ISSN: 2754-4745

Journal of Physical Medicine Rehabilitation Studies & Reports

SCIENTIFIC Research and Community

Research Article

Open Access

Analysis of Gait Parameters in Patients after Triple-Bundle Achilles tendon Reconstruction – Prospective Evaluation of 60 Patients at 3, 6 and 12 Months Post op

Magdalena Syrek[1,4]*, Urszula E Zdanowicz[2], Robert Smigielski[3], Michal Staniszewski[4]

[1]Carolina Medical Center, Physiotherapy Department, Pory 78, 02-757 Warsaw, Poland

[2]Carolina Medical Center, Orthopaedic and Sports Traumatology Department, Pory 78, 02-757 Warsaw, Poland
McGowan Institute for Regenerative Medicine, University of Pittsburgh, 450 Technology Drive, Suite 300, Pittsburgh, PA 15219-3110, USA

[3]Biological Treatment Centre, Orthopaedics Department, LIFE Institute, Grzybowska 43a, 00-855, Warsaw, Poland

[4]Józef Piłsudski University of Physical Education in Warsaw, Department of Physical Education, Marymoncka 34, 00-809, Warsaw, Poland

***Corresponding author**
Magdalena Syrek, Carolina Medical Center, Physiotherapy Department, Pory 78, 02-757 Warsaw, Poland; Józef Piłsudski University of Physical Education in Warsaw, Department of Physiotherapy, Marymoncka 34, 00-809, Warsaw, Poland E-mail: magda.syrek@gmail.com

Received: September 05, 2021; **Accepted:** September 13, 2021; **Published:** September 15, 2021

Background

The Achilles tendon is formed by collagen fibers running from the lateral and medial head of the gastrocnemius muscle and situated deeper soleus muscle. The fascicles are twisted so the fibers from the medial head of the gastrocnemius muscle are located posteriorly (superficially) and the fibers from the lateral head are located anteriorly (deeply). Thus, the fibers from the soleus muscle are located in the central and medial part of the tendon [1]. These units, depending on the side, rotate as left- or right-handed screws (eg, left Achilles tendon rotates against clockwise). The significance of the torsion stems from the fact it occurs at the site where concentrated pressure applies potentially due to rupture enabling forces produced where all the tendon bundles meet. Independently, it is possible to distinguish each separate Achilles tendon musculotendinous unit during a thorough, detailed dissection [2].

Achilles tendon is the strongest one in the human body and has to withstand forces of up to 3,800 N [3]. The treatment of Achilles tendon ruptures should not only focus on restoring Achilles tendon length but also the original strength of the whole muscle-tendon unit [4,5]. The best treatment is still debated [6,7]. There are papers supporting non-operative treatment, traditional open repair as well as percutaneous repair [8-11]. Rehabilitation protocols also vary significantly, with some data suggesting success with early mobilization, particularly in young active patients [12-14].

The goal of operative treatment is to restore full biomechanical function of the tendon (or as similar to physiology as possible) and to restore the ability to correct transmission of contractile forces, which is possible only by careful reconstruction of the three-bundle structure of Achilles tendon [2]. There is no absolute consensus about the best type of surgical repair: some evidence suggests that end-to-end suture techniques lead to more successful outcome with reduced rate of complications when compared to approach focused on tendon augmentation [15,16]. Jaakkola et al. designed a study to compare the tensile strength of ruptured Achilles tendons repaired using either the triple-bundle technique or the Krakow locking loop technique [17]. The difference in average rupture load for the triple-bundle technique and the average rupture load for the Krakow locking loop technique represented a statistically significant superiority in favour of the triple-bundle technique. The same researcher conducted a study to evaluate the triple-bundle technique for acute Achilles tendon rupture repair followed by early (14 days) postoperative ankle range of motion, compared to non-operative treatment with delayed ankle range of motion [18]. Operative treatment reduced immobilization time, allowed safe early-return to weight bearing, and diminished risk of re-rupture compared to non-operative treatment.

