3D Printing for medical devices: Mini review and bibliometric study

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Abstract. The technology of three-dimensional (3D) printing is transforming modern living. 3D printing has been a technical breakthrough because it can swiftly and precisely construct intricate and customized medical items. The study examines the pros and cons of technology as well as the possibilities of 3D printers for medical applications. The study includes bibliometric analysis based on previously published studies as well as a thorough examination of the literature. The paper examines both the benefits and drawbacks of 3D printing as it relates to medical devices. The numerous techniques and applications that can be applied, including stereolithography, fused deposition modeling, and digital light processing, are covered in the article. The outcomes of the systematic literature review demonstrate the possibilities for 3D-printed medical equipment in the fields of surgery, personal gadgets, and eco-friendly based materials. However, because of the delicate nature and intricacy of the materials, combining biodegradable polymers with biological components as a 3D printing material can be an eco-friendly alternative.

1 Introduction

Three-dimensional printing is one of the most impactful technologies these days. Due to its capacity to build complicated and personalized medical devices quickly and accurately, three-dimensional (3D) printing has become a technology that is revolutionizing this industry. This ground-breaking technology[1] has made it possible to manufacture complex gadgets that can no longer be made using traditional techniques like injection molding or machining. In particular, the development of medical devices—which need precise control over the flow of fluids in small volumes—has advanced significantly because of the application of 3D printing technology. In turn, this has improved the performance and dependability of these devices in a variety of medical applications. Researchers and manufacturers are now able to construct medical devices with unmatched precision, accuracy, and reproducibility thanks to 3D printing[2].

Numerous studies[2]–[4] have investigated the possibility of 3D printing for medical devices in the medical industry. 3D printing technology can successfully create medicals devices with complex geometries at a reasonable cost. The affordability of 3D printing as a manufacturing method is a big benefit. Traditional manufacturing techniques are more affordable for mass production, while 3D printing is becoming more affordable for short-run production. For small-sized conventional implants or prosthesis and businesses that produce complex parts or goods that need regular revisions or have low manufacturing numbers, this is especially advantageous. By using less unnecessary materials, 3D printing also lowers manufacturing costs. For example, a 10 mg tablet can be [2]made to order as a 1 mg tablet. Additionally, this procedure can result in dose forms that are less expensive and simpler to provide to patients[5].

In brief, additive manufacturing technology has revolutionized the creation of medical devices by making it possible to manufacture complex and individualized devices quickly and accurately. This technology has had a tremendous positive impact on medical devices because it makes it possible to fabricate tiny devices with precise geometries and fluid flow control. The mentioned sources highlight[2]–[4] recent developments in 3D printing processes, materials, and uses for the medical devices, with a focus on low-cost medical applications. The study also looks at the potential of 3D printing for medical use, as well as the advantages and disadvantages of the technique, as well as the advantages and disadvantages of

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3D-printed devices.

2 Literature Review

2.1 3D Printing on Medical Devices

Laboratory operations can be made smaller by using small items, which are engineered devices that enable the exact routing and manipulation of small fluidic streams. These sophisticated machines are frequently developed specifically for a given use case with the goals of quick analysis and a restricted number of reagents and test materials. A variety of functional features have been documented, and complex shapes can be manufactured because of the field's recent transition from replica molding to 3D printing. Since the technique drastically cuts the time required to go from a concept to a chip, 3D printing has been used more and more in recent years to produce medical devices[6]. The science and technology of medic involves developing methods and apparatus for manipulating and controlling fluids and particles of micron and submicron dimensions.

2.2 System applied on 3D Printing

3D printers were able to print a complex structure with high precision and definition which made the printing output more realistic. From the few techniques above, there's some techniques that can be used commercially and industrially. Those techniques that can be used [7], [8]:

