IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

ISO 3297:2007 Certified ⁜ Impact Factor 8.102 ⁜ Peer-reviewed / Refereed journal ⁜ Vol. 12, Issue 5, May 2023

DOI: 10.17148/IJARCCE.2023.12550

EXTRUSION, INKJET AND LASER ASSISTED BIOPRINTING

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Abstract—The applicability of 3D bioprinting has increased its visibility in regenerative medicine and tissue engineering. Inks made from biomaterials and bioinks may now be printed more easily thanks to technological advancements that have been made in recent years, which has helped to create structures that closely resemble human anatomy. Cross-linked polymeric materials, including hydrogels, have thus been specifically targeted for the creation of bioinks since they ensure cell growth and adherence. Therefore, this concise study provides a brief history of 3D bioprinting technology and clarifies the primary hydrogels employed in the procedure.

Keywords—3D bioprinting; hydrogels; inkjet bioprinting; extrusion bioprinting; laser assisted bioprinting

I. INTRODUCTION

Engineering and biological sciences are connected in the multidisciplinary field of three-dimensional bioprinting. 3DBP is a promising technology for use in tissue engineering and regenerative medicine since it combines cells, growth factors, and biomaterials with additive manufacturing principles [1,2]. The creation of materials that replicate the structure, makeup, and functionality of natural tissues is in fact a therapeutic option. The capacity for regeneration in some damaged organs or tissues is restricted, and their physicochemical and biological makeup is varied and complex. To fulfil biological and mechanical capabilities, 3D bioprinting technology thus employs a variety of biomaterials. The role of hydrogels as a raw material in 3DBP has been highlighted recently in particular [3-5]. In the field of tissue engineering (TE), hydrogels are well-established as scaffolds because of their three-dimensional polymeric networks' remarkable capacity to absorb fluids without disintegrating [6–8]. They typically encourage cellular development, proliferation, and differentiation because of their hydrophilic makeup and porous architecture. They may also serve as carriers for physiologically active compounds or cells [2,11]. However, promising research outcomes using 3DBP hydrogels of natural or synthetic origin are frequently brittle and have low mechanical tenacity [12]. For instance, studies show that the fracture energy of hydrogels for use in cartilage tissue engineering is ten times lower in J/m2 than the fracture energy of natural cartilage (1000 J/m2). However, the architecture of these materials, in terms of geometry, connectivity, and pore size, can be altered by 3D bioprinting hydrogels, incorporating additional mechanical reinforcement mechanisms [9]. Such characteristics are essential for intercellular signalling, accelerating the growth of macroscopically useful biological constructions.

Evolution via 3D printing 3D printing (additive manufacturing) gave rise to the diverse, developing field of bioprinting. Charles W. Hull set the first milestone in 1984 with the development of stereolithography (SLA), which allowed for the printing of three-dimensional objects. utilising a Hewlett Packard (HP) inkjet printer and a graphic plotter, the researcher demonstrated the capability of placing biological items in 1988 utilising cytoscribing technology [13–15]. Years later, 3D laser bioprinting was used to create living cells, proving that it is possible to create tissues with intricate three-dimensional anatomies. Employing the additive manufacturing method, we describe the first three-dimensional charting of thermosensitive gels in a liquid media. Later, in 2002, Landers revealed the existence of the first extrusion-based bioprinter, which was sold under the name "3D-Bioplotter". In 2003, Boland successfully printed living cells using an HP inkjet printer. In order to deposit living cells, Suwan N. Jayasinghe and his team introduced an electro-hydrodynamic jet in 2006. On the basis of free scaffolds, Narotte created synthetic vascular tissue in 2009. In 2012, Skardal and associates used cells from amniotic fluid to do in situ bioprinting in laboratory mice to promote the healing process. The outcomes suggested that treating burns and wounds may be accomplished by bioprinting these cells. To create new goods for society and solve the problems with 3D bioprinting, several sorts of research have been produced. For instance, Zhou (2021) added chondrogenic progenitor cells (CPCs) and fibronectin (FN) to an alginate/gelatin/hyaluronic acid (Alg/Gel/HA) hydrogel in order to optimise the cartilage regeneration process. In order to manipulate pre-vascularized tissues in vitro and study vascularization and bone regeneration in vivo, Nulty. (2021) created a new bioprinting technique. Using a 3D bioprinter with an extrusion-based manufacturing process, Ramasamy (2021) created synthetic

DOI: 10.17148/IJARCCE.2023.12550

skin. The goal of this study was to find a feasible and potentially scalable way to deliver full-thickness rebuilt human skin. Noor (2019) created a unique hydrogel that can be used to print autonomous biological structures like entire hearts with blood veins.