The goal of the rehabilitation is to allow the patient to fully recover their strength and function within the shortest period. Rehabilitation after rupture of the Achilles tendon is slow and it may last longer than 3 months [19]. Despite most of the patients reporting good long-term results, a significant number of patients experience persistent symptoms for years [20]. Abnormal gait is a sign of an incomplete recovery process [20,21]. Spatial and kinetic data collected in a full gait analysis can assess gait abnormalities, including those caused by injuries, and the relationships between plantar flexor muscle-tendon unit properties and walking patterns during rehabilitation [20-22].

The aim of the study was to present changes in walk parameters in patients at three, six and twelve months after surgical triple-bundle Achilles tendon reconstruction.

Material and methods

Participants

Sixty patients (50 men; 10 women) presenting with complete unilateral rupture of the Achilles tendon, treated by two senior surgeons were included in this prospective study. Demographic data can be seen in Table 1. The rupture involved the left and right limb with 30 patients in each group.

Table 1

Variables	Mean	SD	Range
Age (years)	32	6,2	25-51
Body mass (kg)	84,2	11,3	65-120
Height (cm)	180,3	5,8	168-193
BMI (kg/m^2)	25,9	3,1	20-32
Male:female	50:10		
Side	Left 30	Right 30	

All patients underwent Achilles tendon reconstruction at a mean time of 6±4 days post injury followed by immediate, uniform rehabilitation protocol described in a manuscript written by the author of this publication [23]. The general summary of the protocol has also been presented in the next subsection. Inclusion criteria were: 25-60 years of age, a healthy contralateral leg with physiological, clinically determined, alignment of the knee, foot and ankle, no neuromuscular impairments including muscle dystrophies, no other post-traumatic injuries or osteoarthritis of the knee, foot and ankle of the treated leg. Exclusion criteria were: previous surgical treatment of Achilles tendon, heart diseases, liver or kidney insufficiency, oncological problem, haematological diseases, immunological diseases, dermatological diseases, infection, obesity, hyperlaxity.

The diagnosis of Achilles tendon rupture was initially made clinically on the basis of palpable defect at the side of the rupture and positive Thompson test which unveiled a lack of any apparent plantar flexion. An ultrasound scan and magnetic resonance were performed in all cases to confirm the diagnosis.

This study was a part of a project in developing a novel Scaffold-based Tissue engineering Approaches to healing and Regeneration of Tendons and ligaments (START) and was approved by the appropriate Ethics Committee; all subjects gave their informed written consent before entering the study.

Rehabilitation programme

The rehabilitation programme consisted of three sessions per week during six months (mean 6,3±1,9 months, which comes down to the average of 73±5 sessions per subject). All patients were discharged two days after the surgery if the condition of the patient had not been complicated by other factors (mean hospitalization 2,3 days). During first six weeks the patients were kept non-weight bearing and partially immobilized (the cast was split into two parts, allowing its removal during supervised physiotherapy sessions) They began passive and concentric motion of the ankle ranging from 10° to 30° plantarflexion. Six weeks post-surgery all patients underwent a follow-up ultrasound. Each follow-up ultrasound examination of a patient in the program included the following parameters: morphologic characteristics, structure, color Doppler vascularization, tendon's gliding within paratenon and mobility. The parameters were chosen based on literature combined with the experience of the radiologist specializing in orthopedic ultrasound MRI assessment [25-27]. The findings from ultrasound combined with clinical evaluation gave grounds to make a decision to remove the cast and substitute it with a Walker boot with two wedges (4 cm) placed under the heel [28]. Partial weight bearing, up to 25% of patients' body mass, was permitted. At the beginning of the week eight, one wedge was removed and active motion was permitted from 5° of dorsiflexion to 30° plantarflexion. Partial weight bearing was increased to 50% of patients' body mass. After ten weeks patients started walking with full weight. Twelve weeks post-op another control ultrasound was performed along with a clinical examination. Based on gathered findings the decision was made by the surgeon to remove the Walker boot and allow normal footwear. The patients performed mobility and theraband strength exercises, walking forward, backward, side-wards and stairs up and down progressively. Jumping on the trampoline and wobble-board exercises began after 4 months into rehabilitation. Normal sport activity was allowed to be resumed after seven months. All patients followed the same rehabilitation protocol.

Measurements

The protocol of our study consisted of three assessments for the study group: three, six and twelve months after the surgery. Each evaluation included gait parameters analysis (Figure 1).