a. Multi jet modeling (MJM)
   MJM printers are capable of inkjet printing numerous materials simultaneously to construct various things with a variety of material qualities[9]. However, the materials that may be printed on using MJM are costly and exclusive. Anatomical models are typically created using MJM in the medical fields. Due to its high resolution and ability to access numerous materials, MJM is an intriguing technology that has possible applications in the anatomical sector.
b. Digital Micromirror Device-based Projection Printing (DMD-PP)
   The DMD-PP technology, which refers for Digital Micromirror Device-based Projection Printing, is a projections system which contains a digital, controllable mirror that can reflect laser light on the whole plane, allowing for simultaneous curing of every layer[10]. The 3D microstructure was produced utilizing a DMD-PP-capable 3D bioprinter. Theoretically negative Poisson's ratio materials can be printed using DMD-PP technology.
c. Fused Deposition Modelling (FDM)
   Fused deposition modeling (FDM), a type of 3D printing, is a method in which heated thermoplastic material is extruded from a motorized, three-dimensional movable nozzle head[11]. That has movement in three dichromatic dimensions. FDM principles, which are based on layer creation technology, surface chemistry, and heat energy, are used to harden the material. The thermoplastic substance is melted into a semi-solid state by a heating element. Then, using a nozzle, it is extruded layer by layer onto the stage. FDM is currently the most affordable technology, and that is where applications for home printers go. To find MRSA (Methicillin resistant Staphylococcus aureus), 3D printed chips based on Fusion Filament Fabrication (FFF) that may be utilized for bacterial growth, DNA separation, PCR, and gene identification amplified using gold nanoparticle (AuNP) probes were employed.
d. Stereolithography (SLA)
   SLA uses high specificity to manufacture surfaces with fine detail. Furthermore, SLA enables printing without assembly. Due to the limited consumption of medium fluid, SLA systems can preserve a cheap cost while maintaining the high-resolution result. Moreover, SLA printer was designed to be a personal use printer and as such was less expensive, smaller, and quicker. SLA can, however, be used to cure UV[12]. In SL, micro-channels are created by photopolymerizing the channel walls and thereafter, when mold is complete, dries the acquired resin from the channel cavity.
e. Powder Bed Fusion(PBF)[13]
   Laser or electron beams are used in Powder Bed Fusion (PBF) to fuse as well as melt the powder material. EBM (Electron Beam Melting) can be used to make functioning pieces from both plastic and metal, but it needs a vacuum chamber to do so.
f. Binder Jetting[13]
   A powder-based substance is utilized as a binder in the binder jetting process, acting as an adhesive between layers of powder. Although the build material is often in the form of powder and the binder typically takes the form of liquid, this technology is unsuitable for structural parts due to the binding characteristics.
g. Selective Laser Sintering (SLS)[13]
   Using pressure and heat, powdered materials are combined in SLS to create solid objects. SLS is a very adaptable method that can produce complex structure with excellent quality straight from a CAD model. SLS is a layer-by-layer technique carried out with the aid of an electron laser beam, and it may be used with a wide variety of powder materials.

2.3 Application of 3D printing

Extrusion-based manufacturing, inkjet-based printing, and particles fused printing are the three primary types of 3D printing utilized in medical applications. There may be options to make the product with a unique form, color, or texture in particular tailored circumstances. There have been significant advancements in cellulose-based materials that have opened up new research opportunities.

One of the cellulose-based materials, cellulose nanocrystals (CNC), was processed and mixed in a combination of photopolymerizable monomer and photo-initiator[14]. In addition to that, implants may also be made via 3D printing. Medical implants made with 3D printing are used on multiple body parts. In addition to that, implants may also be made via 3D printing. Medical implants made with 3D printing are used on multiple body parts. Some of them are[15]:

a) Prosthetic valves
The precision and durability of 3D printed heart valves may be adjusted for each patient[16], lowering the body's rejection response, and increasing the chances of success of heart valve replacement. Mechanical, biological, interventional, and tissue-engineered heart valves are a few types of the increasingly prevalent artificial heart valves.

b) Orthopedic implants
Methods for repairing bone defects include autumn grafts, allografts, and artificial bone substitutes materials which include metal and polymer materials[17]. Artificial bone scaffolds made by a traditional method that includes gas foaming, fiber bonding, freeze-drying, phase separation, and particle washing cannot precisely control the cell pore shape and pore size of artificial bone scaffolds, which makes the biologically constructed artificial bone scaffold perform poorly to meet the demand.

c) Human organs
The best approach for end-stage renal illness is organ transplantation (ESRD). Artificial organs are now being created using 3D printing technology to replace the donors needed for surgery[18]. Organ transplantation and organ regeneration were made possible by the three-dimensional proximal tubule tissue in vitro model created by 3D printing. Organ transplant issues have been resolved especially with the development of 3D printing technology. However, to print organs, 3D printing now requires enhancing both the resolution of the technology and the sensitivity of biomaterials.

d) Artificial joint prostheses
   1. Total hip arthroplasty (THA)[15]
      Using common prostheses and 3D printed titanium alloy bone, patients with femoral neck fractures, primary hip joints, and secondary osteoarthritis can undergo artificial complete hip replacement surgery.
   2. Finger joint trauma [15]
      Joint transplant, arthroplasty, joint fusion, and partial knee replacement are all used to treat the condition of the finger joints.
   3. Total knee arthroplasty (TKA)[15]
      The covered with articular cartilage of the femur and tibia that have been damaged on each side of the knee are replaced with surgical implants known as knee joint prosthesis.

e) Vascular stents
The precision and consistency of 3D printed heart valves can also be improved[19], the body's rejection feedback can be minimized, and the overall performance of heart valve replacement may continue to increase. Mechanical valves, biological valves, interventional valves, and tissue-engineered valves are a few types of artificial heart valves that are becoming more and more prevalent.

