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Review Article

3D Bio Printing: Classification of Bio-Inks and Bioprinting Technique

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ABSTRACT

Three-dimensional (3D) bioprinting is a revolutionary technique in biomedical engineering, enabling the fabrication of tissue and organ-like structures using bio-inks. This review focuses on the classification of bio-inks and the major bioprinting techniques used in tissue engineering. Bio-inks, the essential component of bioprinting, are categorized into natural and synthetic types. Natural bio-inks such as collagen, gelatin, alginate, and agarose offer excellent biocompatibility, while synthetic polymers like polyethylene glycol (PEG) and polyvinyl pyrrolidone (PVP) provide greater mechanical strength and tunability. Critical properties of bio-inks—printability, biocompatibility, and viscosity—are discussed with respect to their influence on the fidelity and stability of printed structures. Furthermore, this review elaborates on three major bioprinting methods: extrusion-based, inkjet-based, and laser-assisted bioprinting. Each technique is analyzed based on its working principles, resolution, cell viability, and applications. Extrusion-based printing is favored for high-viscosity inks and cell density, inkjet-based printing for cost-effectiveness and precision, and laser-assisted printing for its non-contact, high-resolution output. This review concludes that the selection of appropriate bio-ink and printing technology is crucial for the successful development of engineered tissues, which holds significant potential in regenerative medicine and pharmaceutical research.

INTRODUCTION

The Three-dimensional (3D) printing is also known as additive manufacturing or rapid prototyping [1]. Additive manufacturing is one of the 3D scaffold fabrication method. It is a process of fabricating 3D solid objects from a digital file. The fabrication of 3D printed object is achieved using additive process. An object is created layering or built down successive layer by layer of material until the entire object is created. Each of these layer can be seen as a thinly sliced horizontal cross-section [2]. The main objective of tissues/organ engineering is to reconstruction of

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the damaged or diseased tissue or organ with cells and bio active molecule [3]. In addition 3D bio printing taking image of the damaged or targeted tissue/organ obtained by computed tomography (CT) or magnetic resonance imaging (MRI) scan [4]. Three dimensional (3D) printing was first described by Charles W. Hull in 1986, He named his method 'Stereolithography'. Thin layer of material that can be cured with ultra-violet (UV) light were sequentially printed in layer to form a solid 3D structure [5]. Later application of this process made it possible to create a sacrificial resin molds for fabrication of 3D scaffolds using biological material [6]. bio-ink is the main component used in the 3D printing. these bio ink varies with the printing. And the selection of bio ink is based on their properties like compatibility, printability, viscosity etc., [7]. There are several techniques for 3D bioprinting. They are Laser-assisted printing, Inkjet, extrusion, and stereolithography. Among this extrusion-based bio-printing is the most common method for the bio printing technique [8]. In this review we discuss about the classification of bio-ink and also extrusion-based, inkjet-based and laser-assisted method 3D bioprinting. First we consider the bio-ink classification. Then next, extrusion-based, inkjet-based and laser-assisted method.

2.BIO-INK

Bio-ink is one of the most important requirement for 3D printing, It is composed of cells with biomaterials like hydrogel or cell aggregates and it plays a crucial role to fabricate 3D structure in 3D bio-printing [9]. Bio ink are classified into two types Natural and Synthetic bio-inks.

2.1 NATURAL BIO-INKS

Natural hydrogels or bio-inks are important role in bio inks for 3D bio printing of tissues and organs because, it is highly biocompatible with the other tissues and it is adaptable for the structural and functional organization of cells. Natural polymers are Collagen, Gelatin, Alginate, Agarose, Fibrin etc.,

2.1.1 COLLAGEN

Collagen type I is the main structural protein component of various connective tissues in the extra cellular matrix (ECM) of body and it is the most abundant protein in mammals [10]. Collagen maintain the cell adhesion, proliferation, differentiation and migration [11]. Collagen type I hydrogels shows a greater bio-compatibility and highly bio active presenting cell-adhesion sites. Which have been widely used in many bio medical application [12,13]. Collagen hydrogel is too weak to fabricate the scaffolds so, it is used with other polymers [14].

