Journal of Management and Science
12(4) 2022 67-73
OPEN ACCESS
RESEARCH ARTICLE
DOI: https://doi.org/10.26524/jms.12.66

Production Methods and Marketing of Bioceramic Materials with Artificial Intelligence Supported 3D Printer Models

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Abstract

The field of biomedical engineering relies heavily on materials known as bioceramics due to their many advantages. That's also because bioceramics are often used in the field of tissue engineering as well as implant applications. It is a direct consequence of the effective use of bioceramics. Three-dimensional printing is now the production technology used most often for bioceramics. On the other hand, there are also various approaches (3D Printers). The manufacturing processes have certain commonalities (such as the production of materials in successive layers). Still, they also share some variances (such as the amount of time it takes, the amount of money it costs, and the temperature at which the machine operates). This study contains research on the many ways that may be used to create bioceramics and the benefits and drawbacks of the various methods applied in the manufacturing process.

Keywords: Bioceramics, 3D printing, marketing, product and brand management, artificial intelligence, machine learning, biomedical engineering.

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How to cite this article: Sevgi Aydin, Kemal Gokhan Nalbant, Amirmasoud Alizadeh, Production Methods and Marketing of Bioceramic Materials with Artificial Intelligence Supported 3D Printer Models, Journal of Management and Science, 12(4) 2022 67-73. Retrieved from https://jmseleyon.com/index.php/jms/article/view/623
Received: 2 June 2022 **Revised:** 10 August 2022 **Accepted:** 18 September 2022

1. Introduction

The study of biomaterials is a significant component of biomedical engineering. The most common biomaterials are biometal, bioceramic, biopolymer, and biocomposite. Because bioceramics have a structure comparable to bone in terms of mechanical strength, resistance, and other characteristics, they are often utilized in bone and dental implanting and regeneration. As a result, the technique by which bioceramics are produced is of utmost significance. The additive manufacturing (AM) process, often known as 3D printing, is utilized to create the bioceramics that end up in bone tissue. Additive manufacturing can be accomplished through a variety of processes, including selective laser sintering (SLS), stereolithography (SL), digital light patterning, continuous liquid interface production, fused deposition modeling, direct ink writing (DIW), inkjet printing, electrospinning, and melt electrospinning, to name a few. In addition, some procedures need supplementary materials such as a binder. The AM machine may use either solid (powder) or liquid ingredients for its manufacture (ink).

The size of the biomedical devices market is expected to grow at a rate of 4.5 percent from 2018 to 2023; patient monitoring systems, implant materials, additive manufacturing, and 3DP and other technologies are the major components of medical devices, and they are included in this market; the marketing of medical devices is segmented based on the risks associated with the devices. [1]

The field of study known as biomedical engineering didn't exist long ago. It is generally understood to apply engineering principles to study areas within the living sciences. This definition has widespread acceptance. It combines the design principles used in engineering with the analytical tools used in mathematics, physics, and chemistry to find solutions to problems in fields such as medical, biology, biotechnology, pharmacy, and other related fields. Although it is acknowledged as a field of knowledge per se, biomedical engineering is expanding as a multidisciplinary field among well-established sectors such as engineering, physics, and mathematics. This is because the importance of biomedical engineering is growing from an academic, scientific, and professional standpoint. [2]

Some people are not suited for careers in biomedical marketing. But for extroverted, dedicated researchers who specialize in straightforward communication and are willing to pursue a long career path, it may provide a gratifying alternative to working in academia and the potential to develop products that might help hundreds of millions of people. The field of marketing encompasses a diverse array of subfields and specializations. Some experts directly assist their firms in selecting which goods to bring to market and how to distinguish them from the competition. In contrast, others are more like consultants in their position. Market research companies such as Ipsos Healthcare, which has its North American base in Parsippany, New Jersey, and Bio Plan Associates in Rockville, Maryland, provide information to pharmaceutical clients about customer perceptions using surveys, focus groups, and data analysis. Ipsos Healthcare's North American base is in Parsippany. They used such data to assist brand managers in deciding how to advertise their items. [3] Promoting biomedical treatments and medications, for instance, via campaigns on social media, is an example of biomedical marketing, a subset of social marketing. [3,4]

The pharmaceutical business has provided significant assistance to organized medicine in its efforts to preserve the "status quo." The phrase "important opinion leaders and deciders" is where marketers concentrate a significant amount of their resources and efforts. In as many situations as feasible, the benefits case for medicine or technology will emphasize the critical role that clinical judgment and discretion play in patient care. To adapt to a world where physician control of the prescription process is constrained by reimbursement and cost reduction, physician-focused medical marketing must shift its emphasis away from physicians. As a result of being subjected to various types of scrutiny and pressure, physicians are being compelled to reevaluate their connections with pharmaceutical corporations and the salespeople employed by those businesses. In preparation for a future of "networked healthcare," in which a variety of stakeholders is entangled in the prescription decision, pharmaceutical corporations are committing significant resources to altering their marketing strategies. [5]

2. Biomaterials

In this section, biomaterial categories were investigated.

