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Resonance frequency analysis – indicator of post-implantation morphology of mandibular bone tissue

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This article describes the role of resonance frequency analysis (RFA) as an indicator of the quality of primary implant stability, which is the basis of the goal and confirmed by the results of a clinical case – odontological implantation on edentulous segments of atrophied bone tissue on the right side of the mandible, taking into account the topographic features of its canal, using ultra-short (h = 5.5 mm) implants.

Aim. To highlight the role of resonance frequency analysis during surgical interventions using short (ultrashort) implants in predicting their primary stability and preserving the normal morphology of the mandibular bone tissue.

Materials and methods. The primary stability of 17 dental implants in seven patients was determined using the Penguin Instruments (RFA) technique in declarative units of measurement – the implant stability quotient (ISQ). Values in the range of 75 ISQ meant that the implant had adequate primary stability and could receive and distribute the immediate load on the bone tissue of the edentulous segment.

Results. Following the stages of preparation, 17 ultra-short (h = 5.5 mm × b = 4.0 mm) implants were placed on the edentulous segments of the mandible without an incisional osteotomy path according to the patient rehabilitation protocol. We used the method of resonance frequency analysis to obtain a value of high primary stability of two short subcortical implants in the projection of tooth 4.7 – 92 ISQ and the projection of tooth 4.6 – 90 ISQ. On the 3rd day of the clinical stage of fixation of the supraconstruction, RFA measurements were performed, the values of which showed a significant decrease in the stability quotient of the installed implants in the projection of tooth 4.7 – 61 ISQ and in tooth 4.6 – 74 ISQ. This result made it necessary to revise the rehabilitation plan, adjust the medical prescription sheet and decide to postpone the placement of the all-milled restorative structure on the implants.

Conclusions. The RFA study indicates not only the primary stability of implants but also a full-fledged stage-by-stage clinical prognosis of the further functionality of a prosthetic structure based on short implants with proper preservation of the morphological functionality of bone tissue.

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Резонансно-частотний аналіз – індикатор постімплантаційної морфології кісткової тканини нижньої щелепи

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Описано роль резонансно-частотного аналізу (РЧА) як індикатора якості первинної стабільності імплантатів, що покладено в основу мети та підтверджено результатами аналізу клінічного випадку: виконання одонтологічної імплантації на беззубих сегментах атрофованої кісткової тканини правого боку нижньої щелепи, враховуючи топографічні особливості її каналу та використовуючи ультракороткі (h = 5,5 мм) імплантати.

Мета роботи – висвітлити роль резонансно-частотного аналізу при хірургічних втручаннях із використанням коротких (ультракоротких) імплантатів у прогнозуванні їхньої первинної стабільності та збереженні нормальної морфології кісткової тканини нижньої щелепи.

Матеріали та методи. Первинну стабільність 17 дентальних імплантатів у семи пацієнтів визначали за допомогою техніки Penguin Instruments (РЧА) у декларативних одиницях вимірювання – коефіцієнт стабільності імплантата (КСІ). Значення в діапазоні 75 КСІ вказували, що імплантат має належну первинну стабільність, може отримувати й розподіляти негайне навантаження на кісткову тканину беззубого сегмента.

Результати. Дотримуючись етапів препарування та без проведення нарізного остеотомічного шляху, інстальовано 17 ультракоротких (h = 5,5 мм × b = 4,0 мм) імплантатів на беззубих сегментах нижньої щелепи, відповідно до протоколу реабілітації пацієнтів. Застосували методику резонансно-частотного аналізу, одержали значення високої первинної стабільності двох коротких субкортикальних імплантатів у проєкції 4.7 зуба – 92 КСІ, у проєкції 4.6 – 90 КСІ. На третій день клінічного етапу фіксації супраконструкції виміряли РЧА, що показало суттєве зниження коефіцієнта стабільності у встановлених імплантатах: у

проєкції 4.7 зуба – 61 KCI, 4.6 – 74 KCI. Такий результат спричинив необхідність переглянути план реабілітації, скорегувати листок лікарських призначень; крім того, ухвалили рішення про відтермінування етапу встановлення реставраційної суцільно фрезерованої конструкції на імплантати.

