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Time-resolved multifractal analysis of bioresorbable scaffolds based on piezoelectric fiber materials

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Introduction

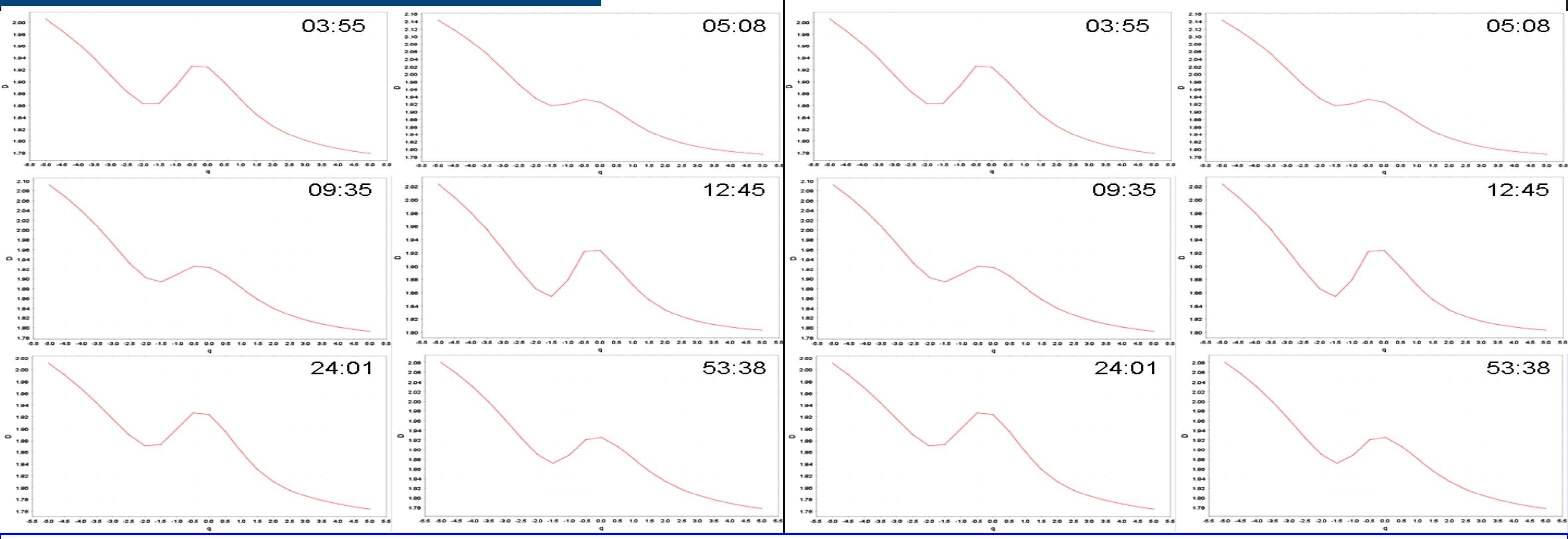
1. **The porosity of fibrillar scaffolds plays a pivotal role in the regeneration of living tissue, significantly influencing cell spreading, proliferation, and differentiation, thereby impacting the overall efficiency of regenerative processes. A genuine fibrillar scaffold comprises fibers and pores of diverse sizes and scales.**
2. **The interconnectivity of the fiber network is intrinsically linked to its mechanical properties. When the scaffold material exhibits piezoelectric characteristics, the application of an electric field to enhance regeneration induces microelectromechanical (MEMS) movement among the fibers, both in relation to one another and in alignment with the applied field.**
3. **This results in alterations to the connectivity parameters of the network, with notable fluctuations or oscillations in the distances between electroactive fibers and pore sizes.**
4. **Consequently, the pathways of signal transduction within the piezoelectric scaffold adapt according to changes in the equivalent circuits of the fiber network.**
5. **Therefore, a straightforward mathematical approach (time-resolved) is essential for assessing beam- / field-induced variations in interfilament distances, network connectivity parameters, and the orientation of fiber ensembles composed of various filaments.**
6. **This extends to the formation of multiscale network and tree-like fractal structures with lateral branches for signal routing, which is critical for the engineering and optimization of electroactive scaffolds.**
7. **We propose employing multifractal analysis for this purpose. We recommend utilizing the multifractal spectra D(q) and f(α), while advising against direct analysis of the scaling behavior for the dynamics of fiber structures for scaffold engineering applications.**

