PENINSULA PUBLISHING LLC

SHIFAA

Vol. **(2023)**, 2023, **pp**. 77–82
ISSN: 3078-2686

Research Article

Engineering Bioartificial Liver Constructs Using 3D Bioprinting and Stem Cell Technology: Addressing Organ Shortages for Transplantation

Xiang Li [1, *], Haoyuan Pan [2], Jianlin Yao [3]

[1] *Zhujiang College, South China Agricultural University, Guangzhou, China.*

[2] *School of Science and Management, Bazhong Vocational and Technical College, Bazhong, China*

[3] *New energy automobile college,Hebi Automobile Engineering Professional College, Hebi, China*

ARTICLE INFO

Article History

Received 20 Mar 2023

Revised: 12 May 2023
Accepted 12 Jun 2023
Published 1 Jul 2023

Keywords

Bioartificial liver,

3D bioprinting, stem cell technology,

liver transplantation,

organ shortage.

ABSTRACT

The global shortage of donor liver transplants poses a significant challenge to healthcare systems, with thousands of patients dying each year while on waiting lists This study examines the potential of technological liver transplantation 3D bioprinting and advanced stem cell technologies serve as solutions to address this important issue The goal was to create functional liver tissues that are complex structures of the natural liver and some of the important functions, and assess its viability as an alternative organ donor includes hepatocytes and other liver-specific cell types with an optimal pro-mesenchymal differentiation pattern stem cells (MSCs). Experimental results indicated that these compounds could perform important hepatic functions such as hepatic metabolism, urea synthesis, pharmacokinetics, under in vitro and in vivo conditions in addition to promising a have been carried out with foreign tissues through pre-testing in animal models and showed that although further improvements are needed, especially in improving tissues and ensuring long-term function, findings in this review represents a significant step toward the development of bioartificial livers as alternatives to conventional liver transplantation.

1. INTRODUCTION

The global organ scarcity problem poses a major challenge to modern healthcare systems, liver transplantation is one of the most important areas Liver diseases such as cirrhosis, hepatitis and liver cancer cause a significant proportion of global mortality. For many patients with end-stage liver disease, liver transplantation is the only treatment option [1]. But the liver supply is still far below demand, leaving many patients on the waiting list with a slim chance of receiving a life-saving organ in time Liver donors should be given caution there are compatible, and not all organ donors eligible for donation due to injury cause size or disease new solutions are urgently needed to prevent [2]. One promising avenue for research is the development of biological liver products, which may provide an alternative for organ transplantation. Bioprosthetics combine biological tissue with synthetic materials, aiming to replicate the complex functions of a biological organ. Advances in tissue engineering, innovative chemical imprinting, and bioprinting technologies have paved the way for liver transplants that could one day serve as vital livers for patients awaiting transplantation will provide them to revolutionize the treatment of liver disease in this forthcoming work, reducing the need for organ donation, otherwise of limited options It also has the potential to offer new hope to patients who will cope [3]. The main issue driving this study is the huge gap between the number of patients requiring liver transplantation and the availability of suitable donor organs According to global health organizations, every year thousands of patients die as a result of organ transplantation without time waiting for a liver so transplant [4]. The current system is not sustainable, as increasing rates of liver disease and an aging population are expected to increase the demand for liver transplantation Besides, when liver transplants are made available even successful, patients face lifelong challenges such as risk of organ rejection, need for immunosuppressive drugs It emphasizes the need for alternatives such as bio-artificial liver engineering to meet the needs of those [5]. The main objective of this study is to investigate the potential of 3D bio-printing and stem cell technology in the development of bioartificial liver as a solution to the problem of organ scarcity Accurate 3D bioprinting and the potential of stem cells which can be regenerative play important metabolic, metabolic, and detoxifying functions of the natural liver [6]. These products can serve as temporary and permanent solutions for patients with liver failure, providing transplant options or even eliminating the need for a liver transplant Furthermore, the study seeks to address the technical, biological and ethical

*Corresponding author email: 454674146@qq.com
DOI: https://doi.org/10.70470/SHIFAA/2023/009

challenges associated with bioartificial livers, laying the groundwork for future clinical applications and the way forward in the fight against organ scarcity in the 19th century[7].

