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Review

Concept and Design of Cutting Tools for Osseodensification in Implant Dentistry

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Abstract: Osseodensification is an innovative surgical instrumentation technique based on additive (non-cutting) drilling using special burs. It is known from the literature, that the osseodensification burs should operate in a clockwise direction to drill holes and in a counterclockwise direction to compact the osteotomy walls. For these purposes, the burs have special design features, like conical contour shape, increased number of helical flutes, and negative rake angle on the peripheral part. However, although other parameters and features of the burs define their overall performance, they are not described sufficiently, and their influence on surgical quality is almost unknown both for clinicians and tool manufacturers. The purpose of the present research is to identify the key design features of burs for osseodensification and their functional relationship with the qualitative indices of the procedure based on an analytical review of research papers and patent documents. It will help to further improve the design of osseodensification burs and thereby enhance the surgical quality and, ultimately, patient satisfaction. Results: The most important design features and parameters of osseodensification burs are identified. Thereon, the structural model of osseodensification bur is first represented as a hypergraph. Based on the analysis of previous research, functional relationships between design parameters of osseodensification burs, osseodensification procedure conditions, and procedure performance data were established and, for the first time, described in the comprehensive form of a hypergraph. Conclusions: This study provides formal models that form the basis of database structure and its control interface, which will be used in the later developed computer-aided design module to create advanced types of burs under consideration. These models will also help to make good experimental designs used in studies aimed at improving the efficiency of the osseodensification procedure.

Keywords: drilling techniques; medical tools; medical instrumentation; osseodensification; osseodensification drilling; dental implant; osseodensification burs cutting tool design; dental instruments; dental cutting tools

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1. Introduction

Dental implant stability, or absence of movement, is a critical factor described for reaching osseointegration and the use of immediate loading protocols [1]. Three different techniques are commonly used in implant site preparation: osteotome, conventional drilling, and piezoelectric surgery [2–4]. The most widely used preparation technique is drilling. Drilling operation involves the cutting, i.e., separation of bone tissue with sharp blades of a rotating tool and extraction of the tissue away from the cutting area with spiral flutes [5]. This creates a cylindrical osteotomy into which the implant fixture will later be inserted. The drilling operation may also be referred to as conventional or subtractive drilling because the material is removed from the bulk of the bone in the form of fine chips. However, the drilling has some limitations during osteotomy, as it may significantly decrease the implant fixation stability and pullout strength [6–10]. Heat generation and vibrations present other disadvantages of bone drilling, which can compromise the geometric accuracy of the osteotomy and lead to other clinical complications [11–13].

Recently, an innovative non-cutting technique to eliminate the drawbacks of conventional drilling, commonly named 'osseodensification', has been introduced in the market and put into clinical practice [14]. Osseodensification is a surgical instrumentation technique where the bone is compacted into open marrow spaces during drilling, increasing implant insertion torque through the densification of osteotomy site walls [15,16]. In contrast with drilling, the osseodensification procedure is considered an additive process since it utilizes the compaction of bone into the walls of the osteotomy chamber being formed, hence increasing bone density [17–20].

Generally, the osseodensification technique can be applied in different clinical situations: low-density bone areas, sub-antral bone grafts, narrow alveolar bone crests, and immediate implant placement in post-extraction sockets [21]. Currently, the osseodensification Densah® burs by Versah® (Jackson, MI, USA) is widely used and reportedly has the best outcome for low-density bones, e.g., when preparing osteotomies for dental implant placement in the mandible or maxilla [22–29]. Osseodensification burs improve bone density around dental implants but do not give a noticeably higher bone height gain or apical density compared to osteotomes [30].

The osseodensification method utilizes several specially designed tapered multi-flute drilling tools (burs). These burs can act in two ways: clockwise (for cutting) to drill bone or counterclockwise (non-cutting direction) to smoothly compact bone [1,15,31]. Designing and manufacturing such special cutting tools for innovative osseodensification approaches are very promising and crucially important medical and technological tasks for the medical industry. In the present paper, a comprehensive analysis of the essential issues and peculiarities of osseodensification non-subtractive burs is given.

The review was conducted using bibliographic Scopus, ScienceDirect, and PubMed databases. According to ScienceDirect, the number of papers with the keyword 'osseodensification' has increased at least 10-fold since 2016, when the technique in question was first introduced by Huwais and Meyer [11] (Figure 1).

Figure 2 displays the tag cloud generated by keywords related to surgical methods, including osseodensification techniques, research and development methods, surgical instrumentation, tools, design parameters, and design methods and techniques. The search was limited to the period from 2019 to the present. As the qualitative measure, the Total link strength attribute indicating the total strength of the co-authorship links of a given researcher with other researchers was used. Thus, according to the search results, the maximum total link strength is observed for the most general keywords 'dental implants' (total link strength of 224,303), 'tooth implant' (179,472), 'tissue engineering' (152,760), 'tooth implantation' (95,407) and osseointegration (76,433). In comparison, the keyword 'osseodensification' currently has a total link strength of 821. The material of dental implants is a highly topical research area, which is proven by the total link strength of the keyword 'dental materials', which is equal to 14,964. As for medical tools and instrumentation, the present review used the keywords 'drilling' (with total link strength of 4999), 'dental cutting tools' (4403), 'cutting tools' (976), 'dental instruments' (911), 'drills' (4806), 'drilling operation' (639), 'drilling parameters' (463), 'dental burs' (244) and 'osseodensifying burs' (27) were used.

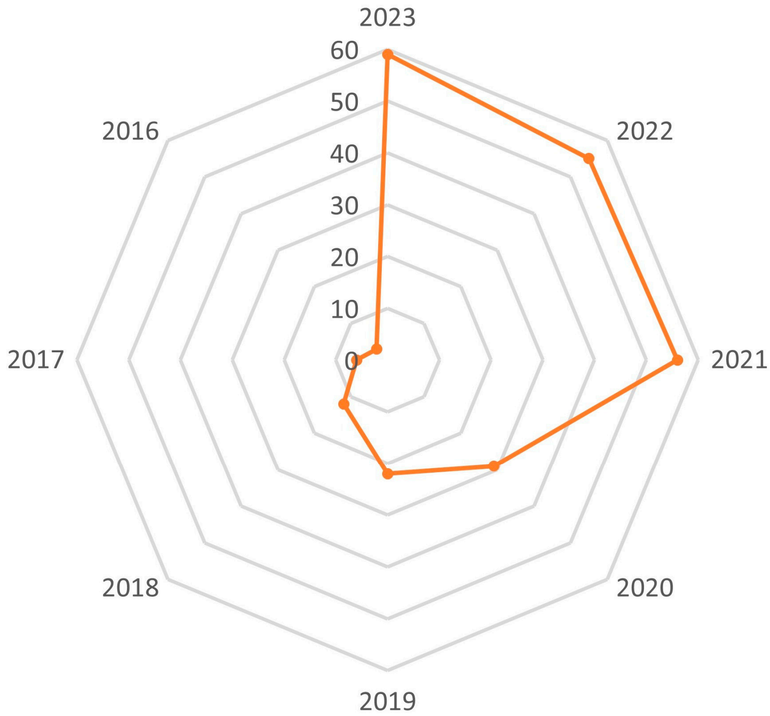


Figure 1. Number of scientific publications in the search results of publications for the keywords ('osseodensification') from 2016 to the present (according to ScienceDirect).

In addition, a number of patents for inventions referred to designs of dental burs and surgical drills were reviewed. All of the patent documents are focused on the gain in efficiency of surgical procedures, which is estimated by improvements in performance indicators. To achieve them, the patents deal with increasing wear resistance of the working part, which widens the technical capabilities and operation performance indicators [32], modifying the geometry of cutting edges of bur [33], and making other improvements in bur design [34]. For osseodensification applications, there is a group of patent documents describing the innovative design features of the burs and their procedure protocol [35–41].

Despite relatively low occurrences of research devoted to medical instrumentation and, in particular, osseodensification burs, it is obvious that improving the performance capabilities of the tools significantly enhances the qualitative indicators of surgical procedure, which is of great importance for the further development of the new osseodensification technique.

Only a few references (mainly patents) contain the recommended values of the design parameters of the osseodensification burs. Moreover, it should be admitted that the issue of the functional relationships between design parameters of the osseodensification bur and the main characteristics of the surgical procedure has not yet been sufficiently studied. This is why more research should be conducted to validate the connections between these features. The present paper should become the basis for comprehensive research on osseodensification burs from both engineering and surgical points of view.

Thus, the key novel contribution of the present study is the comprehensive analysis of engineering and medical requirements to the osseodensification bur. It will provide a solid base for future research and development works that should be devoted to establishing the functional relationships between the design parameters of the burs and qualitative indices of the surgical procedure. This task will include the development of the designing algorithm, specification of the key design features of the burs, and planning the experimental procedure to obtain more clinical evidence of the increasing efficiency. The future development of the burs shall enhance the geometry of the cutting blades and their material properties. Thus, the bur lifetime and cutting ability, as well as preparation efficiency and ergonomic characteristics, will be significantly improved. All this will lead to an improvement in the quality of surgical procedures and contribute to the world manufacturers to extend their production range to satisfy the needs of healthcare facilities.

