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An Interpretative Study of Patients' Lived Experiences with Advanced Scaffold-Based Tissue Engineering and 3D Bioprinted Tissue Implantation Technologies

Silvan Saputra [1]*, Asmail [2]
[1]Indonesia International Institute for Life-Sciences (i3L), Indonesia
[2]PT. Riseta Medica Inovasia, Indonesia
[1] silvanwijayaaa7@gmail.com *, [2]mailmedica97@gmail.com

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ABSTRACT

Regenerative medicine and tissue engineering have rapidly advanced as scientific fields focused on restoring damaged tissues through innovative technologies, specifically scaffold-based tissue engineering constructs and 3D bioprinted tissue implantation technologies. Within this domain, increasing attention has been directed toward understanding how patients encounter and live with these scaffold-based biomaterial implants and 3D bioprinted tissue constructs, particularly as they transition from experimental innovation to clinical application. However, limited knowledge exists regarding how patients subjectively experience, interpret, and integrate scaffold-based and 3D bioprinted tissue implantation procedures into their embodied, emotional, and temporal lives. Here, an interpretative phenomenological approach is used to explore and elucidate the essential meanings of patients' lived experiences following the clinical implantation of scaffold-based engineered tissues and 3D bioprinted tissue constructs. Data were generated through in-depth, multi-phase interviews with patients who had undergone scaffold-supported tissue regeneration or 3D bioprinted tissue implantation and were analyzed using Interpretative Phenomenological Analysis. The findings reveal that patients experience scaffold-based and bioprinted regenerative interventions as a process of embodied negotiation marked by initial bodily alienation and gradual integration. Participants also described altered perceptions of time characterized by uncertainty and waiting, alongside emotional ambivalence shaped by hope, fear, and trust in advanced biofabrication technologies. These experiential dimensions were further embedded in reflective meaning-making processes that reshaped personal identity and understandings of the body in relation to engineered and bioprinted biological constructs. Together, these findings demonstrate that scaffold-based tissue engineering and 3D bioprinted tissue implantation technologies are lived not only as biomedical interventions but as complex human experiences, underscoring the importance of phenomenological approaches for advancing patient-centered knowledge and informing future research and practice in technology-driven regenerative healthcare.

INTRODUCTION

Advances in regenerative medicine and tissue engineering have significantly transformed contemporary healthcare, particularly in the treatment of tissue damage resulting from trauma, degenerative diseases, and complex clinical conditions (Y. Zhang et al., 2022). Innovations such as scaffold-based regeneration and bioprinted tissue implantation are increasingly positioned as promising solutions to restore biological function and improve quality of life (Shi et al., 2020). Within scientific and clinical discourse, these developments are commonly framed in terms of technological progress, therapeutic efficacy, and measurable clinical outcomes, reflecting a broader biomedical orientation toward optimization and innovation in patient care.

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Beyond their scientific and clinical significance, regenerative therapies are embedded within wider social and human contexts in which patients encounter these interventions not merely as medical procedures, but as profound life events (Mukhlis et al. 2023). For individuals undergoing tissue regeneration, the body becomes a site of negotiation between injury, technology, and recovery. Experiences of hope, uncertainty, vulnerability, and anticipation often accompany encounters with advanced medical technologies, particularly when therapies are novel or perceived as experimental (Korn et al., 2020). These experiences are shaped by cultural understandings of the body, illness, and healing, as well as by social relationships with healthcare professionals and institutions. As a result, regenerative medicine is not only a technical endeavor but also a deeply human one, situated at the intersection of biological repair and lived experience.

Current understandings of regenerative therapies remain largely grounded in objective assessments of biological performance and clinical success (Zhu et al., 2020). While such perspectives are essential, they offer limited insight into how patients subjectively experience regenerative interventions in their everyday lives. The meanings individuals attribute to bodily change, healing processes, and technological integration often remain underexplored, despite their relevance to psychological adaptation, trust in medical innovation, and long-term engagement with care (Mukhlis & Saidah, 2025). This gap underscores the need for approaches that attend to experience as it is lived and interpreted by those directly involved. Phenomenology, with its focus on the exploration of meaning and subjective experience, provides a suitable framework for deepening understanding of how regenerative medicine is encountered, embodied, and made sense of within the lifeworld of patients.

Within the broader field of regenerative medicine, research focusing on patients' subjective experiences has increasingly been recognized as a crucial area of inquiry. As regenerative therapies move from experimental settings into clinical practice, attention has gradually shifted toward understanding how patients live through and interpret these interventions (Zhou et al., 2020). Studies grounded in phenomenology and medical humanities have demonstrated that experiences of illness, healing, and medical technology are not merely physiological events but are deeply embedded in individuals' perceptions of their bodies, identities, and futures (Obaid et al., 2021). In this context, exploring how patients experience scaffold-based and bioprinted tissue implantation has become particularly relevant, given the novelty and transformative nature of these interventions.

Despite this growing interest, investigating lived experiences in regenerative medicine presents significant methodological challenges. Much of the existing research relies on quantitative clinical indicators or standardized patient-reported outcome measures, which are limited in their ability to capture the depth, ambiguity, and evolving meanings of patients' experiences (Wang et al., 2022). Even when qualitative components are included, they are often embedded within mixed-method designs that prioritize breadth over depth, resulting in descriptive accounts that insufficiently engage with the experiential and interpretative dimensions of embodiment, temporality, and emotional response (Mukhlis, 2025). Consequently, nuanced aspects such as bodily alienation, uncertainty during healing, and the reconfiguration of personal identity following regenerative interventions remain underrepresented in the literature.