2.1 Biopolymer

Polymers find various applications in medicine, including vascular prostheses, catheters, medication administration, skin prostheses, and ophthalmic prostheses. Additionally, polymers are used in the fields of orthopedics and dentistry. [6] Naturally occurring biopolymers, such as gelatin, and synthetically produced biopolymers, such as polylactic acid (PLA), are the categories that biopolymers fall under. Most synthetic biopolymers are employed in tissue engineering. [7] The biomechanical features of biopolymers are directly tied to their chemical bonds. Biopolymers have a weak Van der Waals interaction between molecules, but they have a strong bond between the atoms that make up each molecule. [8] Depending on the applications, biopolymer scaffolds can be natural or synthetic, biodegradable, or non-biodegradable, but scaffolds should not be toxic. [9]

2.2 Biometal

In bone and tooth regeneration and other biometals applications, biometals such as calcium, magnesium, copper, manganese, and cobalt are often employed because of their biological purpose in the human body . [10] Bimetals often have excellent resistance and strength; as a result, they are used in long-term implants, which must have the same resistance and strength as bone. [11] Corrosion of biometals was impacted by both oxygen and ph. As a result, having a low PH in the blood is one reason for local corrosion of the metal implant. [12,13]

2.3 Biocomposites

One or more phases of materials are often used to construct biocomposites. In addition, materials are produced using natural or biofiber polymers as their base. [14,15] In addition to the more conventional usage of natural fiber composites for biomedical purposes, biocomposites are increasingly being used in orthopedic and dental applications, skin regeneration, and tissue engineering. To be used in biomedical applications, biocomposites and other materials must have certain qualities and be safe for the human body. [16] Plants (like kenaf), minerals (like cotton), and animals all contribute to the composition of natural fibers. [17]

2.4 Bioceramic

The replacement, regeneration, or improvement of tissue and organs, cardiovascular implants, and dental implants may all be accomplished with the help of bioceramics, which are used in tissue and organ engineering. [18,19] Ceramics may be separated into two categories: bioactive (such as calcium phosphate and glass-ceramics) and bioinert (such as alumina). Bioinert ceramics may be found in hip prostheses as well as dental implants. In addition, bioinert ceramics have high resistance and biocompatibility. [20]

2.5 Classification of bioceramics

As can be shown in Table 1, bioceramics may be broken down into three distinct categories.

3. Machine Learning and Artificial Intelligence in Bioceramic Production

Deep learning and machine learning (ML) are two of the most important subfields that fall under the umbrella of artificial intelligence (AI). [22] The best materials and particles are recommended to ML and AL so that they may manufacture new materials or materials that are beneficial for medical purposes. ML is composed of inputs and outputs; hence, ML evaluates inputs and outputs before providing recommendations on the ideal materials for tissue implants. [23]

Additive manufacturing (AM), also known as three-dimensional printing (3DP), is the technique that is most used to produce biomaterials. The biomedical industry accounts for 15.1% of all applications of AM. AM operates on the principle of uploading data to a machine, which is followed by the machine slicing a model and producing materials layer-by-layer in the same manner as the model. This technology is often used to generate biomaterials since ML and AI have the potential to increase material quality while simultaneously lowering production costs. One of the ML methods used in AM is known as powder bed fusion (PBF), which is broken down into three primary subcategories: selective laser melting (SLM), selective laser sintering (SLS), and electron beam melting (EBM) . [22,24,25,26] Figure 1 displays the AM classification that is used in the field of biomedical research.