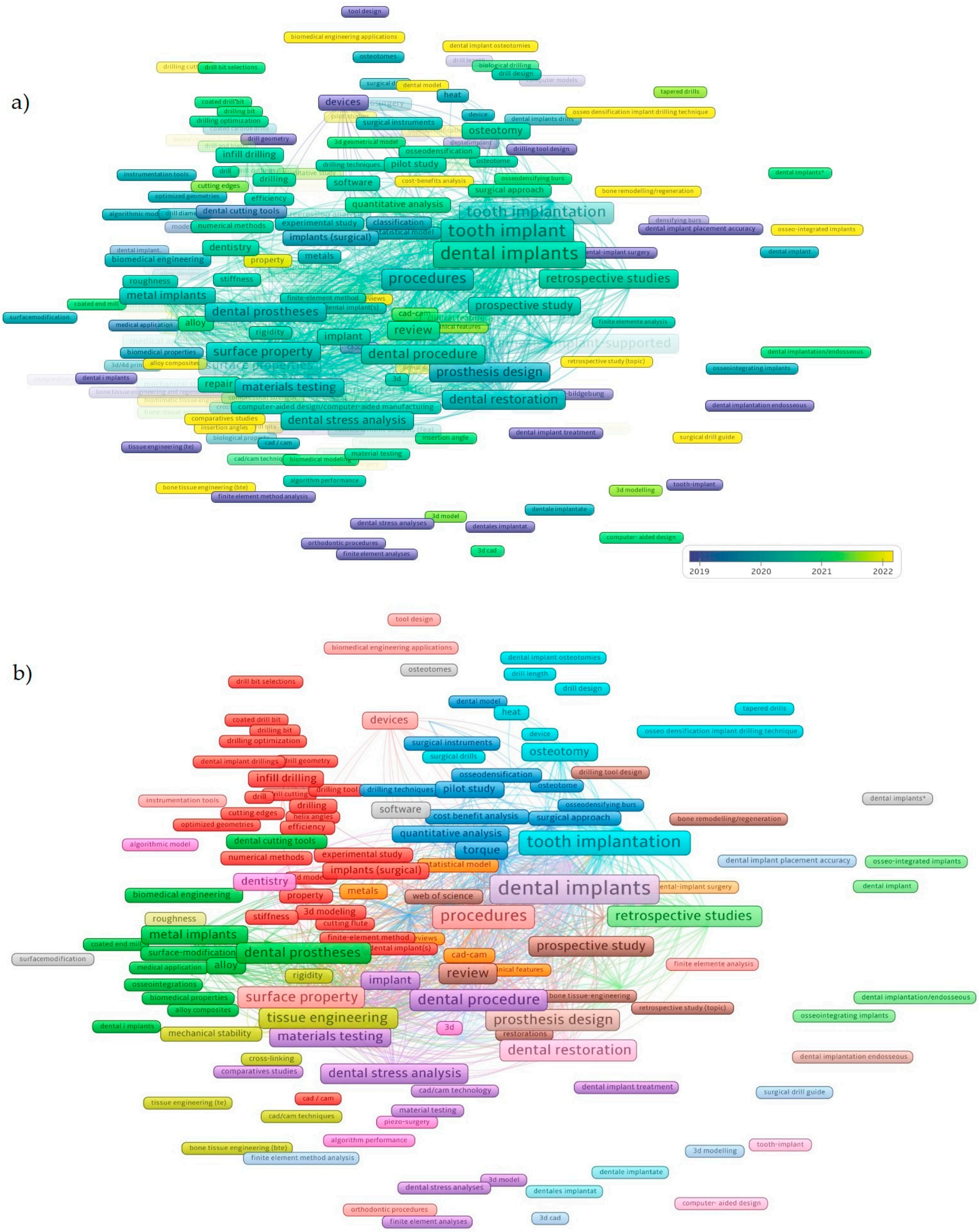


Figure 2. The overlay visualization of word cloud based on the keywords related to osseodensification technique and instrumentation occurring in the research publications from 2019 to the present (according to Scopus, ScienceDirect, and PubMed): (**a**) categorized by years; (**b**) categorized by clusters.

2. Medical Cutting Tools Classification

In surgery, including dentistry, there are many cutting tools used to perform specific actions or carry out desired effects, such as modifying or manipulating biological tissue, providing access for viewing it, or certain manipulations with materials needed during these actions. Medical cutting tools, including the osseodensification burs under consideration, are often quite sophisticated objects, the properties and performance characteristics of which are intricately interconnected with the design parameters [42].

It is obvious that whatever object is being developed or studied, understanding its internal structure and properties helps to make the work more efficient. Due to this, the classification of medical cutting tools shall be developed in order to identify their key features and how they are inherited from a higher class of similar objects. Single-edge and multipoint tools with defined sharp blades, e.g., knives, saws, drills, and milling cutters, are used for different surgical procedures. Abrasive tools like abrasive bonds, abrasive heads, and disks can be considered as a subset of multipoint tools. They are also widely used in dentistry and in other medical applications. In addition, although piezoelectric surgery is not a common cutting technique for site preparation, it is sometimes used for maxillary sinus lifting procedures [43,44].

According to the classification shown in Figure 3, the dental burs belong to the class of rotary multipoint tools and a subclass of milling cutters or mills. Consequently, the structural parts of the burs and their design algorithm are basically the same as those of conventional metal-cutting mills.

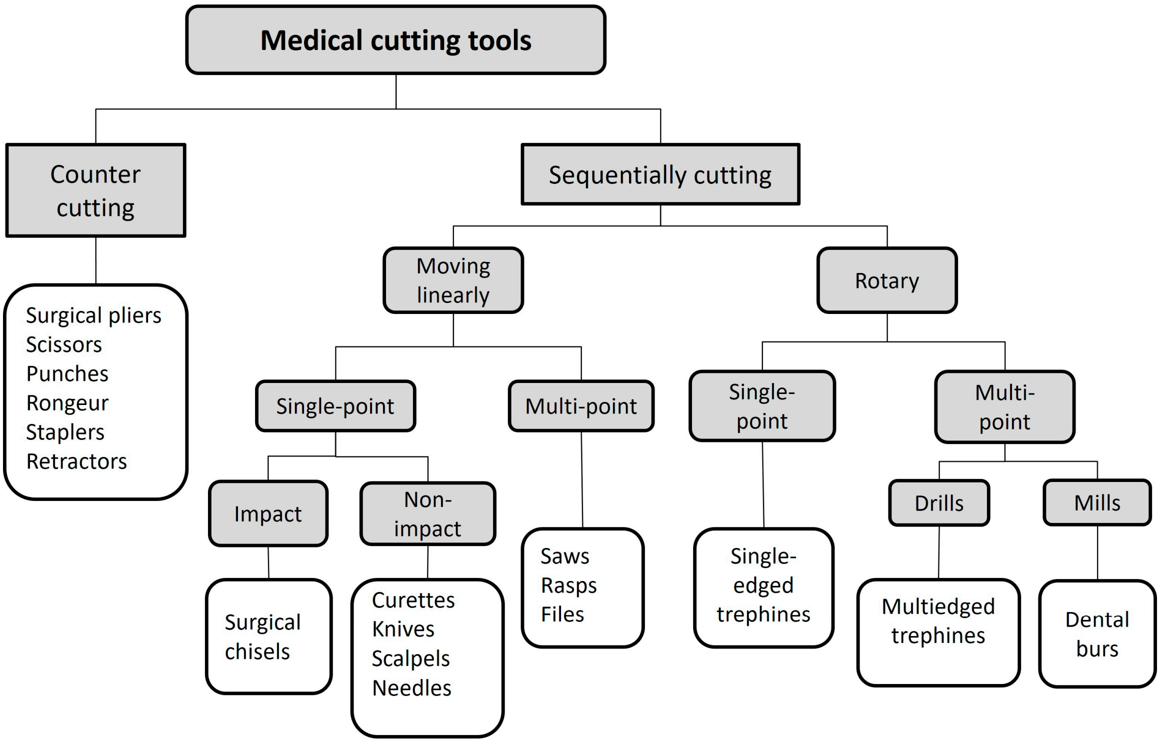


Figure 3. Classification of medical cutting tools.

The most crucial requirement for medical cutting tools used in surgical interventions is their high quality, which can be estimated by the indicators of efficiency and safety [45,46]. These indicators are highly dependent on the material and on the cutting geometry [47,48]. The main geometrical features are the dimensions and orientation of multiple cutting blades positioned in a certain way on the tool's body. At the same time, the cutter's design parameters significantly impact the qualitative indicators of the surgical procedure and, first to be analyzed, is the material of the working part.

3. Materials Used for Surgical Cutting Tools

In biomedical applications, the working parts of cutting tools like dental burs and others undergo bending and compressing loads and friction under the influence of corrosive and surface-active media. During surgical operation, the cutting tools are wearing and can lose their cutting properties because the working surfaces and/or cutting edges experience plastic straining (deformation), brittle rupture, and chipping in the corrosive and surface-active media and for other reasons. Thus, the main requirements for materials providing functional properties of medical cutting tools are usually considered to be the following: high hardness (at least 60–62 HRC), cutting capacity, corrosion resistance, wear resistance, low frictional coefficient, and resistance to small plastic deformations. At the same time, high hot hardness is not as important for medical tools as it is for industrial metal-cutting tools [46].