Висновки. Дослідження РЧА – індикатор не лише первинної стабільності імплантатів, але й повноцінного етапного клінічного прогнозу наступної функціональності протезної конструкції з опорою на короткі імплантати з належним збереженням морфологічної функціональності кісткової тканини.

Сучасні медичні технології. 2023. № 4(59). С. 70-75

With the development of science and technology, minimally invasive research methods are becoming available. The implementation of these methods in practical medicine is taking place to rehabilitate patients with severe bone atrophy, taking into account its morphological characteristics and the laying of important anatomical structures. While earlier there were discussions about the feasibility of using short implants [1] to reduce the amount of surgical intervention and possible iatrogenic effects on the structures of the mandibular canal(s) [2,3,4], today ultra-short implants are widely used, which can receive loads with their distribution to bone tissue and fully restore the chewing efficiency of edentulous jaws [5,6,7].

In order to use the immediate loading technique, especially on short (h = 5.5 mm) implants, it is necessary to understand their primary stability in the morphological environment, which can change dynamically under the influence of factors of internal and external space. This implies that bone density, studied using computed tomography software, is not a stable phenomenon, i. e., it is also dynamic [8,9]. Although this method is characterized by its minimally invasive nature, it does not provide adequate predictions for determining the primary stability of the implant, even with high bone density in both layers. After all, high density can be provided by an auto-, allo-, or xenograft whose augmentation is formed from a solid base and has not undergone remodeling stages in time or for other reasons. Densitometric analysis can give a false impression of primary stability. This is unacceptable in the choice of rehabilitation methods with short and ultra-short implants taking into consideration the topographic features of the mandibular canal(s).

One of the reliable diagnostic methods is resonance frequency analysis (RFA). For the first time after many years of work, it was described by the progressive researcher Meredith in 1996 (Integrative Diagnostics, Sweden) for odontological intraoral use. The gradual improvement of resonance frequency analysis techniques has created modern diagnostic systems that have become a priority for dental surgeons to determine the primary stability of implants. The RFA study provides a prognosis not only for the further functionality of the implant-supported prosthetic structure but also for the proper physiological processes in the bone tissue with the preservation of its morphological functionality [10].

Aim

To highlight the role of resonance frequency analysis during surgical interventions using short (ultra-short) implants in predicting their primary stability and preserving the normal morphology of the mandibular bone tissue.

Materials and methods

The post-implantation stability of seventeen short and ultra-short implants was analyzed in seven patients with loss of the masticatory group of teeth, with mixed bone atrophy of the collar part and the body of the mandible acquired in different time intervals. The obtained values of high (92 ISQ) primary stability of two short subcortical implants placed on the edentulous segment of the human mandible on the right side of seven subjects did not provide a prognosis of its rehabilitation, taking into account the individual anatomical and topographic features of the canal(s), which we present in a detailed description of the clinical case as the results of this work.

The primary stability of implants was determined using the Penguin Instruments resonance frequency analysis (RFA) technique in declarative units of measurement – the implant stability quotient (ISQ). Values in the range of 75 ISQ meant that a short 6.5 mm implant (ultra-short 5.5 mm) was already so stable that it could receive and distribute the immediate load on the bone tissue of the edentulous segment. The evidence of such stability is the absence of a drop in ISQ within 14 days or a change in the range no more than 1–5 ISQ in the initial rehabilitation period.

Resonance frequency analysis was performed following the stated instructions of the above technique, with strict adherence to the methodological sequence, which requires attachment of the MulTipeg™ to the implant and its subsequent vibration due to the received wave of magnetic pulses generated by the device. The device measures the vibration frequency due to the rigidity in the contact zone between the bone and the implant surface and converts it into a scale value from 1 to 99 ISQ. The higher the ISQ is, the better its stability is. RFA measures implant stability as a function of boundary rigidity, which correlates with implant displacement, i.e., micro-mobility.

