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Achilles Tendon Open Surgical Treatment With Platelet-Rich Fibrin Matrix Augmentation: Biomechanical Evaluation

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A R T I C L E I N F O

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A B S T R A C T

The relationship between surgical technique and ankle biomechanical properties after surgery for acute rupture of the Achilles tendon (ATR) has not yet been fully investigated. Platelet-rich fibrin (PRF) matrices seem to play a central role in the complex processes of tendon healing. Our aim was to analyze the biomechanical characteristics, stiffness, and mechanical work of the ankle during walking in patients who had undergone surgery after ATR with and without PRF augmentation. We performed a retrospective review of all consecutive patients who had been treated with surgical repair after ATR. Of the 20 male subjects enrolled, 9 (45%) had undergone conventional open repair of the Achilles tendon using the Krackow technique (no-PRF) and 11 (55%) had undergone surgery with PRF augmentation. An additional 8 healthy subjects were included as a control group. A gait analysis evaluation was performed at 6 months after surgery. The percentage of the stance time of the operated leg, double-support time of the healthy leg, and net work of the ankle during the gait cycle showed statistically significant differences between the no-PRF and the healthy group ($p < .005$). No differences were found between the PRF and healthy groups. Treatment with suture and PRF augmentation could result in significant functional improvements in term of efficiency of motion.

The Achilles tendon (AT), because of its morphology, anatomy, and function, is often implicated in pathologic processes that could bring to an acute rupture (1–4). To date, agreement is lacking regarding the optimal treatment of acute AT rupture (ATR), and different types of interventions, including open and minimally invasive surgery and nonoperative treatment, have been considered as possible therapeutic options (5). Nonoperative management implies the risk of tendon repeat rupture and poor functional outcomes, resulting in a lengthened tendon, with decreased push-off, muscle weakness, and, eventually, gait abnormalities (6). However, surgery allows patients to fully recover their strength and function within a short period. Recently published meta-analyses of randomized control trials suggested that open surgical treatment of ATR can reduce the risk of repeat ruptures compared with nonoperative treatment (7). However, open surgery carries significant risks of surgical complications, including surgical site infections, nerve injuries, and skin adhesions (6–9). Minimally invasive procedures should reduce the risk of surgical complications and retain other benefits of surgical treatment, in particular, functional improvements with less time away from work and sports (7–9). In contrast, some studies have demonstrated no significant differences in strength or repeat rupture rates between operative and nonoperative treatment of Achilles tendon ruptures when nonoperative patients underwent an accelerated rehabilitation protocol (10). Furthermore, recent studies have shown that platelet-rich fibrin (PRF) could be a safe strategy to accelerate tendon cell proliferation healing, stimulate the synthesis of type I collagen, and promote neovascularization both in vivo and in vitro (11). Anitua et al (10) explored the relevance of applying PRF matrices during open surgery in a group of athletes. They found that athletes receiving PRF

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recovered their range of motion earlier, did not develop wound complications, and required less time to resume gentle running and to resume training activities (10). PRF matrices consist of a concentrate of autologous platelets on a fibrin membrane without added external factors (12). Other studies have reported the potential effect of PRF on impaired wound healing (13), which is considered the major potential complication associated with operative treatment of ATR (14,15). Local application of autologous PRF has been identified as playing key roles in tendon healing (16–21), and its use has been proposed as a strategy for enhancing the cellular response to injury within the tendon and, ultimately, the quality of repair. However, despite promising results from animal models, the application of PRF during tendon surgery in humans has shown poor results, with short-term outcomes not significantly different from those obtained with standard surgery (22,23). However, when assessing the success of tendon repair, long-term results are required to determine whether a tendon has regained its biomechanical and functional properties. Starting from 2012, PRF has been routinely used in combination with suture repair for all cases of ATR in our orthopedics surgery and traumatology department. Also, the gait of all patients who undergo AT surgery is analyzed in our movement analysis laboratory. Therefore, we conducted a retrospective analysis across a period in which 2 different surgical approaches to ATR were (i.e., AT suture without or with PRF). We assumed that if these 2 treatments affected tendon healing differently, this would also result in a difference in the mechanical parameters of the repaired tendons and, consequently, their biomechanical properties during walking. Don et al (24) suggested that alterations in the mechanical parameters of the Achilles tendon can lead to changes in muscle activation and, hence, the coordination of motion during gait. They observed that subjects with greater passive stiffness exhibited altered muscle activation patterns that influenced ankle range of motion and increased co-contraction (24).

The goal of operative treatment is to minimize complications related to the surgery and promote healing with early functional recovery that does not compromise repair. Fully understanding the influence of PRF therapy on healing is an area of developing research. Thus, the aim of the present study was to retrospectively analyze the biomechanical characteristics, stiffness, and mechanical work of the ankle during walking in a group of patients who had undergone surgical reconstruction of the Achilles tendon for acute ATR, with or without the addition of PRF during surgery.