II. BIOPRINTING TECHNOLOGIES

Several 3D bioprinting technologies have been developed and optimised to print tissues and organs with increased complexity, targeting applications in tissue engineering and regenerative medicine, as can be shown in However, each technology is constrained by the characteristics of the bioinks, which also affect the material's suitability for bioprinting. Extrusion bioprinters, for example, are needed for materials with high viscosities because they favour a modest flow capacity and preserve the structure of the printed materials for a longer time. A jet bioprinter may use low-viscosity bioinks because they can be easily expelled through a small nozzle without applying excessive pressure. Extrusion and inkjet technology are discussed, and laser-assisted bioprinting is also highlighted.

2.1. Inkjet Bioprinting:- Drop-on-demand inkjet bioprinters with the best speed, accuracy, and resolution for printing biological materials. They can print materials with accuracy and geometric complexity using single- and multi-ink systems. Additionally, they employ thermal and acoustic (piezoelectric) forces to layer-by-layer deposit liquid droplets of a specific size. In the case of thermal force, the bioprinter head is rapidly heated electrically to provide pressure pulses that drive the droplets into the nozzle. Without harming the cells, the temperature of this heating can range from 200°C to 300°C. The pressure required to expel the drop from the nozzle is created by an auditory wave created by the piezoelectric forces. The goal is to employ cell-based bioinks with low viscosity for this class of bioprinter. Additionally, bioink gelation must be done in-place to prevent nozzle clogging, which is one of its drawbacks. For instance, Yerneni (2019) created solid-phase exosomes using a piezoelectric jet bioprinter with the intention of delivering exosomes locally to tissues.

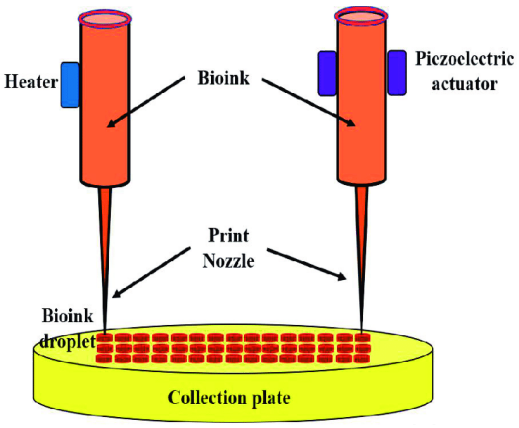

Figure 2.1 Inkjet based bioprinting

2.2. Extrusion-Based Bioprinting :- As it prints bioinks with high viscosity, extrusion-based bioprinting is one of the most popular bioprinting methods today. In this procedure, pneumatic (air) and mechanical (piston and screw) extrusion techniques are used to thread the bioinks through the nozzle. In the pneumatic approach, the force to eject the bioink at a predetermined speed and quantity is provided by the air pressure. Even though it is a straightforward process, bioinks with low viscosity lack control. The vertical and rotational forces used in the mechanical approach control the printing process. When printing with the piston method, the flow is preferred over the bioink. However, failures in the bioink deposition occur for particularly viscous materials. The distribution of bioink in screw-based extrusion, however, is in the microliter range, which can be useful for materials with low viscosities. Extrusion bioprinting is one of the most often used methods for creating artificial tissues and organs, although it has certain drawbacks, including shear stress, which can result in cell death and/or loss of viability, and a low material supply. It is advised to utilise more durable hydrogels and to make nozzle and syringe enhancements because these changes will improve cell viability after printing. A bioink based on chitosan (CH) and guar gum (GG) was created by Cleymand (2021) to be utilised in extrusion-based bioprinters.