Figure 1

Gait analysis was conducted using the ZEBRIS FDM3 (Zebris Medical GmbH, Germany) platform of dimensions 314 x 62 x 2.1 cm with 17,024 sensors and registration frequency of 120 Hz. The platform was connected to the WinFDM software for gait analysis, which records consecutive walks. Each participant walked along the platform three times with a self-preferred speed. The evaluation report included spatial parameters: foot rotation (deg), step length (cm), stance phase (%), swing phase (%) and kinetic parameters: max heel force (N) and max toe force (N).

Participant self-reported level of function was evaluated using the Achilles tendon total rupture score (ATRS) at four and a half (six weeks after Walker boot was removed), six and twelve months post-op. It is a patient-reported instrument with high reliability, validity and sensitivity for measuring the outcome related to symptoms and physical activity after treatment in patients with a total Achilles tendon rupture and can be a good predictor in patient's ability to return to sports after one year after an injury [29,30]. It consists of 10 questions concerning symptoms (first four) and physical activity like walking, running and jumping (see APPENDIX). A patient scoring 0 implies major limitations/symptoms and 10 no limitations or symptoms. Answers from all 10 questions are added to a total score, with 100 being the maximum score.

ATRS

(Achilles Tendon Total Rupture Score)

All questions refer to your limitations/difficulties related to your injured Achilles tendon. Answer every question by grading your limitations/symptoms from 0-10.

Remember (0= Major limitations and 10= No limitations).

Please circle the number that matches your level of limitation

1. Are you limited due to decreased strength in the calf/Achilles tendon/foot?

0 1 2 3 4 5 6 7 8 9 10(No limitations)

2. Are you limited due to fatigue in the calf/Achilles tendon/foot?

0 1 2 3 4 5 6 7 8 9 10(No limitations)

3. Are you limited due to stiffness in the calf/Achilles tendon/foot?

0 1 2 3 4 5 6 7 8 9 10(No limitations)

4. Are you limited due to pain in the calf/Achilles tendon/foot?

0 1 2 3 4 5 6 7 8 9 10(No limitations)

5. Are you limited during activities of daily living?

0 1 2 3 4 5 6 7 8 9 10(No limitations)

6. Are you limited when walking on uneven surfaces?

0 1 2 3 4 5 6 7 8 9 10(No limitations)

7. Are you limited when walking quickly up the stairs or up a hill?

0 1 2 3 4 5 6 7 8 9 10(No limitations)

8. Are you limited during activities that include running?

0 1 2 3 4 5 6 7 8 9 10(No limitations)

9. Are you limited during activities that include jumping?

0 1 2 3 4 5 6 7 8 9 10(No limitations)

10. Are you limited in performing hard physical labour?

0 1 2 3 4 5 6 7 8 9 10(No limitations)

Statistical analysis

The recorded data was statistically analyzed using the STATISTICA package (data analysis software system), Version 12 (StatSoft, Inc., 2014). The Shapiro-Wilk W test revealed that all the demographics and gait parameters data had a normal distribution; therefore, parametric tests were applied in further analysis. The significance of the changes in the temporal and spatial gait parameters and the significance of differences between affected and non-affected lower limbs were evaluated with the repeated measures ANOVA test and the post-hoc Tukey's test (HSD). ATRS scores were evaluated with Friedman ANOVA for nonparametric one-way repeated measures analysis of variance. The significance level was set at $p < 0.05$ for all tests.

Results

The spatial and kinetic parameters after three, six, and twelve months after the surgery are shown in Table 2. After three months (T1) the measurements of step length (understood as a distance between the point of initial contact of one foot and the point of initial contact of the opposite one), stance phase, swing phase and max heel force have shown significant differences when compared to measurements taken after six (T2) and twelve months (T3) in the affected leg. Based on own observations and experience the researchers established a set of spatial and kinetic parameters meant to indicate the level of function restoration. Using these parameters the efficacy of completed rehabilitation protocol was measured six months after the surgery when comparing patients after T2 and T3 (pb) evaluation we observed no significant differences for any gait parameters in affected and non-affected leg.