Patients and Methods

Participants

We analyzed the database of our movement analysis laboratory to retrospectively select male patients who had undergone clinical gait analysis ≥6 months after surgery for the reconstruction of the AT after ATR. The eligibility criteria were completion of a full-body clinical gait analysis and treatment by suture techniques from Krackow, with or without PRF augmentation, at our orthopedics and traumatology department, from 2010 to 2014. Since 2012, all the procedures of AT reconstruction using the Krackow end-to-end suturing technique have been performed with the addition of PRF in the surgical site. The patients treated with PRF augmentation had undergone surgery in the latter period with respect to patients treated without PRF. The clinical medical records of all patients fulfilling the inclusion criteria were screened, and potential participants were excluded if they had a history of previous or contralateral ATR, breaks in the myotendinous junction, tendonitis in the contralateral AT, peripheral neuropathy of the lower limb, and neurologic and/or rheumatologic conditions that can result in gait alterations.

All the procedures were performed in accordance with the ethical standards of our institutions, and all subjects signed a document of informed consent.

Surgical Procedure

All the patients considered in the present study had undergone reconstruction of the Achilles tendon using the Krackow end-to-end suturing technique (25), and the approach for all cases was through a posterior-medial incision. All the procedures were performed by the same orthopedic surgeon (M.G.), with >10 years of experience in AT surgery. All the patients treated with PRF had an 8-mL blood sample taken through a tube containing sodium citrate to inhibit the coagulation cascade and a gel that allows, during the centrifugation process, the separation of

1. The red blood cells, which settle on the bottom of the tube (deep layer of waste)
2. The white blood cells and platelets, which form the so-called buffy coat (middle layer), resting on the gel
3. The noncellular components of the plasma on the surface

The samples were subjected to centrifugation at 3000 rpm for 10 minutes. The protocol used for the analyzed patients included specific jellifying agents, such as calcium gluconate and batroxobin, an enzyme that cleaves fibrin peptide, to induce fibrin polymerization. The final product has a density of fibrin matrix, which is strong enough for application as fibrin glue. The PRF was then applied over the suture site. All patients during the postoperative period underwent the same standard rehabilitation protocol (Table 1).

Biomechanical Analysis

Gait analyses were performed in a standard gait laboratory equipped with 8 infrared cameras (ELITE System BTS, Milan, Italy) and 2 Kistler platforms (Kistler Instruments, Winterthur, Switzerland). Retroreflective spherical markers were placed over prominent bone landmarks to determine the joint centers and segment axis (26). The participants walked barefoot at a self-selected speed along a plain surface approximately 10 m long. Three valid trials (i.e., those in which the subject stepped on the force platforms without adjusting the stride length) were acquired for each subject and the mean value was considered for time per distance and the kinematic and kinetic data throughout the analysis. All kinematic and kinetic data were acquired and digitized at a sampling rate of 100 Hz.

MATLAB software, version 7.0.4 (MathWorks, Natick, MA) and Analyzer software (BTS, Milan, Italy) were used for data processing. A set of spatial-temporal, kinematic, and kinetic outcome measures were calculated for the purposes of the present study. The mean walking speed (m/s), cadence (step/min), stance time (percentage of gait cycle), double support time (percentage gait cycle), swing speed (m/s), and stride length (m) were computed to determine the general characteristic of the walking performance.

For the kinematic parameter, we considered the ankle range of motion in the sagittal plane throughout the gait cycle. The angle of dorsi-plantarflexion of the ankle in our model was measured as the absolute angle (in degrees) between the axis of the leg and the axis of the foot. A 0° ankle position was defined as the point at which the foot segment was perpendicular to the tibia segment. The dorsiflexion angle was considered positive.

The internal dorsi-plantarflexor moment of the ankle has been calculated according to the method of the inverse dynamics (27) and normalized to the body weight [(N × m)/kg]. A moment-angle graph of the ankle during the stance phase of gait cycle was drawn, and the mechanical work (W) produced by the internal forces was calculated as the area under the curve (Fig.) (28). During the rising phase of the loop, the internal moment is plantarflexion and the joint is dorsiflexing; thus, the area beneath

Table 1
Rehabilitation protocol

Period	Rehabilitation Program
0 to 3 wk	Adjustable boot locked out at 30° of plantarflexion; non-weightbearing for 3 wk; pain and edema control; gentle foot movement in boot allowed
4 to 8 wk	Manual full passive range of motion; light active dorsiflexion until gentle stretch of Achilles tendon; slowly increase passive range of motion and stretch on the Achilles tendon; proprioception exercises; intrinsic muscle strengthening; gradually increase weightbearing, as tolerated
8 to 12 wk	Full weightbearing, gait training; wear regular shoe; begin and gradually increase active and resistive exercises of the Achilles tendon; begin cycling and swimming activities
3 to 6 mo	Progress training to jogging/running, jumping, and eccentric loading exercises; noncompetitive sporting activities
8 to 9 mo	Return to physically demanding sport and/or work