2.1.2 GELATIN

Gelatin is a protein material. The main origin of gelatin is animals. It is obtained from the bones, cartilage, tendons, ligaments and skin of animals such as cattle, pigs, and also obtained from fishes or chickens. Gelatin is derived from the partial hydrolysis of collagen obtained from the animals which mentioned in the previous or above sentence. Gelatin is commonly used for increasing emulsification, thickness and elasticity [15,16]. In tissue engineering field it is widely used due to its excellent, bio-compatibility, bio-degradability, non-immunogenicity and also cell-interactivity [17]. Gelatin that undergoes changes in response to external temperature. Gelatin undergoes reversible sol-gel transition by cooling below 35ºC [18].

2.1.3 ALGINATE

Alginate is a polysaccharides naturally occuring anionic polymer derived from sea weeds which is macroscopic algae growing in the marine and

shallow coastal waters and on rocky shores [19]. Alginate is an anionic block co-polymer containing 1,4-linked beta-D-mannuronic (M block) and alpha-L-guluronic acid (G blocks) [20]. Alginate hydrogels are widely used as biomaterials in the tissue engineering, drug delivery system and wound healing [21,22]. When multivalent cation calcium added into the aqueous solution of alginate forms a ionic inter-chain bridges that produce fast sol-gel transition. Cations preferably binding to the alpha-L-guluronic acid (G block) of the chains but in recent studies the M blocks has also has an active role in cross-linking the polymer chain [23].

2.1.4 AGAROSE

Agarose is a hydrophilic polysaccharide, it is extracted from red algae. The main structure of agarose consist of altering the units of beta-D-galactopyranose and 3,6-anhydro-alpha-L-galactopyranosyl units [24]. In nerve regeneration, the agarose is taken as optimal material for scaffold, due to its biocompatibility and stability in spinal cord [25]. It is not biodegradable by the mammals but, degraded in vitro by agarases. They are classified into 3 types based on their cleavage pattern α-agarase, β-agarase and β-porphyranase [26,18].

2.2 SYNTHETIC BIO-INKS

Synthetic hydrogels are used in the 3D bio printing application, including polyethylene glycol (PEG), Polyvinyl pyrrolidine (PVP), poly (L- Lactic) acid (PLA), poly (Latic-co-glycolic) acid (PLGA) etc.,

2.2.1 POLY ETHYLENE GLYCOL(PEG)

Polyethylene glycol is a synthetic polymer. It has both hydrophilic and hydrophobic properties, it is soluble in organic solvents or aqueous solvent and has high biocompatibility[27]. It is applied for wound dressing and drug delivery system [28]. Polyethylene glycol is one of the most widely used hydrogels in the scaffold, drug delivery and cell research [29].

2.2.2 POLYVINYL PYRROLIDINE(PVP)

Polyvinyl pyrrolidine is also known as povidone. It is soluble in water and also soluble in organic solvents. The complex formation of Iodine with polyvinyl pyrrolidine gives effective disinfectant having low toxicity [30]. It is a synthetic polymer which undergoes crosslinking and form hydrogel. These hydrogels synthesized by using many methods such as gamma-radiation, UV-photo crosslinking, electron beam radiation etc., [31].

3.PROPERTIES OF BIO-INKS

Bio-ink required some properties, they are bio-printability, biocompatibility, viscosity etc.,

3.1 BIO PRINTABILITY

Printability is the capacity of bio-ink to form and maintain 3D scaffolds [32]. Bio printability of bio ink was accessed by using various factors like viscosity, surface tension, cross linking ability and ink consistency [33]. Printability is important properties for bio printing, It should be imitate both the shape and cellular architecture [34]. Storage modulus, solid-liquid transition stress and the flow transition index are the three rheological parameters, to predict the printability [35]. Viscosity is playing major role in printability. If the viscosity is low then the deformation and collapse will occur. On the other hand, nozzles will be jammed when the viscosity is high. It must be overcome by increasing temperature(T1) in the nozzles with the mixture and then eject under the cooled temperature (T2). The T1 should be greater than the melting temperature to avoid jamming

nozzle. T2 should be lower than the solidification temperature to fix the printed structure [36].

