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Transfer of the Flexor Hallucis Longus Tendon for Neglected and Degenerative Tendo Achillis Rupture: A Prospective Clinical Study

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SUMMARY

Introduction. The Achilles tendon is one of the most frequently ruptured tendons in the human body. Surgical management commonly includes end to end repairs in acute tears, and chronic ruptures require autologous tendon transfer with Flexor hallucis longus or Flexor digitorum longus.

Methods. A longitudinal observational study was done on 22 confirmed cases of chronic Achilles tendon rupture. Two incision technique of FHL tendon transfer with no exposure/debridement of the Tendoachilles was incorporated and functional outcome with American Orthopaedic Foot and Ankle Society Ankle-Hindfoot score, modified RUPP and Achilles Tendon Total Rupture (ATRS) scores both pre- and post-operatively were evaluated. Wound healing time and complications, heel-floor distance, calf circumference, hallux function and morbidity, graft characteristics and anatomic variation of master Knot of Henry were evaluated. Patients were followed up and assessed at 6 weeks, 3 months, and 6 months post-operatively.

Results. The mean length of the FHL graft obtained from 2 incision technique was 8.09 cm. There was significant improvement in the Heel Rise Height Index from 7 to 63% ($p < 0.0001$), mean AOFAS ankle-hindfoot score from 43.9 to 89.6 ($p < 0.001$), mean ATRS Score from 19.6 to 79 ($p < 0.0001$) and mean Hallux MTP-IP scores to 96.3 ($p < 0.0001$) at 6th month follow up was found. 13 (59%) had "Excellent" modified RUPP scores. 20 (90.9%) had Type I variation while 2 (9.1%) had Type II variation in MKH. Mean length of the graft obtained was 8.09cm. Mean wound healing time was about 13 days and only one had wound complication.

Conclusions. FHL tendon transfer has advantages of requiring minimal dissection, being stronger than FDL and PB and it is an in-phase transfer with the same axis of contraction.

KEY WORDS

Chronic Tendoachilles rupture; FHL tendon transfer; 2 incision technique; functional outcome; anatomical variation of Master Knot of Henry.

BACKGROUND

The Gastrocnemius-soleus complex (triceps surae) traverses both the ankle and the knee joint and consolidates as Achilles tendon, which is the largest, strongest and one of the most common tendons to get ruptured. It is innervated by tibial nerve (1). During various activities like walking, running and jumping, the Achilles tendon unit undergoes both eccentric lengthening and concentric contracture. A relatively avascular zone of 2-6 cm proximal to the insertion was described by Lagergren and Lindholm (2). The cause of tendinopathy is multifactorial, including inflammatory, vascular, biomechanical and degenerative caus-

es. Mechanical overuse, as seen in athletes with repetitive microtrauma to the tendon, old age, the anomalous blood supply, intralesional steroid injections, have been implicated in the weakening of the tendon which makes them more prone for ruptures (3). Patient derived outcome scales have become important to surgeons and researchers as they are a measure of improvement in function following the surgical intervention. Comparing the results of different clinical/surgical interventions will help in constant improvement in the operative techniques. Chronic ruptures are defined as the ruptures which occur after 4-6 weeks following the injury (4). 25% of acute ruptures are missed and progress to chronic Achilles tendinopathy. Patients having Tendoachilles rupture have chronic ankle pain and are unable to walk pain free. They lose the ability to stand on their toes on the affected side, although standing on both toes may be possible with unilateral cases. Patients will not be able to run, as they do not get enough strong push-off by plantar flexion of the ankle. The management of the ruptured tendon is a challenging one. The management of chronic Tendoachilles ruptures is usually different from that of end-to-end suturing done for acute ruptures, as tendon's ends in chronic tears are retracted, undergo degenerative calcification and are atrophied with short and fibrous distal stumps (4). Various procedures have been performed for chronic Tendoachilles rupture including autologous tendon transfer, V-Y myotendinous advancement, Proximal Tendoachilles turndown and other surgeries like transfer/augmentation with tendons of Peroneus Brevis (PB), Flexor Digitorum Longus (FDL), Flexor Hallucis Longus (FHL) tendon. Other materials used are Carbon fiber, Dacron weave and Marlex mesh.

All these surgical procedures have been shown to yield satisfactory clinical results. FHL has mechanical advantage over the other autologous tendon transfers and it is shown to be stronger than the Peroneus Brevis (PB) and twice as strong as the Flexor digitorum longus (FDL) tendon. Another advantage is that it is an isophasic transfer (active in the same phase as the Tendoachilles) and its axis of contraction is the same as that of Tendoachilles (5). FHL, which is also known as the beefy muscle, also provides vascularity to the Achilles tendon. It helps to maintain normal ankle function, decreasing wound healing time, weight bearing, and decrease the wound complications associated with it. Literature review suggests various surgical interventions, although no single technique has been shown to be clearly superior. There exists an anatomical relationship between the tendons of FHL and FDL in the form of tendinous band like interconnections which is known as Master Knot of Henry or Henry's knot. This is anatomically located about 2 cm below the navicular tuberosity and 12 cm proximal to the first Interphalangeal joint. There are different divisions and subdivisions documented in the literature showing variation within different ethnic and racial backgrounds (6-8). This knowledge of the interconnections is very essential to the surgeons during the harvesting of FHL tendon for tendon transfer as they must be released if it is harvested from distal to the MKH. It is also essential to minimize the post-op morbidity and explain probable functional loss. A simple clinical test can help evaluate these interconnections as well (8). The purpose of this study is to assess the functional outcome of all patients who had undergone Achilles tendon repair with FHL tendon transfer at JSS Hospital.