This work is a fragment of a clinical experiment of the planned research topic “Substantiation of rehabilitation of patients with bone atrophy complicated by topographic and anatomical features of the mandibular canal”, with mandatory review by the Biomedical Ethics Commission of Bukovinian State Medical University and approval in the form of Protocol dated 21.10.2021 No. 2. The clinical experiment was conducted after patients familiarized themselves with and signed informed consent to participate in research in compliance with the main provisions of the GCP (1996), the Council of Europe Convention on Human Rights and Biomedicine (dated 04.04.1997), the World Medical Association Declaration of Helsinki on ethical principles for conducting scientific medical research involving human subjects (1964–2013), order of the Ministry of Health of Ukraine dated 23.09.2009 No. 690.

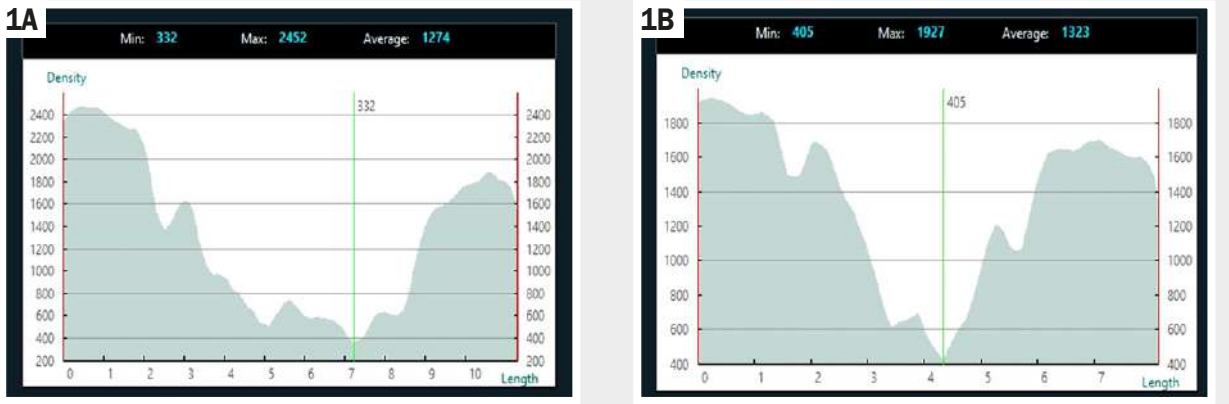

Fig. 1. Densitometric analysis of the bone tissue of the edentulous segment of the mandible on the right side at the stage of planning surgical interventions. **A:** projection of tooth 4.7; **B:** projection of tooth 4.6.