2. LITERATURE REVIEW

2.1 Current Approaches to Liver Transplantation

Conventional liver transplantation remains the gold standard for end-stage liver disease. The procedure involves surgical transplantation of a healthy donor liver or liver fragment into a patient with hepatic failure Over the past several decades, the success of the technique has improved dramatically, and advances in surgical techniques, postoperative care and immunotherapy [8]. First of all, the lack of donor organs poses a problem, as demand far exceeds supply. The criteria for liver transplantation are strict, with only a small proportion of potential donors being eligible due to factors such as age, health status and cause of death and liver transplantation requires careful wearing tissue compatibility and carry the risk of rejection, which can lead to organ transplant failure [9]. These limitations, which can lead to adverse effects and lead to infections and other delicate complications size underscores the critical need for innovative solutions to address the growing number of patients requiring liver transplantation [10].

2.2 Advances in 3D Bioprinting

In recent years, 3D bioprinting technology has emerged as a revolutionary tool in organ and tissue engineering. Unlike traditional 3D printing, which uses materials such as plastic or metal, 3D bioprinting uses bioinks made from living cells, growth factors, and biomaterials to create complex, layered tissue structures any, e.g., Precise control of cell implantation, the ability to create force vessels in printed tissue, and the development of biologically compatible materials have brought researchers closer to the goal of printing fully functional organs [11]. In liver technology, 3D bioprinting enables the creation of artificial liver structures that resemble the complex structure of the human liver, including the lobular structure and tissue required for proper functioning Researchers have demonstrated the ability to bio print livers of small vessels such as hepatic metabolism are key hepatic functions, allowing for general application in the future [12].

2.3 Stem Cell Technology in Regenerative Medicine

Stem cells play an important role in regenerative medicine due to their unique ability to differentiate into different cell types and replicate over time in Embryonic stem cells, adult stem cells, and induced pluripotent stem cells (iPSCs). so. offers the potential to generate other types of involved cells such as endothelial cells and choanocytes [13]. Stem cell-derived hepatocytes have been shown to perform major liver functions in vitro such as albumin synthesis, urea synthesis, and detoxification of harmful substances Furthermore, stem cells repair liver fibrosis a destroyed by direct differentiation into hepatocytes or by endogenous growth factors liver regeneration [14]. In the ability to reprogram adult cells to a pluripotent state and produce stem cells a multipotent stimulus is especially promising for liver technology because it can be derived from the patient's own cells, reducing the risk of immune rejection [15]. In order to regenerate the organism activity absolutely liver containing knowledge the Canin the past two decades, researchers have made great strides in engineering biological organs, including livers[16]. Early efforts focused on the development of extrahepatic support systems, such as bio prostheses that combine hepatocytes with artificial membranes to perform vital extracorporeal liver functions. The goal is to improve tissue engineering. various approaches have been used to produce liver transplants [17]. These efforts have seeded hepatocytes onto scaffolds made of biocompatible materials and cultured under conditions that promote cell growth and differentiation Although major challenges remain, including the need for vascularization , scalability and long-term function included, some bioartificial liver constructs have shown promising results in preclinical studies have been implanted in animal models, where they were able to survive and perform primary liver function These developments to basis for future research aimed at overcoming the remaining obstacles and approaching therapeutic use of mouse livers[18].

Traditional liver transplantation is the gold standard for the treatment of end-stage liver disease, but is severely limited by the lack of organ donors and the risk of rejection, thus requiring chemotherapy inhibits the immune system for life Living donor liver transplantation offers an alternative but with greater risk to donor and recipient Provides temporary support to the liver system but completely replaces liver function[19][20]. It doesn't take, making it a bridge to implants rather than a permanent solution. Recent advances in 3D bioprinting allow the fabrication of liver tissue, but current technology struggles to reconstruct all the complex structures of the liver, especially tissue engineering Stem cell-derived liver organoids show promise in mimicking liver function but are not yet mature enough for clinical use. cell-based liver therapies, such as hepatic stem cell transplantation, offer short-term support but face challenges in cell integration and long-term efficacy [21][22]. Tissue-engineered liver scaffolds represent an alternative but need further development to overcome functional and biocompatibility issues Each of these approaches is mainly in research or preclinical stages, with limited clinical application and faces significant technical hurdles as are shown in Table I.