These methodological limitations have constrained the capacity of prior research to apprehend the essence of patients' experiences with regenerative technologies. Approaches that emphasize measurement, comparison, or predefined categories tend to fragment experience rather than illuminate its lived coherence (Barajaa et al., 2020). As a result, the complex ways in which patients make sense of bioprinted tissue implantation how they negotiate meaning, adapt psychologically, and integrate technological intervention into their sense of self are not yet fully understood (Li et al., 2020). This gap highlights the need for interpretative, experience-centered approaches capable of capturing the richness and depth of lived experience, thereby providing a more comprehensive understanding of regenerative medicine as both a biomedical and human phenomenon.

In the current landscape of regenerative medicine, responses to patient-related challenges associated with advanced tissue engineering interventions have predominantly relied on established practical approaches (Wu et al., 2020). These commonly include the use of clinical outcome

measures, standardized patient-reported outcome instruments, and follow-up protocols designed to monitor functional recovery and biomedical success. Such approaches are widely regarded as sufficient for evaluating therapeutic effectiveness and guiding clinical decision-making, particularly within evidence-based medical frameworks (Mukhlis & Abdullah, 2025). However, their primary focus remains on observable outcomes and predefined indicators, rather than on how patients themselves experience and interpret regenerative interventions within the context of their everyday lives.

While these practical solutions provide valuable information, they are inherently limited in their capacity to capture the depth and complexity of lived experience (Tang et al., 2021). Quantitative metrics and structured assessment tools tend to fragment experience into discrete variables, overlooking the ways in which bodily sensations, emotional responses, temporal perceptions, and identity-related meanings are intertwined. As a result, critical dimensions of patients' encounters with scaffold-based and bioprinted tissue implantation such as feelings of bodily alienation or integration, the experience of uncertainty during prolonged healing, and the existential implications of technologically mediated regeneration remain insufficiently understood (Laubach et al., 2022). Even qualitative elements incorporated into mixed-method designs often prioritize surface-level description over sustained interpretative engagement, limiting their explanatory depth.

These limitations point to a substantive gap in current knowledge: the absence of a holistic, experience-centered understanding of how patients live through and make sense of regenerative therapies. Addressing this gap requires an alternative methodological orientation capable of engaging with experience as it is lived, embodied, and interpreted (Cherry et al., 2021). Phenomenology offers such an approach by foregrounding meaning, context, and subjectivity, thereby enabling the exploration of the essential structures of experience that remain inaccessible through conventional evaluative frameworks (Mukhlis et al. 2025). By adopting a phenomenological perspective, it becomes possible to move beyond functional outcomes and toward a richer comprehension of regenerative medicine as a human experience, situated at the intersection of body, technology, and meaning.

Existing scholarship has increasingly examined patient experiences in contexts where medical technology profoundly alters bodily conditions and life trajectories. Phenomenological and medical humanities studies have shown that experiences of illness, healing, and technological intervention are shaped by embodiment, temporality, and meaning-making processes rather than by physiological change alone (Babilotte et al., 2021). Research on innovative therapies highlights how patients negotiate uncertainty, hope, and trust when outcomes are not fully predictable. However, within regenerative medicine, particularly scaffold-based and bioprinted tissue implantation, such experiential dimensions remain only partially explored (Serafin et al., 2022). This study builds on phenomenological insights into lived experience and extends them into the specific context of regenerative therapeutic interventions.

To directly address this identified gap, the present study employs an interpretative phenomenological approach to explore how patients experience and make sense of scaffold-based and 3D bioprinted tissue implantation. Rather than evaluating clinical outcomes, this study seeks to uncover the essential structures of lived experience, including embodiment, temporality, emotional ambivalence, and identity transformation. By doing so, it responds explicitly to the limitations of outcome-oriented research and contributes an experience-centered perspective that is currently underdeveloped in the regenerative medicine literature.

This article is structured to guide the reader through a coherent exploration of the phenomenon under study. The introduction situates regenerative medicine within its broader scientific and experiential context and articulates the rationale for a phenomenological inquiry. The methods section outlines the interpretative phenomenological design, participant selection, data collection procedures, and analytic approach. The results section presents the core experiential themes derived from participants' narratives. The discussion integrates these findings with existing literature, followed by a conclusion that highlights theoretical and practical implications for regenerative medicine.

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RESEARCH METHODS

Study Design

This study adopted a qualitative phenomenological design to explore the lived experiences of patients undergoing scaffold-based and bioprinted tissue implantation within the context of regenerative medicine (Kobbe et al., 2020). Phenomenology was selected as it is particularly suited to investigating how individuals experience, perceive, and ascribe meaning to complex health-related phenomena that cannot be adequately captured through quantitative measures alone. By focusing on subjective experience, this approach allows for an in-depth understanding of how regenerative therapies are embodied, emotionally processed, and integrated into patients' everyday lives.

An interpretative phenomenological approach was applied, drawing on Heideggerian phenomenology, which emphasizes meaning-making as situated, contextual, and interpretative (Parisi et al., 2020). This orientation is appropriate for examining regenerative interventions that are technologically advanced, clinically uncertain, and experientially rich, as it acknowledges that experiences are always interpreted through participants' prior histories, expectations, and social contexts. The design enabled a nuanced exploration of how patients understand their bodies, time, and identities during and after regenerative treatment.

To ensure that the study captured a broad range of lived experiences, the research design incorporated maximum variation principles within the phenomenological framework. Although IPA prioritizes idiographic depth, deliberate attention was given to sampling participants across different clinical backgrounds, types of tissue implantation, and stages of recovery in order to illuminate both convergent and divergent experiential patterns.

