coatings

Review

Biomaterials in Orthopedic Devices: Current Issues and Future Perspectives

Nina Filip [1,†], Iulian Radu [2,*], Bogdan Veliceasa [3,†], Cristiana Filip [1,*], Mihaela Pertea [4,†], Andreea Clim [1], Alin Constantin Pinzariu [1,†], Ilie Cristian Drochioi [5], Remus Lucian Hilitanu [6] and Ionela Lacramioara Serban [1]

1 Department of Morpho-Functional Sciences (II), Faculty of Medicine, "Grigore T. Popa" University of Medicine and Pharmacy, 700020 Iasi, Romania
2 Department of Surgery, Regional Institute of Oncology, I-st Surgical Oncology, Faculty of Medicine, "Grigore T. Popa" University of Medicine and Pharmacy, 700020 Iasi, Romania
3 Department of Orthopedics and Traumatology, Surgical Science (II), Faculty of Medicine, "Grigore T. Popa" University of Medicine and Pharmacy, 700115 Iasi, Romania
4 Department Plastic Surgery and Reconstructive, Faculty of Medicine, "Grigore T. Popa" University of Medicine and Pharmacy, 700020 Iasi, Romania
5 Department of Oral and Maxillofacial Surgery and Reconstructive, Faculty of Dental Medicine, "Grigore T. Popa" University of Medicine and Pharmacy, 700020 Iasi, Romania
6 Department of Preventive Medicine and Interdisciplinarity, Faculty of Medicine, "Grigore T. Popa" University of Medicine and Pharmacy, 700020 Iasi, Romania
* Correspondence: iulian.radu@umfiasi.ro (I.R.); cristiana.filip@umfiasi.ro (C.F.)
† These authors contributed equally to this work.

Abstract: In orthopedics, bone fixation imposes the use of implants in almost all cases. Over time, the materials used for the implant have evolved from inert materials to those that mimic the morphology of the bone. Therefore, bioabsorbable, biocompatible, and bioactive materials have emerged. Our study aimed to review the main types of implant materials used in orthopedics and present their advantages and drawbacks. We have searched for the pros and cons of the various types of material in the literature from over the last twenty years. The studied data show that consecrated metal alloys, still widely used, can be successfully replaced by new types of polymers. The data from the literature show that, by manipulating their composition, the polymeric compounds can simulate the structure of the different layers of human bone, while preserving its mechanical characteristics. In addition, manipulation of the polymer composition can provide the initiation of desired cellular responses. Among the implanting materials, polyurethane is distinguished as the most versatile polymeric material for use both as orthopedic implants and as material for biomechanical testing of various bone reduction and fixation techniques.

Keywords: orthopedic devices; implants materials; biomechanical tests; polyurethane; titanium-based alloys; biocompatibility; bioceramics

Citation: Filip, N.; Radu, I.; Veliceasa, B.; Filip, C.; Pertea, M.; Clim, A.; Pinzariu, A.C.; Drochioi, I.C.; Hilitanu, R.L.; Serban, I.L. Biomaterials in Orthopedic Devices: Current Issues and Future Perspectives. *Coatings* **2022**, *12*, 1544. https://doi.org/10.3390/coatings12101544

Academic Editor: Devis Bellucci

Received: 20 September 2022
Accepted: 11 October 2022
Published: 14 October 2022

1. Introduction

Over time, for medical purposes, different materials foreign to the human body have been used, such as hair or cellulose used as a suture material, and wood or horn proved to be effective as a material for fixing bone fractures [1,2]. Modern times have brought metals and alloys to the fore as the first choice for the composition of implants, due to their properties: superior strength, reduced risk of rejection, and, above all, biological inertness [3]. Since the Second World War, a new type of compounds, namely synthetically obtained polymers, began to be increasingly used in medical applications, including orthopedics [3,4]. Over time, synthetic materials have evolved from biocompatible and biodegradable materials to bioactive materials today. Data from the literature show that, by manipulating the composition, polymeric compounds can simulate the structure of different tissues while maintaining their mechanical characteristics [3,4]. In addition, by choosing the appropriate type of composition, polymers can initiate targeted cellular responses that favor the healing/repair process. Among the synthetic compounds, polyurethane stands out as one of the most versatile materials, being able to be used as orthopedic implants, covering materials, drainage devices, but also as a material for biomechanical testing of different fracture reduction and fixation techniques [5,6]. The diversity of uses those polyurethanes allow is generated by the fact that, through chemical manipulation, the resulting polyurethanes can mimic many of the structures of human tissues [7]. Knowledge of the mechanical properties of materials and their biocompatibility are the key points for their use in orthopedic surgery.

2. Requirements for Materials Used to Fix Bones

From ancient times, mankind has used different foreign materials for medical purposes, such as employing hair or cellulose as suture material and using wood or horn for bones fracture fixation [1,8–11]. In modern times, metals and alloys have become the first choice in implants utilization, due to their superior strength, lower risk of rejection, and inertness. Since the Second World War, a new class of compounds, the synthetic polymers, have rapidly developed and been increasingly used [12–14]. Regardless of the type of material used, the implant devices must meet general and specific requirements, such as mechanical and biological characteristics.

2.1. General Requirements of Materials for Orthopedic Implant

The basic requirements for implant materials are the clinical and manufacturing properties. As clinical criteria, the materials used for implants must neither be rejected by the body nor generate harmful products [15]. As manufacturing criteria, the materials must allow for the fabrication of the optimum configuration at an affordable price.

2.2. Specific Requirements of Materials for Orthopedic Implant

2.2.1. Mechanical Requirements

The mechanical requirements for an implant are dictated by its use; e.g., strength for loading, elasticity for shear stress. In orthopedics, the implant materials must work in repeated upload/download cycles under different types of forces such as bending, twisting, and shearing stress. Furthermore, implantation devices are subjected to corrosive conditions over long periods of time, which may affect their properties. Therefore, mechanical properties must be accurately assessed in order to maintain fracture reduction. The mechanical properties of the material are evaluated in terms of deformation (strain) produced by an applied force (stress) [16]. The applied stress may be produced by loading, bending, torsion, and compression, or by shear actions. The mechanical properties of an implant material can be assessed using the general stress-strain diagram for the deformation of a material under an imposed external force [17]. The diagram indicates two separate regions: the elastic region, where no deformation occurs, and the plastic region, where deformation is permanent. In the elastic region, the slope of the curve expresses intrinsic stiffness or rigidity (also known as Young's modulus). Rigidity defines the property of a solid body to resist deformation. As stress increases, micro–fractures accumulate, plastic deformations appear, and finally the material breaks up [18]. In the specific case of bones, rigidity is not constant, as is the case for implanted materials. It is said that bone tissue is an anisotropic material. Anisotropy means that a material exhibits different mechanical properties depending on the direction of their determination. Thus, the mechanical properties of the bones depend on the direction of the force application. For example, bone tissue is more rigid when an external force acts in the longitudinal direction of the bone than when it acts on its surface [19].

