusion** The bone quality measured through microarchitectural parameters was good in all the regions of interest for the disk- and screw-shape extra-oral implant anchorage.

**Keywords:** microarchitecture; bone quality; micro-CT

**INTRODUCTION**

Patients with different facial defects (orbital, nasal, auricular) are indicated for craniofacial implant therapy and prosthetic rehabilitation. Majority of them have undergone previous tumor resections, which could cause the lack of the bone needed for implant placement. Good implant stability is important for stable maxillofacial prosthesis anchorage [1, 2]. One of the most important factors for successful implant therapy is the bone quality and quantity [3]. For this reason, implant therapy should be well planned and carefully carried out. For craniofacial implant stabilization, microarchitectural parameters of cortical bone in the targeted implant placement points are particularly important. [2, 3]. The periorbital, the perinasal, and the periauricular region, which are used for implant anchorage, have different bone microstructure, which could affect the final outcome of the implant therapy [3]. Microtomography (micro-computed tomography – micro-CT) is a method to image and quantify bone tissue. It has the capability to assess the architecture and the mechanical properties of the bone [4].

The aim of this paper was to assess cortical bone microarchitectural parameters in the targeted regions for craniofacial implant placement.

**METHODS**

The research was performed at the Laboratory for Anthropology, Institute of Anatomy, School of Medicine, University of Belgrade. The study was reviewed and approved by the Committee on Ethics of the School of Dental Medicine, University of Belgrade (No. 36/14).

A young Caucasian adult's dry skull from the collection of the Laboratory for Anthropology, Faculty of Medicine, University of Belgrade, was selected in order to perform the micro-CT analysis of the targeted implant placement areas and to evaluate the microarchitectural parameters which define the quality of the cortical bone. Sexual and demographic characteristics were moderately expressed, thus the skull used presented an average anatomical sample for the situation.

According to the implant placement points for maxillofacial prosthetic rehabilitation, the following locations were selected: for nasal implants – glabellar part of the frontal bone and lateral walls of the nasal pyramid; for orbital implants – upper and lower (cranial and caudal) lateral edges of the orbit and the body of the zygomatic bone; for auricular implants – the petrous part of the temporal bone (Figure 1).

Based on these targeted implant placement points, the following areas for micro-CT scanning were selected: supraorbital margin – orbit, body of the zygoma, glabella, mastoid process, piriform aperture.

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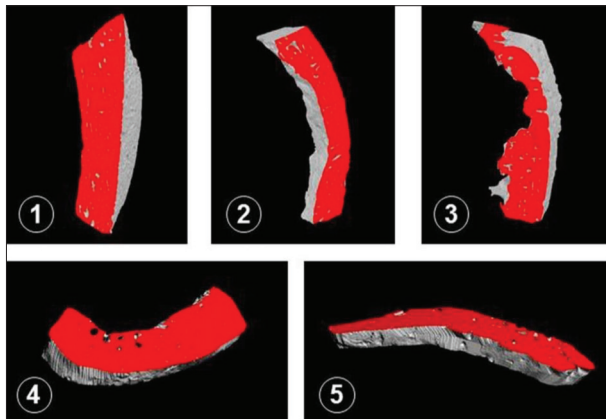
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**Figure 1.** Micro-computed tomography scanning areas



**Figure 2.** Micro-computed tomography scans 3D reconstruction: 1. supraorbital margin – orbit; 2. glabella; 3. mastoid process; 4. body of the zygoma; 5. pyriform aperture – perinasal

A low-speed diamond saw (SYJ-160; MTI Corporation, Richmond, CA, USA) was used to excise bone specimens from the five sites of the skull that correspond to the common implant placement sites in patients (Figure 1).

The specimens were scanned at the Department of Radiology, School of Dental Medicine, University of Belgrade.

The scanning was performed in a bone window with a voltage of 120 kV and a tube current of 40 mAs. A total of 179 axial sections were obtained with a single slice thickness of 0.75 mm.

Each bone sample was scanned in dry state at a resolution of 10  $\mu$ m using micro-CT (SkyScan 1172 x-Ray

**Table 1.** Microarchitectural parameters of the cortical bone measured by microcomputed tomography

Microcomputed tomography parameter	Unit	Description
Cortical thickness	mm	Average thickness of the cortical bone
Cortical porosity	%	Volume of pores in relation to the total volume of the cortical bone
Pore diameter	mm	Average pore diameter
Pore separation	mm	Average distance between pores

Microtomography; SkyScan, Kontich, Belgium). Acquisitions were performed on 85 kV voltages, 118  $\mu$ A pipe current, 1000 ms time exposure, 0.5 mm thick aluminum and copper filter, and 180° rotation. The obtained images were reconstructed using NRecon v.1.6.9.8 software (Micro Photonics Inc., Allentown, PA, USA) with a beam hardening correction of 25%, a ring artefact with a correction of 18%, and a reduction of 2. The images were then analyzed using CTAn 1.14.4.1 software (Bruker-microCT N.V. Company, Kontich, Belgium). 3D reconstructions were made (Figure 2).