Table 2

	T1	T2	T3	p^a T1 vs T2	p^b T2 vs T3	p^c T1 vs T3
foot rotation (deg)						
AL	8,49±3,46	8,82±3,33	8,97±3,49	0,954	0,998	0,807
NAL	10,87±5,72	8,81±3,84	8,92±3,79	<0,001	0,998	<0,001
p (AL vs NAL)	<0,001	0,999	0,999			
step length (cm)						
AL	51,25±13,75	67,43±10,27	70,6±6,2	<0,001	0,161	<0,001
NAL	62,03±11,69	69,33±7,31	71,25±6,24	<0,001	0,700	<0,001
p (AL vs NAL)	<0,001	0,891	0,999			
stance phase (%)						
AL	68,44±4,41	63,49±1,94	62,61±1,63	<0,001	0,247	<0,001
NAL	63,27±3,62	62,64±1,66	62,41±1,55	0,627	0,991	0,263
p (AL vs NAL)	<0,001	0,521	0,998			
swing phase (%)						
AL	31,56±4,41	36,54±1,97	37,39±1,63	<0,001	0,284	<0,001
NAL	36,73±3,62	37,33±1,64	37,6±1,55	0,674	0,986	0,265
p (AL vs NAL)	<0,001	0,598	0,998			
max heel force (N)						
AL	800±138	852±137	851±164	<0,001	0,999	<0,001
NAL	799±140	830±125	848±137	0,309	0,872	<0,001
p (AL vs NAL)	0,999	0,958	0,999			
max toe force (N)						
AL	873±142	904±134	900±135	0,173	0,999	0,309
NAL	810±145	881±123	896±127	<0,001	0,847	<0,001
p (AL vs NAL)	0,103	0,939	0,999			

The parameters are given as a mean ± SD; AL-affected leg; NAL-non-affected leg; T1-evaluation after three months after surgery; T2-evaluation after six months after surgery; T3-evaluation after twelve months after surgery; pa relates to the differences between T1 and T2; pb relates to the differences between T2 and T3; pc relates to the differences between T1 and T3.

When compared to the non-affected leg, only spatial parameters after T1 evaluation were significantly different. Step length and swing phase were significantly shorter and stance phase longer in affected leg. Significant alterations were observed in comparison with the six-month and twelve-month assessments (<0,001). No significant differences were found between affected and non-affected leg after T2 and T3 evaluation.

The patient-reported symptoms (ATRS) improved significantly over time up to twelve months following surgery (Table 3). The comparable level of answers was observed in questions 2, 3 and 4 in assessment after 4.5 and 6 months, which were describing fatigue, stiffness and pain around the Achilles tendon. The big decline of points was observed with the questions related to running and jumping (question 8 and 9) after first evaluation with significant increase after six and twelve months (Figure 2).

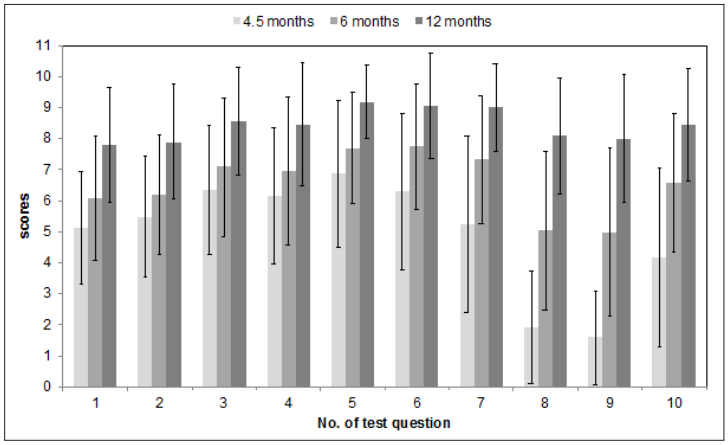

Figure 2

Discussion

The results of the present study show that the key goal of the rehabilitation which is quick yet safe Achilles' tendon strength and function restoration is possible to achieve but requires a proper post-operative evaluation protocol combined with immediate physical therapy programme including immediate, supervised mobilization of the ankle joint.