For surgical and dental cutting tools, special grades of steels, including high-carbon steels and high-carbon stainless steels, are generally utilized. The common name for such materials is 'surgical steels', although there is no formal definition of what exactly constitutes this group of materials. Normally, the traditional surgical steels mainly used for biomedical implants like austenitic SAE 316 stainless and martensitic SAE 440, SAE 420, and 17–4 stainless steels [49], as well as martensitic stainless steel 420HC and 410 have insufficient hardness (usually about 52–58 HRC) and poor cutting edge retention and thus unacceptable for medical cutting tools.

For the reasons mentioned above, the most commonly used materials for medical cutting tools are chromium–nickel and chromium–molybdenum austenitic steel grades and maraging steels. When the chromium content exceeds 11%, it forms an oxide coating, and the steel becomes stainless. Chromium, as well as molybdenum, vanadium, and tungsten, give excellent sharpness and edge retention.

It is also important to take into consideration the adverse effects of nickel ions being released into the human body during surgical interventions. The common recommendation to avoid nickel allergy or other adverse effects is to prevent direct contact of the human body with any nickel-containing material. In addition, high nickel content prevents hardening by heat treatment. Since nitrogen stabilizes the austenitic phase, it can be used instead of nickel in surgical alloys. The nitrogen atom functions similarly to the carbon atom but offers considerable advantages in corrosion resistance. Therefore, the high nitrogen nickel-free austenitic stainless steels are widely used for medical applications [50].

For cutting tools made of conventional high-carbon steels, protection against corrosion can be ensured by coating chromium, nickel, chromium, etc., using the galvanic method. In this case, the coating should usually be removed from the sharp cutting edges. Alternatively, to reduce the heating caused by friction during the bur operation and to extend the tool life, a wear-resistant coating should be applied on the working part of the bur. Usually, the titanium nitride (TiN) coating is the most relevant solution for these purposes.

In recent decades, powder metallurgy technology steels have become widely used in different industries, including biomedicine. The advanced powder surgery steels like M390 Microclean by Bohler have a hardness of about 62–64 HRC, high wear resistance, and high corrosion resistance together with excellent edge retention provided by the addition of chromium, molybdenum, vanadium, and tungsten (about 3–4%). The tool surfaces made of such steel grades can be polished to an extremely high finish, providing perfect cutting capacity.

Table 1 shows comparative data for the most widely used grades of surgical steels and their designation according to different national standards.

As the materials for cutting parts of the surgical and dental tools, the sintered cemented tungsten carbides and tungsten-less cemented carbides (cermets) can be used. Wear and corrosion-resistant coatings composed of carbides, nitrides, borides of ferrum (Fe), chromium (Cr), and other metals or alloys, as well as super hard materials like diamonds, are applied on the working surfaces of the tools [51–53].

Table 1. Chemical composition and hardness of typical materials used for the manufacture of medical cutting tools with the designations according to various national standards.

Material Designation According to the Standards: (1) GOST; (2) AISI; (3) DIN; (4) Others	C, %	Cr, %	Ni, %	Si, %	Mn, %	Hardness After Hardening, HRC	Others
(1) U8A (2) C80W1 (3) 1.1525, C80W1	0.75–0.84	<0.2	<0.25	0.17–0.33	–	58–61	
(1) U10A (2) W5, W110 (3) 1.1545, C105W1, C105W2 (4) T10A	0.95–1.09	<0.2	<0.25	0.17–0.33	0.17–0.28	59–62	
(1) U12A (4) JIS SK2	1.1–1.29	<0.2	<0.25	0.17–0.33	0.17–0.28	61–64	
(1) 30X13, 40X13 (2) 420 (3) 1.4028, 1.4034, X30Cr13, X40Cr13 (4) 3Cr13, Cr13, SUS420J2	0.26–0.44	12–14	<0.6	<0.8	<0.8	55–57	Mo < 4.0 (USA)
(2) 420HC	0.4–0.45	12.5–13.5	<0.08	0.25–0.75	<1.0	40–52	Mo: <0.5 Al: <0.5 Cu: <0.5
(1) 98X18 (2) 440 (3) 1.4125, X105CrMo17, X102CrMo17 (4) JIS SUS440C	0.9–1.0	17–19	<0.6	<0.8	<0.8	60	Ti < 0.2 Mo < 4.0 (USA)
(2) 154CM (4) ATS-34 (Japan)	1.05	14	N/A	0.30%	0.50%	60–64	Mo < 4.00%
(2) Bohler M390 Microclean	N/A	18–20	N/A	N/A	N/A	60–62	Mo, V 3–4%, and W

Ceramics are widely used for dental implant manufacturing [54–56]. Although experimental studies with implant drills made of special grades of cutting ceramics were also conducted, the effectiveness of these materials has not yet been proven [57–59].

The dental burs are often made of tungsten carbide or diamond. Diamond burs seem to give better control and tactile feedback than carbide burs due to the fact that the diamonds are always in contact with the milled tooth in comparison to the single blades of the carbide burs. The heads of other commonly used burs are covered in fine grit, which has a similar cutting function to blades (e.g., high-speed diamond burrs). In dental practice, the diamond heads operating at ultra-high speeds (up to 300,000 rpm) are increasingly being used.

Further, we will consider the burs with the defined cutting edges made of high-carbon stainless steel.

4. Materials Structural Model of a Typical Osseodensification Bur

The graph theory provides a flexible and universal approach to engineering analysis. As for any technical object, the structural model of the osseodensification bur can be visually represented as a hypergraph (Figure 4). In this graph, each vertex or edge denotes the structural part of its parameter. This helps to identify the structural elements of the objects being developed, while the extended version of the graph clearly shows a system of functional relationships between the design features of the object, its operational conditions, and performance and quality indicators. For the osseodensification burs, the graph model is based on the comprehensive analysis of previous studies made by medical professionals and engineers. Based on the system of functional relationships, an initial dataset used for designing the cutting tool can be developed [60].

In Figure 4, the edge l_1 defines the main structural parts of the bur, which include the working part WP (vertex x_1) and the clamping part CP (vertex x_2). The working part is represented by the edge l_{x1} and consists of the cutting edge CE (vertex x_{11}), the working edge WE (vertex x_{12}), the main rake surface MRS (vertex x_{13}), the major flank surface MFS (x_{14}), the auxiliary rake surface ARS (vertex x_{15}) and the auxiliary flank surface AFS (x_{14}). Each of these elements has parameters described by edges lx_{11}–lx_{15} containing the corresponding sets of vertices. Thus, the cutting edge CE is characterized by outer diameter D (vertex x_{111}), core diameter D_{core} (vertex x_{112}), cutting edge rounding radius r (vertex x_{113}), tip angle φ (vertex x_{114}), and others (vertex $x_{11\text{n}}$). The working edge WE has the total operational length L (vertex x_{121}), edge rounding radius r_1 (vertex x_{122}), flute helix angle ω (vertex x_{123}), cone angle φ_1 (vertex x_{124}), and others (vertex $x_{12\text{n}}$). The main rake surface MRS has the following parameters: main rake angle γ (vertex x_{131}), rake surface curvature radius R (vertex x_{132}), and others (vertex $x_{13\text{n}}$). The main flank surface MFS is described by main clearance (relief) angle α (vertex x_{141}), margin width f (vertex x_{142}), flank surface curvature radius R_f (vertex x_{143}), and others (vertex $x_{14\text{n}}$). The auxiliary rake surface ARS has a set of parameters, including auxiliary rake angle γ_1 (vertex x_{151}), a curvature radius of the auxiliary rake surface, R_1 (vertex x_{152}), and others (vertex $x_{15\text{n}}$). The auxiliary flank surface AFS encompasses auxiliary clearance (relief) angle α_1 (vertex x_{161}), auxiliary margin width f_1 (vertex x_{162}), a curvature radius of auxiliary flank surface, R_{f1} (vertex x_{163}), and others (vertex $x_{14\text{n}}$).