The following microarchitectural parameters were evaluated: cortical thickness, cortical porosity, pore diameter, and pore separation (Table 1).

## RESULTS

The obtained results were based on micro-CT scanning evaluation of the microarchitectural parameters in five different positions (Figure 1).

The smallest cortical porosity (Ct.Po.; 4.1%) was determined in the glabella, which suggests that this region has the densest cortical bone. The maximum pore separation (Po.Sp.; 0.5 mm) and small pore diameter (Po.Dm.; 0.1 mm) also speak in favor of dense glabellar cortical bone. Moreover, glabellar cortical thickness (Ct.Th.) showed a value of 1.5 mm. The maximum Ct.Th. (2.7 mm) was found in the zygomatic region, as well as the maximum pore diameter (Po.Dm 0.2 mm). In the orbital region, the value of cortical thickness was also high (Ct.Th. 1.9 mm), although the porosity was somewhat higher (Ct.Po. 6.7 %), which tells about thick but porous cortex. The mastoid part of the temporal bone showed the minimum thickness of the cortical bone (Ct.Th. of 1.2 mm), as well as the smallest Po.Sp. (0.3 mm). Perinasal region showed the highest Ct.Po. values (8.5%) (Table 2).

**Table 2.** Microarchitectural parameters of the cortical bone microcomputed tomography evaluation

Parameter	Position 1 Orbit (supraorbital margin)	Position 2 Glabella	Position 3 Mastoid. Pr.	Position 4 Zygoma.	Position 5 Perinasal (pyriform aperture)
Cortical thickness (mm)	1.9	1.5	1.2'	2.7*	1.4
Cortical porosity (%)	6.7	4.1'	4.3	5.7	8.5*
Pore diameter (mm)	0.1	0.1	0.1	0.2*	0.1
Pore separation (mm)	0.4	0.5*	0.3'	0.4	0.4

\*Highest value for the parameter;  
'lowest value for the parameter

## DISCUSSION

Bone tissue exhibits organization from smaller (nano, micro) to larger (macro) length scales. However, there is a shortage of qualitative information on cortical bone thickness, porosity, as well as on the distribution and size of pore in the midface region and cranium. Therefore, the essence of the present research was to investigate how cortical bone varies in micro-architectural parameters in areas of interest for craniofacial implant placement [5, 6]. Extra-oral (EO) implants are used for anchoring maxillofacial epithesis. A reliable and clinically verified implant therapy includes production of freestanding implant-supported prosthesis [7]. Generally, EO screw-type implants are widely used for this purpose. Due to the anatomical features and thickness of the bone available, the use of conventional EO screw-shaped implants is limited. Good anchoring of enosseal implants requires sufficient bone volume and density [1, 8]. In the case of bone resection, only a small amount of cortical bone is usually left behind. Hence, particularly in the midface area, anchorage of screw-type implants is compromised. The usual locations for screw implant placement are the glabella, mastoid part of temporal bone and upper ridge of orbit. Vertical or even horizontal bone dimensions are often limited after surgery, for example nasal amputation, thus screw type implants often cannot be used [1, 3]. However, disk implants present an optimal alternative whenever implant-retained craniofacial epithesis are indicated, especially when "vertical" bone substance is limited, because such implants require the width rather than the height of bone. Since the thickness of the disk implant plate is 0.6 mm, the minimum amount of the cortical bone where the disk implant could be placed is at least 1 mm, which is far less than minimal requirements for EO screw implants [9, 10]. Disk implants are bi- or multicortically anchored to the cortical bone. The basic premise is that these implants should have absolute primary stability in cortical bone on each side of the disk-plate. The functional load is transferred to the cortical/basal part of the bone [9, 10].

One of the most important factors in the implant therapy is the bone tissue quality. The bone tissue was evaluated and categorized over the years, by different authors [11–15]. However, not a single classification was directly correlated to the implant therapy success. It is not possible to predict the subtle differences in bone quality when applying either the Lekholm and Zarb or Misch classifications [11, 12]. For this reason, Trisi and Rao [13] and Norton and Gamble [14] demonstrated that subjective methods of evaluating bone quality are useful only when clinically assessing up to three classes of bone quality [15].

In spite of this, the use of computed tomography / cone beam computed tomography methods to estimate the degree of bone density is not implemented by implantologists very often.

Nevertheless, the microarchitecture of the bone has an impact on the success of the implant therapy. Microarchitectural parameters like Co.Th., Po.Dm., Co.Po., and Po.Sp. can tell a lot about the bone characteristics, and

help predict the outcome of the EO implant therapy in a certain region of the cranium [3, 16].