In the particular case of a pelvis fracture, the main stress is the loading stress. Here, the general load-curve can be converted into a load deformation curve [20]. The converted diagram allows the calculation of the implantation device's rigidity, in order to compare it with the rigidity of a healthy bone. It is also useful in the case of a simulation, for the assessment of the stiffness of artificial bones that mimic certain bone pathologies; e.g., the osteoporotic bone. In the plastic region, it is possible to determine the final stress that causes the breakage of material through fracture. Thus, parameters that are widely used for characterization of a mechanical implant material are rigidity and failure-load [18,20]. As a conclusion, using load-deformation diagrams, the mechanical properties of the implant can be calculated and the implant resistance estimated.

2.2.2. Biological Requirements

The most important property for an orthopedic device is biological inertness, meaning the lack of reactivity with the biological surroundings. In body conditions, a certain degree of reactivity takes place; thus, limited implant degradation may occur. This is considered acceptable if the process does not impair the mechanical strength, or generate harmful byproducts [21]. Contrary to this initial concept, the most recent approaches consider that a certain controlled reactivity between the implant material and the biological surroundings can be used to accelerate the healing process [22]. The introduction of biomaterials has opened up the possibilities of designing materials with particular properties that facilitate the adaptation of the implant to the mechanical and morphological characteristics of the receiving structure. Dolcimascolo et al. [23] consider that biomaterials used in the last 60 years can be grouped into three generations: bio-inert materials (first generation), bioactive or biodegradable materials (second generation), and the current third generation. The design of the third generation intends that the implanted material triggers specific molecular responses that will accelerate the healing process. In recent studies, a new class of biomaterials has been presented: the fourth generation [24–27]. Categories of biomaterials can be seen in Figure 1.

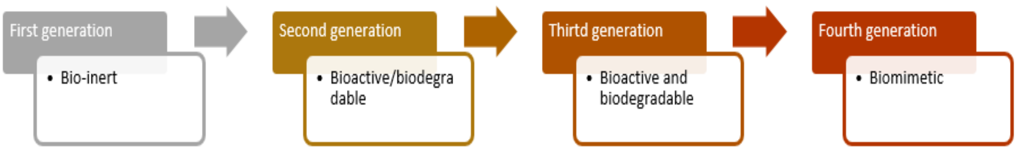

Figure 1. Categories of biomaterials.

This classification outlines the conceptual evolution of the requirements for implant materials. The major requirements pertaining to the first generation had been stiffness and the biological inertness of the materials. Implantation triggers the absorption of non-specific proteins on the surface of the material; a fibrous tissue capsule is formed, and the implant is encapsulated inside, which is a disadvantage for the implant [28]. This led to the design of the second generation of materials. For the second generation, which occurred between 1980 and 2000, the major requirements were the development of bio-absorbable and bioactive materials, while maintaining the mechanical properties of the implant [29,30]. A bio-absorbable material is able to degrade in a progressive manner, allowing the healing and regeneration of tissues. The bioactive material is designed to generate a layer of hydroxyapatite (HA), a natural component of the bone, on the surface of the material instead of the fibrous capsule. It is considered that in vivo stimulation of the production of a hydroxyapatite layer on the implant surface improves the process of mineralization, fixation, and bone regeneration [31,32]. The chemical attachment of various reactive groups on the surface of the polymer causes it to become bio-functional. Thus, this improvement by the second generation materials was possible by modifying the implant surface to promote specific cellular responses, instead of nonspecific responses, as was the case with the first generation [29]. The third generation of biomaterials orientate around the ability to trigger signals that stimulate specific cellular responses at the molecular level. These biomaterials are related to tissue engineering, regenerative medicine, tissue transplantation, and grafting. These biomaterials are designed to be temporary three-dimensional porous structures that are capable of stimulating tissue regeneration, nutrient supply, and possibly, angiogenesis [33,34]. The fourth generation of biomaterials elicits a personalized interaction with cellular processes and microenvironments, which includes four requirements: inertia, activity, receptivity, and autonomy [35].

3. Specific Orthopedic Implant Materials

3.1. Metal Materials

The first materials used for implant devices were metals and alloys, due to their superior strength and a certain biological inertness. Metals selected for the implant include: iron, cobalt, nickel, titanium, and zirconium. The metal combinations aim to obtain specific properties in the final mixture, such as: elasticity, strength, ductility (to reduce the risk of crack failure), and corrosion resistance [36]. Current alloys used in orthopedic metal-based implants include: stainless steels, cobalt-based alloys, and titanium-based alloys. Table 1 summarizes both the advantages and disadvantages of the most important metal materials used in orthopedics.

Table 1. Advantages and disadvantages of metal materials used in orthopedic devices.

Metal Materials	Advantages	Disadvantages	References
Stainless steel (316L)	high resistance, less expensive, easy fabrication	allergic reaction, stress shielding effect	[37–39]
Cobalt-chromium-based alloys (Co-Cr-Mo, Cr-Ni-Cr-Mo)	high corrosion resistance, wear resistance	early implant loosening rate, difficult fabrication	[36,40–42]
Titanium –based alloys (Ti-4Al-4V, Ti-6Al-7Nb, Ti-13Nb-13Zr)	biocompatibility, Young modulus close to bone, excellent corrosion resistance, good osteointegration	expensive, intoxication, bone resorption, allergy	[43–46]
Mg based alloys	biodegradability in vivo, biocompatibility	low mechanical strength, fast degradation	[36,47,48]

3.1.1. Stainless Steel

Stainless steel 18-8 (18% chromium, 8% nickel) is the most common alloy. It has superior corrosion resistance obtained through compositional modifications by using additional metals, especially Cr [37]. The presence of Cr allows Cr_2O_3 to form a strong and adherent layer that favors healing. Stainless steel is widely used in removable orthopedic devices (fracture plates, hip screws) due to its low cost [49,50]. Currently, the new stainless steel-based alloys contain Co-Cr, Ni, Mn, and a high nitrogen content [50]. These types of alloys can be used in combination with polyethylene (PE) for disc prosthesis [51].

3.1.2. Cobalt-Based Alloys

Cobalt-based alloys are superior to stainless steel in terms of strength [42,52]. They have the advantage of better biocompatibility, being more resistant to corrosion than stainless steel, but more expensive to manufacture. Some variants of the alloy composed of cobalt-chromium-molybdenum are especially used for implants in hip prosthesis [22,53]. This alloy version is reserved for metal-to-metal devices due to its high abrasion resistance [54,55].

3.1.3. Titanium-Based Alloys

For orthopedic devices, titanium may be used alone or in alloys with other metals. The use of pure titanium has the following advantages: low weight, very good corrosion resistance, especially in saline solution (due to the formation of an adhesive layer of TiO_2), and the ability to become tightly integrated into the bone [56–59]. This last property greatly improves the long-term behavior of the implant, as well as reduces the risk of loosening and failure of the device. Though titanium-based alloys have proven to be highly corrosion-resistant and biocompatible, there are concerns regarding long-term implantation because of the release of potentially toxic alloying elements and the risk of stress shielding, as their elastic modulus values are still relatively high compared to the elastic modulus of bone. Being an expensive material, titanium-based alloys are currently only used for patients with hypersensitivity reactions to steel or cobalt-chromium alloys [45,46,60].