There are few reports in the literature concerning the use of triple-bundle repair technique [17,18,31], which was used in all cases covered by the study. The surgeons who performed all the reconstructions in the current study were also the creators of the technique and based on their medical recommendations the immediate mobilization was introduced and the presented rehabilitation protocol developed.

The study was designed to quantify the gait abnormalities found after complete unilateral rupture of the Achilles tendon. As expected, at three months after surgery (when the Walker boot was removed), step length and swing phase were significantly shorter and stance phase longer in affected leg [32,22,33]. The muscle weakness and the resulting loss of symmetry within the gait cycle produce a less energy efficient walking pattern [21]. This is consistent with the limited walking distance and diffuse aching in the calf that affects many patients. Our study points to the close relationship between the need for healing progress' monitoring and the development of rehabilitation protocol. The continuous assessment enables physiotherapists to boost the rehabilitation process in a safe way by following the medical recommendations of radiologists and clinicians based on follow-up examinations. The continuous cooperation between doctors and physiotherapists is paramount for patient's safety and recovery, as well as it open doors for new rehabilitation programmes and strategies without risking re-injury. The remodeling phase takes about six weeks, with decreased cellularity, collagen and glycosaminoglycan synthesis. What follows is the tissue consolidation stage that begins at week six and continues up to week ten of rehabilitation. In this period, tissue experience structural changes: from cellular to fibrous, hence patients are allowed to start partial weight bearing. Increased loading prepares Achilles tendon for further rebuilding. After ten weeks into rehabilitation process, the maturation stage begins, with gradual tissue change from fibrous to scar-like tendon over the course of one year [34].

Measurements of the maximum heel force conducted three months after the surgery show much lower values compared to similar evaluation performed after six and twelve months period. Increase in the maximum toe force on the affected side has been frequently observed to co-occur with the decrease in patients' heel force. Such deviation between measurements performed in different rehabilitation stages may be explained by the heel pain that affects patients, particularly in the early stages of rehabilitation. The second gait analysis, taken six months after the injury, shows improvement of all parameters. These findings conflict with work from Costa and colleagues who reported a significant deficit in peak forefoot pressure compared to non-affected side. Meanwhile, the affected sides' functional deficits found by Follak et al. manifest in a decreased active heel lift during the swing phase shortly after toe lift [21,35]. This is most likely stemming from the fact that the weaker the calf muscle strength the worse propulsion initiating the swing phase. These results displayed a marked deficit in plantar flexor strength in relation to estimations of maximum strength which are corroborated by other authors, who also found a strength deficit of plantar flexors using isokinetics [36-38]. According to the literature, the weakened plantar flexors – which could not adequately perform their function during the heel- and toe-lift phases – a compensation mechanism is used to move forward. The body's weight is shifted forward, thus ''inducing'' the next step. This, in turn, increases the load on the forefoot [31].

Similarly to the study described by Garrido et al. [39] we have observed an increase in recorded maximum toe force that would be a subject of continuous improvement in time. Garrido's study also shows that asymmetry regarding propulsion and take-off phases is substantial during the first year after surgery, progressing to normality after this period of time. These results do not correspond with the previous research by Naim et al. [44,40] who studied the evolution of patients' recovery between 8 and 48 months after surgery. In their study, albeit no statistically significant differences between the injured leg and the healthy one were found when the reaction forces of the forefoot against the floor were measured, yet still the difference in values was noted. At the same time no significant variations were observed in relation to plantar flexion in ankle, the period of stepping phase, twisting period on foot and base reaction pressure on heel between the intact and traumatic sides which might indicate a significant elongation in Achilles tendon.

Significant attribute and uniqueness of this study is that it has been based on a uniform rehabilitation protocol completed by all patients. Contrary to rehabilitation programs of Achilles tendon presented in the literature, where full weight bearing in a functional split synthetic cast in equinus was permitted immediately following surgery, our patients started weight bearing later (at six weeks post-op) and were additionally secured from re-injury by a Walker boot worn for next the six weeks. The rehabilitation protocol was being commenced two days post-op in all cases and consisted of plantar strengthening exercises. The non-weight bearing time was fulfilled with manual therapy sessions that decreased joint stiffness and tendon adhesions [34]. The low values of questions in ATRS, related to running and jumping, were correlated with late permission of dynamic exercises during rehabilitation process due to Achilles tendon tissue's healing. Despite of long immobilization, patients have achieved the same or better scores in ATRS and recovered correct walking patterns after six and twelve months after surgery [42-44].