3.2 BIO COMPATABILITY

Bio compatibility is the major properties for preparing hydrogels. Because, the 3D printed structure using hydrogels is transplanted into the human or animal body. So, we must be consider the compatibility [37]. Various experiments is used to determined the bio compatibility like invitro cytotoxicity screening, direct cell culture, agar diffusion testing etc., The bio compatibility is defined as the ability of bio ink for 3D bioprinting to provide its desired activity that will enhance the cell adhesion, proliferation, viability, activity and tissue regeneration without producing toxic or unwanted effect [38].

3.3 VISCOSITY

This is also a important factor for choosing bio ink for3D printing. The stability of the 3D structure may be increased by enhance the viscosity of bio ink but it also leads to clogging the nozzle while, less viscous ink provide compatible with other cells but resist the printability due to poor flow. It should be overcome by regulate the concentration of polymer, molecular weight and temperature [39].

4. METHODS

There are various methods for bioprinting like, Inkjet-based, extrusion-based, laser-assisted, stereolithography, Fused deposition modeling, Vat polymerization [40]. Among these extrusion-based, inkjet-based and laser-assisted are the main bioprinting technique used for 3D bioprinting [41] is discussed below.

4.1 EXTRUSION-BASED BIOPRINTING

Extrusion-based methods are most commonly employed for bioprinting in recent years. It print high densities cell [42]. Bio ink have low viscosity in the range of 30-6 x 107 mpa.s are used in the extrusion based bio printers [43]. While high viscosity can leads to clogging the nozzle tip and it can be overcome by adjusting the nozzle tip diameter [44]. Compared to the laser or inkjet-based system the resolution is low in extrusion-based printing that is 200µm [45]. The distribution of material is achieved by either piston-driven, pneumatic system or screw driven [46]. The principle involved in the extrusion-based bioprinting is the bio ink extrudate from the syringe through nozzle by a continuous force which is driven by pneumatic, piston or screw pressure. The micro filament (extruded material) after solidifying on the substrate it act as an support structure. The substrate may be culture dish or growth medium. It can be influenced by temperature, nozzle diameter, pressure, speed etc., [47]. Among this, pneumatic system show great result with high viscous materials with the help of compressed air as the driving force and it can also have limitation due to the presence of compressed gas it delays the distribution of material [48]. On the other hand piston driven system shows more control over the fluid flow whereas screw based printing provide the more spatial control [49]. Adjustability of viscous, bio ink phase and material-specific bio-fabrication window are the three main factors to print through extrusion printers [50].

4.2 INJLET-BASED BIOPRINTING

Inkjet-based bioprinters are cheap and it also work in the mild conditions [51]. The natural bio-ink is used in the inkjet based bioprinting that is collagen, fibrin etc., [52]. Inkjet based printing is classified into two major categories: Continuous inkjet printing (CIJ) and Drop-on-demand (DOD) inkjet printing [53]. In continuous inkjet printing the liquid ink is directed by a high pressure pump to

form droplets continuously through a microscopic nozzle. Drop-on-demand are two types: Thermal DOD and Piezoelectric DOD. In bioprinting applications, Piezoelectric DOD is recommended because thermal DOD may cause damage or death of living cells and also it have some advantage over CIJ printing because it may have chances of contamination. In DOD the inkjet dispenser eject the bio-ink to form a microspheres droplets further it formed into 2D or 3D pattern by deposition on substrate [54]. When the droplet deposit on the substrate the impact will occur which leads to affect the repeatability and the dimensional accuracy. The impact is based on the droplet velocity and volume [55]. Different physical and chemical crosslinking mechanism such as crosslinking agents, PH and UV-radiation are used to solidify the deposited droplets on the substrate to form 3D structure [56]. The driving force for the ejection onto the substrate is thermal or sound [57]. The droplet size is influenced by temperature thus increase in temperature lead to decrease in the droplet size [58].