In conclusion, even though metallic implants belong to the concepts of the first-generation, they are still in use and they continuously evolve. Proper features of the implant surface, such as roughness, wettability, and electrostatic charges that finally dictate the quality of implant anchorage in bone, can be obtained through a wide variety of surface treatments applied to the metal alloys.

3.2. Non-Metal Materials

3.2.1. Polymeric Materials

Today, polymeric materials are good replacements for many types of materials in all medical fields. The increasing use of polymers is dictated by low production costs and high versatility. Full data on all types of synthetic polymers used in clinical medicine can be found in Mainz's review [61]. In the case of orthopedics, the use of polymers is steadily increasing due to the unlimited possibilities of manipulating their bio-mechanical properties [6,62]. The polymeric biomaterials belonging to the first generation include: polyethylene (PE), polymethylmethacrylate (PMMA), and polyurethanes (PU). These materials are still used today in both the first- and third-generation versions.

Both the advantages and disadvantages of the most important non-metal materials used in orthopedic devices are presented in Table 2.

Table 2. Advantages and disadvantages of some non-metal materials used in orthopedics.

Non-Metal Materials	Advantages	Disadvantages	References
Polyethylene (PE)/ultrahigh molecular weight polyethylene (UHMWPE)	low resistance to friction, resistance to wear, biocompatibility	debris generation along time as a result of wear, osteolysis	[63–70]
Polymethylmethacrylate (PMMA)	good tensile properties and tensile strength	long-term usage can produce cement fragmentation	[71–80]

Polyethylene

Polyethylene is used in total hip and knee arthroplasty, insertion of the tibia, or as a spacer in disc replacement [64,67]. The major benefits of PE use are: low resistance to friction, resistance to abrasion or to impact, and good biocompatibility. A particular type of polyethylene polymer, named ultrahigh molecular weight polyethylene (UHMWPE), associated with metal, is highly used in orthopedic surgery or joint prostheses [70] due to its high load bearing capacity. The main drawback is the possibility of debris generation over time as a result of wear.

Polymethylmethacrylate

Polymethylmethacrylate is also known as "acrylic cement". It is a versatile compound used in ophthalmology, dentistry, as well as orthopedics. In orthopedics, PMMA is used for hip arthroplasty, spinal fracture fixation, internal fracture-fixation plates (so-called "luting"), and as a permanent bone substitute in the treatment of pathologic fractures [81–84]. The most important feature of PMMA is that it can be molded into particular shapes dictated by implant requirements, or be polymerized in situ during the time of surgery. The polymerization process lasts from 6 to 7 min. Used as cement that anchors the prostheses to the bone, PMMA must ensure bone adhesion. For this purpose, the polymer is filled with hydroxyapatite particles; thus, providing a homogeneous load transfer from the implant to the bone [85]. Other advantages of PMMA include good tensile properties, tensile strength, as well as good flexural rigidity. Although it has many advantages, the use of PMMA does have some disadvantages, such as the release of heat and methyl methacrylate monomer (MMA) in the in situ polymerization process. Released MMA causes hemodynamic effects (hypotension and hypoxemia). Another disadvantage of PMMA utilization is its brittleness compared to metal materials. In the particular case of fragility fractures, such as vertebral or sacral osteoporotic fractures, the injection of PMMA has the advantage of improving stability and reducing pain [86]. The main disadvantage of the procedure is the extravasation of the PMMA in the pre-sacral space, spinal canal, sacral foramen, which may affect sacral nerve root, or sacral spinal canal [86].

Polyurethanes

Polyurethane is a very versatile and inexpensive material and is therefore used for many medical purposes. It can be produced in various types that offer specific properties depending on the purpose of the implanted device. These include stiffness, flexibility, mechanical strength, or elasticity. However, the most important property is that it can mimic certain biological structures of the body, especially bone structure. Furthermore, polyurethanes can be made entirely biocompatible (for permanent implantation) and also biodegradable (absorbable scaffolds for tissue regeneration) [87]. The medical use of polyurethane includes vascular catheters [88,89], transparent semipermeable films for wound dressings [90], heart valves [91], ureteral [92], stents, or orthopedic implants [93]. Third-generation PU are used for tissue reinforcement scaffolds (as biodegradable material in combination with urea) [94] or for regeneration of peripheral nerves [95,96]. Polyurethanes are by far the most used material in mechanical testing of orthopedic fixation devices. Their use is justified by the fact that, through chemical modification, polyurethanes can faithfully simulate both the compact structure of the cortical bone and the trabecular structure of the spongy bone. When tested with an externally applied force, the stress-strain curve of the polyurethane foam exhibited a similar behavior to the spongy bone. Thompson et al. [97] tested different types of rigid polyurethane foams and found that the polymer and the spongy bone exhibit similar behavior in the elastic area. Due to the similarity between the human bone and the polymer, a standardization of the polyurethane foams was established based on mechanical behavior for different bone density [98]. As a conclusion, PU foams can be used [99] as human bone replacements to measure important functional parameters (resistance, stability, and rigidity) of orthopedic implants in biomechanical tests.

3.2.2. Ceramics

Due to the increase in the life expectancy of the population and the number of surgical interventions, it is expected that the implants will be very reliable and resistant to breakage in vivo, so that they can provide a service life of more than 30 years. Because they present biocompatibility, high hardness, and high resistance to wear, ceramic materials are generally suitable for bone replacement bearings [36]. The development of ceramics in joint replacement bearings aims to reduce clinical wear, and consequently, reduce the risk of debris-induced osteolysis [100]. Bioceramics are classified into three types: bioinert, that do not interact with living tissues and are non-toxic (zirconia, alumina); biodegradables, that are absorbed and dissolved inside the body (calcium phosphates and hydroxyapatite); and bioactive, that are able to form (bioactive glass). Alumina-zirconia ceramic composites show remarkable stability and mechanical properties, but they have high production costs [101]. Calcium phosphate coatings have been used in orthopedics due to their similarity to the mineral, the bone phase, and presents the advantage of significant biocompatibility and osseointegration with the host tissue. Plasma sprayed calcium phosphate coatings are not uniform, and there is little control over thickness and surface topography, which can lead to implant inflammation when particles are released from them [102].

4. Future Perspectives for the Materials Used in Orthopedics

Currently, the materials widely used in orthopedics are metal, bioceramics, and polymers [103–110]. Recent data suggest that a special interest is being given to biomedical nanotechnology. Ceria nanoparticles or nano-ceria (CeO_2-NPs) were presented with an increased potential for applicability in orthopedics [111–114]. Luo et al. [115] investigated the effect and mechanism of cerium oxide nanoparticles (CeO_2 NPs) in MC3T3-E1 mouse osteoblast precursors, and reported that they improved matrix mineralization and increased osteogenic gene expression. Castiglioni et al. [116] proposed the use of silver nanoparticles to fight infections in orthopedic implants, because those that show antimicrobial activity are smaller than those that exert toxic effects on bone-forming cells in vitro. Samanta et al. [117] highlighted that gold nanoparticles (Au NPs) have antibacterial action. These results demonstrate the positive impact that nanomedicine can have on improving the effectiveness of materials used in orthopedics.