Although the treatment was limited to only one type of surgery and the follow-up period is limited, the early results are promising. In the future longer follow-up is to be considered and compared with the groups of patients undergoing different kinds of surgical repairs as well as to non-surgically treated ruptures.

Conclusions

In conclusion, we coincide with other authors [45-47], that the open three-bundle Achilles tendon reconstruction provides good results in the treatment of acute ruptures of the Achilles tendon, restoring the ankle mobility, as well as gait strength and stability. Despite its relative technical complexity resulting from the inclusion of partial gait analysis (not including 3D analysis), the protocol with all related monitoring procedures i.e. ultrasound and clinical evaluation, shows great potential of becoming a tool that would objectively assess the progression of patients' recovery.

In our experience, spatial and kinetic gait analysis was a useful tool that allowed us to study and quantify the function after Achilles tendon ruptures treated with an open technique.

Nevertheless, we believe that stronger recommendations about management of this condition will require a large randomized controlled trial comparing the different operative and conservative strategies.

References

1. P Szaro, G Witkowski, R Smigielski, P Krajewski, B Ciszek, et al. (2009) Fascicles of the adult human Achilles tendon - an anatomical study, Ann Anat. 191: 586-593.
2. R Śmigielski (2008) Management of partial tears of the gastro-soleus complex, Clinics in Sports Medicine 27: 219-229.
3. C N Maganaris, M V Narici, N Maffulli (2008) Biomechanics of the Achilles tendon, Disabil Rehabil 30: 1542-1547.
4. S P Magnusson, M V Narici, C N Maganaris, M Kjaer (2008) Human tendon behaviour and adaptation, in vivo, J Physiol 586: 71-81.
5. P Sadoghi, C Rosso, V valderrabano, A Leithner, P Vavken, et al. (2012) Initial Achilles tendon repair strength-synthesized biomechanical data from 196 cadaver repairs, Int Orthop. 39: 1947-1951.
6. A Gigante, A Moschini, A Verdenelli, M Del Torto, S Ulisse, et al. (2008) Open versus percutaneous repair in the treatment of acute Achilles tendon rupture: a randomized prospective study, Knee Surg Sports Traumatol Arthrosc. 16: 204-209.
7. B D Twaddle, P Poon (2007) Early motion for Achilles tendon ruptures: is surgery important? A randomized, prospective study, Am J Sports Med. 35: 2032-2038.
8. M Weber, M Niemann, R Lanz, T Muller (2003) Nonoperative treatment of acute rupture of the achilles tendon: results of a new protocol and comparison with operative treatment, Am J Sports Med. 31: 685-691.
9. S Riedl, L Sandberger, K Nitschmann, PJ Meeder, (2002) Suture of fresh Achilles tendon rupture. Comparison of open with percutaneous suture technique, Chirurg. 73: 607-614.
10. F Ceccarelli, L Berti, L Giuriati, M Romagnoli, S Giannini, et al. (2007) Percutaneous and minimally invasive techniques of Achilles tendon repair, Clin Orthop Relat Res. 458: 188-193.
11. J R Lansdaal, J C Goslings, M Reichart, G A Govaert, K M van, et al. (2007) Scherpenzeel, R. Haverlag, K.J. Ponsen, The results of 163 Achilles tendon ruptures treated by a minimally invasive surgical technique and functional aftertreatment, Injury 38: 839-844.
12. N Maffulli, C Tallon, J Wong, K Peng Lim, R Bleakney, et al. (2003) No adverse effect of early weight bearing following open repair of acute tears of the Achilles tendon, J Sports Med Phys Fitness. 43: 367-379.
13. J Wong, V Barrass, N Maffulli, (2002) Quantitative review of operative and nonoperative management of achilles tendon ruptures, Am J Sports Med. 30: 565-575.
14. D M van der Eng, T Schepers, J C Goslings, N W Schep (2013) Rerupture rate after early weightbearing in operative versus conservative treatment of Achilles tendon ruptures: a meta-analysis, J Foot Ankle Surg. 52: 622-628.
15. T Nyyssönen, H Saarikoski, J P Kaukonen, P Lüthje, H Hakovirta, et al. (2003) Simple end-to-end suture versus augmented repair in acute Achilles tendon ruptures: a retrospective comparison in 98 patients, Acta Orthop Scand. 74: 206-208.
