Achilles Tendon Ruptures: Limited Incision Repair

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Abstract: Achilles tendon ruptures are a common injury, and a steadily rising incidence has been noted since the middle of the 20th century. Conservative management is a recognized treatment method, but it bears a higher risk of tendon rerupture compared with surgical treatment. Standard open surgery, however, can lead to complications, such as wound complications and surgical site infection. Hence, efforts have been put into the development of alternative surgical techniques to lower the risk of complications. In the 1970s, Ma and Griffith introduced percutaneous tendon repair by limiting the incision to 6 stab wounds. Subsequently, the open and percutaneous approaches have been merged into limited incision procedures, which include the advantages of both: visual control as well as smaller incisions. The primary limited incision approach consisted in using twisted Kirschner wires as suture guides. They were replaced by specific guiding instruments, such as the Achillon and Percutaneous Achilles Repair System (PARS) device, which rendered the limited incision procedure safer and more standardized. The instruments consist of 4 arms: The outer arms facilitate needle introduction by predetermined holes, the inner arms allow for suture passage exclusively underneath the tendon sheath. The minimally invasive procedures may reduce complication rates, especially regarding wound healing and infection. Limited incision techniques also may reduce sural nerve injury.

Level of Evidence: Diagnostic Level V—expert opinion. See Instructions for Authors for a complete description of levels of evidence.

Key Words: Achilles tendon rupture, limited incision repair, minimally invasive Achilles, Achillon, PARS

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LIMITED INCISION

Acute Achilles tendon ruptures are a common injury, and a steadily rising incidence has been noted since the middle of the 20th century.[1–3] Incidence rates > 50 per 100,000 person-years have been reported in men.[2] This trend may result from increasing sports participation in older adults.[2] In addition, the number of patients of an advanced age has been rising.[2] This patient group is at a higher risk of sustaining an Achilles tendon rupture during activities of daily living and is more prone to developing postsurgical complications, for example, wound infections.[4]

These circumstances confront orthopedic surgeons with a wide variety of patients' needs and require individual treatment decisions. Conservative management avoids potential postsurgical complications, but it is associated with a higher rate of Achilles tendon rerupture.[5] Traditional open surgery, however, bears risk of surgical complications, such as surgical site infection.[6] In an attempt to improve surgical outcomes, diverse percutaneous approaches and techniques based on limited incision have been elaborated successfully since the 1970s.[7–9] While rerupture rates are equally low as in open repair, the number of infections as a major complication has been reduced.[10] Limited incision surgery aims to incorporate the advantages of open and percutaneous repair by permitting a visualization of the tendon repair.

History (Ma Griffith)

Percutaneous Achilles tendon repair for acute closed ruptures was introduced by Ma and Griffith in the 1970s. They aimed to reduce common complications of open repair, such as adhesions and infection, by limiting the incision to several small stab incisions.

Starting at the proximal part of the ruptured tendon, the first 2 incisions are performed about 2.5 cm away from the defect. They are located medially and laterally and initially penetrate only the skin and subcutis. A small hemostat is passed through to separate the tendon sheath from the overlaying tissue.

Thereafter, a straight needle of 7.6 cm in length with a nonresorbable thread (minimum 30 cm in length) is introduced through the lateral stab wound and exits through the medial stab wound, piercing the Achilles tendon perpendicularly to its fibers' course. The free suture ends on both sides are left equally long and threaded each with a needle.

The needles are reinserted pointing 45 degrees distally and passed through the tendon. Before piercing the skin on the contralateral side, the exit sites are prepared by a superficial blade incision and enlarged with a hemostat. Pulling the free suture ends puts the proximal suture under tension. The lateral thread is then equipped with a curved needle, which is reinserted laterally. The needle is passed solely through the subcutaneous tissue next to the rupture gap and exits distally on the ipsilateral side (Fig. 1A). The exit site is enlarged as described earlier. It is located at the midportion of the distal Achilles tendon stump, about 1.25 cm away from the gap. The curved needle is exchanged back for the straight needle. It is reinserted and passed through the Achilles tendon until it reaches the medial skin at the same height. The medial exit site is enlarged before passing the needle through the skin. The thread is put under traction to tighten the lateral suture.