4.3 LASER-ASSISTED BIOPRINTING

Laser-assisted bioprinting (LAB) is a Laser-guided direct writing based on the principle of Laser-Induced Forward Transfer (LIFT) [59]. It is a non-contact printing device [60]. It consist of two horizontal co-planar glass slide, The upper slide is referred as “Donor slide” and the lower slide is referred as “Collector slide”. The upper Donor slide is coated with a two different laser absorbing material that is light absorbing gold layer and a cell layer or biological material. The laser is focused through the upper donor slide into the absorbing gold layer, which locally evaporated. The collector slide provide a suitable environment to the bio-ink (usually a solution embedded with cells) to prevent from the dehydration [61,62]. The donor glass slide in the size range of 26 x 26 x 1 mm and it was cleaned with acetone [63]. The laser source is a solid Nd:YAG crystal laser which is driven by a scanning system consist of two galvanometric mirrors [64]. The resolution of Laser-assisted bioprinting varies depending upon size from picometer to micrometer. The bio-ink viscosity, thickness, surface tension and wettability of substate influence the resolution [65]. It has higher printing accuracy and resolution than nozzle-based printing like extrusion-based and inkjet-based bioprinting. Bio ink having viscosity range of 1-8000 mPa.s used in the Laser-assisted bioprinting. It has a high cell viability than other bioprinting techniques [66].

CONCLUSION

In this review article, the classification of bio ink used in bioprinting and the types of bioprinting techniques are discussed. The 3D bioprinting is useful for the future research related to the pharmaceutical science and medicine. It also a powerful technology used in tissue and organ printing.

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REFERENCES

1. A. Lifton V, Lifton G, Simon S. Options for additive rapid prototyping methods (3D printing) in MEMS technology. Rapid Prototyping Journal. 2014 Aug 12;20(5):403-12. https://doi.org/10.1108/RPJ-04-2013-0038

2. Ozbolat IT. 3D bioprinting: fundamentals, principles and applications. Academic Press; 2016 Nov 21.
3. Upadhyay RK. Role of regeneration in tissue repairing and therapies. J Regen Med Tissue Eng. 2015;4(1):1. https://doi.org/10.7243/2050-1218-4-1
4. Murphy SV, Atala A. 3D bioprinting of tissues and organs. Nature biotechnology. 2014 Aug;32(8):773-85. https://doi.org/10.1038/nbt.2958
5. Su A, Al'Aref SJ. History of 3D printing. In3D printing applications in cardiovascular medicine 2018 Jan 1 (pp. 1-10). Academic Press.
6. Nakamura M, Iwanaga S, Henmi C, Arai K, Nishiyama Y. Biomatrices and biomaterials for future developments of bioprinting and biofabrication. Biofabrication. 2010 Mar 10;2(1):014110. https://doi.org/10.1088/1758-5082/2/1/014110
7. Taghizadeh M, Taghizadeh A, Yazdi MK, Zarrintaj P, Stadler FJ, Ramsey JD, Habibzadeh S, Rad SH, Naderi G, Saeb MR, Mozafari M. Chitosan-based inks for 3D printing and bioprinting. Green Chemistry. 2022;24(1):62-101. https://doi.org/10.1039/D1GC01799C
8. Zhang YS, Haghiashtiani G, Hübscher T, Kelly DJ, Lee JM, Lutolf M, McAlpine MC, Yeong WY, Zenobi-Wong M, Malda J. 3D extrusion bioprinting. Nature Reviews Methods Primers. 2021 Nov 11;1(1):75. https://doi.org/10.1038/s43586-021-00073-8
9. Donderwinkel I, Van Hest JC, Cameron NR. Bio-inks for 3D bioprinting: recent advances and future prospects. Polymer Chemistry. 2017;8(31):4451-71. https://doi.org/10.1039/C7PY00826K
10. Di Lullo GA, Sweeney SM, Korkko J, Ala-Kokko L, San Antonio JD. Mapping the ligand-binding sites and disease-associated mutations on the most abundant protein in the human, type I collagen. Journal of Biological Chemistry. 2002 Feb 8;277(6):4223-31. https://doi.org/10.1074/jbc.M110709200
11. Somaiah C, Kumar A, Mawrie D, Sharma A, Patil SD, Bhattacharyya J, Swaminathan R, Jaganathan BG. Collagen promotes higher adhesion, survival and proliferation of mesenchymal stem cells. PloS one. 2015 Dec 14;10(12):e0145068. https://doi.org/10.1371/journal.pone.0145068
12. Bartolo P, Malshe A, Ferraris E, Koc B. 3D bioprinting: Materials, processes, and applications. CIRP Annals. 2022 Jan 1;71(2):577-97. https://doi.org/10.1016/j.cirp.2022.06.001
13. Khoeini R, Nosrati H, Akbarzadeh A, Eftekhari A, Kavetskyy T, Khalilov R, Ahmadian E, Nasibova A, Datta P, Roshangar L, Deluca DC. Natural and synthetic bioinks for 3D bioprinting. Advanced NanoBiomed Research. 2021 Aug;1(8):2000097. https://doi.org/10.1002/anbr.202000097
14. Kim JS, Hong S, Hwang C. Bio-ink Materials for 3D Bio-printing. Journal of International Society for Simulation Surgery. 2016;3(2):49-59. https://doi.org/10.18204/JISSiS.2016.3.2.049
15. Andreazza R, Morales A, Pieniz S, Labidi J. Gelatin-based hydrogels: potential biomaterials for remediation. Polymers. 2023 Feb 18;15(4):1026. https://doi.org/10.3390/polym15041026
16. Ahmed MA, Al-Kahtani HA, Jaswir I, AbuTarboush H, Ismail EA. Extraction and characterization of gelatin from camel skin (potential halal gelatin) and production of gelatin nanoparticles. Saudi Journal of Biological Sciences. 2020 Jun 1;27(6):1596-601. https://doi.org/10.1016/j.sjbs.2020.03.022