Due to biocompatibility and appropriate mechanical properties, magnesium alloys have recently become the focus of research. At this moment, Mg-based metal alloys represent the new generation of biodegradable metal materials, with a good osseointegration property [105]. In a case study, Holweg et al. [118] focused on intraoperative clinical sites of human bone stabilized with magnesium screws and reported homogeneous degradation with good bone-implant interface. Future research must be concentrated on the direction of alloys with a low degradation rate and an improved mechanical strength, in order to solve load-bearing zone fractures [119].

Current research focuses on both the development of new materials and surface modification strategies. The development of new techniques and strategies on composite coatings to better mimic the structure of human bone would lead to a new generation of orthopedic implants with improved implant integration and bone healing.

The recent development and use of 3D printing technology is rapidly becoming more valuable to the field of orthopedics, but the field of orthopedic implants has not been sufficiently explored. Polymers are one of the most common materials used in 3D-printed bone replacements because of their potential use as filaments for fused deposition modeling, solutions for stereolithography apparatus, and gels for direct ink writing [120]. Feltz et al. [121] evaluated the feasibility of using desktop 3D printers to reproduce surgical implant models using biocompatible materials and reported reduced manufacturing costs, but did not achieve mechanical properties similar to standard stainless-steel implants. In orthopedics, 3D printed materials can be made into implants, prostheses, and create life-size anatomical models [122].

Materials used in orthopedics will continue to evolve in order to reduce implant costs, maintain patient safety, optimize surgical techniques, and reduce the risk of infection.

5. Conclusions

The challenges encountered in orthopedics are: fractures, broken joints, and already diseased bone traumas. In order to restore normal bone function or joints, the use of prosthesis or implantation devices is inevitable. Certain properties of the implant material are mandatory to ensure a total recovery. Current data show that consecrated metal alloys, still widely used, can be successfully replaced by new types of polymers. Synthetic materials based on biocompatible polymers belonging to the latest generation are able to provide multiple possibilities for reproducing the anatomical structure, reabsorbing over a period of time, or generating a specific response from the biological environment. Literature indicates that polyurethanes are the most suitable material for the mechanical testing of orthopedic devices. We also believe that nanotechnology is very important for the success of orthopedic implants. Finally, synthetic materials allow simulations to evaluate the behavior of an implant device; thus, increasing the chances of a successful surgical implantation procedure.

Author Contributions: Conceptualization, N.F. and I.R.; methodology, C.F.; formal analysis, B.V. and M.P.; investigation, N.F., I.R., A.C.P. and C.F; resources, I.C.D.; data curation, A.C.; writing—original draft preparation, A.C.P., A.C. and I.C.D.; writing—review and editing, R.L.H.; visualization, B.V. and M.P.; supervision, I.L.S.; roject administration, N.F. and I.L.S.; All authors have equal contributions. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Marin, E.; Boschetto, F.; Pezzotti, G. Biomaterials and biocompatibility: An historical overview. *J. Biomed. Mater. Res. Part A* **2020**, *108*, 1617–1633. [CrossRef] [PubMed]
2. Chaudhari, A.A.; Vig, K.; Baganizi, D.R.; Sahu, R.; Dixit, S.; Dennis, V.; Singh, S.R.; Pillai, S.R. Future prospects for scaffolding methods and biomaterials in skin tissue engineering: A review. *Int. J. Mol. Sci.* **2016**, *17*, 1974. [CrossRef] [PubMed]
3. Fan, J.; Abedi-Dorcheh, K.; Sadat Vaziri, A.; Kazemi-Aghdam, F.; Rafieyan, S.; Sohrabinejad, M.; Ghorbani, M.; Rastegar Adib, F.; Ghasemi, Z.; Klavins, K.; et al. A Review of Recent Advances in Natural Polymer-Based Scaffolds for Musculoskeletal Tissue Engineering. *Polymers* **2022**, *14*, 2097. [CrossRef] [PubMed]
4. Tsegay, F.; Elsherif, M.; Butt, H. Smart 3D Printed Hydrogel Skin Wound Bandages: A Review. *Polymers* **2022**, *14*, 1012. [CrossRef] [PubMed]
5. Ramakrishna, S.; Mayer, J.; Wintermantel, E.; Leong, K.W. Biomedical applications of polymer-composite materials: A review. *Compos. Sci. Technol.* **2001**, *61*, 1189–1224. [CrossRef]
6. Francis, A. Biological evaluation of preceramic organosilicon polymers for various healthcare and biomedical engineering applications: A review. *J. Biomed. Mater. Res. Part B Appl. Biomater.* **2021**, *109*, 744–764. [CrossRef] [PubMed]
7. Oladapo, B.I.; Zahedi, S.A.; Ismail, S.O.; Olawade, D.B. Recent advances in biopolymeric composite materials: Future sustainability of bone-implant. *Renew. Sustain. Energy Rev.* **2021**, *150*, 111505. [CrossRef]
8. Ghasemi-Mobarakeh, L.; Kolahreez, D.; Ramakrishna, S.; Williams, D. Key terminology in biomaterials and biocompatibility. *Curr. Opin. Biomed. Eng.* **2019**, *10*, 45–50. [CrossRef]
9. Heimann, R.B. (Ed.) *Materials for Medical Application*; Walter de Gruyter GmbH & Co KG: Görlitz, Germany, 2020.
10. Love, B. *Biomaterials: A Systems Approach to Engineering Concepts*; Academic Press: Cambridge, MA, USA, 2017.
11. Hacker, M.C.; Krieghoff, J.; Mikos, A.G. Synthetic polymers. In *Principles of Regenerative Medicine*; Academic Press: Cambridge, MA, USA, 2019; pp. 559–590.
12. Xu, X.; Song, J. Segmental long bone regeneration guided by degradable synthetic polymeric scaffolds. *Biomater. Transl.* **2020**, *1*, 33.
13. Mir, M.; Ali, M.N.; Barakullah, A.; Gulzar, A.; Arshad, M.; Fatima, S.; Asad, M. Synthetic polymeric biomaterials for wound healing: A review. *Prog. Biomater.* **2018**, *7*, 1–21. [CrossRef]
14. Donnaloja, F.; Jacchetti, E.; Soncini, M.; Raimondi, M.T. Natural and Synthetic Polymers for Bone Scaffolds Optimization. *Polymers* **2020**, *12*, 905. [CrossRef]
15. Tian, L.; Tang, N.; Ngai, T.; Wu, C.; Ruan, Y.; Huang, L.; Qin, L. Hybrid fracture fixation systems developed for orthopaedic applications: A general review. *J. Orthop. Transl.* **2019**, *16*, 1–13. [CrossRef]
16. Pal, S. Mechanical properties of biological materials. In *Design of Artificial Human Joints & Organs*; Springer: Boston, MA, USA, 2014; pp. 23–40.
17. Silver, F.H.; Shah, R. Measurement of mechanical properties of natural and engineered implants. *Adv. Tissue Eng. Regen. Med. Open Access* **2016**, *1*, 20–25. [CrossRef]
18. Li, J.; Zhao, Z.; Yin, P.; Zhang, L.; Tang, P. Comparison of three different internal fixation implants in treatment of femoral neck fracture—A finite element analysis. *J. Orthop. Surg. Res.* **2019**, *14*, 76. [CrossRef]
19. Bankoff, A.D.P. Biomechanical characteristics of the bone. *Hum. Musculoskelet. Biomech.* **2012**, *61*, 86.
20. Basso, T. Internal fixation of fragility fractures of the femoral neck: Ex vivo biomechanical studies. *Acta Orthop.* **2015**, *86* (Suppl. S361), S1–S36. [CrossRef]
21. Todros, S.; Todesco, M.; Bagno, A. Biomaterials and Their Biomedical Applications: From Replacement to Regeneration. *Processes* **2021**, *9*, 1949. [CrossRef]
22. Thanigaivel, S.; Priya, A.K.; Balakrishnan, D.; Dutta, K.; Rajendran, S.; Soto-Moscoso, M. Insight on recent development in metallic biomaterials: Strategies involving synthesis, types and surface modification for advanced therapeutic and biomedical applications. *Biochem. Eng. J.* **2022**, *187*, 108522. [CrossRef]
23. Dolcimascolo, A.; Calabrese, G.; Conoci, S.; Parenti, R. Innovative biomaterials for tissue engineering. In *Biomaterial-Supported Tissue Reconstruction or Regeneration*; IntechOpen: London, UK, 2019. [CrossRef]
24. Festas, A.J.; Ramos, A.; Davim, J.P. Medical devices biomaterials—A review. *Proc. Inst. Mech. Eng. Part L J. Mater. Des. Appl.* **2020**, *234*, 218–228. [CrossRef]
25. Bhaskar, B.; Nagarjuna, V. Biomaterials, Tissue Engineering, and Regenerative Medicine: A Brief Outline. In *Biomaterials in Tissue Engineering and Regenerative Medicine*; Springer: Singapore, 2021; pp. 3–17.
26. Basu, B.; Gowtham, N.H.; Xiao, Y.; Kalidindi, S.R.; Leong, K.W. Biomaterialomics: Data science-driven pathways to develop fourth-generation biomaterials. *Acta Biomater.* **2022**, *143*, 1–25. [CrossRef]