Participants

Participants consisted of individuals who had undergone scaffold-based or bioprinted tissue implantation as part of regenerative therapeutic interventions. A purposive sampling strategy was employed to ensure that participants had direct and meaningful experience with the phenomenon under investigation. Inclusion criteria comprised adults aged 18 years or older who had received bioprinted or scaffold-based tissue implantation within the previous 6 to 18 months and were medically stable at the time of data collection. Participants were required to have sufficient communicative ability to articulate their experiences in depth.

Exclusion criteria included individuals with acute post-operative complications requiring intensive clinical intervention, cognitive impairments that could limit reflective capacity, or concurrent participation in other qualitative studies addressing similar experiential domains. A total of 10 participants were included in the study, reflecting the idiographic focus of phenomenological inquiry. The sample included both male and female participants, with ages ranging from early adulthood to late middle age, providing a diverse experiential context relevant to the phenomenon.

Data Collection

Data were collected through in-depth, semi-structured interviews designed to elicit rich descriptions of participants' lived experiences before, during, and after tissue implantation. Interviews were conducted in three phases: pre-implantation, early post-implantation, and follow-up during bodily adaptation, allowing for a longitudinal understanding of experiential change over time. An interview guide was used to ensure consistency across interviews while maintaining flexibility to follow participants' narratives and emerging meanings.

Interviews were conducted in a quiet and private setting, either within a clinical consultation room or via a secure online platform, depending on participant preference and logistical considerations. Each interview lasted approximately 60–90 minutes and was audio-recorded with participants' consent. Efforts were made to create a supportive and non-intrusive environment to facilitate open reflection. Field notes were taken following each interview to capture contextual impressions and preliminary experiential insights.

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Data Analysis

Data analysis followed the principles of Interpretative Phenomenological Analysis (IPA), emphasizing detailed, systematic engagement with individual cases prior to cross-case synthesis. Audio recordings were transcribed verbatim, and transcripts were read repeatedly to achieve immersion in the data. Initial coding focused on identifying meaning units that captured significant aspects of participants' embodied, emotional, and temporal experiences.

Emergent themes were developed through an iterative process of clustering related meaning units within each case, followed by examination of convergences and divergences across cases. This idiographic-to-interpretative process enabled the identification of superordinate themes that reflected shared experiential structures while preserving individual nuance. Qualitative data management software (NVivo) was used to support data organization and coding, without substituting interpretative engagement. The analytical process culminated in the articulation of essential experiential themes grounded in participants' accounts.

Ethical approval for the study was obtained from the relevant institutional research ethics committee prior to data collection. All participants were provided with detailed information about the study objectives, procedures, potential risks, and their rights as participants. Written informed consent was obtained before participation.

Anonymity and confidentiality were ensured through the use of pseudonyms and the removal of identifying information from transcripts and reports. Audio files and transcripts were stored securely and accessed only for research purposes. The study was conducted in accordance with internationally recognized ethical standards for research involving human participants, including principles of respect, beneficence, and voluntary participation.

RESULTS

Encountering the Regenerated Body — Between Alienation and Embodiment

Participants described the post-implantation period as an initial encounter with a body that felt simultaneously familiar and unfamiliar. Many articulated a sense of bodily estrangement in the early stages of recovery, where the implanted tissue was perceived as "not fully mine yet," reflecting a tension between alienation and gradual embodiment.

One participant explained:

"At first, it didn't feel like part of me. It was there, but my body was still asking questions, as if trying to decide whether to accept it or not." (P3)

Over time, however, this sense of foreignness began to shift. As healing progressed, participants reported moments of reconciliation with their bodies, marked by increasing trust in the implanted tissue and renewed bodily confidence. The regenerated tissue was no longer experienced as an external intervention but became integrated into their bodily awareness.

"There was a moment when I stopped thinking about it as something implanted. It just became my body again, moving with me." (P7)

This theme highlights the embodied negotiation patients undergo, where the success of regenerative therapy is experienced not only biologically but also through a deeply personal process of bodily re-appropriation.

Reclaiming the Regenerated Body

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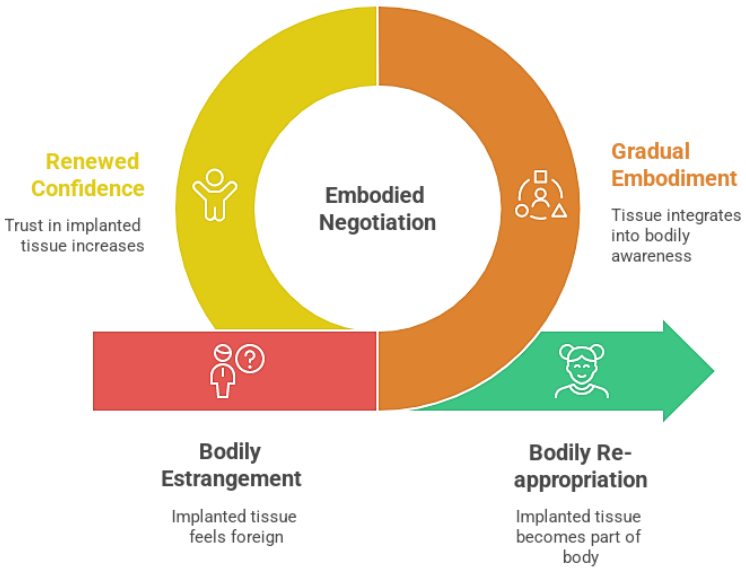

Living in Regenerative Time — Waiting, Uncertainty, and Temporal Stretching

Participants consistently described their recovery as unfolding within a distinct temporal experience characterized by waiting and uncertainty. Time was not perceived linearly but as stretched, suspended, or fragmented, particularly during periods of monitoring and healing assessment.