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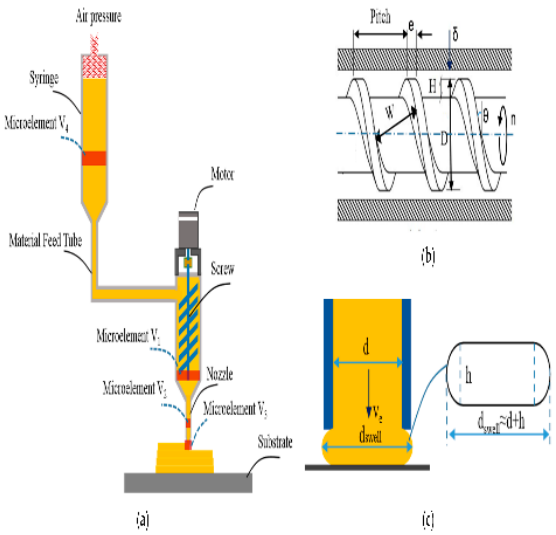

Figure 2.2 Extrusion based biopriting

2.3. Laser Assisted Bioprinting :- The nozzle and contact are not used in this procedure. Three layers—transparent, absorbent, and bioink—are cut by the laser. The absorbent layer is supported by the transparent zone, and the biomaterials are in a physical state of liquid or gel that makes them more easily spreadable. Laser-induced transfer (LIFT), which uses a high-power pulsed laser and a thin absorbent layer between the donor slide and the bioink; matrix-assisted pulsed laser evaporation direct writing (MAPLE-DW); and film-assisted laser-induced direct transfer absorption (AFA-LIFT), which makes use of a thick absorbent layer to prevent direct interaction between the laser and the bioink. Additionally, LAB can print hydrogels with different viscosities and has little impact on cell viability.

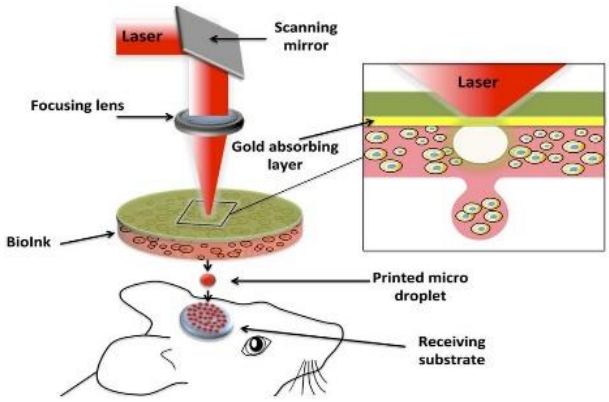

Figure 2.3 Laser based bioprinting

III. HYDROGELS AS BIOINKS OR BIOPRINTING INK

Cells find it difficult to withstand the shear stress brought on by the material's layer-by-layer deposition process, which poses a challenge for the use of cells or cell aggregates as bioinks in 3D bioprinting technologies, particularly extrusion-based printing [1].

3.1 Hyaluronic Acid A linear non-sulfated glycosaminoglycan called hyaluronic acid is found in most connective tissues and the extracellular matrix. Excellent biocompatibility, hydrophilicity, and cytocompatibility are displayed by this natural hydrogel during cell growth. To meet the physicochemical requirements of 3D bioprinting, nonetheless, its poor mechanical performance necessitates crosslinking with other polymers. An excellent alternative to photopolymerization—crosslinking substances in the presence of ultraviolet (UV) rays—is to boost the mechanical strength of hyaluronic acid. In a study by Antich (2020), a novel bioink for 3D bioprinting of cartilage and tissues was created by copolymerizing hyaluronic acid with polylactic acid (PLA). Using the photocrosslinking (UV) process, Kiyotake (2019) created a pentanoate-functionalized hyaluronic acid (PHA) bioink for 3D bioprinting.

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3.2. Collagen Type I collagen is one of the most appealing and another extensively utilised natural hydrogel. It is notable since it is both a part of musculoskeletal tissue and what other tissues require to make up their extracellular matrix. Additionally, collagen has features that are essential to 3D bioprinting, such as biocompatibility, biodegradability, and cell adhesion. Collagen, like hyaluronic acid, has a low mechanical property; however, photopolymerization (UV) can increase this property. The work of Shi 2018 provides evidence for this. Through the photopolymerization of collagen and methacrylated gelatin hydrogel (GelMa), the authors of this study created a novel type of bioink that may be a great option for 3D bioprinting of tissues to repair damage to the epidermis.