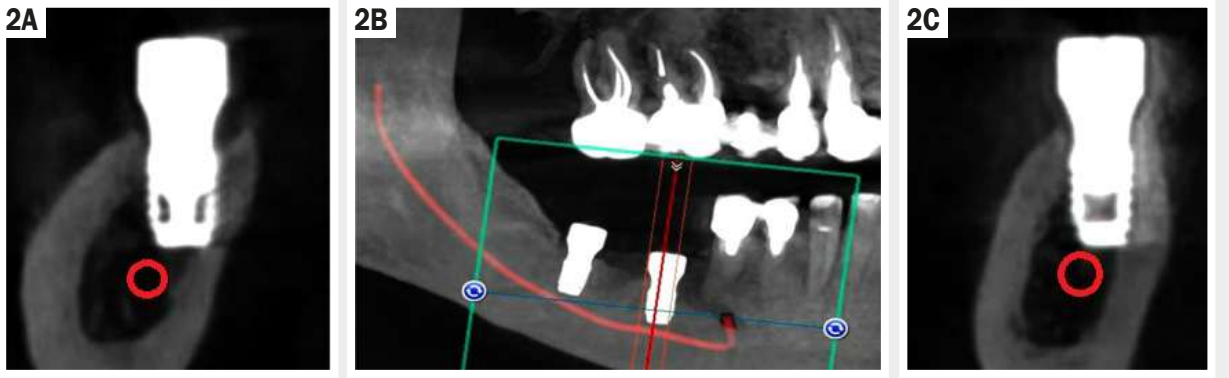

Fig. 2. Computed tomographic analysis after subcortical implant placement. **A:** Sagittal section showing the placed implant and gingival former in the projection 4.7 of the missing tooth with the marking of the mandibular canal; **B:** 2D image of the upper and lower jaws with the reconstruction of the mandibular canal and design of occlusal relations of the supraconstructions; **C:** Sagittal section showing the implant and gingival former in projection 4.6 of the missing tooth with the marking of the mandibular canal.

Results

Preliminary studies of the bone density of the acquired defect of the dentition on the right side of the mandible in projections 4.7 (*Fig. 1A*) and 4.6 (*Fig. 1B*) of the missing teeth showed high values with average values of 1274 conventional gray units (CGU) and 1323 CGU. The lowest mineralization in the trabecular layer was 4.7 + 332 CGU in the projection and 4.6 + 405 CGU in the projection. Such indicators give the right to draw up an initial plan for using the immediate loading protocol on implants.

To choose the implantation method, it is necessary to understand the topographic features of the mandibular canal and take into account its possible morphological variants, which determine the use of the proper size of the implants themselves and their positioning in the jaw body with the subsequent functional reproduction of the occlusal relations of the dentition, due to the superstructural elements.

Considering the above analysis, we chose a protocol for rehabilitating patients using subcortical implants with dimensions h = 5.5 mm × b = 4.0 mm. Carefully observing the stages of preparation, without performing an incisional osteotomy path, these implants were placed on the edentulous segment on the right side of the mandible, and we used the method of resonance frequency analysis to obtain a value of high primary stability of two short implants, in the projection of the 4.7 tooth – 92 ISQ and the projection of the 4.6 – 90 ISQ. Before the end of the operation, gingival formers of the corresponding standard system with a force of 15 N were installed, which were moved out of the occlusal relationship by 4–6 mm (*Fig. 2*).

On the 3rd day, a repeated resonance frequency analysis was performed, which showed a significant decrease in the stability quotient of the implants in the projection of tooth 4.7 – 61 ISQ and in tooth 4.6 – 74 ISQ. This result made it necessary to revise the rehabilitation plan, adjust the medical prescription sheet and decide to postpone the placement of the all-milled restorative structure on the implants.

Taking into account the subjective and objective history of the patient on day 7, after a clinical examination, the implant was found to be luxated in the projection of the 4.7 tooth, which was removed on the same day. The RFA in projection 4.6 dropped to 63 ISQ, which became a vector of alertness to the development of destructive changes. These assumptions were confirmed by the obtained values of densitometric analysis, which also differed significantly in the direction of a sharp decrease, indicating a violation of the structural organization of bone tissue compared to the