Several participants expressed that the waiting period intensified their awareness of time:

"Days felt longer than usual. Every small sensation made me wonder if healing was happening or if something was wrong." (P1)

This altered temporality was closely linked to the experimental nature of bioprinted tissue implantation. The absence of clear benchmarks or predictable recovery timelines amplified feelings of uncertainty, making participants more attuned to bodily sensations and clinical feedback.

"You're constantly measuring time against your body asking, 'Is this normal now?' There's no clear answer." (P5)

Despite this uncertainty, some participants reframed waiting as an active process of hope, where time became a space for cautious optimism rather than passive delay.

Emotional Landscapes — Navigating Hope, Fear, and Trust in Technology

The emotional experiences of participants were marked by a dynamic interplay between hope and fear. Hope was often articulated in relation to the promise of regenerative medicine and the possibility of bodily restoration, while fear stemmed from concerns about rejection, failure, or unforeseen consequences.

One participant shared:

"I placed a lot of hope in this technology, but at the same time, I was scared—scared of being disappointed, scared of complications." (P4)

Trust in medical technology and healthcare professionals played a critical role in mediating these emotions. Participants who reported strong communicative relationships with clinicians expressed greater emotional stability and confidence throughout the recovery process.

"Knowing that the doctors were closely monitoring me made it easier to trust the process, even when I was anxious." (P9)

This theme underscores how emotional experiences are not isolated psychological states but are embedded within relational and technological contexts.

Meaning-Making and Identity — Reconstructing the Self After Regeneration

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Beyond physical recovery, participants engaged in reflective meaning-making processes that reshaped their sense of self and bodily identity. Regenerative therapy prompted participants to reconsider what it meant to have a "natural" body, challenging conventional distinctions between biological and technological embodiment.

Some participants described feeling transformed by the experience:

"It made me think differently about my body—not just as something natural, but as something that can be rebuilt." (P2)

For others, the intervention fostered a renewed appreciation for bodily resilience and adaptability, reinforcing a sense of agency and gratitude.

"I feel like my body has been given a second chance, and that changes how I see myself." (P6)

These reflections reveal how regenerative medicine extends beyond physical repair, influencing identity reconstruction and existential self-understanding.

Collectively, these findings reveal that scaffold-based and bioprinted tissue implantation is experienced as a multidimensional phenomenon encompassing bodily negotiation, altered temporality, emotional ambivalence, and profound meaning-making. Participants' experiences demonstrate that the success of regenerative therapy is not solely defined by clinical outcomes but is deeply rooted in how patients live through, interpret, and integrate the intervention into their embodied and existential lives.

DISCUSSION

Summary of Key Findings

This phenomenological study reveals that patients' experiences of scaffold-based and bioprinted tissue implantation are shaped by embodied negotiation, altered perceptions of time, emotional ambivalence, and ongoing processes of meaning-making (Barros et al., 2020). These findings directly address the central concern raised in the Introduction by demonstrating that regenerative therapies are lived not only as biomedical interventions but as complex, experiential phenomena that reshape how patients relate to their bodies, futures, and identities.

Contribution of the Findings to the Research Questions

The findings offer a substantive response to the overarching research questions by illuminating how patients experience and interpret regenerative interventions beyond measurable clinical outcomes (W. Zhang et al., 2021). First, the study shows that bodily experience following implantation is not immediate integration but an ongoing process marked by tension between alienation and embodiment. This insight advances understanding of how patients come to "inhabit" regenerated tissue over time, revealing that bodily acceptance is experiential and interpretative rather than purely physiological (Mukhlis, Janwari, et al., 2023). Second, the findings demonstrate that regenerative recovery unfolds within a distinctive temporal horizon, where uncertainty and waiting become central dimensions of experience. This temporal disruption explains why patients often experience recovery as emotionally demanding, even when clinical indicators suggest progress.

Furthermore, the study clarifies how emotional responses such as hope, fear, and trust are not isolated psychological states but are embedded in patients' relationships with medical technology and clinical care (Campos et al., 2020). By highlighting the role of trust in mediating emotional stability, the findings contribute a nuanced account of how experiential factors influence patients' engagement with regenerative therapy. Finally, the analysis shows that regenerative interventions prompt reflective processes through which patients reconstruct personal meaning and bodily identity (Radhakrishnan et al., 2021). This contribution is particularly significant, as it demonstrates that regenerative medicine affects not only bodily function but also how individuals understand themselves as embodied beings, thereby extending the scope of inquiry from clinical success to existential adaptation.

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Relation to Existing Literature and Theory

The findings resonate strongly with phenomenological accounts of embodiment in healthcare, particularly the concept of the lived body articulated by Zhai et al. (2020), which emphasizes that bodily change is experienced as a transformation of one's mode of being-in-the-world rather than as a purely biological event. Participants' descriptions of initial bodily alienation followed by gradual integration align with phenomenological analyses of medical technology that frame technological intervention as both enabling and disruptive to embodied experience (Mukhlis, 2025a). In this sense, the present findings extend existing theory by situating these dynamics within the specific context of regenerative and bioprinted tissue implantation, a domain characterized by heightened uncertainty and technological novelty.

The altered experience of time identified in this study also complements prior phenomenological work on illness temporality, which has shown that recovery often involves temporal distortion, anticipation, and waiting (Mazzoni et al., 2020). However, this study adds depth by illustrating how such temporal experiences are intensified in regenerative contexts, where healing trajectories are less predictable and outcomes remain provisional. Similarly, the emotional ambivalence described by participants echoes findings from studies on experimental medicine, which highlight the coexistence of hope and anxiety in technologically innovative treatments (Mukhlis, Arifin, Ridwan, Zulbaidah, et al., 2025). By integrating these emotional dynamics with embodied and temporal experiences, the present study contributes a more holistic understanding of regenerative therapy as a lived phenomenon.

