Establishing MR and ultrasound based model of a properly healing achilles tendon allowing to properly determine the healing stage of the structure: preliminary findings

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Aims and objectives

Diagnostic tests have become an invaluable tool allowing close supervision of post-operative tissues healing.

The observation of calcaneus tendon healing following surgical intervention is based on a clinical examination and current diagnostic images of the healing tendon. Based on the gathered information, the attending physician makes the decisions about the scope and progression of physical therapy protocol. These data also allow the physician to establish whether the patient is ready to resume their daily activities and then return to sports.

There is a need for a maximal refinement of data obtained from imaging diagnostics modalities and the establishment of their correlation with the patient’s clinical state. There are numerous publications on the use of imaging tests such as ultrasound (US) and magnetic resonance (MRI) in the treatment of healing tendons.

However, throughout our analysis of the available literature we have found no publication concerning the Achilles tendon that would combine the results of prospective studies on a large group of patients based on their pre-operative and sequential post-reconstruction follow-up scans (both short- and -long-term). Also, none of the retrieved studies included the assessment based on simultaneous use of two imaging diagnostics modalities that would take into account the elements of morphological, metabolic and functional examination.

The aim of the study was to construct a model of a proper healing progression of the Achilles tendon following a reconstruction based on the model of a healthy tendon combined with sequential testing of reconstructed tendons in conventional images: ultrasound and MRI.

The employment of these two modalities in establishing a healing process observation protocol was important, as the aim was to develop monitoring methods that would be generally available and obtainable with the use of regular equipment.
Images for this section:

Fig. 7: Increased tendon vascularization during the rebuilding period - US Power Doppler
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Methods and materials

The research was carried out as a part of a project carried out within the STRATEGMED framework. The data was based on sets of MRI and ultrasound examinations.

Analysed were cases of 29 healthy volunteers (one-time MR scan and US exam) and progressive evaluation of 60 patients who underwent Achilles tendon reconstruction (one-year follow-up, including 10 prospective MRIs/ultrasound exams per patient).

At the current stage of the study, the follow-up cycle has been completed in 28 cases, however only 27 were included in the analysis since one patient required a revision surgery due to the complications stemming from an infection. The total of four patients have skipped one MRI scan. The remaining members of the study group continue with the examinations according to the research’s agenda.

Each patient is evaluated according to the same protocol: an ultrasound providing the assessment of tendon's structure, vascularization and motion; and an MRI scan (Signa HDXT - PD sequences; T1; T2; T2 *; STIR; T2 * GRETEmin; Water: Ideal Ax 3D FSPGR; and T2-map).

The tests are run at 1 week, 3 weeks, 6 weeks, 9 weeks, 12 weeks, 4.5 months, 6 months, 9 months, and 12 months.

The collected data is being processed and statistically analysed, including the calculation of Haralick’s texture features for the tendon's region of interest (ROI).

Ultrasound exam protocol:

Ultrasound examinations were carried out using the Voluson E-8 Expert with linear heads. For 2-D evaluation a 2D Wide Band Linear Transducer --SP10-16-D H48651MT was used; the FOV set at 33.7mm and the frequency of the emitted wave set at 7-18MHz.

2-D Ultrasound examination provides a morphological evaluation and should assess the entire tendon, scanned transversely and sagittaly. Next step should be a scan with the use of the Power Doppler technique that provides the analysis of the area of the tendon and adjacent tissues - including the fascia compartment and the bursa.

While analysing the scans one should consider the thickness of the tendon, its shape, and ultrasound structure - analysis of the presence of fibrous structure or lack thereof; establishment of regions with abnormal fibrous structure - if there are any, their size should be measured.

Power Doppler imaging is set to evaluate free flows within tissues to maintain technically correct evaluation.
Scans are assessed in terms of presence or absence of vascularisation. If it is present, the vascularised site’s location within the tendon is determined - proximal, middle part, the area of the attachment and vascularisation of adjacent tissues. Also, if the vascularisation is visible, then the level of vascularity is defined as: small, medium and large. Dynamic evaluation is based on the assessment of the presence or absence of resting tension of the reconstructed Achilles tendon.

The second part of the dynamic evaluation is the assessment of the activity of the gastrocnemius muscle and the assessment of the movement, gliding and tension of the tendon in passive and active foot movement (plantar flexion), observed in both the closed and open kinematic chain.

**MRI protocol:**

On the course if this study we have used the GE Signa HDxt 1.5T MRI device with a Phase Array Peripheral Vascular Coil Leg Boots P/N. For the examination, the patient is placed in a supine position with their legs slid into the scanner. The arrangement of the tested foot in the coil is always the same - slight plantar flexion, enforced by the MR coil that additionally protects the healing tendon during the examination.