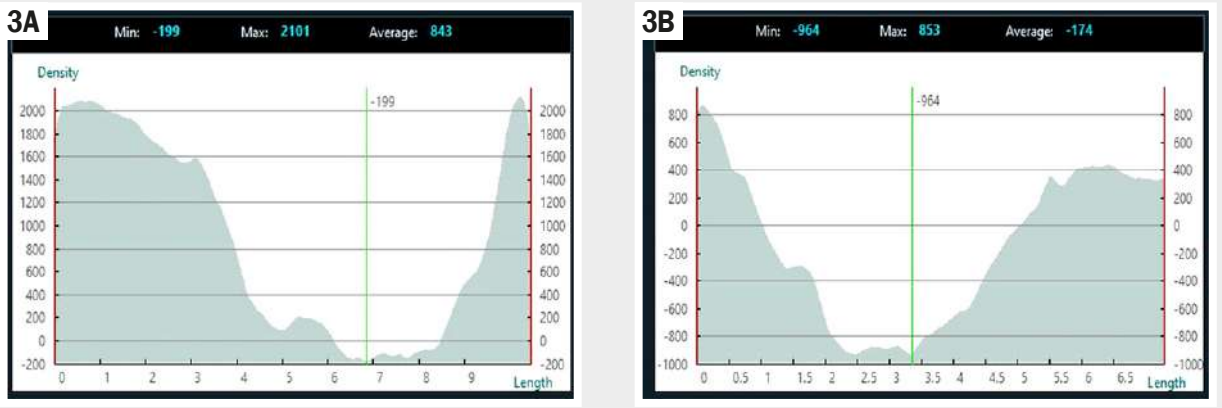

Fig. 3. Densitometric analysis of the bone tissue of the edentulous segment of the mandible on the right side, after and at the stage of implant removal. **A:** projection of tooth 4.7; **B:** projection of tooth 4.6.

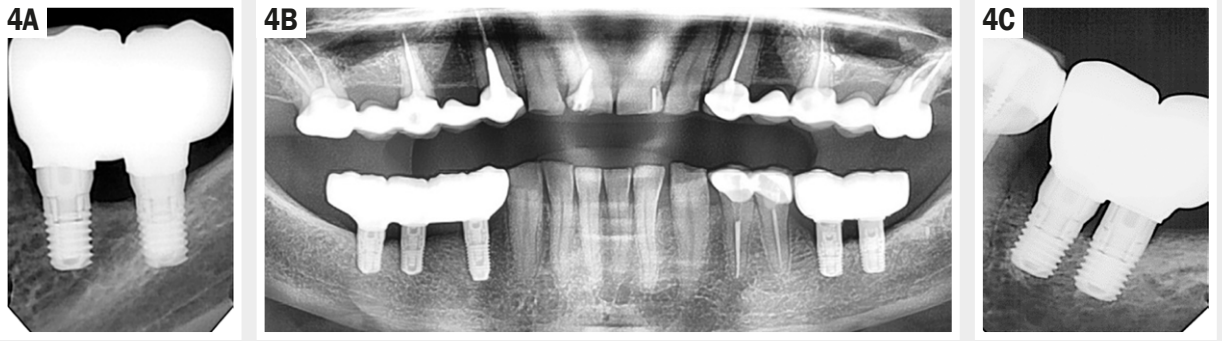

Fig. 4. Radiographic control after fixation of supraconstructions on implants installed at the level of the cortical layer of atrophied bone tissue. **A:** Parallel placement of two implants and cemented prehensile fixation to analog (preparation) abutments on the left side of the mandible; **B:** Bilateral rehabilitation of a patient with final dentition defects, short and ultra-short implants, taking into account the topographic features of the mandibular canal; **C:** Divergent placement of two implants and cement prehensile fixation to analog (preparation) abutments on the left side of the mandible.

primary. In area 4.7 of the removed implant, the minimum density value was negative (-199 CGU), and on the proximal side of the bone implant bed 4.6, which corresponds to the largest zone of the lumen, it was (-964 CGU), indicating the active development of destructive processes in the distal direction of the edentulous segment of the mandible body (*Fig. 3*).

Due to complications and the lack of effect of anti-inflammatory and antibacterial therapy, based on the indicators of a decrease in the implant stability quotient (ISQ), the implant was removed in the 4.6 tooth projection with subsequent extraction of destructive trabecular islands, according to the operation protocols.

Discussion

ISQ values determine localized bone density and depend on clinician's compliance with implant placement techniques, implant design, and post-implant wound healing time. Implants with low and/or decreasing ISQ values pose an increased risk of rejection compared to implants with high and/or increasing values, as stated by the product manufacturer and, accordingly, the developer of this resonance frequency analysis (RFA, Meredith) technique.