27. Allo, B.A.; Costa, D.O.; Dixon, S.J.; Mequanint, K.; Rizkalla, A.S. Bioactive and Biodegradable Nanocomposites and Hybrid Biomaterials for Bone Regeneration. *J. Funct. Biomater.* **2012**, *3*, 432–463. [CrossRef] [PubMed]
28. Gautam, G.; Kumar, S.; Kumar, K. Processing of biomaterials for bone tissue engineering: State of the art. *Mater. Today Proc.* **2022**, *50*, 2206–2217. [CrossRef]
29. Saad, M.; Akhtar, S.; Srivastava, S. Composite polymer in orthopedic implants: A review. *Mater. Today Proc.* **2018**, *5*, 20224–20231. [CrossRef]
30. Sheikh, Z.; Najeeb, S.; Khurshid, Z.; Verma, V.; Rashid, H.; Glogauer, M. Biodegradable Materials for Bone Repair and Tissue Engineering Applications. *Materials* **2015**, *8*, 5744–5794. [CrossRef] [PubMed]
31. Arifin, A.; Sulong, A.B.; Muhamad, N.; Syarif, J.; Ramli, M.I. Material processing of hydroxyapatite and titanium alloy (HA/Ti) composite as implant materials using powder metallurgy: A review. *Mater. Des.* **2014**, *55*, 165–175. [CrossRef]
32. Zakaria, S.M.; Sharif Zein, S.H.; Othman, M.R.; Yang, F.; Jansen, J.A. Nanophase hydroxyapatite as a biomaterial in advanced hard tissue engineering: A review. *Tissue Eng. Part B Rev.* **2013**, *19*, 431–441. [CrossRef] [PubMed]
33. Ning, C.; Zhou, L.; Tan, G. Fourth-generation biomedical materials. *Mater. Today* **2016**, *19*, 2–3. [CrossRef]
34. Serrano, M.C.; Ameer, G.A. Recent insights into the biomedical applications of shape-memory polymers. *Macromol. Biosci.* **2012**, *12*, 1156–1171. [CrossRef]
35. Montoya, C.; Du, Y.; Gianforcaro, A.L.; Orrego, S.; Yang, M.; Lelkes, P.I. On the road to smart biomaterials for bone research: Definitions, concepts, advances, and outlook. *Bone Res.* **2021**, *9*, 12. [CrossRef]
36. Shekhawat, D.; Singh, A.; Bhardwaj, A.; Patnaik, A. A short review on polymer, metal and ceramic based implant materials. *IOP Conf. Ser. Mater. Sci. Eng.* **2021**, *1017*, 012038. [CrossRef]
37. Wall, E.J.; Jain, V.; Vora, V.; Mehlman, C.T.; Crawford, A.H. Complications of titanium and stainless steel elastic nail fixation of pediatric femoral fractures. *J. Bone Jt. Surg.* **2008**, *90*, 1305–1313. [CrossRef]
38. Ghunawat, S.; Relhan, V.; Garg, V.K. Hypersensitivity Reactions to Metal Implants: Clinical, Diagnostic and Treatment Overview. *Indian J. Clin. Dermatol.* **2019**, *2*, 29–34.
39. Chen, Q.; Thouas, G.A. Metallic implant biomaterials. *Mater. Sci. Eng. R Rep.* **2015**, *87*, 1–57. [CrossRef]
40. Brogini, S.; Sartori, M.; Giavaresi, G.; Cremascoli, P.; Alemani, F.; Bellini, D.; Martini, L.; Maglio, M.; Pagani, S.; Fini, M. Osseointegration of additive manufacturing Ti–6Al–4V and Co–Cr–Mo alloys, with and without surface functionalization with hydroxyapatite and type I collagen. *J. Mech. Behav. Biomed. Mater.* **2021**, *115*, 104262. [CrossRef]
41. Solanke, S.; Gaval, V.; Sanghavi, S. In vitro tribological investigation and osseointegration assessment for metallic orthopedic bioimplant materials. *Mater. Today Proc.* **2021**, *44*, 4173–4178. [CrossRef]
42. Aherwar, A.; Singh, A.K.; Patnaik, A. Cobalt Based Alloy: A Better Choice Biomaterial for Hip Implants. *Trends Biomater. Artif. Organs* **2016**, *30*, 50–55.
43. Anene, F.A.; Aiza Jaafar, C.N.; Zainol, I.; Azmah Hanim, M.A.; Suraya, M.T. Biomedical materials: A review of titanium based alloys. *Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci.* **2021**, *235*, 3792–3805. [CrossRef]
44. Thomas, P.; Thomas, M.; Summer, B.; Dietrich, K.; Zauzig, M.; Steinhauser, E.; Krenn, V.; Arnholdt, H.; Flaig, M.J. Impaired wound-healing, local eczema, and chronic inflammation following titanium osteosynthesis in a nickel and cobalt-allergic patient: A case report and review of the literature. *J. Bone Jt. Surg.* **2011**, *93*, e61. [CrossRef]
45. Nasibi, S.; Alimohammadi, K.; Bazli, L.; Eskandarinezhad, S.; Mohammadi, A.; Sheysi, N. TZNT alloy for surgical implant applications: A systematic review. *J. Compos. Compd.* **2020**, *2*, 62–68. [CrossRef]
46. Xu, W.; Lu, X.; Tian, J.; Huang, C.; Chen, M.; Yan, Y.; Wang, L.; Qu, X.; Wen, C. Microstructure, wear resistance, and corrosion performance of Ti35Zr28Nb alloy fabricated by powder metallurgy for orthopedic applications. *J. Mater. Sci. Technol.* **2020**, *41*, 191–198. [CrossRef]
47. Findik, F. Recent developments of metallic implants for biomedical applications. *Period. Eng. Nat. Sci.* **2020**, *8*, 33–57.
48. Lin, X.; Saijilafu; Wu, X.; Wu, K.; Chen, J.; Tan, L.; Witte, F.; Yang, H.; Mantovani, D.; Zhou, H.; et al. Biodegradable Mg-based alloys: Biological implications and restorative opportunities. *Int. Mater. Rev.* **2022**, *67*, 1–39. [CrossRef]
49. Barber, C.C.; Burnham, M.; Ojameruaye, O.; McKee, M.D. A systematic review of the use of titanium versus stainless steel implants for fracture fixation. *OTA Int.* **2021**, *4*, e138. [CrossRef]
50. Mahyudin, F.; Widhiyanto, L.; Hermawan, H. Biomaterials in orthopaedics. In *Biomaterials and Medical Devices*; Springer: Cham, Switzerland, 2016; pp. 161–181.
51. Ghosh, S.; Sanghavi, S.; Sancheti, P. Metallic biomaterial for bone support and replacement. In *Fundamental Biomaterials: Metals*; Woodhead Publishing: Cambridge, UK, 2018; pp. 139–165.
52. Mehta, H.; Kaur, G.; Chaudhary, G.R.; Prabhakar, N.; Kaul, S.; Singhal, N.K. Evaluation of corrosion resistant, antimicrobial and cytocompatible behaviour of cobalt based metallosurfactants self-assembled monolayers on 316L stainless steel surface. *Surf. Coat. Technol.* **2022**, *444*, 128657. [CrossRef]
53. Orlov, A.A.; Sarychev, S.M.; Orlov, A.A. The Effect of Surface Conditions on Corrosion Resistance of a Cobalt-Chromium Alloy. In *Key Engineering Materials*; Trans Tech Publications Ltd.: Bäch, Switzerland; Volume 887, pp. 358–363.
54. Nagay, B.E.; Cordeiro, J.M.; Barão, V.A.R. Alloy materials for biomedical applications. In *Alloy Materials and Their Allied Applications*; Scrivener Publishing LLC: Austin, TX, USA, 2020; pp. 159–189.
55. Baltatu, M.S.; Burduhos-Nergis, D.D.; Burduhos-Nergis, D.P.; Vizureanu, P. *Advanced Metallic Biomaterials*; Materials Research Forum LLC: Millersville, PA, USA, 2022.