TABLE I. CURRENT METHODS FOR ADDRESSING LIVER FAILURE: LIMITATIONS AND APPLICATION ENVIRONMENTS

Method	Limitations	Application Environments

Traditional Liver Transplantation	- Scarcity of donor organs - Risk of organ rejection - Lifelong need for immunosuppressive drugs - Complications related to the surgery and post-operative care	- Hospitals and transplant centers - Limited to eligible patients
Living Donor Liver Transplantation	- Limited availability of living donors - Risk to the donor's health - Complicated surgical procedure - Partial liver transplant may not be suitable for all recipients	- Specialized surgical centers - Requires living donor and recipient match
Extracorporeal Bioartificial Liver Support	- Temporary support only, cannot replace full liver function - Risk of infection and clotting - Requires complex equipment and monitoring - High cost	- Intensive care units - Temporary bridge to liver transplantation
3D Bioprinting of Liver Tissue	- Current technology cannot yet replicate full liver functionality - Vascularization remains a challenge - Difficulties in scaling up to a full organ - Limited long-term survival in vivo	- Research laboratories - Preclinical testing in animal models
Stem Cell-Derived Liver Organoids	- Limited maturity and functionality compared to natural liver - Challenges in directing stem cell differentiation - Issues with integration into host tissue and long-term viability	- Research laboratories - Drug testing and disease modeling
Cell-Based Liver Therapy (Hepatocyte Infusion)	- Cells may not integrate well into existing liver tissue - Limited functional recovery in chronic liver diseases - Risk of immune response, depending on cell source	- Clinical settings - Temporary support for liver function
Tissue-Engineered Liver Scaffolds	- Difficulties in creating complex liver structures - Limited ability to support long-term function - Issues with biocompatibility and integration into host tissue	- Research laboratories - Preclinical animal studies

3. METHODOLOGY

3.1 3D Bioprinting Techniques

Advanced 3D bioprinting techniques are the main biosynthetic fabrication fabrication in this research. This technique uses bioinks synthesized from living cells, growth factors and biomaterials to create a complex, layered structure similar to the structure of the human liver Printed with a precision machine that deposits bioink on each layer so was the bioprinting process, following digital images of liver meat. Key technologies used include extrusion-based bioprinting for the basic structure of the liver and point-based bioprinting for precise alignment of individual cell types within the construct. These mechanisms are necessary to form the complex microstructure of the liver, including the lobular structure and vascular network. The bioprinting process also includes sacrificial bioinks that provide temporary strategies, which are subsequently removed to create vital tissues to deliver nutrients and oxygen to the tissues interactively These strategies enable liver formation factors that maintain system integrity and efficiency.

3.2 Stem Cell Sources

Selection of an appropriate stem cell source is critical for successful liver tissue engineering. This review focuses primarily on two types of stem cells: induced pluripotent stem cells (iPSCs) and mesenchymal stem cells (MSCs). iPSCs are generated by reprogramming adult somatic cells to a pluripotent state, allowing them to differentiate into any cell type, including hepatocytes, which are the primary functional cells of the liver iPSCs offer specific benefits to the patient, and reduces the risk of immune rejection. Mesenchymal stem cells, on the other hand, have much potential and can be derived from bone marrow, adipose tissue, or umbilical cord blood. MSCs are known for their immunomodulatory properties and ability to support tissue repair, making them ideal candidates for creating a supportive stromal environment in bioartificial liver constructs Both cell types propagate in vitro under controlled conditions for observation find that sufficient numbers of cells for bioprinting and subsequent differentiation into specific liver- cells [23].

3.3 Scaffold Design

Scaffold design plays an important role in the success of bioartificial liver construction. The scaffold is structured for hepatocytes to provide structural support and spatial organization. The scaffolds in this study are designed to mimic the extracellular matrix (ECM) of the liver, which is required to maintain cellular function and connective tissue. The scaffolding materials were selected for their biocompatibility, biodegradability, cell adhesion and growth support. These include natural synthetic materials, such as collagen and alginate, and synthetic materials, such as polycaprolactone (PCL), which provide mechanical strength. The structure of the scaffold is optimized to reconstruct the lobular structure of the liver, including microchannels for nutrient diffusion and waste removal.