3.3. Gelatin Gelatin is a polypeptide made by denaturing collagen. Due to its characteristics, including biocompatibility, biodegradability, low cost, ease of manufacturing, and cell affinity, it has been researched for the development of bioink. In addition, crosslinking gelatin with substances like methacrylic anhydride can improve its mechanical qualities. To acquire improved material properties, many types of research have concentrated on printing this functionalized version of gelatin (Gelatin-methacryloyl/GelMA). The work of Jain (2021) is a good illustration of this. In this study, the scientists looked at GelMA bioinks that could be used in an extrusion-based bioprinter and were pre-loaded with mouse fibroblast cells . The findings suggested that the substance might make a suitable option for the production of constructs both with and without cells. Another substance that can be mixed with gelatin is silk fibroin. A bioink based on gelatin-silk fibroin was created in Singh's research (2019). The materials showed strong print fidelity, indicating a significant potential for action in cartilage tissue healing.

3.4. Alginate Natural polysaccharides like alginate are made up of -D-mannuronic acid (M) and -L-glucuronic acid (G). Due to its biocompatibility, printability, low cost, and adaptability, it is commonly utilised in 3D bioprinting. Additionally, the ease with which it gelates in the presence of divalent cations (such Ca+2 and Ba+2) optimises the structural shape of the construct and reduces the impact of shear stress on cells, favouring its use in extrusion and inkjet bioprinting. When used in bioprinting, alginate's rheological parameter needs to be carefully examined because the viscosity of the bioink based on this hydrogel is closely related to its concentration, molecular weight, phenotypic, and cell density. Pure alginate has poor mechanical characteristics and can be challenging to encourage cell proliferation. These drawbacks, however, can be altered when it is combined with other substances. In order to be employed in the extrusion bioprinting process, Wu (2018) created a hybrid bioink (CNCs) based on alginate and cellulose. The outcomes showed that the material had good shear properties, maintained the construct's structure, and caused no cellular damage. Lee (2020) created and added decellularized methacrylated extracellular matrix (dECM) obtained from bone tissues to an alginate-based bioink. The study's findings showed that the material could print 3D-cellular structures while preserving cell viability.

IV. CONCLUSION

This study introduced researchers to extrusion-, inkjet-, and laser-assisted bioprinting techniques in order to demonstrate the potential of bioprinting to provide enhanced in vitro models of exposure and disease. Due to the adaptability this type of technology offers, hydrogels as components of bioinks and biomaterial inks have given rise to the ability to build the best method for simulating microenvironments that replicate the physiological and pathological events of organisms in vivo. The analysis of 41 bioprinted models—including cancer, cardiac, hepatic, and skin models—highlights the extrusion technique as the most popular, the diversity of three-dimensional geometries, and the excellent cellular viability in the post-bioprinted constructions. Bioprinting is being used as a tool to increase the automation, reproducibility, and geometry of in vitro models in comparison to conventional methodologies; however, it is still a technology that needs to be strengthened in order to develop advanced models in terms of heterogeneity, microstructural complexity, dynamism, and integration capabilities with other models to produce multi-organ platforms where systemic responses need to be assessed. Together, we believe that our analysis of current bioprinting technology will deepen our understanding and inspire the creation of crucial in vitro models for the investigation of chemical safety, disease progression, and response to exposure.

REFERENCES

[1] Cui, X. Li, J. Hartanto, Y. Durham, M. Tang, J. Zhang, H. Hooper, G. Lim, K. Woodfield, T. Advances in Extrusion 3D Bioprinting: A Focus on Multicomponent Hydrogel-Based Bioinks. Adv. Healthc. Mater. 2020, 9.

[2] Castilho, M. Levato, R. Bernal, P.N. De Ruijter, M. Sheng, C.Y. Van Duijn, J. Piluso, S. Ito, K. Malda, J. Hydrogel-Based Bioinks for Cell Electrowriting of Well-Organized Living Structures with Micrometer-Scale Resolution. Biomacromolecules 2021, 22, 855–866.Guiru Liu, Lulin Wang and Shan Zou, “A Radar-Based Blind Spot Detection and Warning System for Driver Assistance”, 2017, pp. 2204-2208.