In recent years, artificial intelligence (AI) has seen substantial growth, leading to the development of various applications in various business sectors. In addition, numerous medical applications can benefit from hydroxyapatite coatings that have been thermally sprayed on. This is because hydroxyapatite is a bioactive and osteoconductive material, which means that it can be used to build a solid and stable biological bond with the bone tissue around it. [28]

Printing in three dimensions, also known as additive manufacturing (AM), has grown more popular due to its capacity to construct and produce geometries that are hard to build using conventional techniques. The computer-aided design (CAD) files are used to create a physical product using the layer-by-layer procedure that is used in 3D printing. This approach may be used for practically all materials (including polymers, metals, and ceramics) for advanced manufacturing. The advancement of 3D printing has led to a fast rise in applications in various fields, including biological devices, electronics, wearable devices, soft robotics, and chemical engineering, all of which have adopted the technology to facilitate this growth. The sector of medical devices is another one in which 3D printing is making significant progress and gaining some ground. Because of the ease with which CT and MRI technologies may be used to build the device design directly, a significant amount of research has been conducted on 3D printing in orthopedic devices. In addition, the orthopedic device is a lot less complicated when compared to other organ parts. Developing other organ parts requires bio-inks, and it is more challenging to govern organ performance using today's technologies. AM is often used in orthopedics, namely in joint prostheses, bone grafts and spinal cages, meniscus and cartilage implants, and fixation devices. Other areas of application include cartilage and meniscus implants. The applications may be further subdivided into biodegradable, nondegradable, or permanent implants, depending on which of these four categories they fall within. The materials utilized for each implant differ depending on the application, which is something we will go into more depth about in the following parts of this study. [23]

Dental product performances are impacted not only by the formulation but also by the production engineering process, which includes the design of the CAD file, the printing process, quality control, and postprocessing. As a result, the application of machine learning to the optimization of the printing process is also very significant, and a growing number of research groups are beginning to work on it. The use of machine learning algorithms in 3D printing has the potential to cover a wide range of areas, including 3D printing design, quality, process optimization, slicing acceleration, travel route planning, supporting structures, and the influence of printing materials. All of these elements have the potential to have a direct impact on the final performance of the things that are 3D printed. [23]

4. Bioceramic Production Methods

The many ways of producing bioceramics are investigated in this section.

4.1 Stereolithography

Chuck Hull developed Vat Polymerization or Stereolithography (SLA) in 1986. This method is one of AM techniques for producing porosity and flexible bioceramic, but this method requires more time and is a costly production technique. Chuck Hull developed Vat Polymerization or Stereolithography (SLA). SLA is used in the production of bone scaffolds in addition to dental components derived from bioactive ceramics. [29,30] Ceramics such as bioactive glasses, HA, β-TCP (tricalcium phosphorus), zirconia, and alumina may be produced using the SL process, which is then used in bone healing and the placement of dental implants. [31]

An SLA consists of a resin tank, building platform, mirror, and UV lasers. The UV lasers act on the liquid resin, which generates 3D scaffolds layer-by-layer. When the irradiation of the first layer is complete, the building platforms move higher, and fresh resin covers the layer. [32] The SLA methodology is seen in Figure 2.

4.2 Selective laser sintering

In 1986, Beaman invented a technique known as selective laser sintering (SLS). This strategy uses two different approaches, namely, directly and indirectly. Fabricating materials with low melting points sometimes use direct laser sintering (bioactive glasses, glass ceramics). Crystallization may be readily controlled via an indirect laser sintering process, which is used in manufacturing powder-based materials (HA, BCP). [33.34]

The construction bed, the laser, the powder tank, and the power distributing roller are the primary components that make up the SLS machine. When the first layer of the building is finished, the building bed is moved down, the roller spreads a new layer of powder on the building bed, and the process is repeated repeatedly. The SLS process begins by dividing 3D CAD data. After that, SLS radiates lasers to powder and sinters the particles of powder. [29,32]

The SLS technique has a few disadvantages, including the fact that only the powder form of the material is accepted, the risk posed by lasers, and the fact that this technique is not recommended for use with large parts. The SLS technique's advantages include its low cost and good mechanical properties. [35] The primary operational concept of the SLS approach is seen in Figure 3.

4.3 Direct Ink Writing

Cesarano coined the term "direct in writing" (DIW) in 1997. The DIW technique is a straightforward, low-cost, and quick way of manufacturing; nevertheless, the DIW method has a poor level of precision and needs extra assistance to help in printing; while the printing process is in progress. [32,36]

The suspension or ink tank, the nozzle for extrusion ink, and the building plate are the three primary components that make up a DIW machine. Extrusion nozzle processes include (1) pressure types, (2) piston types (3) screw kinds. [32,37] If the ink is not liquid, it will not be able to pass through the nozzle, and the DIW printer will begin to produce the material layer by layer by the model that was created using CAD software. The suspension that is contained within the DIW ink tank is made up of ceramic powder and water-based solvents. It is recommended that a larger ratio of ceramic powder to solvent be used when making the final material to avoid cracking. (60-65 percent)

This approach generally produces most bioceramics (calcium phosphates, bioactive glasses, calcium silicates). [32,38,39] Figure 4 demonstrates the fundamental operational idea behind the DIW approach.