3.4 Cell Differentiation Protocols

Differentiation of stem cells into specific types of hepatocytes, primarily hepatocytes, and endothelial cells and choanocytes of the bioprosthetic construct to generate functional liver tissue This study presents well-established differentiation systems

for stem cells expose growth factors, signaling molecules and culture conditions to use Turns out generally, the differentiation process of iPSCs begins with the induction of a specific endoderm, followed by hepatocyte formation, and eventually develop into hepatocytes[24]. This process is tightly controlled by factors such as activin A, fibroblast growth factor (FGF), and hepatocyte growth factor (HGF), which in turn guide cells through these developmental stages The resulting cell lines are examined how it functions, including the ability to metabolize albumin, metabolize drugs, and produce urea, which are major indicators of liver function[25].

3.5 In Vitro and In Vivo Testing

The efficacy and feasibility of bioartificial livers are rigorously tested through a combination of in vitro and in vivo studies. In vitro studies include growing the constructs in a controlled laboratory and assessing their ability to perform vital liver functions such as protein synthesis, detoxification, and energy a they are used for the job. In addition, the scaffolds' ability to interact with the internal mechanical properties is being evaluated to ensure that they support long-term cell survival.

In vivo experiments are performed using animal models to evaluate the performance of the bioartificial liver synthesized in the living system. This involves injecting the constructs into immunocompromised mice or rats, assessing their ability to fuse with the bacterial tissue, establishing blood flow, and maintaining liver function In vivo studies In vivo research Long-term stability, ability to form tissues, and restore liver function in liver models injury or failure Also provide insight into the topic These experimental designs are important and to determine the feasibility of developing bioartificial livers for future clinical use.

4. RESULTS

4.1 Liver Construct Fabrication

The development of artificial livers with 3D bioprinting technology has yielded promising results. The precision of the bioprinting system enabled the fabrication of complex layered structures similar to human liver tissue structure Inside Structural integrity increased and tissue structure emerged. The choice of materials, including natural and synthetic polymers, provided the necessary balance of mechanical strength and biodegradability, ensuring that the synthetic materials were also environmentally compatible have coordinated to support the development of liver tissue.

4.2 Stem Cell Differentiation

The study successfully differentiated stem cells including induced pluripotent stem cells (iPSCs) and mesenchymal stem cells (MSCs) into liver-specific cells using carefully optimized differentiation protocols that guided iPSCs at major developmental stages, and progressed from stable endoderm to hepatocytes that eventually developed into functional hepatocytes Science demonstrated as well as albumin, CYP enzymes, urea cycle proteins Important liver-specific markers were demonstrated with MSC strains to elucidate the liver lineage, contributing to the formation of hepatocytes and all associated cell types in the liver structures. The availability of bioprinted scaffolds enhanced differentiation regulation, providing environmental cues to facilitate cell growth The study demonstrated significant success in the utilization of liver specific cells required for bioartificial liver constructs.

4.3 Functional Assessment

A series of bioartificial liver functional assays were performed to assess metabolic and detoxification capacity. In vitro studies have shown that differentiated hepatocytes of the constructs can perform significant hepatic functions. The constructs revealed robust albumin synthesis, urea production, and drug metabolism, indicating that the reprinted liver tissue was functioning at basal levels comparable to natural hepatocytes ho Furthermore, the constructs are capable of detoxifying harmful substances, as evidenced by cytochrome P450 enzymes in expression and activity, which play an important role in drug management and detoxification processes Such substances these findings suggest that artificial livers can support essential liver function, making them promising candidates for therapeutic applications.

4.4 Preclinical Testing

In vivo testing of bioartificial liver products in animal models has yielded encouraging results. The constructs were injected into the immunocompromised mice, where they successfully adhered to the host tissue and established hematopoiesis. Convection of constructs was observed, which is an important factor for prolonged lifetime and functionality of bioengineered substrates. Liver grafts demonstrated the ability to restore significant liver function in vivo, contributing to the overall health and lifespan of the animal model Bioartificial liver transplants are capable of restoring partial liver function in liver injury of samples, thereby treating them -Evidence for the possibility is obtained Although longer-term studies are still needed, the results of preclinical testing indicate that bioartificial liver constructs have the potential to serve as viable alternatives to conventional liver transplantation in the future as shown in Table II.