Once more, the straight needle is exchanged for a curved one. It is passed back through the distal medial opening, through the subcutis, and exited proximally at the closest medial incision. Thereby, the 2 suture ends exit at the middle of the 3 medial incisions.

The Achilles tendon stumps are approximated by putting the suture ends under tension and tightening the knots while applying maximum plantarflexion to the foot. After cutting the suture, the knot settles within the subcutaneous tissue. A maximum of 3 knots is recommended by the authors to avoid the formation of tender nodule granulomas. Positioning the knot on the medial side of the ankle minimizes the risk of sural

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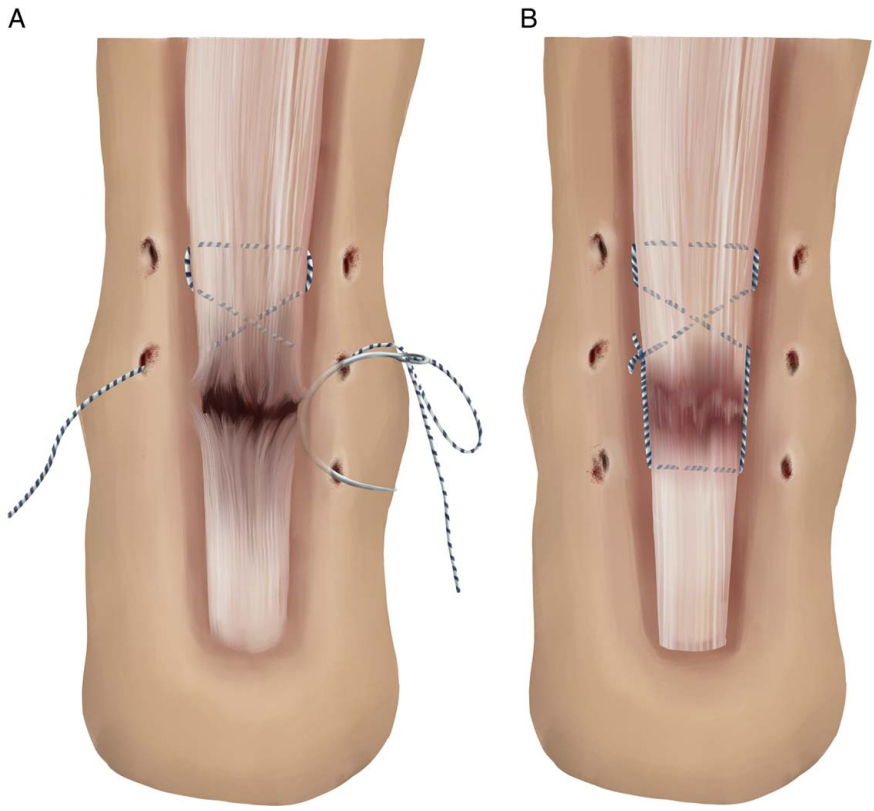

FIGURE 1. Percutaneous Achilles tendon repair by Ma and Griffith. A, Distal passage of the curved needle through the subcutis after having set the proximal sutures. B, Final suture setting.

nerve irritation (Fig. 1B). No additional suturing of the skin is required.

Surgery is followed by 4 weeks of short leg equinus cast without weight-bearing, and additional 4 weeks of low-heel weight-bearing equinus cast. Nine weeks postoperatively, patients start with heel raise exercises targeting the triceps surae. Thirteen weeks after the surgery, patients are given instructions on calf stretching exercises.[7]

Current (Achillon, PARS)

By now, minimally invasive Achilles tendon repair has been improved and standardized by the elaboration of specific guiding instruments, for example, the Achillon device (Newdeal).[8]

The limited incision Achillon procedure can be considered as an upgrade of the technique by Kakiuchi, which was published in 1995. Kakiuchi merged the open and percutaneous approaches into one repair technique, which brought out the advantages of both approaches. The skin incision is limited to a longitudinal opening of 2 cm at the rupture site, which allows for visualization of the gap between the tendon stumps as well as control of the tendon reduction. The longitudinal orientation facilitates an elongation of the incision if necessary. Two bent and twisted Kirschner wires are introduced underneath the paratenon on both sides of the tendon. They serve as a guide to pass the suture transversely through the tendon (Fig. 2). However, the holes of the bent Kirschner wires are targeted without direct visual control, which may result in repeated attempts of inserting the needle correctly and in turn increase the risk of sural nerve damage.[11]

