Implementation of triply periodic minimal surface (TPMS) structure in mesenchymal stem cell differentiation.

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Method Article

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Abstract

Tissue engineers have recently been interested in triply periodic minimum surfaces (TPMSs) for use in creating biomimetic porous scaffolds. Improved cell attachment, migration, and proliferation may be achieved with TPMS scaffolds because of its many benefits, such as a high volume to surface area ratio, reduced stress concentration, and enhanced permeability compared to conventional lattice architectures. Some of the crucial tissue-specific parameters, such permeability, Elastic modulus, and pore size, have been considered by the designers of various TPMS scaffolds described in the literature. These days, triply periodic minimum surface (TPMS) is seen as a leading option for building porous structures due to its smooth edges, fully integrated porous architectures, and mathematically adjustable geometry. Many benefits of TPMS, however, are not being properly used in ongoing studies. This study suggests the future direction of the TMPS in the perspective of the mesenchymal stem cell differentiation to overcome many shortcoming which was faced by the researchers.

Introduction

A new area of biomedical engineering is tissue engineering. In tissue engineering, scientists work to develop biodegradable materials with the desired morphology, in which cells may be seeded and then, after a period, the resulting tissue can be transplanted into a patient [1].

Geometrically triply periodic minimum surfaces (TPMS) are three-dimensional structures with smooth surfaces and reduced limited area. It splits the area in half, creating two nested complex zones whose combined curvatures are zero everywhere on the surface. Under specific boundary circumstances, its area is at its smallest [2]. Because an increase in area necessitates more surface energy, such a surface often happens and TPMS has a propensity to keep its minimum energy in nature. The following are some of the primary distinguishing features of such assembly [3]: (1) Biomimetic designs: These structures are widely employed as biomimetic frameworks for biomedical reasons, and they are often seen in living organisms in nature, such as weevils, butterfly wings, and beetle shells [4]. These structures have cubic symmetry and retain the benefits of low density, high strength, and large specific surface area; (2) Long-Range Order Mathematical modelling using implicit equations may be used to produce TPMS, which is the mathematical definition of TPMS [5, 6]. The qualities of biomaterials may be considerably improved when TPMS is used in their development and production [7]. As a result, we have employed TPMS solid as scaffold architectures and discovered their promising future in tissue engineering. The smooth bending qualities of the TPMS surface with optimal fluid permeability make TPMS-based topologies a more adaptable source than the recently described biomorphic scaffold designs, offering a suitable environment for the healing & regeneration of injured tissue cells. As a result, the geometric properties of TPMS hold considerable promise in the adaptable development of structural systems [8, 9, 10]. The steady progress of AM technology has resulted in the availability of a high-precision technique for producing TPMS porous supports [11, 12].

Surfaces with zero mean curvature are known as minimal surfaces. Tissue engineering specialists have currently been interested in triply periodic minimum surfaces (TPMS) for the creation of bio-inspired porous scaffolds. TPMS-based scaffolds have a relatively high surface area per unit volume in comparison to traditional lattice scaffolds [13]. The greater surface area promotes improved cell adhesion, motility, and proliferation as well as many biological and physiological processes, including ion exchange, diffusion of gases, and nutrient transport enhanced [14]. TPMS scaffolds with high surface-to-volume ratio could give the suitable environment to cells for growth on their surface [15]. In addition, compared to scaffolds with regular lattice structures, the smooth surface with smooth connections reduced stress concentration and improve mechanical characteristics[16].

The human body relies on adult stem cells to maintain homeostasis and repair itself when necessary [17]. Most tissues and organs have been shown to contain adult stem cells, and these cells have been shown to possess both multipotent differentiation potential and the ability to regenerate. By quickly replacing damaged cells, adult stem cells keep tissues functioning normally [18]. Tissues benefit from these rejuvenating degeneration and regeneration cycles, which also aid in the maintenance of tissue functions. Adult stem cells, including progenitor cells & mesenchymal stem cells (MSCs), may be found in abundance in the bone marrow (MSCs). These later cells, known as plastic adhering nonhematopoietic stem cells, aid in the repair of skeletal muscle and other damaged tissues [18]. The ability of MSCs isolated from bone marrow to differentiate into cartilage and bone, as well as their utility in regenerative medicine, are the topics of this article. MSCs can differentiate into a variety of connective tissues, including bone, cartilage, adipose tissue, and tendons [19, 20].