3 Methods

Study of the journal analysis and mapping was managed on April 18, 2023, using Scopus database. The data obtained from Scopus database was related to the use of 3D printing in the medical field. Reason for using Scopus database for having some journals are relevant articles that have been given, identifying research gap, and can be used for comparing research output and the impact of those journals. The process of finding the relevant journals for research topics, systematic literature review, and bibliometric analysis was by filtering out the output using few keywords. The keyword that is used for the search on Scopus database is "3d printing" "low cost" "medical device". All the papers that are obtained from Scopus database are 3593 papers. The following step is seeing the documents released above 2018 until 2022, documents written in English language, and open documents. The last step is assisted with Harzing's Publish or Perish applications that gave journals that related, most cited and have scientific research impact. After the journals are retrieved, the related found data will be used on Systematic Literature Review. The screening process can be seen in Figure 1.

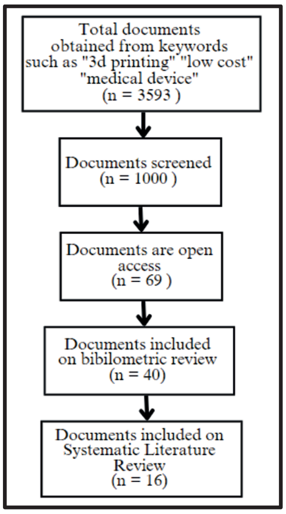

Figure 1 Process of Conducting Literature Review with PRISMA Method

On the process of screening, there are few rules that have been applied. The inclusions and exclusions were inserted into Table 1. Overall, the screening progress has

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40 documents to be used and 16 of them became the main literature review. These 40 papers were added to VOS Viewer so that the links between the subjects covered in each document and the keywords could be obtained. To learn more about 3D printing on medical devices, a systematic literature study of the 16 studies will be conducted.

Table 1 Inclusion and Exclusion Paper

`Inclusion Paper	Exclusion Paper
The scope of analysis from scientific literature review must focused on 3D printing on medical devices	Outside the scope of 3D printing on medical devices
Must be an open access journal	Non-open access journal were excluded
Must be published from 2018 to 2022	Articles that were published under 2018 were excluded
Must be written in English	Other languages besides English were excluded

4 Result and Discussion

4.1 Systematic Literature Review

Systematic literature was obtained from the 16 papers that have been published and selected on Scopus database for the topic 3D printing on medical devices. From Figure 1, the screening process can be seen for getting 16 selected papers to managing the literature review. These 16 papers are included on high index that provides information about the standards and reputation of journals and can give insight for 3D printing low-cost medical devices. As retrieved from the study that have been made, 3D printing low-cost medical devices has potential on surgical field, personal use devices and nature-friendly based materials. The summary is provided in Table 2.

The methods that are frequently utilized are inkjet printing, SLA, FDM, and SLS. Biocompatible polymers as well as biopolymers produced from plants like cellulose, chitosan, collagen, gelatin, and alginate, are among the substances employed. Anatomical models for surgical planning and training, prostheses, orthotics, tissue scaffolds, and other medical equipment can all be produced with 3D printing because to its adaptability. Future applications of 3D printing include personalized medicine, the creation of completely functional organs for transplantation, and multi-material printing techniques. 3D printing generally offers creative solutions, customization, and enhanced patient care. 3D printing plays a crucial role in creating custom-made devices and surgical tools, which leads to a successful surgery so that the costs of surgery tools and treatment cost will be minimized[20].

Due to its potential for low-cost item manufacture, 3D printing has been recognized for its cost effectiveness. This is useful for factories that make goods in small quantities, with a lot of intricacies, or that need frequent revisions[5]. 3D printing recognition of its speed makes it possible to produce medical products like implants and prostheses more quickly than with conventional techniques so that increased productivity would result in lower final product costs[21].