The Achillon device minimizes this risk as it predetermines the path trajectories of the needle. The device consists of 4 branches: The 2 inner branches are adapted to the Achilles tendon shape and therefore slightly v-shaped, the outer branches run in a parallel fashion. In addition, the device is provided with a micrometric screw to allow branch width adaption. The branches are provided with several small holes located at the same level to easily pass a straight needle through all branches. Preferably, holes located distant with regard to the tendon gap should be used for suturing to create a stable tendon repair. While the original device consisted of stainless steel, additional single-use instruments made of rigid polymer were developed soon after.

A longitudinal skin incision of up to 2 cm is preformed medially to the tendon rupture site. Underneath the subcutaneous tissue, the paratenon is incised and equipped with stay sutures. Following the careful inspection of the individual aspect of the tendon rupture, the 2 internal branches of the Achillon device are inserted underneath the tendon sheath pointing proximally. While advancing the branches until complete introduction, the distance between them is gradually widened by adjusting the integrated micrometric screw. The proximal tendon stump is retained distally by a small clamp. The surgeon can palpate the tendon in between the branches and thereby ascertain the correct final positioning of the instrument. Subsequently, 3 individual, transverse sutures are performed proximally. For every suture, a straight needle of 12 cm in length and a diameter of 1.6 mm is equipped with a slowly resorbable number 1 thread and passed through all 4 Achillon branches (Fig. 3A). The device is retracted, and simultaneously, the distance between the branches is reduced to the initial position. Thereby, all sutures pass beneath the tendon sheath, exclusively through the Achilles tendon, and exit on

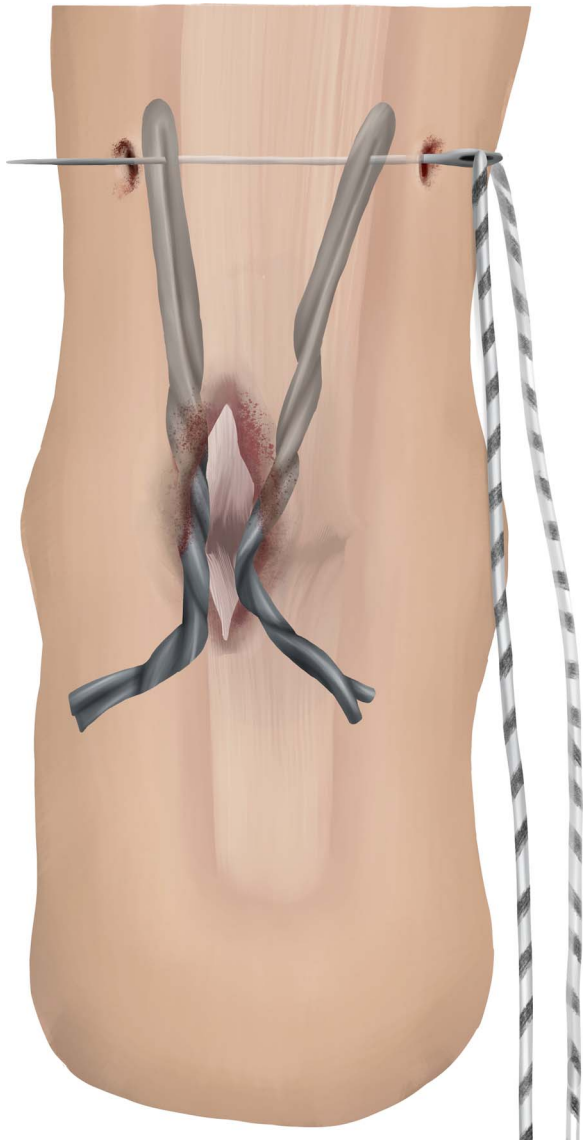

FIGURE 2. Limited incision Achilles tendon repair by Kakiuchi: Two Kirschner wires are introduced underneath the paratenon as suture guides.