Following the recommendations of the developer of the RFA technique, when determining the stability of an implant with values above 70 ISQ, it is recommended that the clinical choice be made to use the one-stage or immediate loading technique. However, we did not take into account the design of the implants, which have a sloping shoulder, designed for subcortical crosslinking and the creation of a reliable rigid tissue barrier that provides long-term and stable protection not only from the external environment but also provides long-term and reliable stability of the implant, due to the high mineralization of the cortical layer.

Of course, medium and long implants h >7.0 mm have an additional intercostal contact area, which compensates for the above-mentioned characteristic of the implant design. After all, ensuring osteointegration processes over time adds complete stability and functionality to the implant structure, which is ineffective for short subcortical implants h = 5.5 mm.

The preparation protocol provides a suitable cylindrical-conical implant bed concerning the size of the selected implant, and the formed space (distance) between its shoulder and the cortical layer of bone tissue significantly reduces stability during functional action, which cannot be stated in our case. After all, the implants have not yet been subjected to immediate loading.

Implants placed at the cortical layer's level are characterized by an extended external cone design and have an additional high primary stability due to their resistance to remodeling the

cortical layer of bone tissue. We prove this statement in the application of clinical protocols for the installation of (ultra-short) implants at the level of the cortical layer as a method of choice, taking into account the topographic features of the mandibular canal(s) in the case of bone atrophy and rapid (immediate) rehabilitation of patients, up to seven days, with the loss of the masticatory group of teeth, as shown in the images in *Fig. 4*. Their values were stable at all stages of the rehabilitation period and ranged from ±7 ISQ.

The development of modern artificial intelligence technologies makes it possible to successfully implement a preclinical plan during controlled surgical interventions, including dental implantation, with proper primary stability [11]. However, it is programmatically impossible to determine the stability of implants as an indicator of their further functionality at the clinical stages – before fitting and fixation of the supraconstructions.

Presented as an electronic poster at the 2019 Annual Session of the American College of Orthopedic Surgeons in Miami, Florida, the authors' work was awarded second place for innovative research and offered a universal, non-odontic, open source program, 3D Slicer/Blender, which can be used to plan and perform a controlled implant placement operation taking into account the morpho-topographic features of the jaw structures, minimizing errors in the formation of the implant bed and, in fact, their angulation [12]. However, the lack of the possibility of applying it in the staged clinical analysis of implant stability requires additional paraclinical targeted research methods.

Modern original research aimed at achieving implant positioning accuracy, especially angular deviation, through introducing the THETA robotic system indicates that such achievements may become promising tools in dental implantation in the future. Nevertheless, further clinical analysis and research are needed to evaluate the current results [13].

A new view of the implementation of digital surgical templates provides a prediction of the primary stability of implants. It negates the use of navigation sleeve systems designed to create accurate osteotomy paths and, accordingly, the primary stability of implants. It lacks further clinical analysis of the course of early dynamic processes of bone tissue that may affect their functionality [14,15].

Another factor for studying the subject of resonance frequency analysis and its application in odontological clinical practice is the overall ergonomic efficiency, simplicity of the technique, lack of consumables, and seconds of analysis time.

Conclusions

1. The pressure created during implant placement in high-density bone tissue, without an incisional osteotomy path, increasing the force from 75 N to "∞" from the value of the primary implant stability of 92 ± 8 ISQ, can lead to a temporary cessation of even diffuse nutrition and promote phagocytic activity in the dense trabecular layer of bone tissue and be considered as a patho-etiological factor.

2. Resonance frequency analysis is a priority and reliable technique, an effective indicator of the primary stability of short (ultra-short) implants at all stages of clinical rehabilitation of patients.

Prospects for further research include the study of possible morphological and histological changes in bone tissue around the installed short and ultra-short implants using the immediate loading technique.

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