56. Kaur, M.; Singh, K. Review on titanium and titanium based alloys as biomaterials for orthopaedic applications. *Mater. Sci. Eng. C* **2019**, *102*, 844–862. [CrossRef]
57. Baltatu, M.S.; Tugui, C.A.; Perju, M.C.; Benchea, M.; Spataru, M.C.; Sandu, A.V.; Vizureanu, P. Biocompatible titanium alloys used in medical applications. *Rev. Chim.* **2019**, *70*, 1302–1306. [CrossRef]
58. Rony, L.; Lancigu, R.; Hubert, L. Intraosseous metal implants in orthopedics: A review. *Morphologie* **2018**, *102*, 231–242. [CrossRef]
59. İzmir, M.; Ercan, B. Anodization of titanium alloys for orthopedic applications. *Front. Chem. Sci. Eng.* **2019**, *13*, 28–45. [CrossRef]
60. Jin, W.; Chu, P.K. Orthopedic implants. *Encycl. Biomed. Eng.* **2019**, *1*, 3.
61. Maitz, M.F. Applications of synthetic polymers in clinical medicine. *Biosurface Biotribology* **2015**, *1*, 161–176. [CrossRef]
62. Singh, D.K.; Verma, R.K. Contemporary Development on the Performance and Functionalization of Ultra High Molecular Weight Polyethylene (UHMWPE) for Biomedical Implants. *Nano LIFE* **2021**, *11*, 2130009. [CrossRef]
63. Zivic, F.; Affatato, S.; Trajanovic, M.; Schnabelrauch, M.; Grujovic, N.; Choy, K.L. (Eds.) *Biomaterials in Clinical Practice: Advances in Clinical Research and Medical Devices*; Springer: Cham, Switzerland, 2017.
64. Jefferies, C.; Al-Malaika, S.; Sheena, H.H. New and novel stabilisation approach for radiation-crosslinked Ultrahigh Molecular Weight Polyethylene (XL-UHMWPE) targeted for use in orthopeadic implants. *Polym. Degrad. Stab.* **2021**, *183*, 109462. [CrossRef]
65. Boschetto, F.; Ngoc Doan, H.; Phong Vo, P.; Zanocco, M.; Zhu, W.; Sakai, W.; Adachi, T.; Ohgitani, E.; Tsutsumi, N.; Mazda, O.; et al. Antibacterial and Osteoconductive Effects of Chitosan/Polyethylene Oxide (PEO)/Bioactive Glass Nanofibers for Orthopedic Applications. *Appl. Sci.* **2020**, *10*, 2360. [CrossRef]
66. Bistolfi, A.; Giustra, F.; Bosco, F.; Sabatini, L.; Aprato, A.; Bracco, P.; Bellare, A. Ultra-high molecular weight polyethylene (UHMWPE) for hip and knee arthroplasty: The present and the future. *J. Orthop.* **2021**, *25*, 98–106. [CrossRef]
67. Wahed, S.B.; Dunstan, C.R.; Boughton, P.C.; Ruys, A.J.; Faisal, S.N.; Wahed, T.B.; Salahuddin, B.; Cheng, X.; Zhou, Y.; Wang, C.H.; et al. Functional Ultra-High Molecular Weight Polyethylene Composites for Ligament Reconstructions and Their Targeted Applications in the Restoration of the Anterior Cruciate Ligament. *Polymers* **2022**, *14*, 2189. [CrossRef]
68. Said, A. Ultra-High-Molecular-Weight-Polyethylene (UHMWPE) as Desired Polymer Material for Biomedical. *Khalij-Libya J. Dent. Med. Res.* **2022**, *6*, 11–16. [CrossRef]
69. Hinz, N.; Dehoust, J.; Schroeter, J.; Schulz, A.P.; Hartel, M.J.; Lutz, C.; Frosch, K.H.; Wendlandt, R. Biomechanical in vitro analysis of a novel flexible implant for pubic symphysis disruption using an ultra-high molecular weight polyethylene fiber cord. *Clin. Biomech.* **2022**, *95*, 105652. [CrossRef]
70. Kasser, M.J. Regulation of UHMWPE biomaterials in total hip arthroplasty. *J. Biomed. Mater. Res. Part B Appl. Biomater.* **2013**, *101*, 400–406. [CrossRef]
71. Kammerlander, C.; Neuerburg, C.; Verlaan, J.J.; Schmoelz, W.; Miclau, T.; Larsson, S. The use of augmentation techniques in osteoporotic fracture fixation. *Injury* **2016**, *47*, S36–S43. [CrossRef]
72. Scolaro, J.A.; Lackman, R.D. Surgical management of metastatic long bone fractures: Principles and techniques. *JAAOS-J. Am. Acad. Orthop. Surg.* **2014**, *22*, 90–100.
73. Grechenig, S.; Gänsslen, A.; Gueorguiev, B.; Berner, A.; Müller, M.; Nerlich, M.; Schmitz, P. PMMA-augmented SI screw: A biomechanical analysis of stiffness and pull-out force in a matched paired human cadaveric model. *Injury* **2015**, *46*, S125–S128. [CrossRef]
74. Yaacobi, E.; Sanchez, D.; Maniar, H.; Horwitz, D.S. Surgical treatment of osteoporotic fractures: An update on the principles of management. *Injury* **2017**, *48*, S34–S40. [CrossRef]
75. Moazen, M.; Mak, J.H.; Etchels, L.W.; Jin, Z.; Wilcox, R.K.; Jones, A.C.; Tsiridis, E. The effect of fracture stability on the performance of locking plate fixation in periprosthetic femoral fractures. *J. Arthroplast.* **2013**, *28*, 1589–1595. [CrossRef]
76. Kumar, P.A.; Irudhayam, J.S.; Naviin, D. A review on importance and recent applications of polymer composites in orthopaedics. *Int. J. Eng. Res. Dev.* **2012**, *5*, 40–43.
77. Nixon, A.J.; Auer, J.A.; Watkins, J.P. Principles of fracture fixation. In *Equine Fracture Repair*; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2019; pp. 127–155.
78. Corró, S.; García-Albó, E.; Andrés-Peiró, J.V.; Teixidor, J.; Tomás, J. Bone Defect Management and Augumentation of Distal Femoral Fractures with Polymethylmethacrylate Bone Cement. *J. Musculoskelet. Res.* **2022**, *25*, 2250013. [CrossRef]
79. Grant, K.D.; Busse, E.C.; Park, D.K.; Baker, K.C. Internal fixation of osteoporotic bone. *JAAOS-J. Am. Acad. Orthop. Surg.* **2018**, *26*, 166–174. [CrossRef]
80. Hsu, R.Y.; Ramirez, J.M.; Blankenhorn, B.D. Surgical considerations for osteoporosis in ankle fracture fixation. *Orthop. Clin.* **2019**, *50*, 245–258. [CrossRef]
81. Allizond, V.; Comini, S.; Cuffini, A.M.; Banche, G. Current Knowledge on Biomaterials for Orthopedic Applications Modified to Reduce Bacterial Adhesive Ability. *Antibiotics* **2022**, *11*, 529. [CrossRef]
82. Sa, Y.; Yang, F.; Wang, Y.; Wolke, J.G.; Jansen, J.A. Modifications of poly (methyl methacrylate) cement for application in orthopedic surgery. In *Cutting-Edge Enabling Technologies for Regenerative Medicine*; Springer: Singapore, 2018; Volume 1078, pp. 119–134.
83. Shirvan, A.R.; Nouri, A.; Wen, C. Structural polymer biomaterials. In *Structural Biomaterials*; Woodhead Publishing: Cambridge, UK, 2021; pp. 395–439.
84. Hamdy, T.M. Polymers and ceramics biomaterials in orthopedics and dentistry: A review article. *Egypt. J. Chem.* **2018**, *61*, 723–730. [CrossRef]
85. Kenny, S.M.; Buggy, M. Bone cements and fillers: A review. *J. Mater. Sci. Mater. Med.* **2003**, *14*, 923–938. [CrossRef]