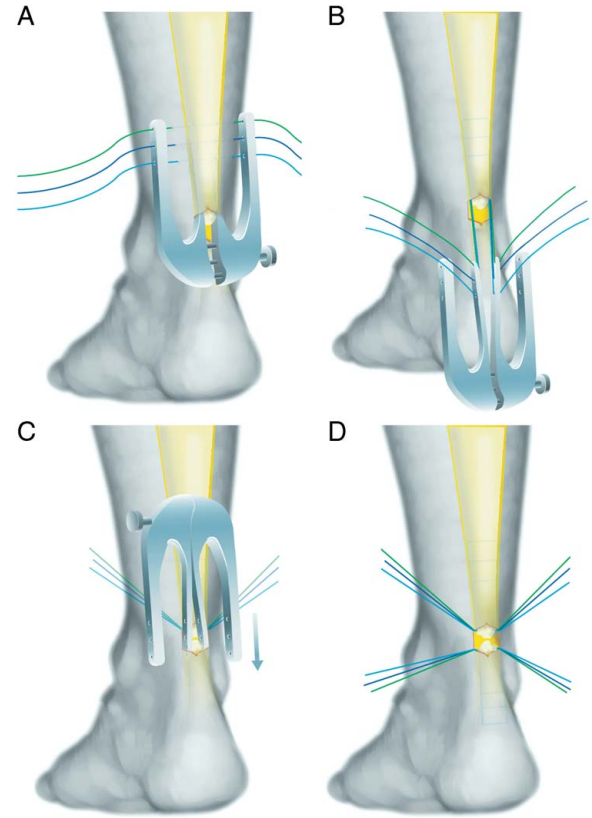

FIGURE 3. Achillon Limited incision Achilles tendon repair. A, The proximal tendon stump is equipped with 3 sutures. B, The Achillon device is retracted. The sutures pass in a peritendinous fashion and exit through the initial incision. C, The instrument is inserted in distal direction until further introduction is limited by the calcaneus. D, The distal tendon stump is prepared in the same fashion as proximally. After device retraction all suture ends exit at the initial incision and are arranged for knotting while holding the foot in moderate plantarflexion.

both sides through the initial incision near the tendon gap (Fig. 3B). Each thread is clamped to ensure correct knotting in the end. The instrument is then inserted in distal direction until further introduction is limited by the calcaneus (Fig. 3C). The same steps of tendon stump preparation are performed distally (Fig. 3D). Subsequently, the corresponding proximal and distal suture ends are tensioned, paired, and knotted while holding the foot in moderate plantarflexion. Comparing the ankle position with the contralateral limb can help to reestablish the appropriate tension of the injured tendon. The paratenon and the skin are closed. The patient is equipped with a below-knee orthosis in a 30-degree plantarflexed position immediately after surgery.

This position is kept for 2 weeks, and patients are allowed for partial weight-bearing to up to 20 kg. From the third week on, patients are allowed to actively move their ankle (dorsiflexion limited to 0 degrees) without load, work on thigh strength, and train on an exercise bike. After 3 weeks, patients should have acquired neutral ankle position, the orthosis is fixed at 0 degrees plantarflexion, and patients are allowed to fully load the operated limb. Jogging is allowed 3 months after surgery. More strenuous physical activity is recommended from the seventh postoperative month on.[8]

Another approach similar to the Achillon technique is represented by the Percutaneous Achilles Repair System (PARS; Arthrex Inc.), which has been in use since 2010. While the former approach involves solely nonlocking sutures, the latter is augmented with locking sutures. They enhance resistance to cyclic loading and therefore may allow for earlier postoperative mobilization.[12] Analogous to the Achillon instrument, the PARS device consists of 4 arms. The incision is performed horizontally and 1 cm proximally to the rupture site. If necessary, the incision can be extended proximally or distally by an "L-shaped" incision or in proximal and distal direction by a "Z-shaped" incision. As in the Achillon approach, the inner arms of the device are advanced on both sides of the proximal tendon stump beneath the paratenon.[9,13] The holes of the instrument are numbered and designated either for usual repair sutures (1, 2, and 5) or sutures with loop ends (3, 4, 6, and 7) (Fig. 4). The sites 1 and 2 each are passed by a needle equipped with a repair suture. They run transversely through the tendon