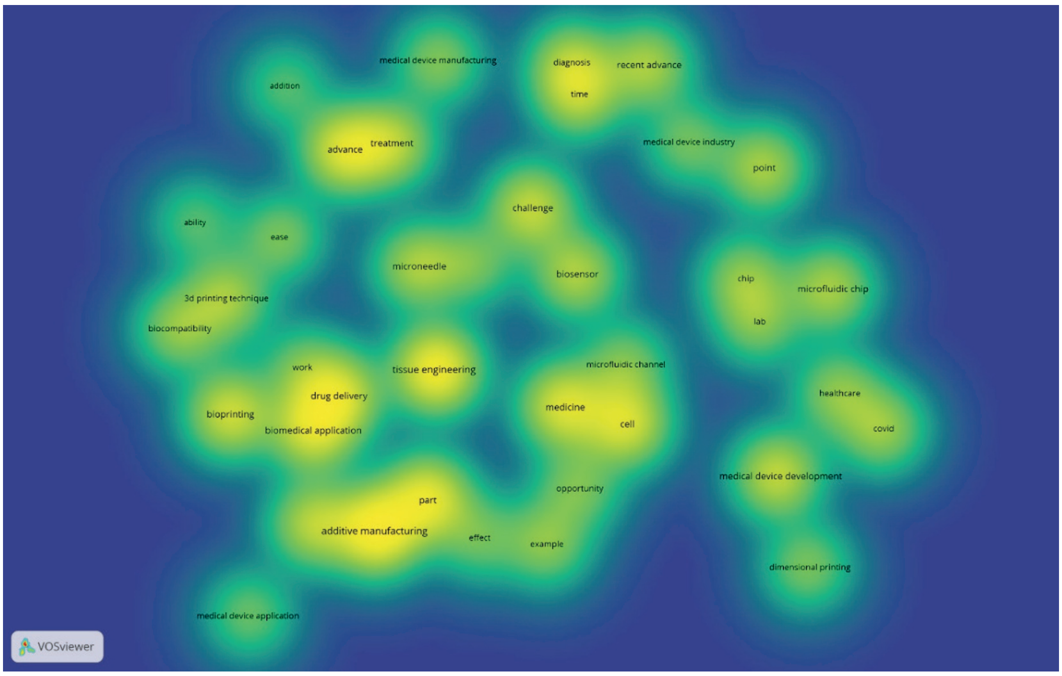

Figure 2 Data of Visualization 3D Printing on Medical Devices

Table 2 Summay of Key Papers

Type(s) of approach	Parameters	Results	Reference
Materials that can be used on 3D printing devices	3D printing using nature-friendly based materials	Though natural-derived biopolymers can be employed as sustainable 3D printing alternatives, the delicate nature and complexity of the constituents present significant difficulties. In the review, biopolymers such cellulose, chitosan, collagen, gelatine, and alginate are discussed.	[14]
Framework for the appropriate use of 3D printing in medical purpose	3D printing devices for body use and quality control	The methods employed are powder bed fusion, stereolithography, fused deposition modeling, and selective laser sintering. materials made of polymers, metals, and ceramics that are biocompatible. This standard offers suggestions for methods of quality assurance and validation, including standardized protocols, image data verification, and post-processing quality assurance.	[3].
The different 3D printing technique and biomaterials that can be used.	Techniques, materials, and future perspective.	Here, inkjet printing, stereolithography, and fused deposition modeling are employed as 3D printing technologies. The biomaterials can be utilized to create biodegradable polymers, hydrogels, bio ceramics, tissue scaffolds, and other medicinal devices. In the future, complex structures will be created using multi-material printing processes, and 3D printed customized medical equipment will be created.	[2]
The various materials and methods for 3D printing, as well as the benefits and design factors connected with 3D printing.	Materials, methods, and applications	The various methods of 3D printing that can be applied, including stereolithography, fused deposition modeling, and digital light processing, are covered in the article. Polymers are the materials employed. Point-of-care diagnostics, drug discovery, and tissue engineering are the current applications.	[6]
The different 3D printing techniques and materials that can be used, as well as the advantages and design considerations associated with 3D printing.	Materials, method, and advantages	The article discusses the many 3D printing techniques that can be employed, such as stereolithography, fused deposition modeling, and digital light processing. The materials used are polymers. Customizable designs, the opportunity for quick prototyping, and the freedom to build intricate geometries are some of the benefits.	[22]
Using microneedle for many purposes such as transdermal drug delivery	Customizable, microneedle, simple, material	Customizable devices need high-precision fabrication techniques and use microneedles for fabricating, so it became simple and low-cost. The material used is photopolymer resin.	[23]
3D printing technology in the fabrication of medical materials, specifically microneedles and biosensors	Materials, techniques, microneedle, and biosensors	The use of progressive 3D printing technique used are stereolithography, fused deposition modeling, and inkjet printing. Material used such as biocompatible polymers. 3D printing allows complex structure for microneedle geometries and complex sensors geometries of biosensors	[24]
Various techniques and materials used for producing different pharmaceutical dosage forms and devices.	Techniques, materials, and microneedle	Techniques used are FDM, SLA, BJ, PBP. The materials used are Progesterone-eluting poly (lactic acid) PLA/polycaprolactone (PCL), antimicrobial PCL. The potential benefits of using additive manufacturing to fabricate microneedles.	[25]
The many 3D printing methods and materials that can be employed, as well as any potential benefits and legal issues that may be involved.	Techniques, materials and future directions	Technique used as fused deposition modeling, stereolithography, and selective laser sintering. Materials such as poly (lactic acid) (PLA), poly (vinyl alcohol) (PVA), and ethylene vinyl acetate (EVA), poly (ethylene glycol) (PEG), oligo (poly (ethylene glycol) fumarate) (OPF) and poly (acrylic acid) derivatives (PAA). For future directions, the use of bioprinting to produce tissue and organ replacements and the use of 3D printing for personalized medicine.	[26]
The techniques and materials used as the 3D printing technologies advanced	Techniques, materials, and bioprinting	The methods are the most popular 3D printing method is fused deposition modeling (FDM), which is followed by stereolithography (SLA), selective laser	[27]