86. Soles, G.L.; Ferguson, T.A. Fragility fractures of the pelvis. *Curr. Rev. Musculoskelet. Med.* **2012**, *5*, 222–228. [CrossRef]
87. Davis, F.J.; Mitchell, G.R. Polyurethane based materials with applications in medical devices. In *Bio-Materials and Prototyping Applications in Medicine*; Springer: Boston, MA, USA, 2008; pp. 27–48.
88. Mathew, E.; Domínguez-Robles, J.; Larrañeta, E.; Lamprou, D.A. Fused Deposition Modelling as a Potential Tool for Antimicrobial Dialysis Catheters Manufacturing: New Trends vs. Conventional Approaches. *Coatings* **2019**, *9*, 515. [CrossRef]
89. Pruitt, L.; Furmanski, J. Polymeric biomaterials for load-bearing medical devices. *JOM* **2009**, *61*, 14–20. [CrossRef]
90. Mayet, N.; Choonara, Y.E.; Kumar, P.; Tomar, L.K.; Tyagi, C.; Du Toit, L.C.; Pillay, V. A comprehensive review of advanced biopolymeric wound healing systems. *J. Pharm. Sci.* **2014**, *103*, 2211–2230. [CrossRef]
91. Bezuidenhout, D.; Williams, D.F.; Zilla, P. Polymeric heart valves for surgical implantation, catheter-based technologies and heart assist devices. *Biomaterials* **2015**, *36*, 6–25. [CrossRef]
92. Blaheta, R.A.; Oertl, A.; Freisleben, H.J.; Nelson, K.; Ackermann, H.; Haferkamp, A.; Engl, T. Detection of early DJ-stent encrustation by sonographic twinkling-artifacts–A pilot study. *Cent. Eur. J. Urol.* **2017**, *70*, 107.
93. Ong, K.L.; Yun, B.M.; White, J.B. New biomaterials for orthopedic implants. *Orthop. Res. Rev.* **2015**, *7*, 107–130. [CrossRef]
94. Giza, E.; Frizzell, L.; Farac, R.; Williams, J.; Kim, S. Augmented tendon Achilles repair using a tissue reinforcement scaffold: A biomechanical study. *Foot Ankle Int.* **2011**, *32*, 545–549. [CrossRef]
95. Faroni, A.; Mobasseri, S.A.; Kingham, P.J.; Reid, A.J. Peripheral nerve regeneration: Experimental strategies and future perspectives. *Adv. Drug Deliv. Rev.* **2015**, *82*, 160–167. [CrossRef] [PubMed]
96. Zafar, F.; Sharmin, E. (Eds.) *Polyurethane*; BoD–Books on Demand, IntechOpen: Rijeka, Croatia, 2012.
97. Thompson, M.S.; McCarthy, I.D.; Lidgren, L.; Ryd, L. Compressive and shear properties of commercially available polyurethane foams. *J. Biomech. Eng.* **2003**, *125*, 732–734. [CrossRef]
98. Calvert, K.L.; Trumble, K.P.; Webster, T.J.; Kirkpatrick, L.A. Characterization of commercial rigid polyurethane foams used as bone analogs for implant testing. *J. Mater. Sci. Mater. Med.* **2010**, *21*, 1453–1461. [CrossRef] [PubMed]
99. Bredbenner, T.L.; Haug, R.H. Substitutes for human cadaveric bone in maxillofacial rigid fixation research. *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endodontol.* **2000**, *90*, 574–580. [CrossRef] [PubMed]
100. Piconi, C. Ceramics for joint replacement: Design and application of commercial bearings. In *Advances in Ceramic Biomaterials*; Woodhead Publishing: Cambridge, UK, 2017; pp. 129–179.
101. Piconi, C.; Sprio, S. Oxide Bioceramic Composites in Orthopedics and Dentistry. *J. Compos. Sci.* **2021**, *5*, 206. [CrossRef]
102. Wang, W.; Ouyang, Y.; Poh, C.K. Orthopaedic implant technology: Biomaterials from past to future. *Ann. Acad. Med.* **2011**, *40*, 237.
103. Ma, H.; Suonan, A.; Zhou, J.; Yuan, Q.; Liu, L.; Zhao, X.; Zhang, Y.G. PEEK (Polyether-ether-ketone) and its composite materials in orthopedic implantation. *Arab. J. Chem.* **2021**, *14*, 102977. [CrossRef]
104. Badulescu, O.V.; Filip, N.; Sirbu, P.D.; Bararu-Bojan, I.; Vladeanu, M.; Bojan, A.; Ciocoiu, M. Current practices in haemophilic patients undergoing orthopedic surgery-a systematic review. *Exp. Ther. Med.* **2020**, *20*, 1–4. [CrossRef]
105. Tsakiris, V.; Tardei, C.; Clicinschi, F.M. Biodegradable Mg alloys for orthopedic implants—A review. *J. Magnes. Alloy.* **2021**, *9*, 1884–1905. [CrossRef]
106. Pattanayak, S.; Sahoo, S.K. Micro engraving on 316L stainless steel orthopedic implant using fiber laser. *Opt. Fiber Technol.* **2021**, *63*, 102479. [CrossRef]
107. Badulescu, O.V.; Sirbu, P.D.; Ungureanu, C.; Pînzariu, A.; Cojocaru, E.; Filip, N.; Bararu-Bojan, I.; Vladeanu, M.; Ciocoiu, M. Orthopedic surgery in hemophilic patients with musculoskeletal disorders: A systematic review. *Exp. Ther. Med.* **2021**, *22*, 995. [CrossRef]
108. Badulescu, O.V.; Ciocoiu, M.; Filip, N.; Veringa, V. Tranexamic acid-major antifibrinolytic agent used to achieve hemostasis in hemophilic patients with anti-factor VIII antibodies who must undergo total joint replacement. *Rev. Chim.* **2019**, *70*, 638–641. [CrossRef]
109. Filip, A.; Alexa, O.; Sirbu, P.D.; Filip, C.; Andrusca, L.; Pascal, I.A.; Oprea, S.; Badulescu, O.V. Assessment of the Mechanical Properties of Orthopedic Screws Coated with Polyurethane Acrylate Containing Hydroxyapatite, Intended to Fix the Fragility Fractures. *Mater. Plast.* **2019**, *56*, 1028. [CrossRef]
110. Filip, A.; Badulescu, O.V.; Sirbu, P.D.; Veliceasa, B.; Puha, B.; Pascal, I.A.; Andrusca, L.; Oprea, D.; Filip, C.; Alexa, O. Preliminary investigation on mechanical properties of polymer coating screws for the future fragility fracture fixation. *Mater. Plast.* **2019**, *56*, 559. [CrossRef]
111. Li, H.; Xia, P.; Pan, S.; Qi, Z.; Fu, C.; Yu, Z.; Kong, W.; Chang, Y.; Wang, K.; Wu, D.; et al. The advances of ceria nanoparticles for biomedical applications in orthopaedics. *Int. J. Nanomed.* **2020**, *15*, 7199. [CrossRef]
112. Kalyanaraman, V.; Naveen, S.V.; Mohana, N.; Balaje, R.M.; Navaneethakrishnan, K.R.; Brabu, B.; Murugan, D.S.; Kumaravel, T.S. Biocompatibility studies on cerium oxide nanoparticles–Combined study for local effects, systemic toxicity and genotoxicity via implantation route. *Toxicol. Res.* **2019**, *8*, 25–37. [CrossRef]
113. Soni, M.; Mehta, P.; Soni, A.; Goswami, G.K. Green nanoparticles: Synthesis and applications. *IOSR J. Biotechnol. Biochem.* **2018**, *4*, 78–83.
114. Nikolova, M.P.; Chavali, M.S. Metal oxide nanoparticles as biomedical materials. *Biomimetics* **2020**, *5*, 27. [CrossRef]
115. Luo, J.; Zhu, S.; Tong, Y.; Zhang, Y.; Li, Y.; Cao, L.; Kong, M.; Luo, M.; Bi, Q.; Zhang, Q. Cerium Oxide Nanoparticles Promote Osteoplastic Precursor Differentiation by Activating the Wnt Pathway. *Biol. Trace Elem. Res.* **2022**, *201*, 1–9. [CrossRef]