FIGURE 4. Percutaneous Achilles Repair System (PARS) Limited incision tendon repair: The outer arm of the device has predetermined holes for repair suture (1, 2, 5) or loop end suture (3, 4, 6, 7) passage.

and exit the skin on the other side, resulting in equal suture ends medially and laterally. At the holes 3 and 4, loop sutures are introduced, which pass the tendon obliquely and therefore in a crisscross manner. At position 3, the loop end stays at the side of needle introduction. At position 4, the free end stays at the side of needle introduction, and the loop end is passed on to the other side. Thereby, the 2 loopholes are located on opposite sides (Fig. 5). Once the PARS device is pulled out, the suture ends of position 1 are clamped together. The remaining suture ends are arranged in the following order on each side: the end of suture number 2 proximally, followed by the loop end, and by the free end of the loop suture distally. The following step, which is performed on each side, serves to place the lock: The repair suture (number 2) is passed distally underneath the other 2 suture ends, then over the free end of the loop suture, and finally into the loop. Alternatively, the suture passing under and over can be repeated once more before passing it through the loop (Fig. 6). It should be pulled through for at least 4 cm to secure the shuttling. By pulling on the free ends of the loop sutures, both repair sutures are shuttled through the tendon and out on the other side. The repair suture ends are pulled to firmly

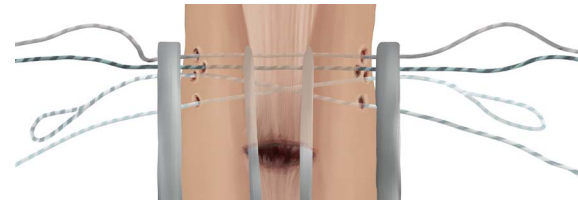

FIGURE 5. Percutaneous Achilles Repair System (PARS) Limited incision tendon repair: PARS device in situ with passed sutures at the proximal tendon stump.

lock the suture. The locking is successful if pulling on one side does not provoke any slipping of the opposite suture end. The same sutures are performed on the distal part of the ruptured tendon. Subsequently, the corresponding proximal and distal suture ends are tied while keeping the foot in moderate plantarflexion.[13,14]

It is possible to perform an additional suture through hole 5. Yet, it may display insufficient hold due to its proximity to the tendon gap and tendon fraying. Further suture variations exist, for example, performing an additional locking suture at the level of holes 5 (locking repair suture), 6, and 7 (corresponding loop sutures) or locking suture 1 as well as suture 2 by passing both threads together under and over and through the loop.[13,14]

The PARS procedure was further developed to avoid suture slippage near the rupture gap. The introduction of the Achilles Midsubstance SpeedBridge repair (Arthrex Inc.) in 2016 implied bony suture fixation to the calcaneus, which replaced suture knotting. The proximal tendon stump is prepared with the help of the PARS jig as described above. However, the same procedure is not performed distally. Instead, 2 longitudinal incisions of maximum 1 cm are made on both sides of the Achilles tendon right below the area of maximal convexity of the posterior calcaneal tuberosity. At each incision, a 3.5 mm drill and a drill guide are inserted. From the

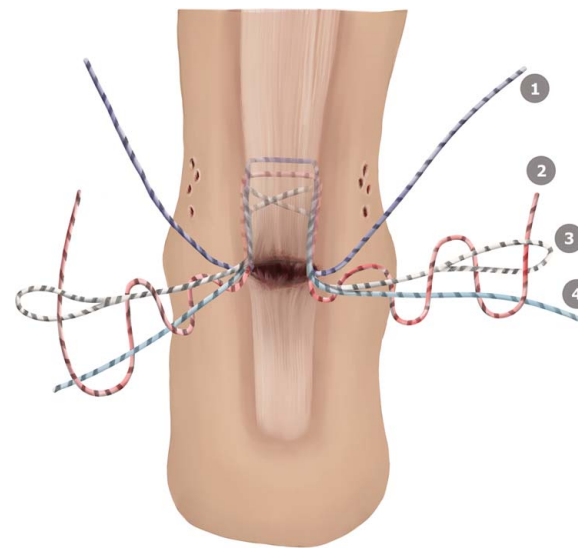

FIGURE 6. Percutaneous Achilles Repair System (PARS) Limited incision tendon repair: The suture lock is placed by passing the suture 2 (repair suture) once or twice underneath the sutures 3 (loop suture) and 4 (loop suture, free end), over suture 4, and into the loop of suture 3 (suture numbers are referring to the right side of the figure).