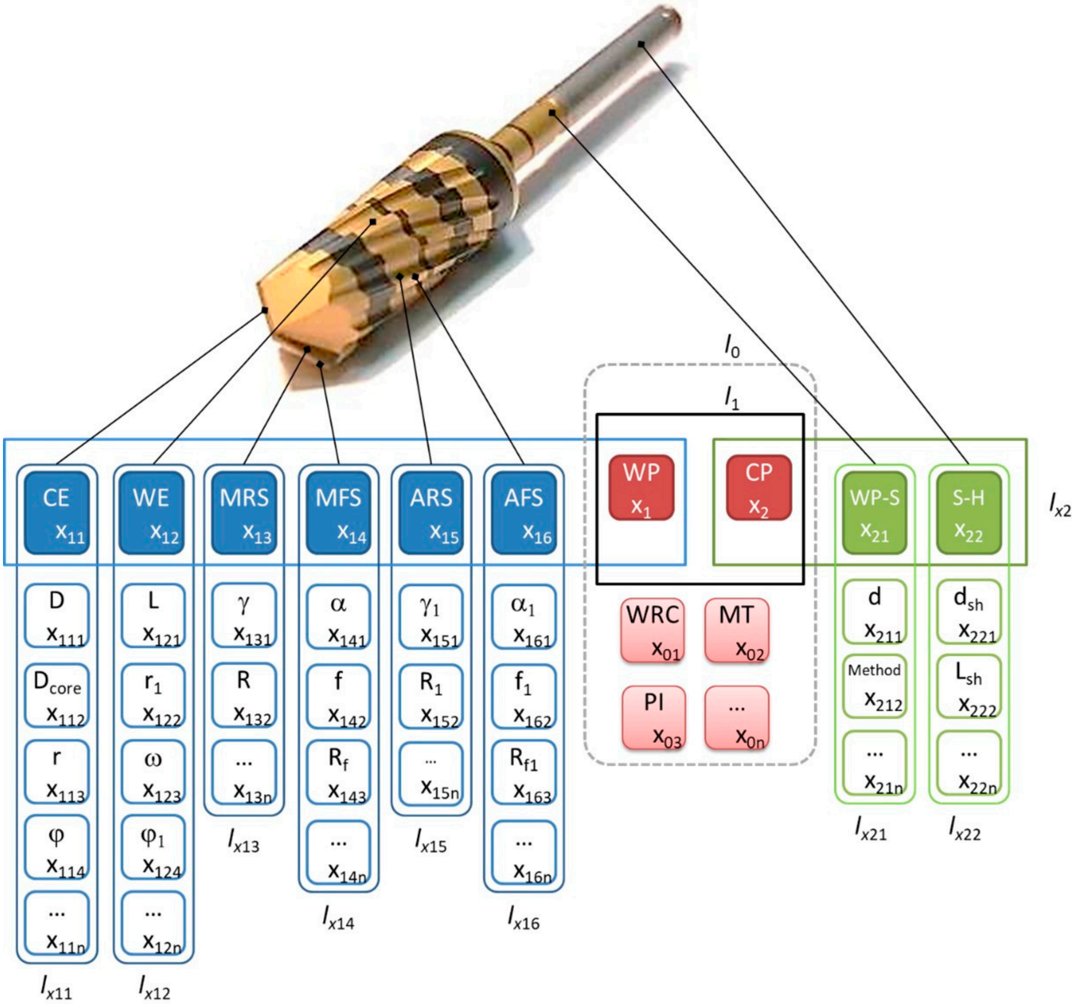


Figure 4. Hypergraph structural model of the osseodensification bur (on the example of Versah® bur).

Similarly, the clamping part of the bur (edge l_{x2}) is composed of structural elements for connecting the working part to the shank WP-S (vertex x_{21}). This connecting element is characterized by its own set of parameters represented in the graph by the edge lx_{21}. This edge includes the following elements: coupling diameter d (vertex x_{211}), coupling method parameters (vertex x_{212}), and others (vertex $x_{21\text{n}}$). The connection between the bur as a whole and the dental handpiece is shown as the edge lx_{22}, which consists of the diameter of shank d_{sh} (vertex x_{221}), length of shank L_{sh} (vertex x_{222}), and others (vertex $x_{22\text{n}}$). In addition, the bur has other properties and parameters (wear-resistant coating, parameters of manufacturing technology, performance indicators, and others). These characteristics are represented in the graph by the edge l0 with vertices $x_{01}\ldots x_{0n}$, respectively.

The hierarchy of structural parts of osseodensification bur, its structural elements and their parameters are described on the hypergraph by the functional links between edges and vertices $\{x_1, l_{x1}\}$, $\{x_2, l_{x2}\}$, $\{x_{11}, l_{x11}\}$, $\{x_{12}, l_{x12}\}$, $\{x_{13}, l_{x13}\}$, $\{x_{14}, l_{x14}\}$, $\{x_{15}, l_{x15}\}$, $\{x_{16}, l_{x16}\}$, $\{x_{21}, l_{x21}\}$. Consequently, the general structure of the osseodensification bur can be described as follows:

$$l_0 = \bigcup_{i=1}^{2} x_i \bigcup_{i=1}^{n} x_{0i} = \bigcup_{i=1}^{6} x_{1i} \bigcup_{i=1}^{2} x_{2i} \bigcup_{i=1}^{n} x_{0i} = \bigcup_{i=1}^{n} x_{11i} \bigcup_{i=1}^{n} x_{12i} \bigcup_{i=1}^{n} x_{13i} \bigcup_{i=1}^{n} x_{14i} \bigcup_{i=1}^{n} x_{15i} \bigcup_{i=1}^{n} x_{16i} \bigcup_{i=1}^{n} x_{21i} \bigcup_{i=1}^{n} x_{22i} \bigcup_{i=1}^{n} x_{0i} \quad (1)$$

The sum of the sets forms the set of unique parameters used to develop a database of design and technological solutions related to the considered cutting tool. It shall also be utilized in computer-aided design (CAD) systems to make a parametric geometric model of the osseodensification bur.

5. Design Features of Osseodensification Burs

Generally, a dental bur consists of three main parts: the head, the neck, and the shank. Some designs of burs (e.g., tungsten carbide burs) may have cutting blades on their head. The multipoint burs with the defined cutting edges are equipped with sharp cutting blades that may be positioned at different angles measured in the radial, axial, or normal cross-section of the bur with respect to the axis of symmetry or to another imaginary straight line. More obtuse angles will produce a negative rake angle, which increases the strength and longevity of the bur. More acute angles will produce a positive rake angle, where the blade is sharper but which wears and dulls more quickly.

For the osseodensification operations, a bur shall be equipped with at least four spiral cutting edges and channels, called flutes. Conventional, or subtractive, drilling procedure involves cutting the bone tissue with the cutting edges and removing debris from the hole through the flutes. This requires a positive rake angle for better entrance into the tissue and an optimal cutting process when removing a small thickness of the tissue material during one revolution of the bur. Typically, the twist burs (drills) designed for the osteotomy have two or three flutes and a 25 to 35-degree rake angle. Conventional drilling shall be performed in a clockwise direction [61]. A drawing of a typical osseodensification bur designed by the Versah® with the parameter designations according to the hypergraph model is shown in Figure 5.

Conversely, the specially designed burs for osseous densification shall have more flutes (four or more) and a large negative rake angle. In this case, the edges are non-cutting, and they progressively increase the diameter of the precursor hole and densify the osteotomy site walls. This design allows the bone to be preserved by autografting bone particles against the bed walls through an entry and exit movement. The typical range of rotational speed both for drilling (clockwise direction) and osseous densification (counterclockwise) procedures is 300–1200 rpm, depending on the density of the bone [1,11].

When performing surgical operations, it is crucially important to prevent event short-term overheating or heating up to the 41° C threshold in the operation zone. Usually, the densifying burs have a tapered shape because it is reported [62] that tapered tools with three or four flutes generate less heat than the cylindrical drill with two or three flutes, respectively. It is explained that the entire length of the tapered multi-flute drill interacts with the bone, distributing heat over a greater surface area and causing deformation, mass loss, and wear of burs [48,63–80].

Based on the standard design procedure of traditional metal cutting tools, a typical minimum set of parameters required for designing osseodensification burs was identified. The values of these parameters were obtained from the literature and patent review and are represented in the form of Table 2. As can be seen from the Table, some parameters either remain undetermined, or their values are given in a too wide range. Thus, further research and experimental studies are required to establish the reasonable values of these parameters, taking into account the surgical quality and manufacturing constraints.