Adult fibroblastoid multipotent stem cells having a high ability for self-renewal and differentiation are known as mesenchymal stem cells (MSCs). These cells have been extracted from a variety of human tissues, including as lung, bone marrow, adipocytes, the matrix of the umbilical cord, and tendon [21]. Stem cells are essential to tissue engineering of continually self-renewing tissues, such as skin and bone marrow, despite the numerous difficulties and ethical dilemmas associated with their usage[22]. Due to their multipotency, stem cells have tremendous promise for treating a variety of human disorders. In addition to biochemical signals, the microenvironment's biophysical features, such as mechanical stress, substrate material properties, and cell shape control stem cell retention and differentiation. Extracellular matrix stiffness, which has major influence on stem cell self-renewal & commitment, is becoming more and more inspiringly understood because of the development of biomimetic substrate [23, 24]. Typically, stem cell differentiation is improved by ECM stiffness phenomenon, which is like the rigidity of native tissue. Genetic makeup and the selection of stem cell destiny are impacted by a complex and linked network of interaction between various signals that are brought by matrix rigidity[25].

Proposed Method

In this study, we can connect different angles of methods to improve the mesenchyme cell differentiation by using TPMS scaffold sheets as substrate. So, we employ TPMS to build thin-walled scaffolds called TPMS sheet scaffolds, where TPMS is reinforced and given a solid substance. TPMS structures are

frequently approximated using the implicit technique, which depicts surfaces via nodal equations and associated zero-valued surfaces. Investigating the structure-property connections for TPMS scaffolds was done using FE analysis. The scaffolds' Young's modulus calculated using the commercial FE program Abaqus/Standard. Because TPMS sheet scaffolds are made up of thin-walled structures, they were modeled utilizing a 3D linear triangular finite element model. Geometric linearity and an elastic range material were considered during the simulation[26].

To influence stem cell development into various lineages, a TPMS scaffold with varying stiffness will created using the suggested technique. It is well-known from literature that a certain matrix stiffness encourages stem mesenchyme cells to differentiate into a particular lineage. For mesenchymal, neuropathic, myogenic, and osteogenic development, the ideal stiffness ranges are 10–50 Pa, 0.11–1 kPa, 7–17 kPa, and 25–40 kPa, respectively[27].

Using these all techniques we can successfully make a substrate which give every possible enhanced environment to MSCs stem cells to differentiate. In this way we can improve the differentiation of the mesenchyme stem cell using TPMS as substrate and whole preview of the method is shown in figure [1].

Conclusion

Considering that transplant rejection by the recipient may be a limiting step in bringing stem cell-based treatments from "bedside to bedside," the growing body of information suggesting that MSCs are suppressive made them an even more intriguing alternative for regenerative medicine. The capacity of MSCs to differentiate is largely responsible for their therapeutic promise. Multiple instructive cues from the microenvironment, which includes numerous biological substances (soluble and insoluble) & biomechanical factors, control MSC destiny and commitment. The success of MSC development and their involvement to the healing process are highly dependent on these biophysical and biochemical parameters.

In the proposed method we are confident that according to this method we can improve the differentiation of the mesenchyme stem cell differentiation and gives suitable environment to improve the factors which enhance the differentiation. In Future TMPS is promising candidate for the differentiation platform which is under consideration for substrate.