17. Dias JR, Baptista-Silva S, De Oliveira CM, Sousa A, Oliveira AL, Bártolo PJ, Granja PL. In situ crosslinked electrospun gelatin nanofibers for skin regeneration. European Polymer Journal. 2017 Oct 1;95:161-73. https://doi.org/10.1016/j.eurpolymj.2017.08.015
18. Gasperini L, Mano JF, Reis RL. Natural polymers for the microencapsulation of cells. Journal of the royal society Interface. 2014 Nov 6;11(100):20140817. https://doi.org/10.1098/rsif.2014.0817
19. Lee KY, Mooney DJ. Alginate: properties and biomedical applications. Progress in polymer science. 2012 Jan 1;37(1):106-26. https://doi.org/10.1016/j.progpolymsci.2011.06.003
20. Rowley JA, Madlambayan G, Mooney DJ. Alginate hydrogels as synthetic extracellular matrix materials. Biomaterials. 1999 Jan 1;20(1):45-53. https://doi.org/10.1016/S0142-9612(98)00107-0
21. Augst AD, Kong HJ, Mooney DJ. Alginate hydrogels as biomaterials. Macromolecular bioscience. 2006 Aug 7;6(8):623-33. https://doi.org/10.1002/mabi.200600069
22. Sahoo DR, Biswal T. Alginate and its application to tissue engineering. SN Applied Sciences. 2021 Jan;3(1):30. https://doi.org/10.1007/s42452-020-04096-w
23. Donati I, Holtan S, Mørch YA, Borgogna M, Dentini M, Skjåk-Bræk G. New hypothesis on the role of alternating sequences in calcium− alginate gels. Biomacromolecules. 2005 Mar 14;6(2):1031-40. https://doi.org/10.1021/bm049306e
24. Krömmelbein C, Mütze M, Konieczny R, Schönherr N, Griebel J, Gerdes W, Mayr SG, Riedel S. Impact of high-energy electron irradiation on mechanical, structural and chemical properties of agarose hydrogels. Carbohydrate Polymers. 2021 Jul 1;263:117970. https://doi.org/10.1016/j.carbpol.2021.117970
25. Zhang LM, Wu CX, Huang JY, Peng XH, Chen P, Tang SQ. Synthesis and characterization of a degradable composite agarose/HA hydrogel. Carbohydrate Polymers. 2012 May 16;88(4):1445-52. https://doi.org/10.1016/j.carbpol.2012.02.050
26. Chi WJ, Chang YK, Hong SK. Agar degradation by microorganisms and agar-degrading enzymes. Applied microbiology and biotechnology. 2012 May;94:917-30. https://doi.org/10.1007/s00253-012-4023-2
27. Inada Y, Takahashi K, Yoshimoto T, Ajima A, Matsushima A, Saito Y. Application of polyethylene glycol-modified enzymes in biotechnological processes: organic solvent-soluble enzymes. Trends in Biotechnology. 1986 Jul 1;4(7):190-4. https://doi.org/10.1016/0167-7799(86)90244-1
28. Boateng JS, Matthews KH, Stevens HN, Eccleston GM. Wound healing dressings and drug delivery systems: a review. Journal of pharmaceutical sciences. 2008 Aug 1;97(8):2892-923. https://doi.org/10.1002/jps.21210
29. Park JS, Woo DG, Sun BK, Chung HM, Im SJ, Choi YM, Park K, Huh KM, Park KH. In vitro and in vivo test of PEG/PCL-based hydrogel scaffold for cell delivery application. Journal of Controlled Release. 2007 Dec 4;124(1-2):51-9. https://doi.org/10.1016/j.jconrel.2007.08.030
30. Haaf F, Sanner A, Straub FJ. Polymers of N-vinylpyrrolidone: synthesis, characterization and uses. Polymer Journal. 1985 Jan;17(1):143-52. https://doi.org/10.1295/polymj.17.143