The following sequences were established within the framework of the protocol:

1. **Localisation sequence - 3 Plane Loc;**
2. **SAG PD sequence in sagittal planes; No. of layers - 20; layer thickness: 2mm; FOV - 16cm; TE: 35.5ms TR: 2000ms;**
3. **Ax T2 * GRE TE MIN sequence; No. of layers - 40; layer thickness: 3.5mm; FOV - 15cm; TE: 4.1ms TR: 600ms**
4. **Ax T2 * sequence; No. of layers - 25; layer thickness: 3.5mm; FOV - 15cm; TE: 16ms TR: 620ms**
5. **Ax T1 sequence; No. of layers - 25; layer thickness 3.5mm; FOV - 15cm; TE: 25.96ms TR: 360ms**
6. **Ax T2 sequence; No. of layers - 25; layer thickness 3.5mm; FOV - 15cm; TE: 91.4ms TR: 3000ms**
7. **Ax PD sequence; No. of layers - 25; layer thickness 3.5mm; FOV - 15cm; TE: 34.03ms TR: 1320ms**
8. **Sag T2* sequence; No. of layers - 20; layer thickness: 2mm; FOV - 15cm; TE: 16ms TR: 600ms**
9. **Cor T2* sequence; No. of layers - 17; layer thickness: 2mm; FOV - 16cm; TE: 16ms TR: 600ms**
10. **Sag STIR sequence; No. of layers - 17; layer thickness: 2mm; FOV - 16cm; TE: 20.0808ms TR: 3000ms**

The morphological assessment was made using the Carestream Solutions program.
The segmentation of the tendons was done in the Ax T2 * GRE TE MIN sequences that allowed to obtain information on the tendon volume (Osirix).
Fig. 8: Example tendon segmentation - generated 3D images (Osirix)

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Fig. 9: Achilles tendon healing in ultrasound examination

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Results

Based on the MRI scans and ultrasound exams, the healing tendon pattern was determined through ultrasound/MRI visualisation, volume and cross-section measurements, dynamic ultrasound and Power Doppler (PD) vascularisation. The image of healing disorders was defined in morphological ultrasound/MRI images and dynamic ultrasound examinations. The research has confirmed the superiority of MRI over ultrasound in evaluating the Achilles tendon structure. Yet still, the same data point to the validity of dynamic ultrasound and PD vascularisation in detecting healing disorders while establishing whether the healing progression follows the proper tendon healing pattern.

Due to the incomplete group of patients, it is too early to draw conclusions that would allow the definite development of the observation and assessment method.

Analysis of the MRIs and ultrasound examinations performed in the early post-surgical period (7, 14 and 21 days from the tendon's reconstruction) was not typically made in the past. Neither as a part of our own every-day clinical practice, nor within the scope of the studies described in the retrieved literature. First, reviewing systematically done MRI and ultrasound scans of all patients who have undergone the reconstructive procedure allowed for the observations of the tendon following a particular surgical procedure (which will be taken into account in the analysis of remodelling of the scar of the calcaneus tendon in the future analysis).

Secondly, a significant superiority of MR examination over ultrasound in displaying the tendon’s architecture after the surgery has been established. Subsequent MR and US follow-up examinations performed after the surgery allowed to observe and document morphological changes in the reconstructed tendon. In the scope of the first tests: after a week, then at 3 and 6 weeks post-op, the tendon image remained quite similar and stable compared to the previous scans but with visible ongoing remodelling/healing of the tissue. The Anastomosis zone becomes blurred and remodelled, while swelling of the tendon and adjacent tissues decreases. The consolidation and remodelling of the scar within the zone is visible. At this stage, assessing whether the intraoperative Achilles resting tension was obtained is extremely important, as it indicates proper tension of the muscle bellies and their correct fusion. Our findings so far indicate that in the case of proper tendon fusion, the active tendon movement is already observed 1 week after the procedure.

Around 9th week - up to 4.5 months, pronounced thickening of the tendon is observed, with tendon’s structure disorder visible in MR images in all sequence. Some patients have had areas where the tendon’s structure was thinner, quite similar to partial tears - which may be the result of active remodelling at the level of the earlier rupture or the disruption of the healing process resulting from secondary microdamages. In subsequent imaging examinations of such cases, reactive thickening of the tendon was visualised.
with gradual remodelling of the scar and subsequent gradual normalisation of the tendon image in evaluations after 9 and 12 months post-op.

Thickening and swelling of the scar in some patients is asymptomatic, in some cases we have observed pain, skin changes and/or redness. The above changes require further observation and statistical elaboration of results in connection with the data obtained through statistical and IT analyses (in development) as well as in correlation to the clinical and rehabilitation outcomes.