Micro-CT evaluation can provide an insight to biomechanical properties of the midfacial bones, their thick cortical bone structure, zones of strength, as well as the areas containing thin cortical bone which are considered weak and fragile. However, recent studies revealed that bones of the midfacial skeleton exhibit remarkable regional variations in structure and elastic properties. These variations have been frequently suggested to result from different involvement of cortical and trabecular bone in the transfer of forces. This is why precise evaluation of the areas intended for implantation is important [17, 18, 19].

By examining the microarchitecture of the cortical bone in the orbit, glabella, peripheral region of the aperture piriformis, zygomatic bone, it was understood that the qualitative value of the cortical bone tissue in these localizations was optimal for insertion of disk implants, that are cortically anchored, which is a good alternative for retention of maxillofacial prosthesis. This bone area is typically resistant to infection because of its high mineralization. Furthermore, these bone areas are stable to resorption [3, 9, 10]. That is why the cortical bone was of interest for this study.

The maximum Ct.Th. value was in the zygomatic region (2.7 mm) and slightly smaller in the orbital region (1.9 mm). Glabella, piriform aperture (perinasal bone area) showed smaller Ct.Th. (1.5 mm and 1.4 mm, respectively). Because of relatively dense cortical bone in those areas, disk implants can be used [1, 3, 9]. When the microarchitectural parameters were higher (Co.Po. and Co.Th.), and when there is a sufficient amount of bone for triple disk implants, it would be justified to use this kind of implants because of better stability. Single- or double-disk implants could be used in the limited bone quality and quantity when the Ct.Th. is smaller and Co.Po. lower.

Mastoid part of the temporal bone showed the minimum Ct.Th. (1.2 mm) as well as small Ct.Po. (4.3 mm). Anatomically and microarchitecturally, this part of the temporal bone is suitable only for screw EO implants. Screw-type EO implants are similar to short oral (dental) implants; however, there are some differences when it comes to the shape. EO implants have a flange design around their neck to prevent an unwanted drop of the implant, intracranial in the mastoid region. This is justified even more because this region has the smallest cortical thickness, which was shown in this study. For this reason, the implant placement has to be very carefully performed because thin cortex can be easily disrupted [3, 16].

According to other researches where Ct.Th. was higher, the implant stability was more satisfactory. In addition, according to implant stability quotient by resonant frequency analysis, where Ct.Po. was the smallest, Po.Dm./Po.Sp. the greatest, the implant stability was the best. This suggests that the cortical bone characteristics and microarchitectural parameters may determine the outcome of the implant therapy [20–24].

Micro-CT evaluation of cortical bone on the dry skull cadaver model, on certain implant placement points, can give insight into the cortical bone properties, which can

provide valuable guidelines when planning complex implant-retained prosthetic restoration.

## CONCLUSION

The bone quality measured through microarchitectural parameters was good in all the regions of interest for the disk- and screw-shape EO implant anchorage.

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## Процена кортикалне кости микрокомпјутерском томографијом за краниофацијалну имплантологију

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### САЖЕТАК

**Увод** Добра стабилност имплантата један је од најважнијих фактора за успешну имплантолошку терапију. Овај предуслов је применљив на све типове имплантата, оралне и екстраоралне, краниофацијалне имплантате. Један од најважнијих фактора за задовољавајућу стабилност имплантата је квалитет кости, нарочито кортикалне кости, што је одређено микроархитектонским параметрима.

Циљ је био процена микроархитектонских параметара кортикалне кости на циљаним регијама за постављање краниофацијалних имплантата.

**Методе** Квалитет кости на циљаним локализацијама одређен је микрокомпјутерском томографијом на кадаверичном моделу. Регије од интереса за постављање имплантата биле су: периорбитална, периназална и периаурикуларна

регија. Испитани микроархитектонски параметри су кортикална дебљина (*Ct.Th.*), кортикална порозност (*Ct.Po.*), пречник пора (*Po.Dm.*) и сепарација пора (*Po.Sp.*).

**Резултати** Најмања *Ct.Po.* (4,1%) и највећа *Po.Sp.* (0,5 mm) утврђене су у глабели. Највећа *Ct.Th.* (2,7 mm) и *Po.Dm.* (0,2 mm) пронађене су у зигоматичкој регији. Мастоидни део темпоралне кости показао је најмању *Ct.Th.* (1,2 mm) и *Po.Sp.* (0,3 mm). Највећа *Ct.Po.* (8,5%) била је у периназалној регији.

**Закључак** Квалитет кости измерен микроархитектонским параметрима био је задовољавајући у свим регијама од интереса за сидрење екстраоралних имплантата облика диска и шрафа.

**Кључне речи:** микроархитектура; квалитет кости; микрокомпјутерска томографија