Methods

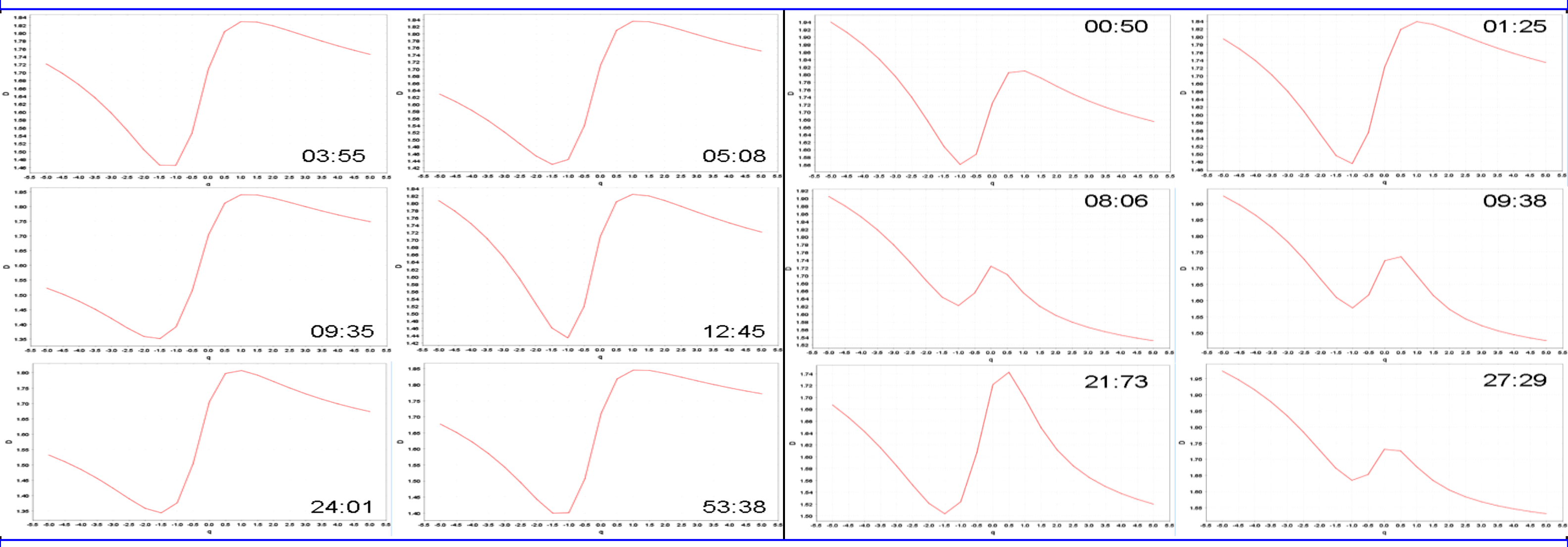
Time-resolved SEM studies of the PHB scaffold fiber dynamics were performed by JEOL JSM T330-A scanning electron microscope with the image acquisition systems developed by O.V. Gradov and P.L. Alexandrov.

The image or data was processed using HARFA software for a series of video recordings obtained under the electron beam. Processing of the time-resolved SEM data was performed using the box counting algorithms. The following multifractal parameters were calculated: *D(q)* – a multifractal spectrum where *Dq* is a generalized dimension for a dataset and *Q* is an arbitrary set of exponents; *f(α)* – another type of a multifractal spectrum allowing to determine the fractal dimension at *Q* = 0; *M(q)* - as the "total mass" or sum of pixels in all "boxes" for the arbitrary scale ("box size" in box counting method).