The graph presents a statistical analysis of the calcaneus tendon's volume in patients who completed a full MRI diagnostic cycle - segmentation and measurements were performed using the OSIRIX software.

In contrast to our preliminary assumptions - partly based on own previous experiences, it has been established that ultrasound examination has a lower practical value while evaluating postoperative anatomy, remodelling of the scar and the presence of possible secondary tendon injuries. The intra-tendinous area of the rupture, currently observed in 6 patients, was not visible as damage to the structure on the ultrasound. During the US exam, at the level of the secondary damage/rupture, the only recorded symptoms were the thickening of the tendon was recorded (in comparison to the previous US) by 14 up to approx. 20mm in the A-P and significantly increased tendon vascularization. The worsening of the tendon's function in the dynamic examination was also noted. The above new data and observations result from the direct correlation of the obtained ultrasound images in comparison with the MRIs done at the same time.

On the other hand, the Power Doppler ultrasound examination is a very valuable tool for the assessment of the vascularisation when combined with the analysis of the MRI sequences. Doubtlessly, the ultrasound examination allows for the dynamic evaluation of the healing of the Achilles tendon, as well as the evaluation of the presence of tendon adhesions to the adjacent tissues, tendon tension evaluation, and muscle and tendon function.

In 3 out of 60 patients, a partial re-rupture occurred (up to 2 weeks after the primary surgery). One patient underwent revision surgery, the other 2 patients were treated conservatively. In patients treated conservatively, full remodelling of the ruptured area was established by the imaging diagnostic tests performed so far. These patients though, did not achieve the complete restoration of the tendon's function indicated by the dynamic ultrasound evaluation, yet still a partial improvement was observed.
**Fig. 1:** MRI of Achilles tendon - imaging of tendon remodeling in the early postoperative period

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Fig. 2: MRI of Achilles tendon - imaging of tendon remodeling in the early postoperative period

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**Fig. 3:** MRI of Achilles tendon - imaging of tendon remodeling and maturation - typical swelling and thickening of the tendon approx. 4.5-6 months after reconstruction

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Fig. 4: MRI of Achilles tendon - good Achilles tendon maturation after reconstruction in the period of 9-12 months post reconstruction

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**Fig. 5:** MRI of Achilles tendon - low tendon signal indicates advanced good remodeling - observation in T2 * min sequences

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Fig. 6: The evaluation of the Achilles tendon maturation - different appearance of tendon in several sequences at the same level - the MRI study

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Fig. 10: MRI - Despite the initial abnormal images - accident rerupture 1st postop - the patient's Achilles has underwent proper remodelling. The mature tendon's images were satisfactory, indicating the completion of healing process. But the tendon dynamic function was insufficient in US evaluation.

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Fig. 11: MRI - Despite the initial abnormal images - accident rerupture 1st postop - the patient's Achilles has underwent proper remodelling. The mature tendon's images were satisfactory, indicating the completion of healing process. But the tendon dynamic function was insufficient in US evaluation.

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Fig. 12: MRI - Despite the initial abnormal images - accident rerupture 1st postop - the patient's Achilles has underwent proper remodelling. The mature tendon's images were satisfactory, indicating the completion of healing process. But the tendon dynamic function was insufficient in US evaluation.

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**Fig. 13:** MRI - Despite the initial abnormal images - accident rerupture 1st postop - the patient's Achilles has underwent proper remodelling. The mature tendon's images were satisfactory, indicating the completion of healing process. But the tendon dynamic function was insufficient in US evaluation.

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**Fig. 14:** Partial rerupture of Achilles tendon after an effort of 4.5 months after reconstruction, which is evident in the study MRI, but is not visible in US. Very good healing of tendon before reinjury.

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Fig. 15: Partial rerupture of Achilles tendon after an effort of 4.5 months after reconstruction, which is evident in the study MRI, but is not visible in US. Very good healing of tendon before reinjury.

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Fig. 16: Partial rerupture of Achilles tendon after an effort of 4.5 months after reconstruction, which is evident in the study MRI, but is not visible in US. Very good healing of tendon before reinjury.

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Fig. 17: Anova and Turkey post hoc test, least squares means 95% confidence interval

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Fig. 18: Anova and Turkey post hoc test, least squares means 95% confidence interval. Statistically significant changes between tendon volume in time were marked with an asterisk.

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Conclusion

The results obtained so far indicate the significance of MRI in the assessment of morphological Achilles tendon healing.

The results require further validation after the conclusion of the follow-up cycle for all patients.

Ultrasound and MR examinations of patients after Achilles tendon reconstruction indicate that it is possible to establish and perform designed protocols, both in the preoperative period - immediately after the injury - as well as in the early postoperative period.
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