16. S Giannini, M Girolami, F Ceccarelli, F Catani, S Stea, et al. (1994) Surgical repair of achilles tendon ruptures using polypropylene braid augmentation 15: 372-375.
17. J L Jaakkola, W C Hutton, J L Beskin, G P Lee (2000) Achilles tendon rupture repair: biomechanical comparison of the triple bundle technique versus the Krakow locking loop technique, 21: 14-17.
18. J L Jaakkola, J L Beskin, L H Griffith, G Cernansky (2001) Early ankle motion after triple bundle technique repair vs. casting for acute Achilles tendon rupture, 22: 979-984.
19. N Olsson, K Nilsson-Helander, J Karlsson, B I Eriksson, R Thomée, et al. (2011) Major functional deficits persist 2 years after acute Achilles tendon rupture, Knee Surg Sports Traumatol Arthrosc. 19: 1385-1393.
20. M L Costa, D Kay, S T Donell, (2005) Gait abnormalities following rupture of the tendo Achillis: a pedobarographic assessment, J Bone Joint Surg Br. 87: 1085-1088.
21. R Don, A Ranavolo, A Cacchio, M Serrao, F Costabile, et al. (2007) Relationship between recovery of calf-muscle biomechanical properties and gait pattern following surgery for achilles tendon rupture, Clin Biomech (Bristol, Avon). 22: 211-220.
22. I M Garrido, J C Deval, M N Bosch, D H Mediavilla, V P Garcia, et al. (2010) Treatment of acute Achilles tendon ruptures with Achillon device: clinical outcomes and kinetic gait analysis, Foot Ankle Surg. 16: 189-194.
23. A Rosińska, M Syrek (2016) carolina pl carolina.pl/START. [online] https://carolina.pl/wp-content/uploads/2016/09/Start_Rehabilitacja-Sciegna-Achillesa_publikacja.pdf.
24. S Gitto, A Guja Draghi, Ch Bortolotto, F Draghi (2016) Sonography of the Achilles tendon after complete rupture repair. What the radiologist should know, J Ultrasound Med. 35: 2529-2536.
25. B Ciszkowska-Łysoń, R Śmigielski, U Zdanowicz, M Drwięga, M Bień, et al. (2010) Role of ultrasonography in diagnosis of Achilles tendon partial ruptures, Congress ECR 2010, Poster nr: C-2380 [online] https://dx.doi.org/10.1594/ecr2010/C-2380.
26. A Rosińska, R Śmigielski, B Ciszkowska-Łysoń (2015) Significant role of ultrasound imaging as biofeedback tool allowing for initial design and further modification of original physiotherapy protocol created for patients who underwent Achilles tendon reconstruction, Congress ECR 2015, Poster nr: C-2190 [online] https://dx.doi.org/10.1594/ecr2015/C-2190.
27. B Ciszkowska-Łysoń, U Zdanowicz, A Rosińska, M Syrek, R Smigielski, et al. (2018) Establishing MR and ultrasound based model of a properly healing Achilles tendon allowing to properly determine the healing stage of the structure: preliminary findings, Congress ECR Poster nr: C-3209 [online] https://dx.doi.org/10.1594/ecr2018/C-3209.
28. S Gitto, A Guja Draghi, Ch Bortolotto, F Draghi (2016) Sonography of the Achilles Tendon After Complete Rupture Repair: What the Radiologist Should Know, J Ultrasound Med. 35: 2529-2536.
29. K Nilsson-Helander, R Thomeé, KG Silbernagel, P Thomeé, E Faxén, et al. (2007) The Achilles tendon Total Rupture Score (ATRS): development and validation, Am J Sports Med. 35: 421-426.
30. M S Hansen, M Christensen, T Budolfsen, T F Østergaard, T Kallemose, et al. (2016) A Troelsen, K.W. Barfod, Achilles tendon Total Rupture Score at 3 months can predict patients' ability to return to sport 1 year after injury, Knee Surg Sports Traumatol Arthrosc. 24: 1365-1371.
31. R K Marti RK, C van der Werken, P R Schütte, T J Bast (1983) Operative repair of ruptured Netherlands J Surg. 35: 61-68.
32. A P Chan, Y Y Chan, D T Fong, PY Wong, H Y Lam, et al. (2011) Clinical and biomechanical outcome of minimal invasive and open repair of the Achilles tendon, Sports Med Arthrosc Rehabil Ther Technol. 20; 3: 32.
33. K G Silbernagel, R Willy, I Davis (2012) Preinjury and postinjury running analysis along with measurements of strength and tendon length in a patient with a surgically repaired Achilles tendon rupture, J Orthop Sports Phys Ther. 42: 521-529.
34. P Sharma, N Maffulli (2005) Tendon injury and tendinopathy: healing and repair, J Bone Joint Surg Am. 87: 187-202.