Together, these connections demonstrate that the findings do not merely replicate existing knowledge but enrich it by offering a context-specific phenomenological account of regenerative medicine (Russell et al., 2020). The study thus complements biomedical and ethical discussions in the field by foregrounding patient experience as a central dimension of understanding and evaluating regenerative interventions.

Implications of the Findings

The findings of this study carry important scientific and practical implications for regenerative medicine and patient-centered healthcare (Meamar et al., 2021). By revealing how patients experience scaffold-based and bioprinted tissue implantation as an embodied, temporal, and meaning-laden process, the study underscores the need to consider experiential dimensions alongside biological outcomes when evaluating therapeutic success. These insights suggest that clinical effectiveness cannot be fully understood without attending to how patients gradually integrate regenerated tissue into their bodily awareness and everyday lives (Mukhlis, Maryam, et al., 2023). From a professional perspective, the findings highlight the significance of communication, trust, and relational care in supporting patients as they navigate uncertainty and emotional ambivalence during regenerative treatment.

At a broader level, the study contributes to social and cultural understandings of how emerging medical technologies are lived and interpreted by those who encounter them directly (Huang et al., 2022). Regenerative medicine, as shown in participants' accounts, challenges conventional notions of bodily integrity and naturalness, prompting patients to renegotiate their identities in relation to technologically mediated healing. Recognizing these experiences has implications for clinical practice, policy, and education, particularly in preparing healthcare professionals to engage with patients' concerns, expectations, and reflective meaning-making processes (Mukhlis et al., 2024). Although grounded in a specific clinical context, these findings are relevant to wider populations undergoing innovative or experimental medical interventions, where similar experiential dynamics of hope, uncertainty, and adaptation are likely to arise.

Limitations of the Study

Several limitations should be acknowledged when interpreting the findings of this study. As a phenomenological inquiry with a relatively small, purposively selected sample, the findings are not intended to be statistically generalizable to all patients undergoing regenerative therapies (Yang et al.,

2021). The study focused on individuals who were willing and able to articulate their experiences in depth, which may have limited the inclusion of perspectives from patients with different communicative capacities or more acute clinical conditions. Additionally, the contextual specificity of scaffold-based and bioprinted tissue implantation within particular clinical settings may have shaped participants' experiences in ways that differ from other regenerative or biomedical interventions.

Methodologically, the interpretative nature of phenomenological analysis involves an inherent degree of subjectivity, as meanings are co-constructed through engagement with participants' narratives (Zhao et al., 2020). While strategies such as reflexive analysis and engagement with existing literature were used to enhance rigor, alternative interpretations of the data remain possible (Wu et al., 2021). These limitations should be understood not as weaknesses but as characteristics of qualitative, experience-centered research, which prioritize depth and contextual understanding over breadth.

Prospective Directions for Future Research

The findings of this study open several avenues for future research in regenerative medicine and related fields. Further phenomenological studies could explore experiences across different types of regenerative interventions, clinical conditions, or cultural contexts to deepen understanding of how meaning-making and embodiment vary across settings (Chen et al., 2020). Longitudinal research extending beyond the early and mid-stages of recovery may also provide insight into how experiences of regenerated tissue evolve over longer periods of time and how they influence long-term adaptation and quality of life.

In addition, future research could integrate phenomenological insights with complementary qualitative or ethically informed approaches to inform the design of patient-centered clinical pathways in regenerative medicine. By building on the experiential structures identified in this study, subsequent research may contribute to more holistic frameworks for evaluating innovative medical technologies, bridging biomedical innovation with human experience. Such efforts have the potential to enrich both theoretical understanding and practical application within the evolving landscape of regenerative healthcare.

CONCLUSION

This study examined the lived experiences of patients undergoing scaffold-based and bioprinted tissue implantation within the context of regenerative medicine, addressing the need to understand how such interventions are meaningfully experienced beyond clinical outcomes. The findings demonstrate that regenerative therapy is lived as a process of embodied negotiation, altered temporality, emotional ambivalence, and ongoing meaning-making. By foregrounding patients' subjective experiences, this study responds to limitations in prior research that has largely emphasized biological performance and functional indicators. The results contribute a phenomenological understanding that situates regenerative medicine as both a biomedical and human practice. Importantly, these findings have direct implications for clinical practice. First, pre-implantation counseling protocols may benefit from incorporating discussions not only about procedural risks and expected functional outcomes, but also about potential embodied and emotional experiences, including feelings of bodily alienation, uncertainty, and identity adjustment. Second, post-operative follow-up models could integrate structured reflective conversations or patient-centered narrative assessments to support psychological adaptation alongside physiological recovery. Third, interdisciplinary collaboration between surgeons, rehabilitation specialists, and psychosocial care providers may enhance patient support by recognizing regenerative implantation as an existential as well as a biological transition. This perspective enhances patient-centered approaches by highlighting the importance of experiential dimensions in shaping engagement, adaptation, and perceived success of therapy. In practical terms, incorporating phenomenologically informed insights into clinical guidelines may improve patient trust, long-term adherence to rehabilitation, and overall satisfaction with scaffold-based and bioprinted regenerative interventions. Future studies may extend this work by exploring diverse regenerative contexts, longer recovery trajectories, or cross-cultural experiences using phenomenological or complementary qualitative approaches. Further research is particularly

needed to (1) compare experiential patterns across different clinical conditions and implantation sites, (2) investigate long-term identity reconstruction beyond the first year post-implantation, (3) examine clinician–patient communication dynamics in technology-intensive regenerative care, and (4) integrate qualitative findings with longitudinal clinical data to develop more holistic evaluative frameworks. Additionally, multi-site or international studies could illuminate how cultural beliefs about the body and technology influence adaptation to scaffold-based and 3D bioprinted tissue implantation.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