		sintering (SLS), digital light processing (DLP), and binder jetting. Acrylonitrile Butadiene Styrene (ABS), nylon, and PLA are the materials employed. The aim is to build fully functional organs for transplantation, but 3D printing is currently utilized to create biological tissue.	
The devices utilize fluid inertia to manipulate and control fluid flow	Techniques, materials, performance	The employed SLA and DLP as their methods. Photopolymer resins, transparent materials, and biocompatible materials are the materials employed. The ability to fabricate complex and exact microchannel geometries, which are necessary for producing greater inertial effects, is a benefit of 3D printing. This can improve control over particle focussing, separation, and mixing.	[28]
Few techniques are utilized to produce low-cost simulation model of training.	Techniques, materials, complex structure	These methods include SLA, SLS, and FDM. Materials like thermoplastics, photopolymer resins, and powdered substances are used. Complex structures and disorders that are difficult to mimic using conventional methods can be created using 3D printing.	[4]
Build a scaffold that might support cellular alignment and tissue regrowth	Technique and materials	The scaffold's primary structure was produced using a 3D printing technology, and its fibres were produced using an electrospinning approach. Polycaprolactone (PCL) is the substance utilized for the scaffold.	[29]
Enable the creation of surgical guides and implants, allow for patient-specific surgical planning, and provide useful teaching resources.	Technique, materials, and education	Among these techniques are SLA, SLS, and FDM. Materials include polyethylene glycol (PEG), polyether ether ketone, and polylactic acid (PLA) (PEEK). On realistic models, surgeons and other medical personnel can practice procedures, honing their abilities and enhancing patient safety.	[30]
The creation of novel sensing technologies with applications in healthcare, environmental monitoring, and biotechnology is facilitated by improvements in 3D printing.	Techniques and material	The techniques are SLA and DLP. Material used are photopolymer resin, poly (methyl methacrylate) (PMMA) or polystyrene (PS), polydimethylsiloxane (PDMS)	[31]
The fields of additive manufacturing and 3D printing have significantly advanced the biomedical industry.	Techniques and materials, tissue engineering	The techniques are SLA, SLS and DLP. Material used are polylactic acid (PLA), polyethylene glycol (PEG), or polyurethane hydrogels and bioinks. It makes it possible to build scaffolds that assist cell development and encourage tissue regeneration.	[32]