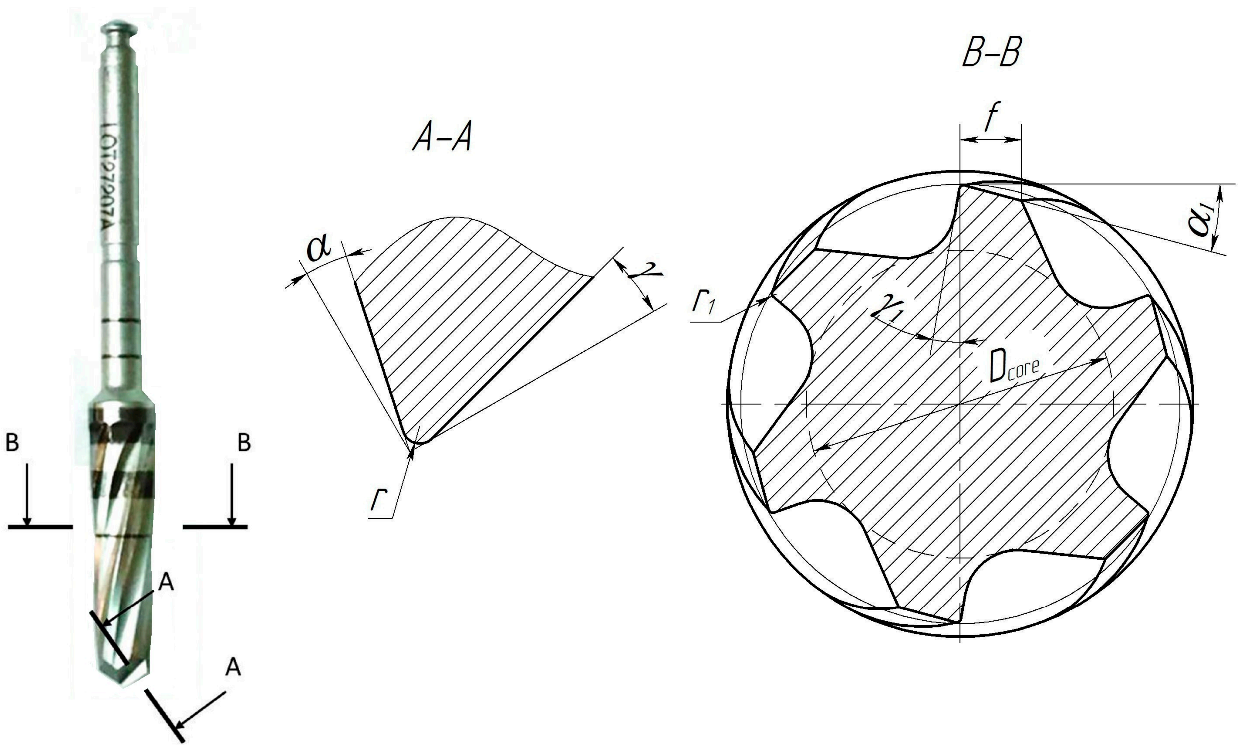


Figure 5. Drawing of the Versah® osseodensification bur: D_{core}—core diameter, A-A cross-section normal to the cutting edge; B-B—radial cross-section; f—margin width; r—cutting edge rounding radius; r_1—edge rounding radius; γ—main rake angle in the A-A cross-section; α—main clearance angle in the A-A cross-section; γ_1—auxiliary rake angle in the B-B cross-section; α_1—auxiliary clearance angle in the B-B cross-section.

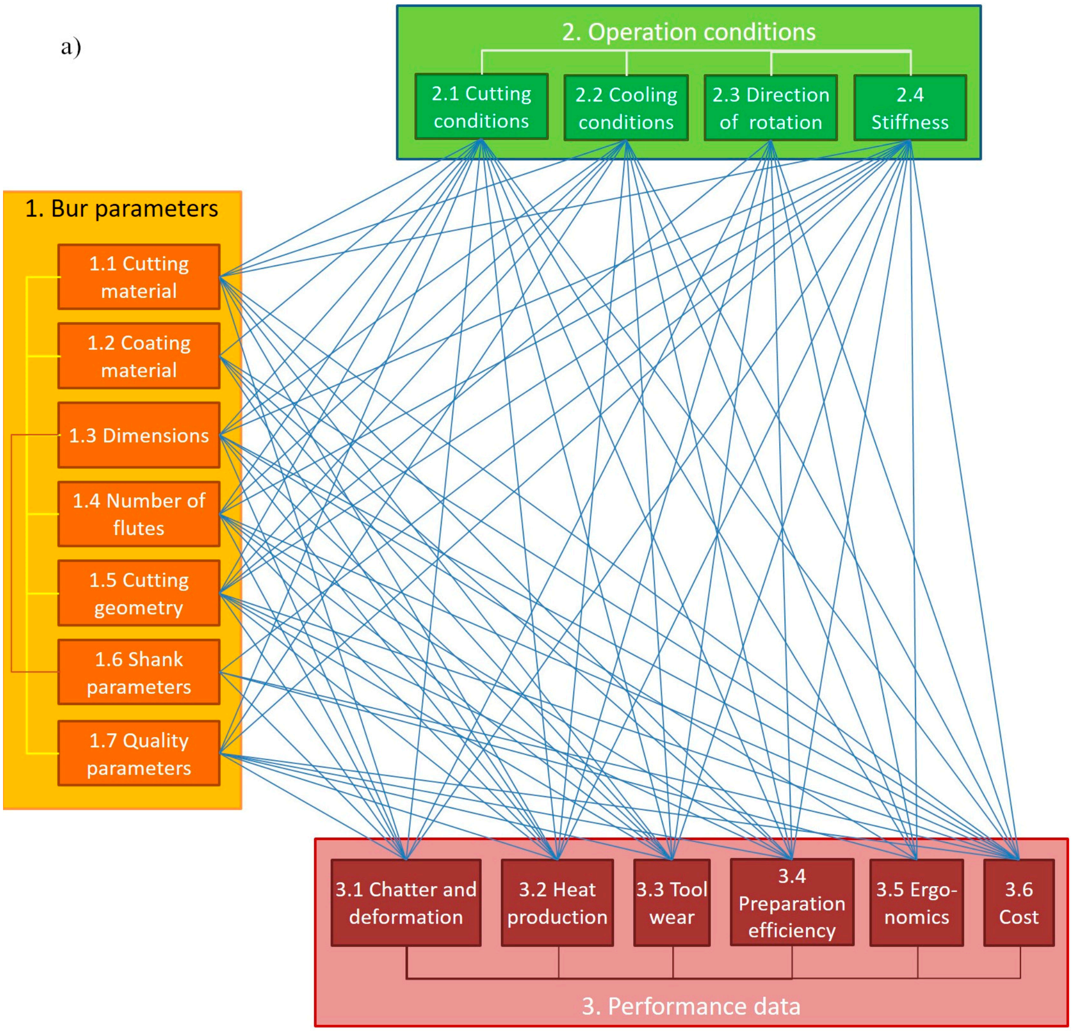
Figure 6a represents a system of functional relationships between three main groups of features and properties, i.e., parameters of osseodensification burs, osseodensification operation conditions, and procedure performance data. As can be seen, there are links not only between blocks belonging to different groups but within each group, too. Thus, the system can also be thought of as a hypergraph, like the one described above. The corresponding sets of parameters were identified based on the analysis of previous studies and the authors' engineering and surgeon experience. Therefore, this system can be flexibly changed if necessary. On the whole, such a model forms the database structure, which will be further integrated into the CAD module under development for the complex design of the burs.

The most important parameters of burs (blocks 1.1–1.7) are described above. In addition, it should be specified that the bur quality parameters (block 1.7) include the roughness of the working surfaces, the accuracy of the working and clamping parts of the bur, and the parameters of the workflow of the bur manufacturing. The cutting conditions (block 2.1) are represented by the rotational speed and feeding speed of the bur (usually controlled by the hand of a surgeon). The direction of rotation (block 2.3) can be formally considered as a cutting condition, but it was decided to make it a separate item since it plays a key role in the osseodensification procedure. Cooling conditions (block 2.2) describe how the cooling water reaches the osteotomy site. Stiffness (block 2.4) characterizes how the bur resists the dynamic deforming forces during operation. The performance data blocks (3.1–3.6) are mostly self-explanatory, except for the preparation efficiency (block 3.4), which is a complex criterion of a good osseointegration.

Table 2. The most important design parameters of osseodensification burs.

	Parameter	Recommended Value	Comment
Material			
	Hardness, HRC	>55	Ensures high cutting capability and good cutting edge retention [34]
	Ultimate strength, MPa	Not determined	Prevents deforming, cracking, and breakage of the tool [34]
	Thermal conductivity	Not determined	Dissipates heat in the tool's body [34]
	Wear-resistant coating (grade)	Titanium nitride (TiN)	Reduces heating, extends tool life [34]
	Corrosion resistance	Chromium content higher than 12%	Prevents corrosion [34]
	Antiallergic properties	Nickel content lower than 0.25%	Helps to avoid nickel allergy or other adverse effects [38]
Cutting part			
	Shape (outline)	Cylindrical	Preferred for conventional subtractive drilling of the pilot hole in the osteotomy [25]
		Cone-shaped	Being equipped with 4 or more flutes generates less heat than conventional cylindrical drills [44]
	Outer diameter	0.4–6 mm	For conical bur, the diameter shall be gradually increased as the burs enter deeper into the pilot hole [16,21,75]
	Body length	10–25 mm	[25]
	Core diameter	Not determined	Influences the bur strength, depth of flutes, and hence the removal of debris from the osteotomy
	Number of flutes	4 or more	The leaps of 4-flute drills provide better heat distribution than ones with 2 or 3 flutes regardless of the conicity or the cylindricity of the drill [44]
	Conicity angle	Recommended range of 1–5°, best results with 2°36′ [25]	Influences the heating and densification capability
	Rake angle	Zero or positive for cutting Large negative for osseodensification (−1–−75°, usually in a range of 30°). This is a function of distance from the apical end of the bur [25]	Positive value gives much better cutting ability and absence of bone residue in the osteotomy. Negative rake promotes the osteotomy site wall compaction due to lateral bone displacement, allowing the preservation of bone by autografting bone particles against the bed walls through an entry and exit movement [1].
	Tip angle	30–75° [25]	Influences the positioning in the osteotomy and entrance into cutting
	Clearance angles at main cutting edges (apical end of bur)	First clearance angle is 30–60°, best results with 6–28° The second clearance angle is about 40° [25]	Determines the bone compaction capability. Influences the heating and toughness of the tooth
	Cutting edge rounding radius	Not determined	Influences the heating and working capacity
	Flute helix angle	5–20° [25]	Influences the removal of material from the hole and osteotomy site walls compaction capability
Shank			
	Standard	Cylindrical	Typically, the diameter is either 1.6 mm (1/16 inches) or 2.35 mm (3/32 inches)
		Tapered	May be preferred for larger diameters

a)



b)