REFERENCES

Babilotte, J., Martin, B., Gudurić, V., Bareille, R., Agniel, R., Roques, S., Héroguez, V., Dussauze, M., Gaudon, M., Le Nihouannen, D., & Catros, S. (2021). Development and characterization of a PLGA-HA composite material to fabricate 3D-printed scaffolds for bone tissue engineering. *Materials Science and Engineering C*, *118*. Scopus. https://doi.org/10.1016/j.msec.2020.111334

Barajaa, M. A., Nair, L. S., & Laurencin, C. T. (2020). Bioinspired Scaffold Designs for Regenerating Musculoskeletal Tissue Interfaces. *Regenerative Engineering and Translational Medicine*, *6*(4), 451–483. Scopus. https://doi.org/10.1007/s40883-019-00132-3

Barros, J. A. R., Melo, L. D. R. D., Araújo, R. A. R. D., Ferraz, M. P., Azeredo, J. C. V. D. R., Pinheiro, V. M. D. C., Colaço, B. J. A., Fernandes, M. H. R., Sousa Gomes, P. D. S., & Monteiro, F. J. (2020). Encapsulated bacteriophages in alginate-nanohydroxyapatite hydrogel as a novel delivery system to prevent orthopedic implant-associated infections. *Nanomedicine: Nanotechnology, Biology, and Medicine*, *24*. Scopus. https://doi.org/10.1016/j.nano.2019.102145

Campos, F., Bonhome-Espinosa, A. B., Chato-Astrain, J., Sánchez-Porras, D., Garciá-Garciá, Ó. D., Carmona, R., Lopez-Lopez, M. T., Alaminos, M., Carriel Araya, V., & Rodríguez, I. A. (2020). Evaluation of Fibrin-Agarose Tissue-Like Hydrogels Biocompatibility for Tissue Engineering Applications. *Frontiers in Bioengineering and Biotechnology*, *8*. Scopus. https://doi.org/10.3389/fbioe.2020.00596

Chen, S., Shi, Y., Zhang, X., & Ma, J. (2020). Evaluation of BMP-2 and VEGF loaded 3D printed hydroxyapatite composite scaffolds with enhanced osteogenic capacity in vitro and in vivo. *Materials Science and Engineering C*, *112*. Scopus. https://doi.org/10.1016/j.msec.2020.110893

Cherry, C., Maestas, D. R., Han, J., Andorko, J. I., Cahan, P., Fertig, E. J., Garmire, L. X., & Elisseeff, J. H. (2021). Computational reconstruction of the signalling networks surrounding implanted biomaterials from single-cell transcriptomics. *Nature Biomedical Engineering*, *5*(10), 1228–1238. Scopus. https://doi.org/10.1038/s41551-021-00770-5

Huang, B., Li, P., Chen, M., Peng, L., Luo, X., Tian, G., Wang, H., Wu, L., Tian, Q., Li, H., Yang, Y., Jiang, S., Yang, Z., Zha, K., Sui, X., Liu, S., & Guo, Q. (2022). Hydrogel composite scaffolds achieve recruitment and chondrogenesis in cartilage tissue engineering applications. *Journal of Nanobiotechnology*, *20*(1). Scopus. https://doi.org/10.1186/s12951-021-01230-7

Kobbe, P., Laubach, M., Hutmacher, D. W., Alabdulrahman, H., Sellei, R. M., & Hildebrand, F. (2020). Convergence of scaffold-guided bone regeneration and RIA bone grafting for the treatment of a critical-sized bone defect of the femoral shaft. *European Journal of Medical Research*, *25*(1). Scopus. https://doi.org/10.1186/s40001-020-00471-w

.

Korn, P., Ahlfeld, T., Lahmeyer, F., Kilian, D., Sembdner, P., Stelzer, R., Pradel, W., Franke, A., Rauner, M., Range, U., Stadlinger, B., Lode, A., Lauer, G., & Gelinsky, M. (2020). 3D Printing of Bone Grafts for Cleft Alveolar Osteoplasty – In vivo Evaluation in a Preclinical Model. *Frontiers in Bioengineering and Biotechnology*, *8*. Scopus. https://doi.org/10.3389/fbioe.2020.00217

Laubach, M., Suresh, S., Herath, B., Wille, M.-L., Delbrück, H., Alabdulrahman, H., Hutmacher, D. W., & Hildebrand, F. (2022). Clinical translation of a patient-specific scaffold-guided bone regeneration concept in four cases with large long bone defects. *Journal of Orthopaedic Translation*, *34*, 73–84. Scopus. https://doi.org/10.1016/j.jot.2022.04.004

Li, Z., Wu, N., Cheng, J., Sun, M., Yang, P., Zhao, F., Zhang, J., Duan, X., Fu, X., Zhang, J., Hu, X., Chen, H., & Ao, Y. (2020). Biomechanically, structurally and functionally meticulously tailored polycaprolactone/silk fibroin scaffold for meniscus regeneration. *Theranostics*, *10*(11), 5090–5106. Scopus. https://doi.org/10.7150/thno.44270

Mazzoni, E., D'Agostino, A., Iaquinta, M. R., Bononi, I., Trevisiol, L., Rotondo, J. C., Patergnani, S., Giorgi, C., Gunson, M. J., Arnett, G. W., Nocini, P. F., Tognon, M., & Martini, F. (2020). Hydroxylapatite-collagen hybrid scaffold induces human adipose-derived mesenchymal stem cells to osteogenic differentiation in vitro and bone regrowth in patients. *Stem Cells Translational Medicine*, *9*(3), 377–388. Scopus. https://doi.org/10.1002/sctm.19-0170

Meamar, R., Ghasemi-Mobarakeh, L., Norouzi, M.-R., Siavash Dastjerdi, M., Hamblin, M. R., & Fesharaki, M. (2021). Improved wound healing of diabetic foot ulcers using human placenta-derived mesenchymal stem cells in gelatin electrospun nanofibrous scaffolds plus a platelet-rich plasma gel: A randomized clinical trial. *International Immunopharmacology*, *101*. Scopus. https://doi.org/10.1016/j.intimp.2021.108282

Mukhlis, L. (2025a). A Phenomenological Study of Personal Spiritual Experiences in Navigating Religious Pluralism within Interfaith Communities. *Irfana: Journal of Religious Studies*, *1*(6), 212–220.