Achilles tendon centerline pointing distally, the drilling is slightly inclined in the coronal plane and slightly oriented from posterior to anterior (sagittal plane), for example, resulting in a lateral drill hole oriented from posterolateral to anteromedial and from proximal to distal. Drill holes of at least 19 mm depth are created and tapped for later 4.75-mm SwiveLock anchor insertion. A Banana SutureLasso is introduced at each incision site, passed through the tendon in proximal direction, and out at the initial proximal incision. It is used to pick up the proximal sutures, shuttle them distally through the tendon, and out at the distal incisions. Under visual control and with tendon palpation, the sutures are put under maximum tension to close the gap between both tendon stumps. Two 4.75-mm SwiveLock anchors are used to fix the sutures to the calcaneus at the predrilled holes. Simultaneously, plantarflexion is applied with regard to the contralateral ankle position. Maximal plantarflexion should be avoided as overtensioning the tendon is more likely with the Achilles Midsubstance SpeedBridge system due to the rigid anchor fixation.[13,14]

Outcomes and Complications

The cohort, which was described within the primary article on percutaneous Achilles tendon repair by Ma and Griffith, consisted of 18 patients and was followed for up to 40 months postoperatively. Apart from 2 minor complications, a tender nodule at the knot site and 1 case of a skin retraction dimple, Ma and Griffith did not observe any other complications, such as rerupture or infection. Twelve months postoperatively, 12 patients were available for plantarflexion strength assessment. They reached a mean record of 86% compared with the contralateral side.[7]

However, further research reported less favorable results.[15–17] By now, several attempts have been made to increase the safety of the procedure by modifying and reinforcing the original technique.[15,18–20] Moreover, real-time intraoperative ultrasonography has been introduced to improve suture positioning and confirm stump approximation.[18,20]

The Achillon approach was initially approved by a cadaveric study and subsequently performed on 87 consecutive patients in a prospective multicenter study. Three Swiss level-1 hospitals took part in the study. The mean age of the patients was about 37 years. The rupture was located 3 to 5 cm (range) above the calcaneal tuberosity. On average, the surgery was performed within 3 days after the initial trauma (maximum: 13 d) and took 27 minutes.

In total, 82 patients were available for follow-up evaluation. The follow-up time was 26 months on average and ranged up to 42 months. No major complications in terms of wound healing disturbances, infections, or sensory impairments were observed. Three reruptures were noted: 2 within the first 3 postoperative weeks in patients, who against recommendation did not wear the orthosis, and one in a patient sustaining an accident at 12 weeks postsurgery. The remaining patients reached a mean American Orthopaedic Foot and Ankle Society (AOFAS) score of 96 points at the latest follow-up. Functional tests did not detect any significant differences between the operated and contralateral limb, and all patients returned to their preinjury level of professional and sporting activities (including 5 members of Swiss national sports teams).[8]

Similar results were presented by Tasatan and colleagues in a mid-term 5-year follow-up of 20 patients treated with an Achillon-like device. No infections, wound healing disturbances, or sensory problems were existent. At 18 months postsurgery, the AOFAS score accounted for 99 points on average. Patients were followed up until the fifth postoperative year without any signs of pain or functional loss.[21]

A 2018 meta-analysis by Alcelik and colleagues compared the Achillon technique to open tendon repair and included over 200 patients per group. The overall complication rate was significantly smaller after the limited incision procedure with an odds ratio of 0.17 in favor of the Achillon procedure.[22]

One of the first reports on PARS outcomes was published in terms of a retrospective cohort study, which compared 101 consecutive PARS interventions with 169 open surgeries (Krackow suture). After a mean follow-up time of 9 months (minimum 3 mo), a trend towards less complications was observed in the PARS group. Its total complication rate was 5%, including superficial wound dehiscence and foreign-body reaction to the suture material. Regarding functional outcome at 5 months, 98% of the patients within the PARS group had returned to their baseline activities compared with 82% of the patients treated with the open procedure.[23]

