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50. Internationales Wissenschaftliches Kolloquium
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L. Molnár / E. Solti / A. Bojtos

Improvement of Active Silicon Tendon-Implant

ABSTRACT

This paper presents an overview about research into improvement of active human tendon implant. It will be introduced the mechanical behaviour of human tendon based on measuring and will be started the optimization process to find an adequate cross section for tendon implant to fulfil more better its function and will be introduced a numerical simulation of movement of finger.

INTRODUCTION

Aim of research is working-out of such implant family which is able to fulfil its requirement much better than nowadays used tendon implants. Nowadays used implants have a round cross section with fibre reinforcing. Tendon implant can fulfil demands most of all if its mechanical properties are greatly equal to healthy tendon's behaviour. When is needed to use tendon implant in surgery?

- If tendon is so high teared that there is not possible to stich together.
- If active movement of finger is not possible and former operation was not successful.
- To avoid muscular atrophy.

FUNCTION AND MECHANICAL TEST OF TENDON

Main function of tendon is providing force transmission between muscles and bones. If tendon is so high teared that there is not possible to stitch together ends of tendon implantation is needed. In phase of healing function of implant are force transmission and providing of evolution of new sliding surface keeping the maximal moving ability of joints.

In order to create a good-quality silicon tendon-implant a series of tensile tests were taken on real human tendons taking from non-living human body. From these results behaviour and mechanical attributes of real tendons can be approximated. So in the future better implants can be created and so their attributes can be as close as possible to the real ones. For the experiment tendons only on outer part of the lower arm were investigated. The reason why it was needed that the tendons have to be long enough to use them in the tensile-tests. Following types of muscle-tendons were used (**Fig. 1., Fig. 2**.):

- m. flexor digitorum superficialis,
- m. pollicis longus,
- m. extensor digitorum,
- m. flexor digitorum profundus.

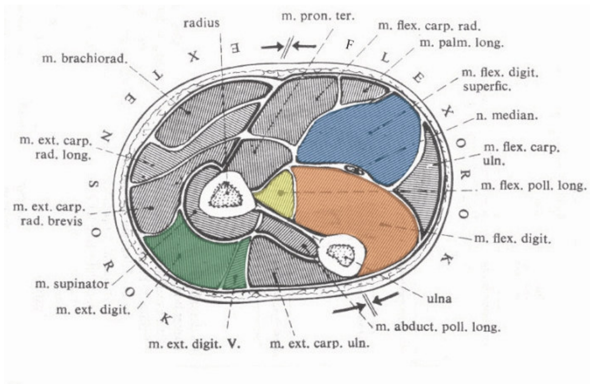

Fig. 1. Intersection of lower arm – the investigated muscles are coloured

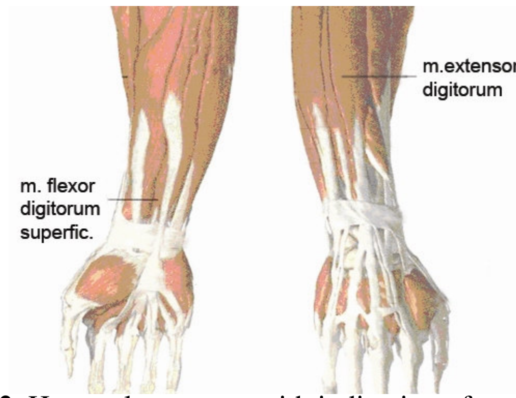

Fig. 2. Human lower-arm with indication of two investigated muscles

Fixing of tendons were solved with composite plates taking advantage of closing with force and shape (**Fig. 3.**). Tensile tests were made with different tension velocity (20, 40, 80 mm/min). During evaluation of tension test's results the non constant cross-section of tendons gave a difficulty to get the real stress.

Typical characteristic of tendon is showed in **Fig. 4**. Tensile curve starts mostly with concave type and follows a fluctuation which due to parallel running collagen fibers. Collagen fibres are tearing gradually during loading and some of them can bear lower and other much higher tension force.