4.4 Fused Deposition Modeling (FDM):

The components of an FDM machine include a filament tank, a build platform, and a pair of nozzles. The construction filaments are stored in the second tank, while the support filaments are stored in the first. Ceramic filaments are constructed using ceramic powder and a thermoplastic binder. The ratio of ceramic powder to other components in ceramic filaments ranges from 45 to 60 percent. The use of a binder in ceramic filaments serves the purpose of minimizing the risk of the finished product developing cracks. After the first layers have been manufactured, the building bed moves downwards, and the process is repeated repeatedly. 3D models are split into layers using CAD software, then sent to an FDM machine, which builds the models layer by layer using filaments extruded from nozzles.

The resistance of the ceramics produced using this approach is low compared to the resistance created using other methods. [41,42,43,44] The benefits of this method are that it is economical, easy, and may be utilized in manufacturing complicated and broad ceramics. Figure 5 shows the fundamental concept that underpins the DIW approach.

Table 1- Classification of bioceramics [21]

Bioinert	Bioactive	Biodegradable
Yttria-stabilized tetragonal zirconia (Y-TZP)	Hydroxyapatite(HA)	β-Tricalcium phosphate (β-TCP)
Aluminumoksida (Alumnina)	Bioglasses or glass-ceramics	α-Tricalcium phosphate (α-TCP)
Silicon nitride	SiO_2(A-W)	Dicalcium phosphate anhydrate (DCP or DCPA)
Silicon carbide	MgO (A-W)	Calcium pyrophosphate (CPP)
Carbon	Na_2O(Ceravital)	Dicalcium phosphate dihydrate (DCP_2 or DCPD)
Sintered HA	MgO (Ceravital)	Tetracalcium phosphate (TeCP)
$CaAl_2O_4$	CaO(Ceravital)	Octacalcium phosphate (OCP)
Si_3N_4	K_2O(Ceravital)	Amorphous calcium phosphate (ACP)

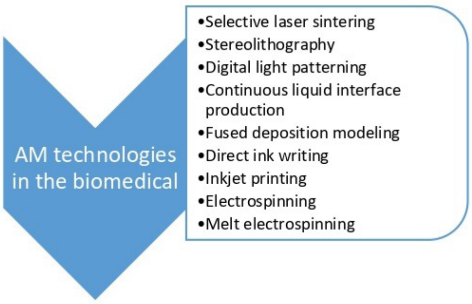

Fig. 1. AM categorization used in biomedical research [27]

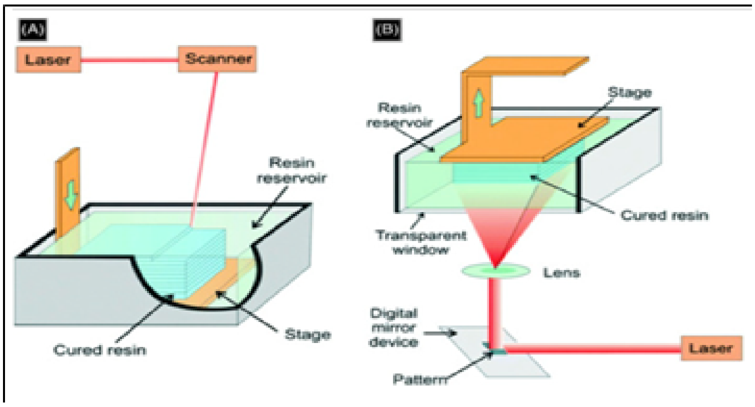

Fig. 2. SLA technique [30]

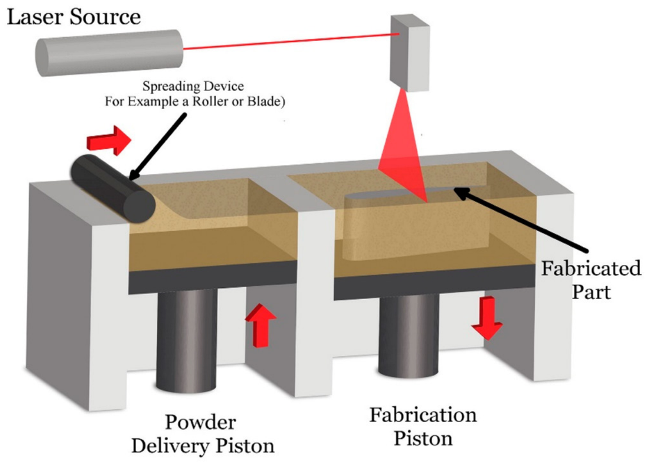

Fig. 3. The fundamental operating idea of the SLS method [29]

