A Vibrational Therapy for Chronic Back Pain: Mathematical Modelling of Macrodeformation and Microvibration

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1 Introduction

Cell vibrations and corresponding time patterns are well-established diagnostics in cardiology and sports medicine. The microvibrations in skeletal muscle cells, being observed already years ago at the Universität Erlangen by means of high resolution videomicroscops, also represent a body-specific time pattern or rhythm in frequency windows of 8 – 12 Hz. The absence of these microvibrations in outer space missions as well as in degenerative tissue processes indicates their relevance for physiological transport processes in the extracellular matrix [1]. The new vibrational therapy MaRhyThe™ mechanically stimulates the diseased muscle tissue and leads to a synchronization effect, the so-called entrainment [2]. This innovative therapy got the PCT and US patent and is used in present day modern medicine. Clinically evaluated studies have been done in governmental rehabilitation-clinics of the RVA, FaberCastell, Rodenstock and at Daimler AG since 1998. Chronic and severe back pain as well as knee and hip-problems are meanwhile main indications for using MaRhyThe™.

In this contribution, we show how mathematical modelling and numerical simulation can assist in gaining a better understanding of vibrational therapies such as MaRhyThe™. We outline a mechanical model for the cell's microvibrations and demonstrate how it can be coupled with a macroscopic model for the muscle tissue. The ultimate vision is to be able to accurately predict the dynamics of the muscle at different length and time scales so that the validity of the underlying physiological assumptions can be tested. On this road towards a realistic multi-level model, we present the first steps and also a methodology that should be open to further extensions in the direction of systems biology.

2 Mathematical Model

At the macroscopic scale, the deformation of muscle tissue can be modelled by a system of partial differential equations (PDEs)

$$\begin{aligned} \rho\ddot{\mathbf{u}} - \mathbf{div}\, \boldsymbol{P}(\boldsymbol{u}, p) &= \boldsymbol{f}, \\ \tfrac{p}{\kappa} + J(\boldsymbol{u}) - 1 &= 0 \end{aligned}$$

for the unknown displacement field $\boldsymbol{u}(x,t)$ and the pressure $p(x,t)$, depending on space x and time t. For the microvibration at the cell level, we use a chain of nonlinear coupled oscillators

$$\begin{aligned} &\ddot{y}_n + \omega_n^2 y_n - \mu(1-y_n^2)\dot{y}_n \\ &-D_n\left(\tfrac{1}{2}(y_{n+1}+y_{n-1})\right) + c(\boldsymbol{u}) = 0 \end{aligned}$$

with individual frequency ω_n, Van-der-Pol parameter μ, and coupling parameter D_n. The forcing function $c(\boldsymbol{u})$ evaluates the displacement at the macroscale.

As discussed in [3], this coupled model can be analyzed by means of numerical simulation methods such as the Finite Element Method. In this way, we can now study the effect of an external excitation, as it is applied in the vibrational therapy, on the muscle tissue and on the individual cells. Fig. 1 shows on the left the therapy with a massaging device and on the right a snapshot of the numerical simulation with the resulting deformation of the muscle, in this case Musculus Biceps Brachii. Furthermore, the synchronization process at the cell level depending on system parameters and coupling mechanisms can be investigated.

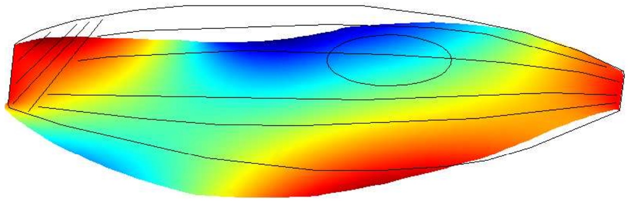

Fig. 1: Vibrational therapy and deformation of muscle tissue

3 Results and Conclusions

One of the objectives of this mathematical model is to determine whether an externally-driven microvibration applied to the muscle tissue can cause synchronization of the cellular oscillators. As shown in [3] by recording the coherence, a measure for synchronicity, along the simulation runs, the model indeed verifies the hypothesis. At appropriate frequency ranges or windows, the external excitation synchronizes the microvibrations. Fig. 2 depicts the coherence of the cellular oscillators by plotting each time step of the simulation. After an initial start-up phase, the synchronization becomes stronger and stronger, and eventually the coherence parameter travels on a elliptic trajectory around the origin.

The simulations runs, however, also revealed that the synchronization is very sensitive with respect to changes in the parameters, in the coupling model, and in the natural frequencies of the oscillators. This emphasizes the relevance of the appropriate frequency window and also indicates that random variations of the external frequency might deteriorate the coherence. From these results, we can conclude that the natural time structures or patterns of the skeletal muscle in the frequency window of 8-12 Hz play a particular role as order parameter for the vibrational therapy MaRhyThe™.

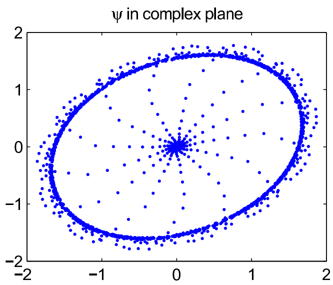

Fig. 2: Coherence in complex plane

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