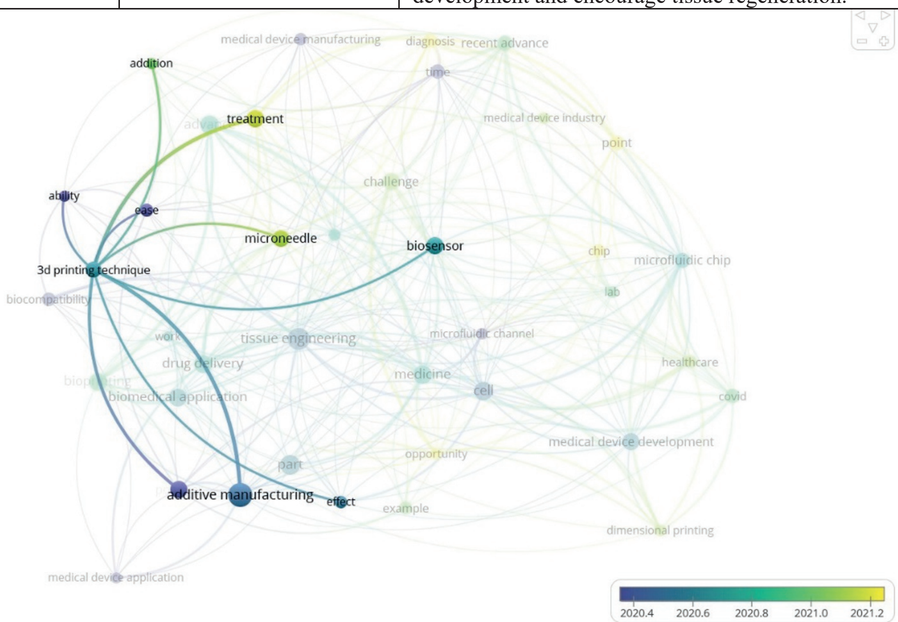

Figure 3 Overlay Sub-division Visualization 3D Printing on Medical Devices

4.2 4.2. Bibliometric Analysis

Bibliometric analysis is an analytical technique used to examine bibliometric data found in books, articles, and journal articles on a specific subject. The VOS viewer application, which is useful to visualize the gathered data, is used in the analysis process. Additionally, we search for published journals, articles, or papers that are pertinent to the topics we are interested in and published within a specific year range using the Publish or Perish application. In a search conducted on Publish or Perish with the topic "3D printing "low cost" medical device", we get the results of 40 papers that are related to this topic from 2018 to 2022. All the 40 papers will then be reviewed further at the next stage which is screening, and we continue by looking for certain words in the sentences contained in the 40 papers so that we can narrow our search and examine more deeply.

Two categories—overlay visualization, and density visualization—are used to categorize the outcomes of data visualization using VOS viewer. Density information from 3D-printed on medical devices processed with the VOS viewer program is shown in Figure 2. How often or not a word is frequently addressed in papers is shown by the colour in the picture. The more intense the consistency colours, the more frequently the word has been mentioned in earlier research; conversely, the more translucent the colour, the less frequently it has been discussed in earlier studies. For example, when compared to medical device applications, which have a bright yellow tint because they are infrequently covered in studies, additive manufacturing, for instance, has a darker yellow tone since it is more frequently discussed. Therefore, since there are few studies that cover this, issues that are rarely mentioned or have a lighter shade can be used as new fields for further research. For example, in this case, microneedle has a lighter shade than tissue engineering, medical device industry also has a darker tone among the others. From this, we can conclude that the number of research that are done is still narrow.

The yellow lines and dots indicate subjects that are commonly addressed in scholarly papers around 2021, according to the overlay visualization's representations, which were gathered from VOS viewer. The yellow lines and dots indicate subjects that are commonly addressed in scholarly papers around 2021, according to the overlay visualization's representations, which were gathered from VOS viewer.Additionally, it is clear that the darker the color of the dots and lines, the earlier the topic was addressed. For example, Figure 3 3D Printing on Medical Devices VOS Viewer Overlay Outcome demonstrates that the blue color is a subject that is frequently discussed around the year 2020. The volume of writing on a subject also influences how frequently or infrequently it is covered in other articles.

Figure 3 Overlay Sub-division Visualization 3D Printing on Medical Devices illustrates 40 topics connected to 3D printing and medical devices, as can be observed. We were able to identify a research gap between the themes of 3D printing methods and medical devices development out of the forty topics because our main topic is related to the manufacturing of medical devices development using 3D printing. This research gap demonstrates the lack of a current study that examines the connection between the two subjects. As a result, we will study and carry out more extensive research on the 3D printing method for manufacturing of the development of medical devices.

5 Conclusion

The paper presents a systematic literature review and bibliometric analysis based on existing papers. This paper discusses 3D printing on medical devices with keywords 3D printing, and medical devices. There are few rules of inclusion and exclusion that applied to screening the journals through the systematic process and the researchers retrieved 16 journals that have relevance to the topic on this paper. The 16 journals were reviewed and summarized to the systematic literature review. The system literature review focused on 3D printing's future potentials and the usage of natural resources materials that are safe for human body contact. Biomaterials have consequences for the human body's compatibility, application flexibility, increased biocompatibility, enhanced tissue regeneration and repair, controlled medication delivery, improved diagnostics, and minimally invasive medical treatments.

Biomaterials made of chitosan and gelatin are becoming more common and offer important benefits including flexibility. Potential options for successful tissue regeneration include those that exhibit biocompatibility, the capacity to create three-dimensional porous scaffolds that resemble extracellular matrices, bioactivity, biodegradability, adjustable characteristics, and cost-effectiveness[33],[34]. Researchers also discovered that the potential for 3D printing with development of medical devices technology still requires more study. Although there aren't many uses for 3D printing, scientists have discovered several more uses that might be explored further. By conducting more research, the development of 3D printing could be more successful in the future and can lower the cost of medical device production.