116. Castiglioni, S.; Cazzaniga, A.; Locatelli, L.; Maier, J.A.M. Silver Nanoparticles in Orthopedic Applications: New Insights on Their Effects on Osteogenic Cells. *Nanomaterials* **2017**, *7*, 124. [CrossRef]
117. Samanta, A.; Podder, S.; Kumarasamy, M.; Ghosh, C.K.; Lahiri, D.; Roy, P.; Bhattacharjee, S.; Ghosh, J.; Mukhopadhyay, A.K. Au nanoparticle-decorated aragonite microdumbbells for enhanced antibacterial and anticancer activities. *Mater. Sci. Eng. C* **2019**, *103*, 109734. [CrossRef]
118. Holweg, P.; Labmayr, V.; Schwarze, U.; Soomer, N.; Ornig, M.; Leithner, A. Osteotomy after medial malleolus fracture fixed with magnesium screws ZX00—A case report. *Trauma Case Rep.* **2022**, *42*, 100706. [CrossRef]
119. Antoniac, I.; Miculescu, M.; Manescu, V.; Stere, A.; Quan, P.H.; Paltânea, G.; Robu, A.; Earar, K. Magnesium-Based Alloys Used in Orthopedic Surgery. *Materials* **2022**, *15*, 1148. [CrossRef]
120. Memarian, P.; Pishavar, E.; Zanotti, F.; Trentini, M.; Camponogara, F.; Soliani, E.; Gargiulo, P.; Isola, M.; Zavan, B. Active Materials for 3D Printing in Small Animals: Current Modalities and Future Directions for Orthopedic Applications. *Int. J. Mol. Sci.* **2022**, *23*, 1045. [CrossRef]
121. Feltz, K.P.; MacFadden, L.N.; Gieg, S.D.; Lough, C.P.; Bezold, W.A.; Skelley, N.W. Mechanical properties of 3D-printed orthopedic one-third tubular plates and cortical screws. *J. 3D Print. Med.* **2022**, *6*, 129–145. [CrossRef]
122. Li, B.; Zhang, M.; Lu, Q.; Zhang, B.; Miao, Z.; Li, L.; Zheng, T.; Liu, P. Application and Development of Modern 3D Printing Technology in the Field of Orthopedics. *BioMed Res. Int.* **2022**, *2022*, 8759060. [CrossRef]