	1.1	1.2	1.3	1.4	1.5	1.6	1.7
2.1	1	1	1	1	1	0	1
2.2	1	1	1	1	1	0	1
2.3	0	0	0	0	1	0	0
2.4	1	0	1	1	1	1	1

c)

	1.1	1.2	1.3	1.4	1.5	1.6	1.7
3.1	1	0	1	1	1	1	1
3.2	1	1	0	1	1	0	1
3.3	1	1	1	1	1	0	1
3.4	1	1	0	1	1	0	1
3.5	0	0	1	0	0	1	1
3.6	1	1	1	1	1	1	1

d)

	2.1	2.2	2.3	2.4
3.1	1	1	1	1
3.2	1	1	1	1
3.3	1	1	1	1
3.4	1	1	1	1
3.5	1	1	1	1
3.6	1	1	1	1

Figure 6. Model of functional relationships between main features and properties of osseodensification burs, procedure conditions, and performance data: (**a**)—hypergraph representation; (**b**)—relationships between osseodensification bur design parameters and osseodensification operation conditions; (**c**)—relationships between osseodensification bur design parameters and performance data; (**d**)—relationships between osseodensification operation conditions and performance data.

To create a database for the CAD system, this hypergraph can be represented as a set of three incidence matrices shown in Figure 6b,c. For better clarity, different colors were used to indicate the type of links (or their weight factors, if that is more convenient). The red color shows that there is no connection between parameters, or it can hardly be described. Yellow says that the connection is established empirically and cannot be described analytically, rather than, for example, by an equation with a series of correction factors. Green indicates that the relationship can be represented as an analytical expression. It is important to emphasize that the link types shown in Figure 6b,c were identified for the dental application, but for the metalworking industry, many of the same or similar connections may have a mathematical representation.

6. Conclusions

In this article, an analysis of multipoint cutting tools used for the innovative osseodensification procedure was performed. Based on the studies performed by previous researchers related to instrumentation and methods of osseodensification, the classification of medical cutting tools was developed. It became the basis for the graph structural model, which allows the identification of the principal structural components and the main requirements for their properties.

An analysis of cutting materials used for surgery cutting tools with the designations according to various national standards was completed. It showed a number of alloys that can be reasonably chosen for the manufacture of dental cutting tools, including osseodensification burs. The main requirements for the cutting tool material are high hardness, corrosion resistance, and cutting edge retention. To reduce undesired frictional heating, the wear-resistant coating can be applied to the working part of the bur.

The most typical design features of osseodensification burs were analyzed. The analysis results showed that many structural parameters of osseodensification burs are undetermined or have too wide a range of recommended values. This means that further research should be conducted to establish the appropriate values of the bur's design parameters, which will improve the qualitative indicators of the surgical procedure. To achieve this, a specialized CAD module for osseodensification burs design will be created. The formal models being carried out in the present article provide a versatile approach to making comprehensive designs of experiments for future studies dedicated to improving the efficiency of the osseodensification procedure.

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References

1. Cáceres, F.; Troncoso, C.; Silva, R.; Pinto, N. Effects of osseodensification protocol on insertion, removal torques, and resonance frequency analysis of BioHorizons® conical implants. An ex vivo study. *J. Oral Biol. Craniofac. Res.* **2020**, *10*, 625–628. [CrossRef]
2. Stavropoulos, A.; Nyengaard, J.R.; Lang, N.P.; Karring, T. Immediate loading of single SLA implants: Drilling vs. osteotomes for the preparation of the implant site. *Clin. Oral Implant. Res.* **2008**, *19*, 55–65. [CrossRef] [PubMed]
3. Stübinger, S.; Biermeier, K.; Bächi, B.; Ferguson, S.J.; Sader, R.; von Rechenberg, B. Comparison of Er: YAG laser, piezoelectric, and drill osteotomy for dental implant site preparation: A biomechanical and histological analysis in sheep. *Lasers Surg. Med.* **2010**, *42*, 652–661. [CrossRef] [PubMed]

4. Torroni, A.; Lima Parente, P.E.; Witek, L.; Hacquebord, J.H.; Coelho, P.G. Osseodensification Drilling vs Conventional Manual Instrumentation Technique for Posterior Lumbar Fixation: Ex-Vivo Mechanical and Histomorphological Analysis in an Ovine Model. *J. Orthop. Res.* **2021**, *39*, 1463–1469. [CrossRef] [PubMed]
5. Pandey, R.K.; Panda, S. Drilling of bone: A comprehensive review. *J. Clin. Orthop. Trauma* **2013**, *4*, 15–30. [CrossRef]
6. Punnoose, K.; Kumar, G.A.; Mahesh, B.; Govindarajulu, R.; Amalorpavam, V.; Ebinu, A.; Babu, J.S.; Swarnalatha, C.; Nayyar, A.S. Osseodensification implant site preparation technique and subsequent implant stability: A pilot study. *J. Orthod. Sci.* **2022**, *11*, 50. [CrossRef]
7. Delgado-Ruiz, R.; Gold, J.; Somohano Marquez, T.; Romanos, G. Under-Drilling versus Hybrid Osseodensification Technique: Differences in Implant Primary Stability and Bone Density of the Implant Bed Walls. *Materials* **2020**, *13*, 390. [CrossRef]
8. Almutairi, A.S.; Walid, M.A.; Alkhodary, M.A. The effect of osseodensification and different thread designs on the dental implant primary stability. *F1000Res* **2018**, *7*, 1898. [CrossRef]
9. Coelho, P.G.; Marin, C.; Teixeira, H.S.; Campos, F.E.; Gomes, J.B.; Guastaldi, F.; Anchieta, R.B.; Silveira, L.; Bonfante, E.A. Biomechanical evaluation of undersized drilling on implant biomechanical stability at early implantation times. *J. Oral Maxillofac. Surg.* **2013**, *71*, e69–e75. [CrossRef]
10. Lahens, B.; Neiva, R.; Tovar, N.; Alifarag, A.M.; Jimbo, R.; Bonfante, E.A.; Bowers, M.M.; Cuppini, M.; Freitas, H.; Witek, L.; et al. Biomechanical and histologic basis of osseodensification drilling for endosteal implant placement in low density bone. An experimental study in sheep. *J. Mech. Behav. Biomed. Mater.* **2016**, *63*, 56–65. [CrossRef]
11. Huwais, S.; Meyer, E.G. A Novel Osseous Densification Approach in Implant Osteotomy Preparation to Increase Biomechanical Primary Stability, Bone Mineral Density, and Bone-to-Implant Contact. *Int. J. Oral Maxillofac. Implant.* **2017**, *32*, 27–36. [CrossRef]
12. Giro, G.; Tovar, N.; Marin, C.; Bonfante, E.A.; Jimbo, R.; Suzuki, M.; Janal, M.N.; Coelho, P.G. The effect of simplifying dental implant drilling sequence on osseointegration: An experimental study in dogs. *Int. J. Biomater.* **2013**, *2013*, 230310. [CrossRef] [PubMed]
13. Bertollo, N.; Walsh, W.R. Drilling of bone: Practicality, limitations and complications associated with surgical drill bits. *Biomech. App.* **2011**, 53–83. [CrossRef]
14. Bhargava, N.; Perrotti, V.; Caponio, V.C.A.; Matsubara, V.H.; Patalwala, D.; Quaranta, A. Comparison of heat production and bone architecture changes in the implant site preparation with compressive osteotomes, osseodensification technique, piezoelectric devices, and standard drills: An ex vivo study on porcine ribs. *Odontology* **2023**, *111*, 142–153. [CrossRef] [PubMed]
15. Oliveira, P.G.F.P.; Bergamo, E.T.P.; Neiva, R.; Bonfante, E.A.; Witek, L.; Tovar, N.; Coelho, P.G. Osseodensification outperforms conventional implant subtractive instrumentation: A study in sheep. *Mater. Sci. Eng. C* **2018**, *90*, 300–307. [CrossRef]
16. Campos, F.E.; Gomes, J.B.; Marin, C.; Teixeira, H.S.; Suzuki, M.; Witek, L.; Zanetta-Barbosa, D.; Coelho, P.G. Effect of drilling dimension on implant placement torque and early osseointegration stages: An experimental study in dogs. *J. Oral Maxillofac. Surg.* **2012**, *70*, e43–e50. [CrossRef]
17. Mullings, O.; Tovar, N.; Abreu de Bortoli, J.P.; Parra, M.; Torroni, A.; Coelho, P.G.; Witek, L. Osseodensification Versus Subtractive Drilling Techniques in Bone Healing and Implant Osseointegration: Ex Vivo Histomorphologic/Histomorphometric Analysis in a Low-Density Bone Ovine Model. *Int. J. Oral Maxillofac. Implant.* **2021**, *36*, 903–909. [CrossRef]
18. Inchingolo, A.D.; Inchingolo, A.M.; Bordea, I.R.; Xhajanka, E.; Romeo, D.M.; Romeo, M.; Zappone, C.M.F.; Malcangi, G.; Scarano, A.; Lorusso, F.; et al. The Effectiveness of Osseodensification Drilling Protocol for Implant Site Osteotomy: A Systematic Review of the Literature and Meta-Analysis. *Materials* **2021**, *14*, 1147. [CrossRef]
19. de Carvalho Formiga, M.; Grzech-Leśniak, K.; Moraschini, V.; Shibli, J.A.; Neiva, R. Effects of Osseodensification on Immediate Implant Placement: Retrospective Analysis of 211 Implants. *Materials* **2022**, *15*, 3539. [CrossRef]
20. Padhye, N.M.; Padhye, A.M.; Bhatavadekar, N.B. Osseodensification—A systematic review and qualitative analysis of published literature. *J. Oral Biol. Craniofac. Res.* **2020**, *10*, 375–380. [CrossRef]
21. Fontes Pereira, J.; Costa, R.; Nunes Vasques, M.; Salazar, F.; Mendes, J.M.; Infante da Câmara, M. Osseodensification: An Alternative to Conventional Osteotomy in Implant Site Preparation: A Systematic Review. *J. Clin. Med.* **2023**, *12*, 7046. [CrossRef]
22. Aloorker, S.; Shetty, M.; Hegde, C. Effect of Osseodensification on Bone Density and Crestal Bone Levels: A Split-mouth Study. *J. Contemp. Dent. Pr.* **2022**, *23*, 162–168.
23. Haggag, M.; Said, W.; Attia, A.; Tawfik, M. Evaluation of Bone Density after Bone Condensation around Immediate Loaded Dental Implants using Different Techniques. *J. Amer. Sci.* **2020**, *16*, 33–42. [CrossRef]
24. Hashem, A.H.; Khedr, M.F.; Hosny, M.M.; El-Destawy, M.T.; Hashem, M.I. Effect of Different Crestal Sinus Lift Techniques for Implant Placement in the Posterior Maxilla of Deficient Height: A Randomized Clinical Trial. *Appl. Sci.* **2023**, *13*, 6668. [CrossRef]
25. Hung, C.C.; Liu, T.C. Graftless Sinus Augmentation via Crestal Sinus Floor Elevation using Densah Burs with Simultaneous Implant Placement: A Clinical Report after Two Years in Service. *SVOA Dent.* **2023**, *4*, 128–136. [CrossRef]
26. Lahens, B.; Lopez, C.D.; Neiva, R.F.; Bowers, M.M.; Jimbo, R.; Bonfante, E.A.; Morcos, J.; Witek, L.; Tovar, N.; Coelho, P.G. The effect of osseodensification drilling for endosteal implants with different surface treatments: A study in sheep. *J. Biomed. Mater. Res. Part B* **2019**, *107*, 615–623. [CrossRef]
27. Mangalekar, S. *Osseodensification. To Cut or To Condense*; LAP LAMBERT Academic Publishing: London, UK, 2023; p. 124.
28. Riad, A.; Fahmy, A.; el Khourazaty, N. Evaluation of implant's primary stability using Densah bur versus expander in patients with missing maxillary premolar (A randomized clinical trial). *Egypt. Dent. J.* **2021**, *67*, 1487–1495. [CrossRef]
29. Densah® Bur & Versah® Universal Guided Surgery System Instructions for Use. Available online: https://www.versah.co.uk/storage/uploads/Versah%20Catalogue%20and%20Manual%20Updated.pdf (accessed on 3 November 2023).