Fig. 3. Test piece

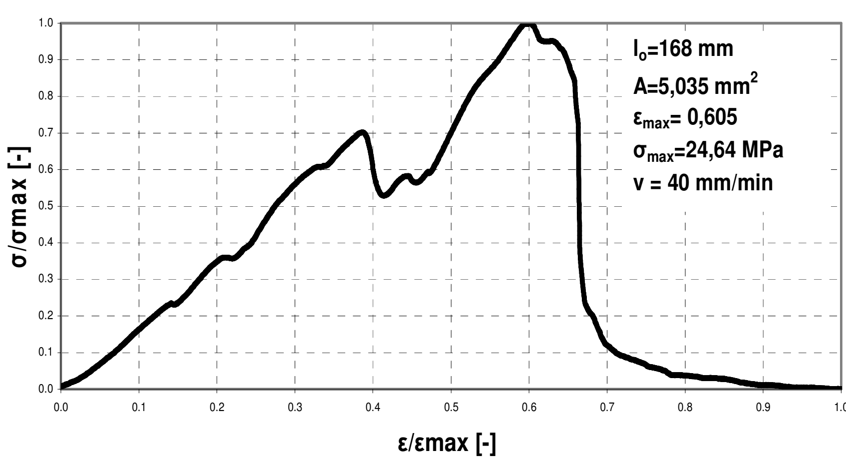

Fig. 4. Typical characteristic of tendon

Concerning results of the tensile tests we can state that maximal value of tension force in tendon was between F_{min}= 60 N and F_{max}= 406 N. Using initial cross-section stress can be derived from tensile force which represents a value between σ_{min}= 5,69 and σ_{max}= 59,33 [MPa].

	Maximum tension force [N]	Displacement [mm]	Maximum Stress [MPa]	Maximum Strain [-]	Cross-section area [mm^2]
Mean value	**207**	**77,54**	**18,78**	**0,88**	**12,75**
Max. value	406	124	59,33	2,39	32,5
Min. value	60	44	5,69	0,45	2,1

Table 1. Summary of tension test's results

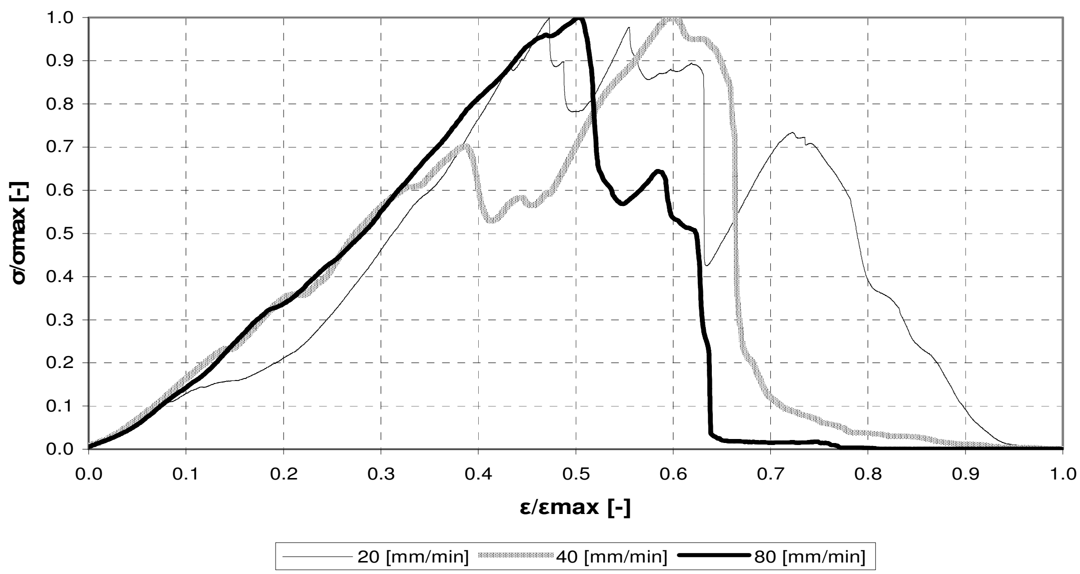

Fig. 5. Effect of tension velocity on tendon's characteristic (m. flexor digitorum profundus)

Tension velocity makes a small effect on the slope at the beginning of characteristic. Characteristic with velocity of 80 mm/min compared to other reach very fast maximum without many fluctuation and decrease fast to reach zero force. This behaviour can be explained that collagen fibres do not have enough time for re-arrangement ot velocity of 80 mm/min.

SHAPE OPTIMIZATION OF TENDON IMPLANT

Optimization is started in this research because the currently used implants have a round cross-section versus oval shape. In one case we fixed the area of cross section and changed the one side radius to analyse the effect for bending stiffness. Other optimization aspect was keeping boundary constant. The aim is to reach such bending stiffness which real tendons have. Unit force were applied on silicone tendons as loading.