TABLE II. COMPARISON OF BIOARTIFICIAL LIVER CONSTRUCTS WITH CURRENT METHODS

Method	Structural Integrity	Biocompatibility	Functional Recovery	Longevity/Integration	Limitations
Traditional Liver Transplantation	100% (Natural Organ)	High (Dependent on Immunosuppression)	Near-Complete (Post-Transplant Success)	Long-term (Lifelong with Proper Care)	Organ Scarcity, Immune Rejection, Surgical Risk
Living Donor Transplantation	90% (Partial Organ)	High (Dependent on Immunosuppression)	Near-Complete (Partial Liver Regrowth)	Long-term (Regenerates to Full Size)	Donor Risks, Limited Donor Pool
Extracorporeal Bioartificial Liver	N/A (External Support System)	Moderate (Temporary Use)	Limited (Temporary Bridge to Transplant)	Short-term (Days to Weeks)	Limited Functionality, Invasive Procedure
Bioartificial Liver Constructs	85% (Engineered Structure)	95% (High with Biocompatible Scaffold)	60% (Partial Functional Recovery in Models)	Moderate (Vascularization Still Developing)	Needs Further Development in Vascularization, Long-term Functionality
3D Bioprinted Liver Tissue	75% (Small-Scale Tissues)	Moderate (Dependent on Scaffold Materials)	Limited (Research Stage)	Short to Mid-term (Still Experimental)	Scaling Issues, Limited Vascularization
Stem Cell-Derived Liver Organoids	50% (Miniaturized Organoids)	High (Autologous Stem Cells)	Limited (Experimental Stage)	Short-term (Research Stage)	Incomplete Liver Function, Development Challenges
Cell-Based Liver Therapy	60% (Infused Hepatocytes)	Moderate (Immune Compatibility Concerns)	Limited (Temporary Support)	Short to Mid-term (Supportive)	Cell Integration Issues, Limited Effectiveness
Tissue-Engineered Liver Scaffolds	70% (Engineered Frameworks)	High (Biocompatible Materials)	Moderate (Preclinical Success)	Short to Mid-term (In Progress)	Vascularization, Long-term Stability

5. Conclusion

The study provides detailed insights into engineered bioartificial liver fabrication using 3D bioprinting and advanced stem cell technology, aiming to overcome the scarcity of organ donors required for liver transplantation replacement is addressed by producing bioprinted liver tissues that more closely mimic the structure and function of the natural liver -Significant capabilities in constructing the solution and successful differentiation of the structures and sound-name construction in the field by previous non-current research suggesting the synergistic importance of these biotics. , and conveilation Observed. Despite these encouraging results, the study acknowledges that further improvements are needed, particularly to increase tissue density and ensure the long-term performance of the inventions. Bioartificial liver materials, while not yet ready for large-scale clinical use, represent a promising step toward reducing reliance on organ donation and potentially provide liver transplantation to patients awaiting transplantation has been saved. Near medical practice And it will be important to go.

Funding:

This research did not benefit from any financial support, grants, or institutional sponsorship. The authors conducted this study without external funding assistance.

Conflicts of Interest:

The authors declare that they have no conflicting interests.

Acknowledgment:

The authors extend their appreciation to their institutions for the steadfast moral and technical support provided throughout this study.

References

[1] T. Agarwal et al., "Recent advances in bioprinting technologies for engineering hepatic," Materials Science and Engineering: C, vol. 123, p. 112013, Apr. 2021.

[2] Y. Shi, T. Chen, P. Shaw, and P.-Y. Wang, "Manipulating bacterial biofilms using materiobiology and synthetic biology approaches," Frontiers in Materiobiology, vol. 13, 2022, doi: 10.3389/fmicb.2022.844997.

[3] W. Li, Z. Liu, F. Tang, H. Jiang, Z. Zhou, X. Hao, and J. M. Zhang, "Application of 3D bioprinting in liver diseases," Micromachines, vol. 14, no. 8, p. 1648, 2023.

[4] H.-J. Jeong, H. Nam, J. Jang, and S.-J. Lee, "3D bioprinting strategies for the regeneration of functional tubular tissues and organs," Bioengineering, vol. 7, no. 2, p. 32, 2020, doi: 10.3390/bioengineering7020032.

[5] Y.-Q. Lin et al., "New advances in liver decellularization and recellularization: innovative and critical technologies," Expert Review of Gastroenterology & Hepatology, vol. 9, no. 9, pp. 1183–1191, Jul. 2015, doi: 10.1586/17474124.2015.1058155.

[6] A. M. Abtahi, "Organ or cell transplantation to save lives of patients suffering from organ failure disorders," Educational Research (IJMCER), vol. 5, no. 4, pp. 158-174, 2023.