31. Lopérgolo LC, Lugão AB, Catalani LH. Direct UV photocrosslinking of poly (N-vinyl-2-pyrrolidone)(PVP) to produce hydrogels. Polymer. 2003 Sep 1;44(20):6217-22. https://doi.org/10.1016/S0032-3861(03)00686-4
32. Rodríguez-Rego JM, Mendoza-Cerezo L, Macías-García A, Carrasco-Amador JP, Marcos-Romero AC. Methodology for characterizing the printability of hydrogels. International Journal of Bioprinting. 2023;9(2). https://doi.org/10.18063/ijb.v9i2.667
33. Chung JH, Naficy S, Yue Z, Kapsa R, Quigley A, Moulton SE, Wallace GG. Bio-ink properties and printability for extrusion printing living cells. Biomaterials Science. 2013;1(7):763-73. https://doi.org/10.1039/C3BM00012E
34. Kyle S, Jessop ZM, Al-Sabah A, Whitaker IS. 'Printability'of candidate biomaterials for extrusion based 3D printing: state-of-the-art. Advanced healthcare materials. 2017 Aug;6(16):1700264. https://doi.org/10.1002/adhm.201700264
35. Ji H, Zhao J, Chen J, Shimai S, Zhang J, Liu Y, Liu D, Wang S. A novel experimental approach to quantitatively evaluate the printability of inks in 3D printing using two criteria. Additive Manufacturing. 2022 Jul 1;55:102846. https://doi.org/10.1016/j.addma.2022.102846
36. He Y, Yang F, Zhao H, Gao Q, Xia B, Fu J. Research on the printability of hydrogels in 3D bioprinting. Scientific reports. 2016 Jul 20;6(1):29977. https://doi.org/10.1038/srep29977
37. Saroia J, Yanen W, Wei Q, Zhang K, Lu T, Zhang B. A review on biocompatibility nature of hydrogels with 3D printing techniques, tissue engineering application and its future prospective. Bio-Design and Manufacturing. 2018 Dec;1:265-79. https://doi.org/10.1007/s42242-018-0029-7
38. Kim J. Characterization of biocompatibility of functional bioinks for 3D bioprinting. Bioengineering. 2023 Apr 9;10(4):457. https://doi.org/10.3390/bioengineering10040457
39. Fatimi A, Okoro OV, Podstawczyk D, Siminska-Stanny J, Shavandi A. Natural hydrogel-based bio-inks for 3D bioprinting in tissue engineering: a review. Gels. 2022 Mar 14;8(3):179. https://doi.org/10.3390/gels8030179
40. Vanaei S, Parizi MS, Salemizadehparizi F, Vanaei HR. An overview on materials and techniques in 3D bioprinting toward biomedical application. Engineered Regeneration. 2021 Jan 1;2:1-8. https://doi.org/10.1016/j.engreg.2020.12.001
41. Kačarević ŽP, Rider PM, Alkildani S, Retnasingh S, Smeets R, Jung O, Ivanišević Z, Barbeck M. An introduction to 3D bioprinting: possibilities, challenges and future aspects. Materials. 2018 Nov 6;11(11):2199. https://doi.org/10.3390/ma11112199
42. Placone JK, Engler AJ. Recent advances in extrusion-based 3D printing for biomedical applications. Advanced healthcare materials. 2018 Apr;7(8):1701161. https://doi.org/10.1002/adhm.201701161
43. Puertas-Bartolomé M, Włodarczyk-Biegun MK, Del Campo A, Vázquez-Lasa B, San Román J. 3D printing of a reactive hydrogel bio-ink using a static mixing tool. Polymers. 2020 Aug 31;12(9):1986. https://doi.org/10.3390/polym12091986
44. Ramesh S, Harrysson OL, Rao PK, Tamayol A, Cormier DR, Zhang Y, Rivero IV. Extrusion bioprinting: Recent progress, challenges, and future opportunities.