Moreover, from the result of systematic literature review and VOS viewer, researchers find a gap between 3D printing techniques and medical devices development. Furthermore, researchers recommend further research about 3D printing techniques and medical devices development with nature-based materials (e.g., chitosan, polymer, hydroxyapatite, and xenografts). Researchers believe this research will be able to produce medical devices with the help of 3D printing techniques.

References

[1] H. Becker and L. E. Locascio, "Polymer microfluidic devices," *Talanta*, **56**. 267–287 (2002), doi: 10.1016/S0039-9140(01)00594-X.

[2] K. Tappa and U. Jammalamadaka, "Novel biomaterials used in medical 3D printing

techniques," *J. Funct. Biomater.*, **9**, 17 (2018), doi: 10.3390/jfb9010017.

[3] L. Chepelev *et al.*, "Radiological society of north america (RSNA) 3D printing special interest group (SIG): guidelines for medical 3D printing and appropriateness for clinical scenarios," *3D Print. Med.*, **4**, 1–38 (2018).

[4] J. P. Lichtenberger, P. S. Tatum, S. Gada, M. Wyn, V. B. Ho, and P. Liacouras, "Using 3D Printing (Additive Manufacturing) to Produce Low-Cost Simulation Models for Medical Training," *Mil. Med.*, **183**, 73–77 (2018), doi: 10.1093/milmed/usx142.

[5] C. Lee Ventola, "Medical applications for 3D printing: Current and projected uses," *P T*, **39**, 704–711 (2014).

[6] G. Weisgrab, A. Ovsianikov, and P. F. Costa, "Functional 3D Printing for Microfluidic Chips," *Adv. Mater. Technol.*, **4**, 1900275 (2019), doi: 10.1002/admt.201900275.

[7] C. M. B. Ho, S. H. Ng, K. H. H. Li, and Y.-J. Yoon, "3D Printed Microfluidics for Biological Applications," *Lab on Chip*, **15**, 3627-3637 (2015), doi: 10.1039/x0xx00000x.

[8] N. Bhattacharjee, A. Urrios, S. Kang, and A. Folch, "The upcoming 3D-printing revolution in microfluidics," *Lab on Chip*, **16**, 1720–1742 (2016), doi: 10.1039/c6lc00163g.

[9] K. Kitsakis, J. Kechagias, N. Vaxevanidis, and D. Giagkopoulos, "Tolerance Analysis of 3d-MJM parts according to IT grade," *IOP Conf. Ser. Mater. Sci. Eng.*, **161**, (2016), doi: 10.1088/1757-899X/161/1/012024.

[10] E. J. Mott *et al.*, "Digital Micromirror Device (DMD)-based 3D printing of poly(propylene fumarate) scaffolds," *Physiol. Behav.*, **61**, 301-311 (2016), doi: 10.1016/j.msec.2015.11.071.Digital.

[11] A. Gosset, D. Barreiro-Villaverde, J. C. B. Permuy, M. Lema, A. Ares-Pernas, and M. J. A. López, "Experimental and numerical investigation of the extrusion and deposition process of a poly(Lactic acid) strand with fused deposition modeling," *Polymers*, **12**, 1–20 (2020), doi: 10.3390/polym12122885.

[12] T. Finnes and T. Letcher, "High Definition 3D Printing-Comparing SLA and FDM Printing Technologies," *J. Undergrad. Res.*, **13**, 3 (2015)

[13] R. Singh *et al.*, "Powder bed fusion process in additive manufacturing: An overview," *Mater. Today Proc.*, **26**, 3058–3070 (2019), doi: 10.1016/j.matpr.2020.02.635.

[14] J. Liu, L. Sun, W. Xu, Q. Wang, S. Yu, and J. Sun, "Current advances and future perspectives of 3D printing natural-derived biopolymers," *Carbohydr. Polym.*, **207**, 297–316 (2019), doi: 10.1016/j.carbpol.2018.11.077.

[15] Z. Wang and Y. Yang, "Application of 3D Printing in Implantable Medical Devices," *Biomed Res. Int.*, **2021**, 6653967 (2021), doi: 10.1155/2021/6653967.

[16] V. Tuncay and P. M. A. van Ooijen, "3D printing for heart valve disease: a systematic review," *Eur. Radiol. Exp.*, **3**, 9 (2019), doi: 10.1186/s41747-018-0083-0.

[17] J. A. Calvo-Haro *et al.*, "Conceptual evolution of 3D printing in orthopedic surgery and traumatology: from 'do it yourself' to 'point of care manufacturing,'" *BMC Musculoskelet. Disord.*, **22**, 1–10 (2021), doi: 10.1186/s12891-021-04224-6.