When comparing standard open with limited incision procedures regarding complications, similarities can be found: Both are usually performed in <60 minutes, which may make general anesthesia and tourniquet-related complications negligible.[24]

In general, however, fewer complications have been reported after limited incision repair. A meta-analysis with over 350 patients and a mean follow-up time of 4 to 30 months showed a lower risk for delayed wound healing, infections, and ankle stiffness in patients treated with limited incision surgery compared with open surgery. Grassi and colleagues stated that for every 10 surgeries performed by limited incision instead of open procedures one infection could be avoided. Regarding sural nerve damage and rerupture rate, no difference was noted between open and limited incision procedures.[10]

Skin perfusion over the Achilles tendon plays an important role in surgical wound healing. It has been demonstrated to vary depending on the ankle positioning: Healthy subjects showed greatest perfusion at 20 degrees of plantarflexion. A mean fall of 35% and 15% was observed at 40 degrees of plantarflexion and in neutral position, respectively. These findings oppose excessive plantarflexion in postoperative casts, as it may increase the risk of wound necrosis and infection.[25]

The development of wound infection is associated with several factors, for example, diabetes, smoking, increased age, vascular complications, longer tourniquet time, and higher estimated blood loss.[4,26,27] Differences between infection rates as important as 0% versus 21% have been reported for percutaneous and open surgical approaches, respectively,[19] but most modern series of open repair do have a low infection rate.[6]

Controversy exists over the risk of sural nerve injury. On the one hand, techniques like Achillon or PARS imply final suture positioning underneath the tendon sheath and therefore rule out sural nerve entrapment. On the other hand, the blind needle passage through the guide does not guarantee a safe passage through all tissue layers without piercing the nerve. In a cadaveric study examining the Achillon device in proximal orientation, Aibinder and colleagues found sural nerve violation in 14.8% (n = 8) of all needle passes (n = 54). Yet, no complete transections or lasting nerve entrapments were observed, as all sutures passed out of the nerve once the instrument was withdrawn. Moreover, clinical outcomes have been considerably more favorable. Therefore, not every intraoperative nerve injury may lead to clinically perceivable, lasting complications, and it may be debated to which extent these results are of clinical relevance. In the same study, the amount of needle passes through the nerve varied depending on the degree of device rotation. Placing it in 30 degrees of external rotation with regard to the dissection table lead to significantly less nerve violation

compared with neutral position ($P = 0.038$) or 30 degrees of internal rotation ($P = 0.001$). However, manipulating the instrument's orientation should not compromise the biomechanical stability of the construct.[28] The influence of device rotation on the risk of nerve violation has been proven by further studies. Surgeons should be aware of the anatomic course and relationship of the Achilles tendon and sural nerve to minimize the risk of nerve damage and ensure a biomechanically strong tendon repair. These aspects were investigated in a magnetic resonance imaging study, which showed that the tendon runs in a twisted and externally rotated fashion instead of in a perfect medial-to-lateral plane. Therefore, it has been suggested to add about 10 degrees of external rotation (in relation to the bimalleolar axis) to the PARS device's final position next to the proximal tendon stump. The degree of external rotation of the device at the distal stump should account for about 15 degrees due to greater distal external rotation of the tendon. These adjustments may optimize the suture trajectory through the tendon.[29]

A limitation of the minimally invasive techniques is the restricted visualization of the rupture site. It may be more difficult to thoroughly repair associated structures, such as the paratenon. Similarly, the ability to adequately debride the degenerative tendon may be limited in Achilles tendon ruptures, which follow tendinosis. However, it is possible to elongate the incision proximally or distally if necessary.