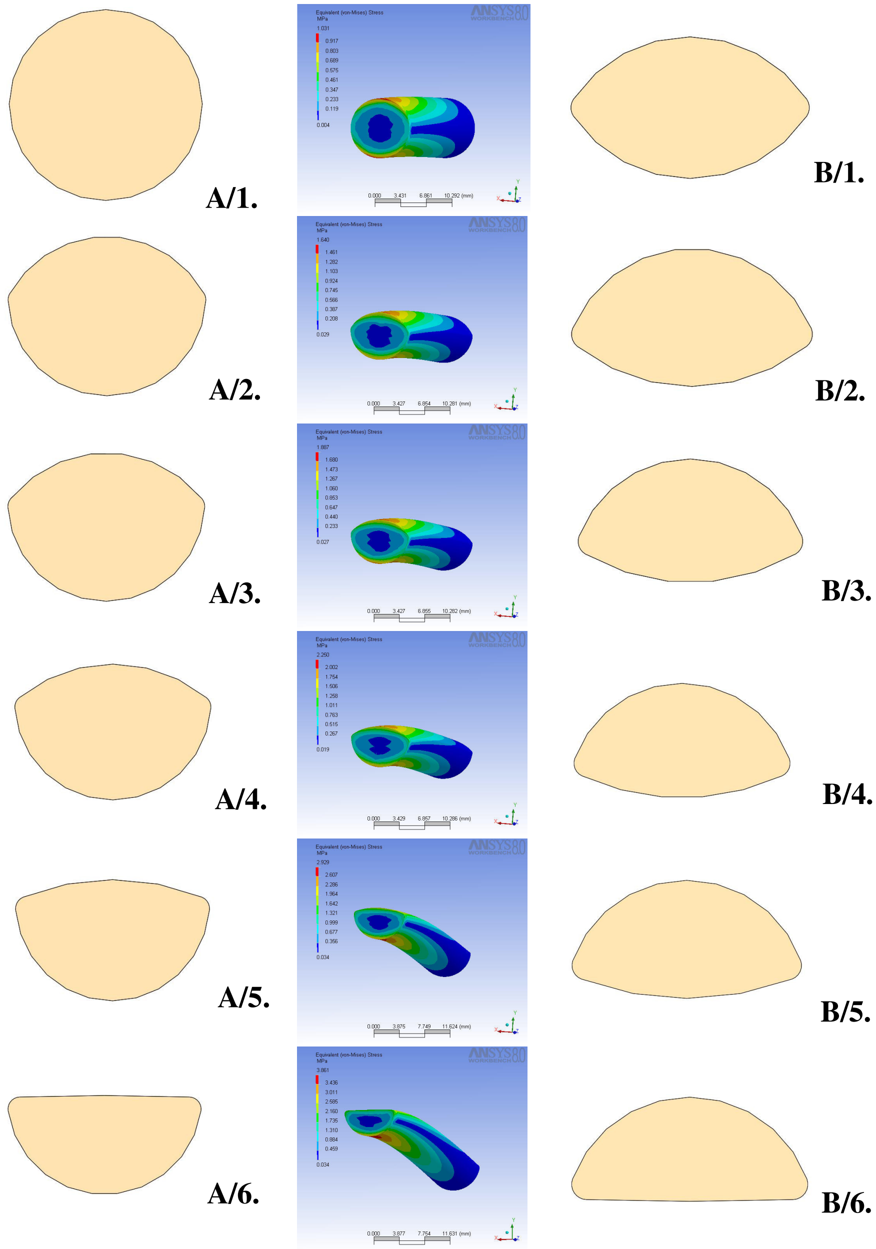

Table 2. Analysed shapes of cross section with constant area (column A) and with constant boundary (column B)

Evaluating of optimization we founded that with shape A/6 or B/6 we can decrease significant the bending stiffness to approach real bending behaviour. In results it is shown a significant changing in bending stiffness jumping from shape B/5 to B/6. (**Fig. 6.)**

Fig. 6. Optimization keeping boundary constant

NUMERICAL SIMULATION OF FINGER'S MOVEMENT

To check under real circumstances the tendon implant we need to build up a virtual model with knuckles and tendons. With this model we will be able to predict the maximum allowable load of finger (hand) without damage of tendon implant. So patient can avoid the further injury in tendon and reach healing fast. Standing-up of an adequate model based on CT exposures. Tendons work with a nonlinear strain-stress characteristic only in tension like in reality. They are fixed in several points to joints. This paper present a 2D simulation about movement of finger, 3D simulation will be published later.

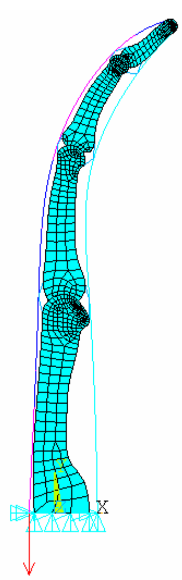

Fig. 7. FE model of finger

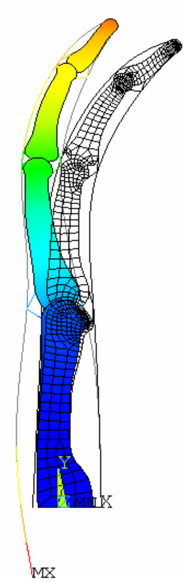

Fig. 8. Phase of movement

Used type of analyses was transient which took 1 second. During this time the tension tendon was excited by force. As results we received 26 [mm] total deformation at end of finger.

SUMMARY

As conclusion we can declare that finger tendons have a maximum tension force about 400 [N] and their behaviour is greatly depends on dynamical effect. There was built up a 2D numerical model to analyse the loading of tendons.

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