[3] Hahn, L. Beudert, M. Gutmann, M. Keßler, L. Stahlhut, P. Fischer, L. Karakaya, E. Lorson, T. Thievessen, I. Detsch, R. From Thermogelling Hydrogels toward Functional Bioinks: Controlled Modification and Cytocompatible

DOI: 10.17148/IJARCCE.2023.12550

Crosslinking. Macromol. Biosci. 2021, 21, 1–9Ushemadzoro Chipengo, "Full Physics Simulation Study of Guardrail Radar- Returns for 77GHz Automotive Radar Syatems", vol.6, 2018, pp.70053-70060.

[4] Han, X. Chang, S. Zhang, M. Bian, X. Li, C. Li, D. Advances of Hydrogel-Based Bioprinting for Cartilage Tissue Engineering. Front. Bioeng. Biotechnol. 2021, vol 9, pp 1–14.

[5] Ventura, R.D. An Overview of Laser-assisted Bioprinting (LAB) in Tissue Engineering Applications. Med. Lasers 2021, 10, 76–81.

[6] Lima, T.d.P.d.L. Passos, M.F. Skin wounds, the healing process, and hydrogel-based wound dressings: A short review. J. Biomater. Sci. Polym. Ed. 2021, vol 32, pp 1910–1925.

[7] Passos, M.F. Dias, D.R.C. Bastos, G.N.T. Jardini, A.L. Benatti, A.C.B. Dias, C.G.B.T. Maciel Filho, R. pHEMA hydrogels: Synthesis, kinetics and in vitro tests. J. Therm. Anal. Calorim. 2016, vol 125, pp 361–368..

[8] Dorishetty, P. Dutta, N.K. Choudhury, N.R. Bioprintable tough hydrogels for tissue engineering applications. Adv. Colloid Interface Sci. 2020, vol 281, pp 102163.

[9] Tayler, I.M. Stowers, R.S. Engineering hydrogels for personalized disease modeling and regenerative medicine. Acta Biomater. 2021, vol 132,pp 4–22.

[10] Gu, Z. Fu, J. Lin, H. He, Y. Development of 3D bioprinting: From printing methods to biomedical applications. Asian J. Pharm. Sci. 2020, vol 15, pp 529–557.

[11] Zhou, Y. Qin, R. Chen, T. Zhang, K. Gui, J. 3D bioprinting modified autologous matrix-induced chondrogenesis(AMIC) technique for repair of cartilage defects. Mater. Des. 2021, vol 203, pp. 213-216.

[12] Nulty, J. Freeman, F.E. Browe, D.C. Burdis, R. Ahern, D.P. Pitacco, P. Lee, Y.B. Alsberg, E. Kelly, D.J. 3D Bioprinting of prevascularised implants for the repair of critically-sized bone defects. Acta Biomater. 2021, vol 126, pp 154–169.

[13] Liu, N. Ye, X. Yao, B. Zhao, M. Wu, P. Liu, G. Zhuang, D. Jiang, H. Chen, X. He, Y. et al. Bioactive Materials Advances in 3D bioprinting technology for cardiac tissue engineering and regeneration. Bioact. Mater. 2021, vol 6, pp 1388–1401.

[14] Mao, H. Yang, L. Zhu, H. Wu, L. Ji, P. Yang, J. Gu, Z. Progress in Natural Science: Materials International Recent advances and challenges in materials for 3D bioprinting. Prog. Nat. Sci. Mater. Int. 2020, vol 30, pp 618–634.

[15] Vijayavenkataraman, S. Yan, W.C. Lu, W.F Wang, C H. Fuh, J.Y.H. 3D bioprinting of tissues and organs for regenerative medicine. Adv. Drug Deliv. Rev. 2018, vol 132, pp 296–332.

[16] Williams, D. Thayer, P. Martinez, H. Gatenholm, E. Khademhosseini, A. A perspective on the physical, mechanical and biological specifications of bioinks and the development of functional tissues in 3D bioprinting. Bioprinting 2018,vol 9, pp19–36.

[17] Heid, S. Boccaccini, A.R. Advancing bioinks for 3D bioprinting using reactive fillers: A review. Acta Biomater. 2020, vol 113, pp 1–22.