Mukhlis, L. (2025b). Spiritual Grounds for Economic Growth: A Qualitative Exploration of Rural Indonesian Women's Transformative Journeys Through Mosque-Led Empowerment Programs. *Servina: Jurnal Pengabdian Kepada Masyarakat*, *1*(8), 289–298.

Mukhlis, L., & Abdullah, M. N. (2025). *Hukum Keluarga Islam di Indonesia* (1st ed.). Mukhlisina Revolution Center.

Mukhlis, L., Arifin, T., Ridwan, A. H., & Zulbaidah. (2024). Integrating Artificial Intelligenceand Maqāṣid al-Syarī'ah: Revolutionizing Indonesia's Sharia Online Trading System. *Computer Fraud and Security*, *2024*(11), 301–309. https://doi.org/10.52710/cfs.238

Mukhlis, L., Arifin, T., Ridwan, A. H., & Zulbaidah. (2025). Reorientation of Sharia Stock Regulations: Integrating Taṣarrufāt al-Rasūl and Maqāṣid al-Sharī'ah for Justice and Sustainability. *Journal of Information Systems Engineering and Management*, *10*(10s), 58–66. https://doi.org/10.52783/jisem.v10i10s.1341

Mukhlis, L., Arifin, T., Ridwan, A. H., Zulbaidah, Rosadi, A., & Solehudin, E. (2025). Reformulation of Islamic Stock Law: The Application of Taṣarrufāt al-Rasūl and Maqāṣid al-Syarī'ahto Develop a Dynamic and Sustainable Islamic Capital Market in Indonesia. *Journal of Posthumanism*, *5*(3), 1–13. https://doi.org/10.63332/joph.v5i3.913

Mukhlis, L., Janwari, Y., & Syafe`i, R. (2023). INDONESIA STOCK EXCHANGE: THEORETICAL AND PHILOSOPHICAL ANALYSIS OF MUDHARABAH AND MUSYARAKAH CONTRACTS. *Yurisprudentia: Jurnal Hukum Ekonomi*, *9*(2), 243–264. https://doi.org/10.24952/yurisprudentia.v9i2.8466

`

Mukhlis, L., Maryam, S., & Sormin, S. A. (2023). Model Pembelajaran Living History Berbasis PjBL Untuk Meningkatkan Keterampilan Histografi Mahasiswa. *Jurnal Educatio FKIP UNMA*, *9*(4), 1800–1809. https://doi.org/10.31949/educatio.v9i4.5595

Mukhlis, L., & Saidah, Y. (2025). Dynamics of Nature-Based learning in Developing Children's Motoricic Skills: Teacher and Parent Perspectives. *HUMANISMA: Journal of Gender Studies*, *9*(1), 64–79. http://dx.doi.org/10.30983/humanisme.v4i2.9366

Mukhlis, L., Suradi, Janwari, Y., & Syafe`i, R. (2023). Sosialisasi Saham Syariah sebagai Instrumen Pengembangan Ekonomi Masyarakat di Badan Kontak Majelis Taklim (BKMT) Kabupaten Mandailing Natal. *Jurnal Pengabdian Multidisiplin*, *3*(2), 2–9. https://doi.org/10.51214/japamul.v3i2.604

Obaid, M. L., Camacho, J. P., Brenet, M., Corrales-Orovio, R., Carvajal, F., Martorell, X., Werner, C., Simon, V., Varas, J., Calderón, W., Guzman, C. D., Bono, M. R., San Martín, S., Eblen-Zajjur, A., & Egaña, J. T. (2021). A First in Human Trial Implanting Microalgae Shows Safety of Photosynthetic Therapy for the Effective Treatment of Full Thickness Skin Wounds. *Frontiers in Medicine*, *8*. Scopus. https://doi.org/10.3389/fmed.2021.772324

Parisi, C., Salvatore, L., Veschini, L., Serra, M. P., Hobbs, C., Madaghiele, M., Sannino, A., & Di Silvio, L. (2020). Biomimetic gradient scaffold of collagen–hydroxyapatite for osteochondral regeneration. *Journal of Tissue Engineering*, *11*. Scopus. https://doi.org/10.1177/2041731419896068

Radhakrishnan, S., Nagarajan, S., Belaid, H., Farha, C., Iatsunskyi, I., Coy, E., Soussan, L., Huon, V., Barés, J., Belkacemi, K., Teyssier, C., Balme, S., Miele, P., Cornu, D., Kalkura, N., Cavaillés, V., & Bechelany, M. (2021). Fabrication of 3D printed antimicrobial polycaprolactone scaffolds for tissue engineering applications. *Materials Science and Engineering C*, *118*. Scopus. https://doi.org/10.1016/j.msec.2020.111525