30. Elghobashy, M.T.M.; Shaaban, A.M.; Melek, L.N.F. Radiographic comparison between Densah burs and osteotome for graftless internal sinus lifting with simultaneous implant placement: A randomized clinical trial. *Int. J. Oral Maxillofac. Surg.* **2023**, *52*, 388–395. [CrossRef]
31. Seo, D.-J.; Moon, S.-Y.; You, J.-S.; Lee, W.-P.; Oh, J.-S. The Effect of Under-Drilling and Osseodensification Drilling on Low-Density Bone: A Comparative Ex Vivo Study. *Appl. Sci.* **2022**, *12*, 1163. [CrossRef]
32. Samojlovich, M.I.; Ivakhin, A.V.; Pastushenko, V.N. Dental Borer. RU 2269966, 20 February 2006.
33. Moon, D.K.; Eom, T.G.; Li, T.E. Implant Surgical Drill. RU 2515400, 10 May 2014.
34. Vinokur, V.S.; Ignashin, Y.P.; Utyashev, R.A.; Shakirov, N.K.; Shvetsov, M.A. Dental Drill. RU 2007967, 28 February 1994.
35. Burke, E.; Sollberger, D.; Nussbaumer, S.; Holst, S.; Geiselhoeringer, H.; Quarry, A.; Weitzel, J. Dental Tool. RU 2794293, 14 April 2023.
36. Huwais, S. Autografting Tool with Enhanced Flute Profile and Methods of Use. WO 2017/124079, 20 July 2017.
37. Huwais, S. Autografting Osteotome. US 10039621, 7 August 2015.
38. Huwais, S. Fluted Osteotome and Surgical Method for Use. US 9022783, 5 May 2015.
39. Huwais, S. Hollow-Point Condensing-Compaction Tool. US 2022/0160371, 26 May 2022.
40. Huwais, S. Autografting Tool for Deep Reach Applications. WO 2020097144, 14 May 2020.
41. Huwais, S. Hollow-Point Condensing-Compaction Tool. WO 2020210442, 15 October 2020.
42. Jackson, C.J.; Ghosh, S.K. On the evolution of drill-bit shapes. *J. Mech. Work. Technol.* **1989**, *18*, 231–267. [CrossRef]
43. De Santis, R.; Gloria, A.; Russo, T.; D′Amora, U.; Rodrigues, D.; Colella, F.; Ronca, D.; Ambrosio, L. An analysis on the inserts for piezoelectric bone surgery: The effect of cutting and sterilization processes. *Int. J. Eng. Innov. Technol.* **2015**, *4*, 174–180.
44. Sagheb, K.; Kumar, V.V.; Azaripour, A.; Walter, C.; Al-Nawas, B.; Kämmerer, P.W. Comparison of conventional twist drill protocol and piezosurgery for implant insertion: An ex vivo study on different bone types. *Clin. Oral Implant. Res.* **2017**, *28*, 207–213. [CrossRef] [PubMed]
45. Pavlíková, G.; Foltán, R.; Horká, M.; Hanzelka, T.; Borunská, H.; Šedý, J. Piezosurgery in oral and maxillofacial surgery. *Int. J. Oral Maxil. Surg.* **2011**, *40*, 451–457. [CrossRef] [PubMed]
46. Sabitov, V.K. *Meditsinkiye Instrumenty [Medical Instruments]*; Meditsina: Moscow, Russia, 1985; p. 173.
47. Tuijthof, G.; Frühwirt, C.; Kment, C. Influence of tool geometry on drilling performance of cortical and trabecular bone. *Med. Eng. Phys.* **2013**, *35*, 1165–1172. [CrossRef] [PubMed]
48. Mendes, G.C.B.; Padovan, L.E.M.; Ribeiro-Júnior, P.D.; Sartori, E.M.; Valgas, L.; Claudino, M. Influence of implant drill materials on wear, deformation, and roughness after repeated drilling and sterilization. *Implant. Dent.* **2014**, *23*, 188–194. [CrossRef] [PubMed]
49. Surgical Stainless Steel. Available online: https://en.wikipedia.org/wiki/Surgical_stainless_steel (accessed on 3 November 2023).
50. Yang, K.; Ren, Y. Nickel-free austenitic stainless steels for medical applications. *Sci. Technol. Adv. Mat.* **2010**, *11*, 014105. [CrossRef]
51. Grigoriev, S.; Peretyagin, N.; Apelfeld, A.; Smirnov, A.; Yanushevich, O.; Krikheli, N.; Kramar, O.; Kramar, S.; Peretyagin, P. Investigation of MAO Coatings Characteristics on Titanium Products Obtained by EBM Method Using Additive Manufacturing. *Materials* **2022**, *15*, 4535. [CrossRef]
52. Grigoriev, S.; Peretyagin, N.; Apelfeld, A.; Smirnov, A.; Rybkina, A.; Kameneva, E.; Zheltukhin, A.; Gerasimov, M.; Volosova, M.; Yanushevich, O.; et al. Investigation of the Characteristics of MAO Coatings Formed on Ti6Al4V Titanium Alloy in Electrolytes with Graphene Oxide Additives. *J. Compos. Sci.* **2023**, *7*, 142. [CrossRef]
53. Grigoriev, S.; Peretyagin, N.; Apelfeld, A.; Smirnov, A.; Morozov, A.; Torskaya, E.; Volosova, M.; Yanushevich, O.; Yarygin, N.; Krikheli, N.; et al. Investigation of Tribological Characteristics of PEO Coatings Formed on Ti6Al4V Titanium Alloy in Electrolytes with Graphene Oxide Additives. *Materials* **2023**, *16*, 3928. [CrossRef]
54. Solís Pinargote, N.W.; Yanushevich, O.; Krikheli, N.; Smirnov, A.; Savilkin, S.; Grigoriev, S.N.; Peretyagin, P. Materials and Methods for All-Ceramic Dental Restorations Using Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) Technologies—A Brief Review. *Dent. J.* **2024**, *12*, 47. [CrossRef]
55. Smirnov, A.; Volosova, M.; Peretyagin, P.; Bartolomé, J. Tribological behaviour of a 3Y-TZP/Ta ceramic-metal biocomposite against ultrahigh molecular weight polyethylene (UHMWPE). *Ceram. Int.* **2018**, *44*, 1404–1410. [CrossRef]
56. Sotova, C.; Yanushevich, O.; Kriheli, N.; Grigoriev, S.; Evdokimov, V.; Kramar, O.; Nozdrina, M.; Peretyagin, N.; Undritsova, N.; Popelyshkin, E.; et al. Dental Implants: Modern Materials and Methods of Their Surface Modification. *Materials* **2023**, *16*, 7383. [CrossRef] [PubMed]
57. Koo, K.-T.; Kim, M.-H.; Kim, H.-Y.; Wikesjö, U.M.E.; Yang, J.-H.; Yeo, I.-S. Effects of Implant Drill Wear, Irrigation, and Drill Materials on Heat Generation in Osteotomy Sites. *J. Oral Implant.* **2015**, *41*, e19–e23. [CrossRef] [PubMed]
58. Oliveira, N.; Alaejos-Algarra, F.; Mareque-Bueno, J.; Ferrés-Padró, E.; Hernández-Alfaro, F. Thermal changes, and drill wear in bovine bone during implant site preparation. A comparative in vitro study: Twisted stainless steel and ceramic drills. *Clin. Oral Implant. Res.* **2012**, *23*, 963–969. [CrossRef] [PubMed]
59. Sumer, M.; Misir, A.F.; Telcioglu, N.T.; Guler, A.U.; Yenisey, M. Comparison of Heat Generation During Implant Drilling Using Stainless Steel and Ceramic Drills. *J. Oral Maxillofac. Surg.* **2011**, *69*, 1350–1354. [CrossRef]
60. Grechishnikov, V.A.; Isaev, A.V.; Kozochkin, M.P. A Generalized Approach to Designing Profile Milling Cutters Equipped with Replaceable Throw-Away Ceramic Cutting Inserts. In Proceedings of the International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon 2020), Vladivostok, Russia, 6–7 October 2020; pp. 1–8. [CrossRef]
61. Alifarag, A.; Lopez, C.; Neiva, R.; Tovar, N.; Witek, L.; Coelho, P. Atemporal osseointegration: Early biomechanical stability through osseodensification. *J. Orthop. Res.* **2018**, *36*, 2516–2523. [CrossRef]