Bioprinting. 2021 Mar 1;21:e00116. https://doi.org/10.1016/j.bprint.2020.e00116
45. Miri AK, Mirzaee I, Hassan S, Oskui SM, Nieto D, Khademhosseini A, Zhang YS. Effective bioprinting resolution in tissue model fabrication. Lab on a Chip. 2019;19(11). https://doi.org/10.1039/C8LC01037D
46. Chen DX, Chen DX. Extrusion bioprinting of scaffolds: an introduction. Extrusion bioprinting of scaffolds for tissue engineering applications. 2019:1-3. https://doi.org/10.1007/978-3-030-03460-3_1
47. Gu Z, Fu J, Lin H, He Y. Development of 3D bioprinting: From printing methods to biomedical applications. Asian journal of pharmaceutical sciences. 2020 Sep 1;15(5):529-57. https://doi.org/10.1016/j.ajps.2019.11.003
48. Shah PP, Shah HB, Maniar KK, Özel T. Extrusion-based 3D bioprinting of alginate-based tissue constructs. Procedia CIRP. 2020 Jan 1;95:143-8. https://doi.org/10.1016/j.procir.2020.06.007
49. Pati F, Jang J, Lee JW, Cho DW. Extrusion bioprinting. InEssentials of 3D biofabrication and translation 2015 Jan 1 (pp. 123-152). Academic Press. https://doi.org/10.1016/B978-0-12-800972-7.00007-4
50. Derakhshanfar S, Mbeleck R, Xu K, Zhang X, Zhong W, Xing M. 3D bioprinting for biomedical devices and tissue engineering: A review of recent trends and advances. Bioactive materials. 2018 Jun 1;3(2):144-56. https://doi.org/10.1016/j.bioactmat.2017.11.008
51. Dababneh AB, Ozbolat IT. Bioprinting technology: a current state-of-the-art review. Journal of Manufacturing Science and Engineering. 2014 Dec 1;136(6):061016. https://doi.org/10.1115/1.4028512
52. Fatimi A, Okoro OV, Podstawczyk D, Siminska-Stanny J, Shavandi A. Natural hydrogel-based bio-inks for 3D bioprinting in tissue engineering: a review. Gels. 2022 Mar 14;8(3):179. https://doi.org/10.3390/gels8030179
53. Chen XH, Yang X, Luo YW, Zhang QH. Inkjet classification based on a few letters. Forensic Science International. 2021 Aug 1;325:110869. https://doi.org/10.1016/j.forsciint.2021.110869
54. Xu H, Casillas J, Xu C. Effects of printing conditions on cell distribution within microspheres during inkjet-based bioprinting. AIP Advances. 2019 Sep 1;9(9). https://doi.org/10.1063/1.5116371
55. Wu D, Xu C. Predictive modeling of droplet formation processes in inkjet-based bioprinting. Journal of Manufacturing Science and Engineering. 2018 Oct 1;140(10):101007. https://doi.org/10.1115/1.4040619
56. Peng W, Datta P, Ayan B, Ozbolat V, Sosnoski D, Ozbolat IT. 3D bioprinting for drug discovery and development in pharmaceutics. Acta biomaterialia. 2017 Jul 15;57:26-46. https://doi.org/10.1016/j.actbio.2017.05.025
57. Tripathi S, Mandal SS, Bauri S, Maiti P. 3D bioprinting and its innovative approach for biomedical applications. MedComm. 2023 Feb;4(1):e194. https://doi.org/10.1002/mco2.194
58. Friederich A, Binder JR, Bauer W. Rheological control of the coffee stain effect for inkjet printing of ceramics. Journal of the American Ceramic Society. 2013 Jul;96(7):2093-9. https://doi.org/10.1111/jace.12385
59. Guillemot F, Souquet A, Catros S, Guillotin B, Lopez J, Faucon M, Pippenger B, Bareille R, Rémy M, Bellance S, Chabassier P. High-