Russell, C. S., Mostafavi, A., Quint, J. P., Panayi, A. C., Baldino, K., Williams, T. J., Daubendiek, J. G., Sánchez-Rodríguez, V., Bonick, Z., Trujillo-Miranda, M., Shin, S. R., Pourquié, O., Salehi, S., Sinha, I., & Tamayol, A. (2020). In Situ Printing of Adhesive Hydrogel Scaffolds for the Treatment of Skeletal Muscle Injuries. *ACS Applied Bio Materials*, *3*(3), 1568–1579. Scopus. https://doi.org/10.1021/acsabm.9b01176

Serafin, A., Culebras, M. C., Carsí, M., Ortiz-Serna, P., Sanchís, M. J., Garg, A. K., Oliveira, J. M., Koffler, J., & Collins, M. N. (2022). Electroconductive PEDOT nanoparticle integrated scaffolds for spinal cord tissue repair. *Biomaterials Research*, *26*(1). Scopus. https://doi.org/10.1186/s40824-022-00310-5

Shi, X., Cheng, Y., Wang, J., Chen, H., Wang, X., Li, X., Tan, W., & Tan, Z. (2020). 3D printed intelligent scaffold prevents recurrence and distal metastasis of breast cancer. *Theranostics*, *10*(23), 10652–10664. Scopus. https://doi.org/10.7150/thno.47933

Tang, P., Song, P., Peng, Z., Zhang, B., Gui, X., Wang, Y., Liao, X., Chen, Z., Zhang, Z., Fan, Y., Li, Z., Cen, Y., & Zhou, C. (2021). Chondrocyte-laden GelMA hydrogel combined with 3D printed PLA scaffolds for auricle regeneration. *Materials Science and Engineering C*, *130*. Scopus. https://doi.org/10.1016/j.msec.2021.112423

Wang, W., Xiong, Y., Zhao, R., Li, X., & Jia, W. (2022). A novel hierarchical biofunctionalized 3D-printed porous Ti6Al4V scaffold with enhanced osteoporotic osseointegration through osteoimmunomodulation. *Journal of Nanobiotechnology*, *20*(1). Scopus. https://doi.org/10.1186/s12951-022-01277-0

Wu, Z., Meng, Z., Wu, Q., Zeng, D., Guo, Z., Yao, J., Bian, Y., Gu, Y., Cheng, S., Peng, L., & Zhao, Y. (2020). Biomimetic and osteogenic 3D silk fibroin composite scaffolds with nano MgO and mineralized hydroxyapatite for bone regeneration. *Journal of Tissue Engineering*, *11*. Scopus. https://doi.org/10.1177/2041731420967791

.

Wu, Z., Xie, S., Kang, Y., Shan, X., Li, Q., & Cai, Z. (2021). Biocompatibility evaluation of a 3D-bioprinted alginate-GelMA-bacteria nanocellulose (BNC) scaffold laden with oriented-growth RSC96 cells. *Materials Science and Engineering C*, *129*. Scopus. https://doi.org/10.1016/j.msec.2021.112393

Yang, C., Ma, H., Wang, Z., Younis, M. R., Liu, C., Wu, C., Luo, Y., & Huang, P. (2021). 3D Printed Wesselsite Nanosheets Functionalized Scaffold Facilitates NIR-II Photothermal Therapy and Vascularized Bone Regeneration. *Advanced Science*, *8*(20). Scopus. https://doi.org/10.1002/advs.202100894

Zhai, M., Zhu, Y., Yang, M., & Mao, C. (2020). Human Mesenchymal Stem Cell Derived Exosomes Enhance Cell-Free Bone Regeneration by Altering Their miRNAs Profiles. *Advanced Science*, *7*(19). Scopus. https://doi.org/10.1002/advs.202001334

Zhang, W., Zhang, Y., Zhang, A., Ling, C., Sheng, R., Li, X., Yao, Q., & Chen, J. (2021). Enzymatically crosslinked silk-nanosilicate reinforced hydrogel with dual-lineage bioactivity for osteochondral tissue engineering. *Materials Science and Engineering C*, *127*. Scopus. https://doi.org/10.1016/j.msec.2021.112215

Zhang, Y., Lin, T., Meng, H., Wang, X., Peng, H., Liu, G., Wei, S., Lu, Q., Wang, Y., Wang, A., Xu, W., Shao, H., & Peng, J. (2022). 3D gel-printed porous magnesium scaffold coated with dibasic calcium phosphate dihydrate for bone repair in vivo. *Journal of Orthopaedic Translation*, *33*, 13–23. Scopus. https://doi.org/10.1016/j.jot.2021.11.005

Zhao, R., Chen, S., Zhao, W., Yang, L., Yuan, B., Ioan, V. S., Antoniac, A. V., Yang, X., Zhu, X., & Zhang, X. (2020). A bioceramic scaffold composed of strontium-doped three-dimensional hydroxyapatite whiskers for enhanced bone regeneration in osteoporotic defects. *Theranostics*, *10*(4), 1572–1589. Scopus. https://doi.org/10.7150/thno.40103

Zhou, L. N., Wang, J. C., Zilundu, P. L. M., Wang, Y. Q., Guo, W. P., Zhang, S. X., Luo, H., Zhou, J. H., Deng, R. D., & Chen, D. F. (2020). A comparison of the use of adipose-derived and bone marrow-derived stem cells for peripheral nerve regeneration in vitro and in vivo. *Stem Cell Research and Therapy*, *11*(1). Scopus. https://doi.org/10.1186/s13287-020-01661-3

Zhu, S., Chen, P., Chen, Y., Li, M., Chen, C., & Lu, H. (2020). 3D-Printed Extracellular Matrix/Polyethylene Glycol Diacrylate Hydrogel Incorporating the Anti-inflammatory Phytomolecule Honokiol for Regeneration of Osteochondral Defects. *American Journal of Sports Medicine*, *48*(11), 2808–2818. Scopus. https://doi.org/10.1177/0363546520941842