Declarations

Availability of data and material: All data is provided with in the paper

Conflict of Interest: Author has no conflict of interest

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Figures

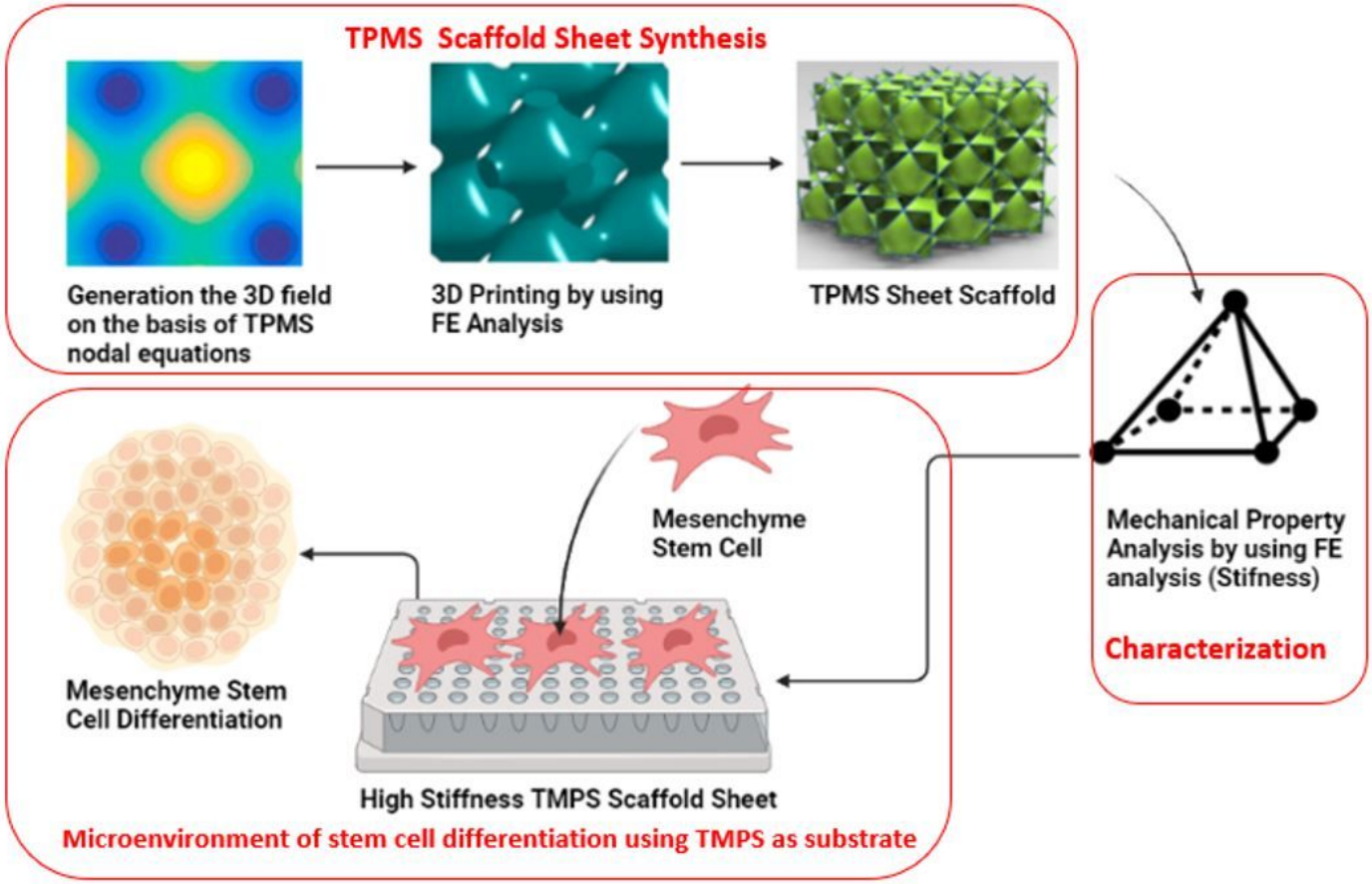

Figure 1

Mechanism of TMPS in Mesenchyme stem cell differentiation