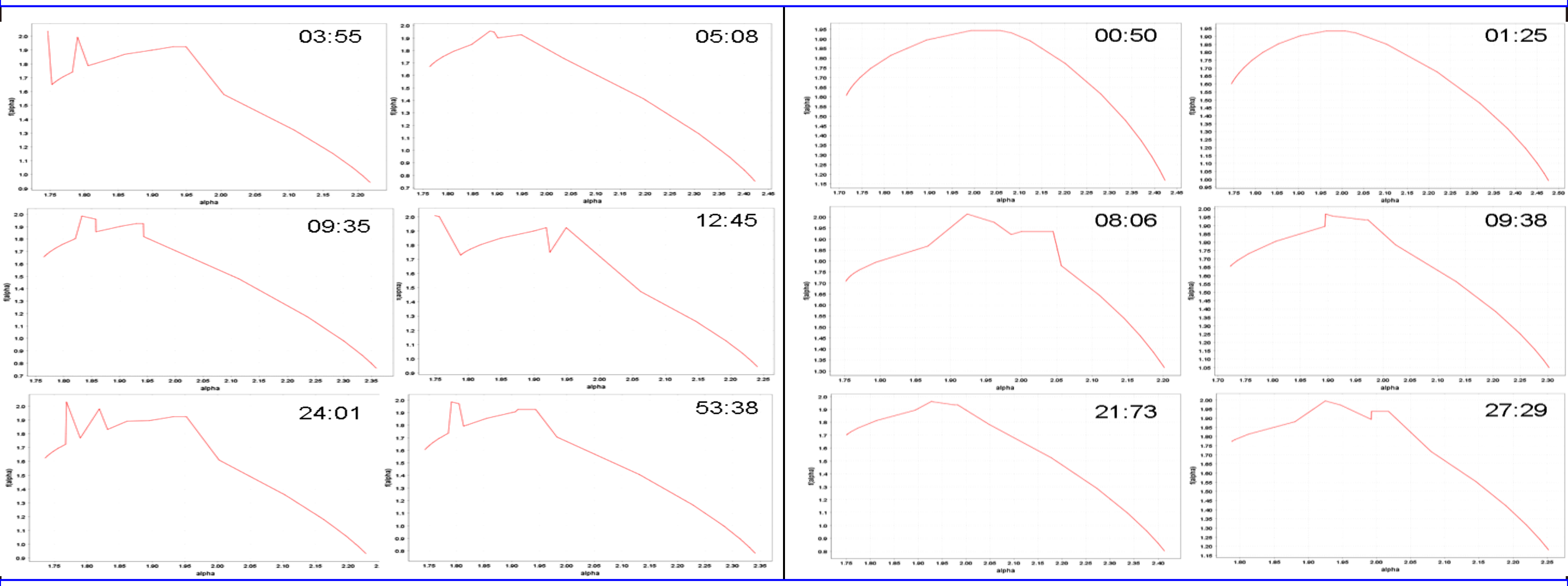
Results



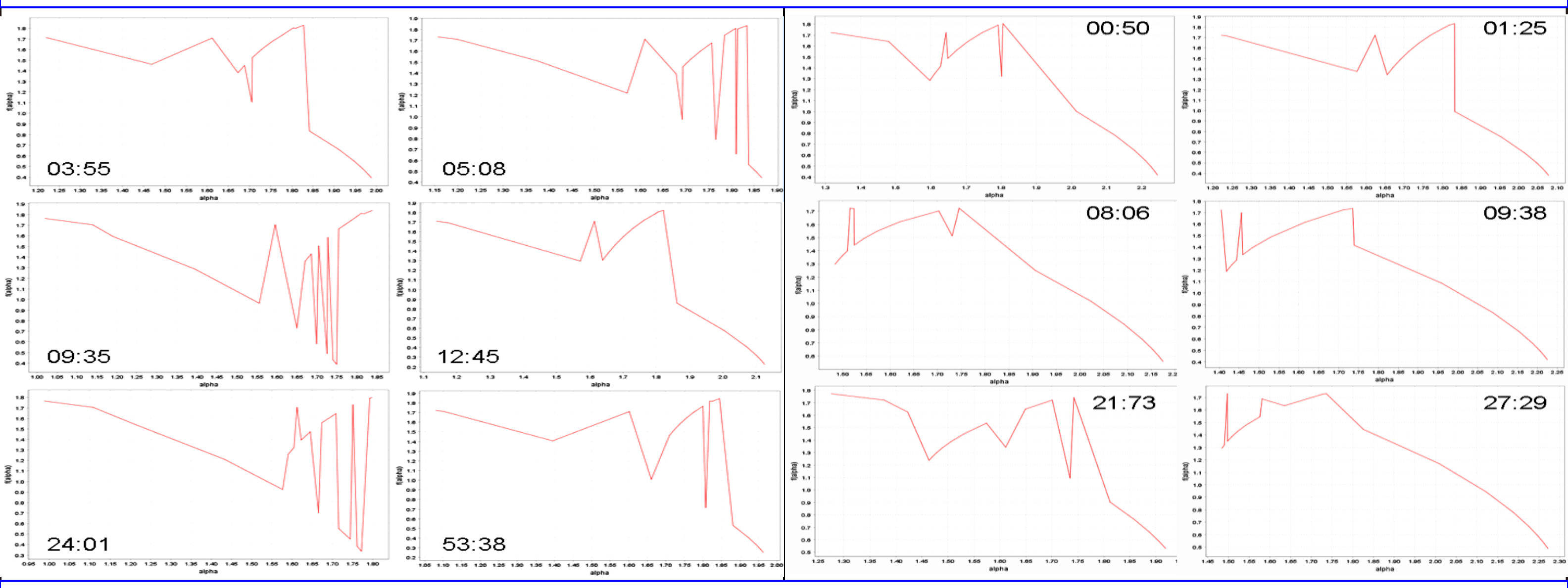
D(*q*) for the PHB scaffold fiber structure dynamics calculated with a geometric box counting method.



D(*q*) for the PHB scaffold fiber structure dynamics calculated with a arithmetic box counting method.



f(α) for the PHB scaffold fiber structure dynamics calculated with a geometric box counting method.



f(α) for the PHB scaffold fiber structure dynamics calculated with a arithmetic box counting method.

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