The ability to resist against biomechanical strain after tendon repair has been evaluated by several studies. Demetracopoulos and colleagues analyzed cadaveric Achilles tendons repaired either by the Achillon or PARS technique. The specimens were stressed by cyclic loading, which simulated passive ankle motion (20 to 100 N, 1000 cycles, 1 Hz) in a first stage and walking in a 1-inch heel lift boot (20 to 190 N until a gap formation of 9.5 mm) in the second stage. While the same number of cycles provoked a 5 mm gap in both groups, significantly fewer cycles lead to the formation of a 2 and 9.5 mm gap in the Achillon group, with 16 cycles in Achillon versus 59 in PARS and 1066 in Achillon versus 1288 in PARS (median), respectively. Eventually, PARS specimens demonstrated greater resistance to maximum loading until failure than Achillon specimens ($P = 0.005$). While PARS repairs showed mostly suture breakage, Achillon sutures were typically pulled out of the tissue instead.[12] However, these differences may be less pronounced in the surgical environment, where optimal percutaneous suture placement is less evident than in open-approach specimen preparation as performed in the above-mentioned laboratory study.[30]

A similar analysis compared the resistance of the traditional Krackow suture, the PARS technique, and the knotless anchor secured PARS during cyclic loading (20 to 100 N, 1000 cycles, 1 Hz). The study showed a clear tendency towards a greater resistance in the knotless PARS repairs during cyclic loading as well as ultimate loading to failure, although without reaching statistical significance except for gap comparison at 1000 cycles ($P = 0.040$).[31]

In addition, in a study by Clanton and colleagues the longest survival during progressive loading was observed in cases of knotless repair as opposed to specimens treated with Krackow, Achillon, and traditional PARS. However, the mean ultimate failure strength was similar between the groups. Regarding early elongation after the first 10 loading cycles, open Krackow repair performed significantly better. Irrespective of the technique used, the first 10 cycles caused the majority of elongation.[30]

In case of very distal ruptures, anchor-related tendon repair may be of particular interest.[32]

Despite the results being mixed to some extent, they may be in favor of successful early rehabilitation, especially after techniques involving locking sutures and anchors, which may be of major importance in high-level athletes. An article by Byrne and colleagues presented the case of an elite bobsled pilot, who suffered an acute rupture of the Achilles tendon and was treated after 11 days with knotless anchor fixation at the calcaneum. He underwent an intensive early rehabilitation process and was able to compete on an international level during the fifth postoperative month, followed by participation in the Winter Olympic Games about 7 months after surgery. At the 12- and 24-month follow-up, the athlete did not present any impairments and was training at his preinjury level.[33]

While repair strength analyses in biomechanical laboratories can provide valuable insights, the results observed in the clinical setting are decisive. An important body of research suggests that surgery, including minimally invasive procedures, is associated with a lower rate of rerupture compared with conservative treatment.[5] Comparing operative to nonoperative treatment, the assumption of fewer reruptures after operative treatment has been challenged, notably by Willitis and colleagues. However, the authors noted that their study was underpowered. The power analysis was based on previously reported rerupture rates of 13% and 2.5% after conservative and surgical treatment, respectively. This implies a difference in rerupture rates > 5-fold, which could not have been detected by the study.[34] A recent meta-analysis, which evaluated complication rates reported by randomized controlled trials, found rerupture rates of 12.1% and 3.6% after nonsurgical and surgical (open and minimally invasive) treatment, respectively. Therefore, it supports previous data. In an analysis of studies, which focused on surgical tendon repair, the authors found equal rerupture rates after open and minimally invasive surgery (0%).[6] These findings are supported by a further meta-analysis, which demonstrated mean rates of tendon reruptures accounting for 1.5% after minimally invasive procedures (original and modified Ma Griffith, Achillon, Tenolig (FH ORTHO; modified Bunnel) and 2.5% after open repair.[35] A meta-analysis by Gatz et al,[24] which included the PARS procedure in addition, found similar results.

To conclude, several therapeutical approaches to acute closed ruptures of the Achilles tendon exist, each of them having their own advantages. Nonsurgical treatment shows the best results regarding complications other than rerupture. However, complications after surgical treatment, in particular wound infection, have been successfully reduced by developing minimally invasive procedures.[6]

As the risk of tendon rerupture has been decreased by surgery, and different surgical techniques do not vary greatly regarding rerupture rates, future research should focus on minimizing the risk of further complications, for example, nerve injury, as well as on optimizing rehabilitation protocols. The variety of treatment options allow for a patient-specific approach, targeting individual demands and considering the individual state of health. Especially patients with high demands may opt for minimally invasive surgery.

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