35. N Follak, D Ganzer, H Merk (2002) The utility of gait analysis in the rehabilitation of patients after surgical treatment of Achilles tendon rupture, Eur J Orthop Surg Traumatol. 12: 90-95.
36. H Alfredson, T Pietilä, L Ohberg, R Lorentzon (1998) Achilles tendinosis and calf muscle strength. The effect of short-term immobilization after surgical treatment, Am J Sports Med. 26: 166-171.
37. B R Mandelbaum, M S Myerson, R Forster (1995) Achilles tendon ruptures. A new method of repair, early range of motion, and functional rehabilitation, Am J Sports Med. 23: 392-395.
38. M Syrek, R Śmigielski, M Staniszewski, M Wychowański (2019) The characteristics of plantar flexors and dorsiflexors strength in patients after complete three-bundle Achilles tendon reconstruction, Advances in Rehabilitation. 2: 37-45.
39. I M Garrido IM, J C Deval, M N Bosch, D H Mediavilla, VP Garcia, et al. (2010) Treatment of acute Achilles tendon ruptures with Achillon device: clinical outcomes and kinetic gait analysis, Foot Ankle Surg. 16: 189-194.
40. F Naim, A Simşek, S Sipahioğlu, E Esen, G Cakmak, et al. (2005) Evaluation of the surgical results of Achilles tendon ruptures by gait analysis and isokinetic muscle strength measurements, Acta Orthop Traumatol Turc. 39: 1-6.
41. A N Agres, G N Duda, T J Gehlen, A Arampatzis, W R Taylor, et al. (2015) Increased unilateral tendon stiffness and its effect on gait 2-6 years after Achilles tendon rupture, Scand J Med Sci Sports. 25: 860-867.
42. N Olsson, KG Silbernagel, BI Eriksson, M Sansone, A Brorsson, et al. (2013) Stable surgical repair with accelerated rehabilitation versus nonsurgical treatment for acute Achilles tendon ruptures: a randomized controlled study, Am J Sports Med. 41: 2867-2876.
43. U Kim, Y S Choi, GC Jang, YR Choi (2017) Early rehabilitation after open repair for patients with a rupture of the Achilles tendon, Injury. 48: 1710-1713.
44. J A Zellers, D H Cortes, P Corrigan, L Pontiggia, K G Silbernagel, et al. (2018) Side-to-side differences in Achilles tendon geometry and mechanical properties following achilles tendon rupture, Muscles Ligaments Tendons J. 7: 541-547.
45. J D Calder, T S Saxby, Early (2005) active rehabilitation following mini-open repair of Achilles tendon rupture: a prospective study, Br J Sports Med. 39: 857-859.
46. H G Jung, K B Lee, S G Cho, T R Yoon (2008) Outcome of achilles tendon ruptures treated by a limited open technique, Foot Ankle Int. 29: 803-807.
47. R Bevoni, A Angelini, G D'Apote, L Berti, I Fusaro, et al. (2014) Long term results of acute Achilles repair with triple-bundle technique and early rehabilitation protocol, Injury 45: 1268-1274.