throughput laser printing of cells and biomaterials for tissue engineering. Acta biomaterialia. 2010 Jul 1;6(7):2494-500. https://doi.org/10.1016/j.actbio.2009.09.029

60. Han T, Nag A, Afsarimanesh N, Mukhopadhyay SC, Kundu S, Xu Y. Laser-assisted printed flexible sensors: a review. Sensors. 2019 Mar 25;19(6):1462. https://doi.org/10.3390/s19061462
61. Sorkio A, Koch L, Koivusalo L, Deiwick A, Miettinen S, Chichkov B, Skottman H. Human stem cell based corneal tissue mimicking structures using laser-assisted 3D bioprinting and functional bioinks. Biomaterials. 2018 Jul 1;171:57-71. https://doi.org/10.1016/j.biomaterials.2018.04.034
62. Koch L, Kuhn S, Sorg H, Gruene M, Schlie S, Gaebel R, Polchow B, Reimers K, Stoelting S, Ma N, Vogt PM. Laser printing of skin cells and human stem cells. Tissue Engineering Part C: Methods. 2010 Oct 1;16(5):847-54. https://doi.org/10.1089/ten.tec.2009.0397
63. Gruene M, Unger C, Koch L, Deiwick A, Chichkov B. Dispensing pico to nanolitre of a natural hydrogel by laser-assisted bioprinting. Biomedical engineering online. 2011 Dec;10:1-1. https://doi.org/10.1186/1475-925X-10-19
64. Guillotin B, Souquet A, Catros S, Duocastella M, Pippenger B, Bellance S, Bareille R, Rémy M, Bordenave L, Amédée J, Guillemot F. Laser assisted bioprinting of engineered tissue with high cell density and microscale organization. Biomaterials. 2010 Oct 1;31(28):7250-6. https://doi.org/10.1016/j.biomaterials.2010.05.055
65. Ventura RD. An overview of laser-assisted bioprinting (LAB) in tissue engineering applications. Medical Lasers; Engineering, Basic Research, and Clinical Application. 2021 Jun 30;10(2):76-81. https://doi.org/10.25289/ML.2021.10.2.76
66. Dou C, Perez V, Qu J, Tsin A, Xu B, Li J. A state-of-the-art review of laser-assisted bioprinting and its future research trends. ChemBioEng Reviews. 2021 Oct;8(5):517-34. https://doi.org/10.1002/cben.202000037

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