[18] S. Agarwal, S. Saha, V. K. Balla, A. Pal, A. Barui, and S. Bodhak, "Current Developments in 3D Bioprinting for Tissue and Organ Regeneration–A Review," *Front. Mech. Eng.*, **6**, (2020), doi: 10.3389/fmech.2020.589171.

[19] A. M. Sousa, A. M. Amaro, and A. P. Piedade, "3D Printing of Polymeric Bioresorbable Stents: A Strategy to Improve Both Cellular Compatibility and Mechanical Properties," *Polymers*, **14**, 1099 (2022), doi: 10.3390/polym14061099.

[20] I. Ursan, L. Chiu, and A. Pierce, "Three-dimensional drug printing: A structured review." *Journal of the American Pharmacists Association*, **53**, 136–144 (2013), doi: 10.1331/JAPhA.2013.12217.

[21] Y. E. Choonara, L. C. Du Toit, P. Kumar, P. P. D. Kondiah, and V. Pillay, "3D-printing and the effect on medical costs: a new era?," *Expert Rev. Pharmacoecon. Outcomes Res.*, **16**, 23–32 (2016), doi: 10.1586/14737167.2016.1138860.

[22] S. van den Driesche, F. Lucklum, F. Bunge, and M. J. Vellekoop, "3D printing solutions for microfluidic chip-to-world connections," *Micromachines*, **9**, 71 (2018), doi: 10.3390/mi9020071.

[23] K. J. Krieger, N. Bertollo, M. Dangol, J. T. Sheridan, M. M. Lowery, and E. D. O'Cearbhaill, "Simple and customizable method for fabrication of high-aspect ratio microneedle molds using low-cost 3D printing," *Microsystems Nanoeng.*, **5**, 42 (2019), doi: 10.1038/s41378-019-0088-8.

[24] D. Fan *et al.*, "Progressive 3D Printing Technology and Its Application in Medical Materials," *Front. Pharmacol.*, **11**, 1–12 (2020), doi: 10.3389/fphar.2020.00122.

[25] C. I. Gioumouxouzis, C. Karavasili, and D. G. Fatouros, "Recent advances in pharmaceutical dosage forms and devices using additive manufacturing technologies," *Drug Discov. Today*, **24**, 636–643 (2019), doi: 10.1016/j.drudis.2018.11.019.

[26] E. Lepowsky and S. Tasoglu, "3D printing for drug manufacturing: A perspective on the future of pharmaceuticals," *Int. J. Bioprinting*, **4**, 1–13 (2018), doi: 10.18063/IJB.v4i1.119.

[27] Y. Bozkurt and E. Karayel, "3D printing technology; methods, biomedical applications, future opportunities and trends," *J. Mater. Res.*

Technol., **14**, 1430–1450 (2021) doi: 10.1016/j.jmrt.2021.07.050.

[28] S. Razavi Bazaz *et al.*, “3D Printing of Inertial Microfluidic Devices,” *Sci. Rep.*, **10**, 1–14 (2020), doi: 10.1038/s41598-020-62569-9.

[29] C. Vyas, G. Ates, E. Aslan, J. Hart, B. Huang, and P. Bartolo, “Three-Dimensional Printing and Electrospinning Dual-Scale Polycaprolactone Scaffolds with Low-Density and Oriented Fibers to Promote Cell Alignment,” *3D Print. Addit. Manuf.*, **7**, 105–113 (2020), doi: 10.1089/3dp.2019.0091.

[30] D. Shilo, O. Emodi, O. Blanc, D. Noy, and A. Rachmiel, “Printing the Future—Updates in 3D Printing for Surgical Applications,” *Rambam Maimonides Med. J.*, **9**, e0020 (2018), doi: 10.5041/rmmj.10343.

[31] J. F. Rusling, “Developing Microfluidic Sensing Devices Using 3D Printing,” *ACS Sensors*, **3**, 522–526 (2018), doi: 10.1021/acssensors.8b00079.

[32] P. Ahangar, M. E. Cooke, M. H. Weber, and D. H. Rosenzweig, “Current biomedical applications of 3D printing and additive manufacturing,” *Appl. Sci.*, **9**, 1713, (2019), doi: 10.3390/app9081713.

[33] K. YAO *et al.*, “Chitosan/Gelatin Network Based Biomaterials in Tissue Engineering,” *Biomed. Eng. Appl. Basis Commun.*, **14**, 115–121 (2002), doi: 10.4015/s1016237202000176.

[34] S. Bhat and A. Kumar, “Biomaterials and bioengineering tomorrow’s healthcare,” *Biomatter*, **3**, 1–12 (2013), doi: 10.4161/biom.25887.