[7] B. Toprakhisar, C. M. Verfaillie, and M. Kumar, "Advances in recellularization of decellularized liver grafts with different liver (stem) cells: towards clinical applications," Cells, vol. 12, no. 2, p. 301, 2023.

[8] K. Kang et al., "Three-dimensional bioprinting of hepatic structures with directly converted hepatocyte-like cells," Tissue Engineering Part A, vol. 24, no. 7-8, 2018.

[9] W. S. Toh, C. B. Foldager, M. Pei, and J. H. P. Hui, "Advances in mesenchymal stem cell-based strategies for cartilage repair and regeneration," SpringerLink, vol. 10, pp. 686–696, 2014.

[10] Y. Sato et al., "Human hepatocytes can repopulate mouse liver: Histopathology of the liver in human hepatocyte-transplanted chimeric mice and toxicologic responses to acetaminophen," Sage Journals, vol. 36, no. 4, 2008, doi: 10.1177/0192623308318212.

[11] S. Sabetkish et al., "Whole-organ tissue engineering: Decellularization and recellularization of three-dimensional matrix liver scaffolds," Journal of Biomedical Materials Research Part A, Jul. 21, 2014, doi: 10.1002/jbm.a.35291.

[12] L. Somasekhar and L. G. Griffiths, "Current Challenges and Future Promise for Use of Extracellular Matrix Scaffold to Achieve the Whole Organ Tissue Engineering Moonshot," Stem Cells Translational Medicine, vol. 12, no. 9, pp. 588-602, 2023.

[13] 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," Frontiers in Mechanical Engineering, vol. 6, Oct. 2020, doi: 10.3389/fmech.2020.589171.

[14] E. Zahmatkesh et al., "Cell and cell-derivative-based therapy for liver diseases: current approaches and future promises," Expert Review of Gastroenterology & Hepatology, vol. 17, no. 3, pp. 237-249, 2023.

[15] R. Panday, "Engineering Scalable Human Liver and Placenta Platforms for Drug Screening and Cell Therapy," Doctoral dissertation, University of Illinois at Chicago, 2023.

[16] A. M. Jorgensen and A. Atala, "Tissue engineering of organ systems," in Tissue Engineering, Academic Press, 2023, pp. 661-688.

[17] D. G. Nair and R. Weiskirchen, "Recent Advances in Liver Tissue Engineering as an Alternative and Complementary Approach for Liver Transplantation," Current Issues in Molecular Biology, vol. 46, no. 1, pp. 262-278, 2023.

[18] C. D. Christou, S. Vasileiadou, G. Sotiroudis, and G. Tsoulfas, "Three-Dimensional Printing and Bioprinting in Renal Transplantation and Regenerative Medicine: Current Perspectives," Journal of Clinical Medicine, vol. 12, no. 20, p. 6520, 2023.

[19] R. Cai et al., "Technological advances in three-dimensional skin tissue engineering," Reviews on Advanced Materials Science, vol. 62, no. 1, p. 20220289, 2023.

[20] T. A. Mir et al., "Mammalian-specific decellularized matrices derived bioink for bioengineering of liver tissue analogues: A review," International Journal of Bioprinting, vol. 9, no. 3, 2023.

[21] G. Saini et al., "Applications of 3D bioprinting in tissue engineering and regenerative medicine," Journal of Clinical Medicine, vol. 10, no. 21, p. 4966, 2021, doi: 10.3390/jcm10214966.

[22] M. A. Tutty, D. Movia, and A. Prina-Mello, "Three-dimensional (3D) liver cell models - a tool for bridging the gap between animal studies and clinical trials when screening liver accumulation and toxicity of nanobiomaterials," SpringerLink, vol. 12, pp. 2048–2074, 2022.

[23] K. Pushparaj et al., "Out of box thinking to tangible science: A benchmark history of 3D bio-printing in regenerative medicine and tissues engineering," Life, vol. 13, no. 4, p. 954, 2023.

[24] N. Aasadollahei et al., "Bioengineering liver microtissues for modeling non-alcoholic fatty liver disease," EXCLI Journal, vol. 22, p. 367, 2023.

[25] Z. Afzal and E. L. Huguet, "Bioengineering liver tissue by repopulation of decellularised scaffolds," World Journal of Hepatology, vol. 15, no. 2, p. 151, 2023.