[18] Das, S. Basu, B. An Overview of Hydrogel-Based Bioinks for 3D Bioprinting of Soft Tissues. J. Indian Inst. Sci. 2019,vol 99, pp 405–428.

[19] Hu, T. Cui, X. Zhu, M. Wu, M. Tian, Y. Yao, B. Song, W. Niu, Z. Huang, S.; Fu, X. 3D-printable supramolecular hydrogels with shear-thinning property: Fabricating strength tunable bioink via dual crosslinking. Bioact. Mater. 2020, vol 5, pp 808–818.

[20] Kabirian, F. Mozafari, M. Decellularized ECM-derived bioinks: Prospects for the future. Methods 2020, vol 171, pp 108–118.

[21] Li, X. Liu, B. Pei, B. Chen, J. Zhou, D. Peng, J. Zhang, X. Jia, W. Xu, T. Inkjet Bioprinting of Biomaterials. Chem. Rev. 2020, vol 120, pp 10793–10833.

[22] Zhang, B. Gao, L. Ma, L. Luo, Y. Yang, H. Cui, Z. 3D Bioprinting: A Novel Avenue for Manufacturing Tissues and Organs. Engineering 2019, vol 5, pp 777–794.

[23] Shah, P.P. Shah, H.B. Maniar, K.K. Özel, T. Extrusion-based 3D bioprinting of alginate-based tissue constructs. Procedia CIRP 2020, vol 95, pp 143–148.

[24] 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 Rev. 2021,vol 8, pp 517–534.

[25] Murphy, S.V. De Coppi, P. Atala, A. Opportunities and challenges of translational 3D bioprinting. Nat. Biomed. Eng. 2020, vol 4, pp 370–380.

[26] 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. Bioact. Mater. 2018, vol 3, pp 144–156.

[27] Hong, N. Yang, G.H. Lee, J.H. Kim, G.H. 3D bioprinting and its in vivo applications. J. Biomed. Mater. Res.-Part B Appl. Biomater. 2018, vol 106, pp 444–459.

[28] Piao, Y. You, H. Xu, T. Bei, H.P. Piwko, I.Z. Kwan, Y.Y. Zhao, X. Biomedical applications of gelatin methacryloyl hydrogels. Eng. Regen. 2021, vol 2, pp 47–56.

[29] Chimene, D. Kaunas, R. Gaharwar, A.K. Hydrogel Bioink Reinforcement for Additive Manufacturing: A Focused Review of Emerging Strategies. Adv. Mater. 2020, vol 32, pp 1–22.

International Journal of Advanced Research in Computer and Communication Engineering
ISO 3297:2007 Certified ⁜ Impact Factor 8.102 ⁜ Peer-reviewed / Refereed journal ⁜ Vol. 12, Issue 5, May 2023
DOI: 10.17148/IJARCCE.2023.12550

[30] Chimene, D. Miller, L. Cross, L.M. Jaiswal, M.K. Singh, I. Gaharwar, A.K. Nanoengineered osteoinductive bioink for 3D bioprinting bone tissue. ACS Appl. Mater. Interfaces 2020, vol 12, pp 15976–15988.
[31] Jovic, T.H. Combellack, E.J. Jessop, Z.M. Whitaker, I.S. 3D Bioprinting and the Future of Surgery. Front. Surg. 2020, vol 7, pp 1–10.
[32] Im, S. Choe, G. Seok, J.M. Yeo, S.J. Lee, J.H. Kim, W.D. Lee, J.Y. Park, S.A. An osteogenic bioink composed of alginate, cellulose nanofibrils, and polydopamine nanoparticles for 3D bioprinting and bone tissue engineering. Int. J. Biol. Macromol. 2022, vol 205, pp 520–529.
[33] Genova, T. Roato, I. Carossa, M. Motta, C. Cavagnetto, D. Mussano, F. Advances on bone substitutes through 3d bioprinting. Int. J. Mol. Sci. 2020, 21, 7012.
[34] Ng, W.L. Qi, J.T.Z. Yeong, W.Y. Naing, M.W. Proof-of-concept: 3D bioprinting of pigmented human skin constructs. Biofabrication 2018, 10.
[35] Silva, P. Marques, A.P. Fernandes, M.G. Skin Mechanobiology and Biomechanics: From Homeostasis to Wound Healing. Adv. Biomech. Tissue Regen. 2019.