62. Soldatos, N.; Pham, H.; Fakhouri, W.D.; Ngo, B.; Lampropoulos, P.; Tran, T.; Weltman, R. Temperature Changes during Implant Osteotomy Preparations in Human Cadaver Tibiae Comparing MIS® Straight Drills with Densah® Burs. *Genes* **2022**, *13*, 1716. [CrossRef]
63. Kay, J.; Gilman, L.; May, T. The tri-spade drill for endosseous dental implant installation. *J. Oral Implantol.* **1991**, *17*, 424–428.
64. Grigoriev, S.; Yanushevich, O.; Krikheli, N.; Vereschaka, A.; Milovich, F.; Andreev, N.; Seleznev, A.; Shein, A.; Kramar, O.; Kramar, S.; et al. Investigation of the Nature of the Interaction of Me-MeN-(Me,Mo,Al)N Coatings (Where Me = Zr, Ti, or Cr) with a Contact Medium Based on the Ni-Cr System. *Coatings* **2022**, *12*, 819. [CrossRef]
65. Natali, C.; Ingle, P.; Dowell, J. Orthopaedic bone drills—Can they be improved? Temperature changes near the drilling face. *J. Bone Jt. Surg. Br.* **1996**, *78*, 357–362. [CrossRef]
66. Chacon, G.E.; Bower, D.L.; Larsen, P.E.; McGlumphy, E.A.; Beck, F.M. Heat Production by 3 Implant Drill Systems after Repeated Drilling and Sterilization. *J. Oral Maxillofac. Surg.* **2006**, *64*, 265–269. [CrossRef] [PubMed]
67. Gehrke, S.A.; Neto, H.L.; Mardegan, F.E. Investigation of the effect of movement and irrigation systems on temperature in the conventional drilling of cortical bone. *Br. J. Oral Maxillofac. Surg.* **2013**, *51*, 953–957. [CrossRef]
68. Gehrke, S.A.; Pazetto, M.K.; de Oliveira, S.; Corbella, S.; Taschieri, S.; Mardegan, F.E.C. Study of temperature variation in cortical bone during osteotomies with trephine drills. *Clin. Oral Investig.* **2014**, *18*, 1749–1755. [CrossRef] [PubMed]
69. Ercoli, C.; Funkenbusch, P.D.; Lee, H.J.; Moss, M.E.; Graser, G.N. The influence of drill wear on cutting efficiency and heat production during osteotomy preparation for dental implants: A study of drill durability. *Int. J. Oral Maxillofac. Implant.* **2004**, *19*, 335–349.
70. Eriksson, A.R.; Albrektsson, T.; Albrektsson, B. Heat caused by drilling cortical bone. Temperature measured in vivo in patients and animals. *Acta Orthop. Scand.* **1984**, *55*, 629–631. [CrossRef] [PubMed]
71. Eriksson, A.R.; Adell, R. Temperatures during drilling for the placement of implants using the osseointegration technique. *J. Oral Maxillofac. Surg.* **1986**, *44*, 4–7. [CrossRef]
72. Grigoriev, S.; Pristinskiy, Y.; Volosova, M.; Fedorov, S.; Okunkova, A.; Peretyagin, P.; Smirnov, A. Wire Electrical Discharge Machining, Mechanical and Tribological Performance of TiN Reinforced Multiscale SiAlON Ceramic Composites Fabricated by Spark Plasma Sintering. *Appl. Sci.* **2021**, *11*, 657. [CrossRef]
73. Salomó-Coll, O.; Auriol-Muerza, B.; Lozano-Carrascal, N.; Hernández-Alfaro, F.; Wang, H.-L.; Gargallo-Albiol, J. Influence of bone density, drill diameter, drilling speed, and irrigation on temperature changes during implant osteotomies: An in vitro study. *Clin. Oral Investig.* **2021**, *25*, 1047–1053. [CrossRef]
74. Abboud, M.; Delgado-Ruiz, R.A.; Kucine, A.; Rugova, S.; Balanta, J.; Calvo-Guirado, J.L. Multi-stepped drill design for single-stage implant site preparation: Experimental study in Type 2 bone. *Clin. Implant. Dent. Relat. Res.* **2015**, *17* (Suppl. S2), e472–e485. [CrossRef]
75. Yacker, M.J.; Klein, M. The effect of irrigation on osteotomy depth and bur diameter. *Int. J. Oral Maxillofac. Implant.* **1996**, *11*, 634–638.
76. Augustin, G.; Davila, S.; Mihoci, K.; Udiljak, T.; Vedrina, D.S.; Antabak, A. Thermal osteonecrosis and bone drilling parameters revisited. *Arch. Orthop. Trauma Surg.* **2008**, *128*, 71–77. [CrossRef] [PubMed]
77. Scarano, A.; Piattelli, A.; Assenza, B.; Carinci, F.; Di Donato, L.; Romani, G.L.; Merla, A. Infrared Thermographic Evaluation of Temperature Modifications Induced during Implant Site Preparation with Cylindrical versus Conical Drills. *Clin. Implant. Dent. Relat. Res.* **2009**, *13*, 319–323. [CrossRef] [PubMed]
78. Sartori, E.M.; Shinohara, E.H.; Ponzoni, D.; Padovan, L.E.; Valgas, L.; Golin, A.L. Evaluation of deformation, mass loss, and roughness of different metal burs after osteotomy for osseointegrated implants. *J. Oral Maxillofac. Surg.* **2012**, *70*, e608–e621. [CrossRef] [PubMed]
79. Allsobrook, O.F.; Leichter, J.; Holborrow, D.; Swain, M. Descriptive study of the longevity of dental implant surgery drills. *Clin. Implant. Dent. Relat. Res.* **2011**, *13*, 244–254. [CrossRef]
80. Tur, D.; Giannis, K.; Unger, E.; Mittlböck, M.; Rausch-Fan, X.; Strbac, G.D. Thermal effects of various drill materials during implant site preparation-Ceramic vs. stainless steel drills: A comparative in vitro study in a standardised bovine bone model. *Clin. Oral Implant. Res.* **2021**, *32*, 154–166. [CrossRef]