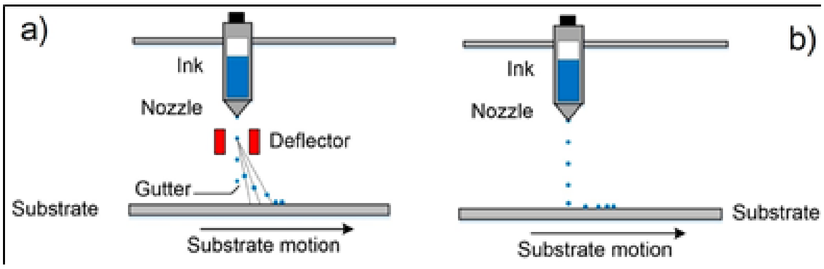

Fig. 4. The DIW method's basic working principle [40]

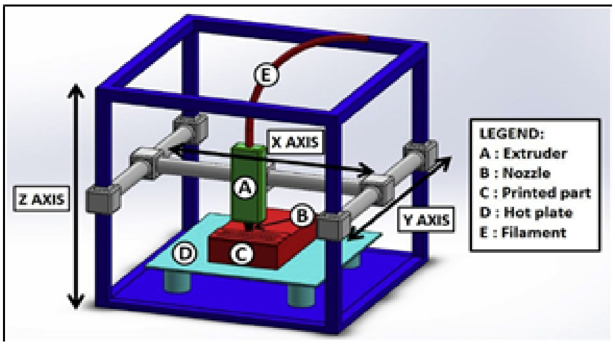

Fig. 5. The basic idea behind the DIW technique [44]

5. Conclusion

The ability of machine learning to interpret vast quantities of data, learn, and put actions into motion quickly and consistently has been shown throughout this study in several cases to accelerate the development of biomaterials. Too far, however, machine learning has only been applied to a limited subset of research on biomaterials, and there has been no successful application of machine learning to the clinical development of biomaterials such as dental implants. Experimentation and data collecting in biomaterials are not standardized, resulting in variances from lab to lab and country to country. This is one of the primary reasons why this occurs. It might be challenging to compare and assess the data from various research organizations since, for instance, the chemicals and cell lines used for output biological response tests are often unique to each research group. Even when using the same printer, an item may be produced in various ways or constructed with various tilt degrees since different 3D printing methods employ various printing processes. Consequently, it isn't easy to acquire a dataset that is sufficiently big and objectively comparable to do machine learning modifications. [23]

In many circumstances, the data is incorrect, and the information on many input parameters is unavailable. For instance, not many materials can be used for dental printing, and those that may be used are often proprietary. Because of this, the knowledge of the chemical inputs is considered a trade secret and is not shared with the users. The input characterization of each group's materials may have been carried out by various organizations using various techniques and apparatus. For instance, each study group may have employed a slightly different surface approach; hence, if AFM data were precisely compared, significant sections of the dataset would be missing. This would be the case if the AFM data were directly compared. [23]

The industry of additive manufacturing is growing at a fast rate and has developed into a vital technology for the production of biomaterials, notably 3D Printing. The fact that the qualities of biomaterials may be preserved in a biological setting without suffering any degradation is the characteristic of biomaterials that are considered the most essential. Bioceramics are put to use in the process of repairing or regenerating the rigid connective tissue that makes up the skeleton. Age is a factor in determining whether or not one needs these various elements. After the age of 30, a person's bone density begins to decline, resulting in their bones becoming more fragile. Additive manufacturing, commonly known as 3D printing, is an innovative material processing technology widely used to build bioceramic components or scaffolds in a layered and observant way. Additive manufacturing, or AM, is also often referred to as an additive fabrication. As a result, the manufacture of bioceramics needs to emphasize significantly on 3D printers. It is essential to invest money in the development of technologies that make use of artificial intelligence and machine learning. In addition, concerns such as the marketing of bioceramics to these technologies must be emphasized more in the relevant body of scholarly research.

Acknowledgement

Nill

Funding

No funding was received to carry out this study.

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