MATERIALS AND METHODS

This was a longitudinal study done in JSS Medical College, Mysuru, India, from September 2019 to September 2021 on 22 patients. Ethical clearance was obtained from Institution Ethical Committee for the study (JSS/MC/PG/5189/2019-20 - Date of approval: November 14, 2019). After obtaining consent from patients, clinically and radiologically confirmed cases with Tendoachilles ruptures were included in the study. Patients who were known cases of Type II Diabetes mellitus, B/L Achilles tendon tears and those with open wound or clinically detectable focus of active infection were excluded from the study.

Tear was confirmed radiologically with USG with which even the defect was noted. MRI was done to confirm the diagnosis. Heel floor distance was measured manually with an inch tape and Heel Rise Height Index, defined as heel-rise height (injured)/heel-rise height (un-injured) and is calculated as percentage. Calf circumference was also measured with an inch tape at 10 cm distal to the tibial tuberosity and average of 3 readings was taken.

After obtaining consent and pre-anesthetic checkup, all the patients underwent FHL tendon transfer by 2 Incision technique performed by a single surgeon.

Under Spinal anesthesia, Tourniquet control was used for all the cases. All the surgeries were performed by the same surgeon. A mini-invasive technique was employed in this study. Surgery was done in supine position with sand bag elevation under the hip to facilitate flexion, abduction, and external rotation. 1st incision was placed Posteromedial to the Tendoachilles. Skin is elevated along with the paratenon to avoid skin necrosis and wound complications, keeping in mind the precarious blood supply in this region. FHL is identified and isolated through 1st incision and confirmed by pulling the tendon and checking for passive dorsiflexion of the great toe. Next, the 2nd incision was placed just below the Navicular tuberosity. Dissection was done between the 1st and 3rd layers of the foot; Master Knot of Henry was visualized, and its anatomical variation was noted (**figure**

1). The interconnections of FHL and FDL were released and FHL was incised as distally as possible through this exposure. The distal stump of FHL was tenodesed to FDL tendon with absorbable suture keeping the great toe in neutral to avoid excessive tension. Tag suture was applied to the proximal stump using Ethibond (Synthetic, Braided and Non-absorbable Polyethylene suture material) 6-0 and the freed FHL is then delivered through the 1st incision. The time required for MKH finding and release, and the percentage of time required was calculated. Graft length (measured from the musculotendinous junction to the distal tip) and graft thickness using graft sizer was also noted intra operatively. Using core reamer of appropriate size, calcaneal tunnel was made with the guidance of angle guide from superomedial to inferolateral direction just medial to the insertion of Tendoachilles under C arm guidance. The tag suture is then drawn through this Osteo-calcaneal tunnel and secured using a titanium interference screw of appropriate size with foot held in 10° of plantar flexion. Thorough wash was given, and wound was closed in layers, by approximating the skin along with the paratenon in the proximal incision. Dressing was done and dorsal slab was applied with foot in 10-15°.

Nowhere in the procedure followed, was the degenerated/chronic tear of Tendoachilles exposed or debrided. The native tendon was left in place. This was done so as to prevent the possible complication of wound healing and skin necrosis due to the precarious blood supply in this region. Broad spectrum IV antibiotic was given for 2 days followed by dressing on post-op day (POD) 2 and switched to oral antibiotic for 5 days if wound was healthy. Follow-up dressings were done on POD 5 and POD 10. Patient was followed up after 2 weeks Post Op, and suture removal was done if healed and healthy. The slab is reapplied for 2 more weeks following which it is converted to boot cast with foot in neutral position at the end of 4th week Post Op. Partial weight bearing is started as tolerated with the help of adjustable quadrangular walker. At the end of 6 weeks, patients are encouraged to wean off the walker and boot cast as soon as possible, and ROM exercises of the ankle are started. Patient is assessed for calf circumference, AOFAS Ankle Hindfoot Score, ATRS Score, AOFAS Hallux MTP-IP Score. Patient is allowed to perform Heel Rises gradually after 6 weeks.

Patients were called for follow up at 3months and 6 months for assessing Heel Rise Height Index, Calf Circumference, AOFAS Ankle Hindfoot Score, ATRS Score, Modified RUPP Score and AOFAS Hallux MTP-IP Score.

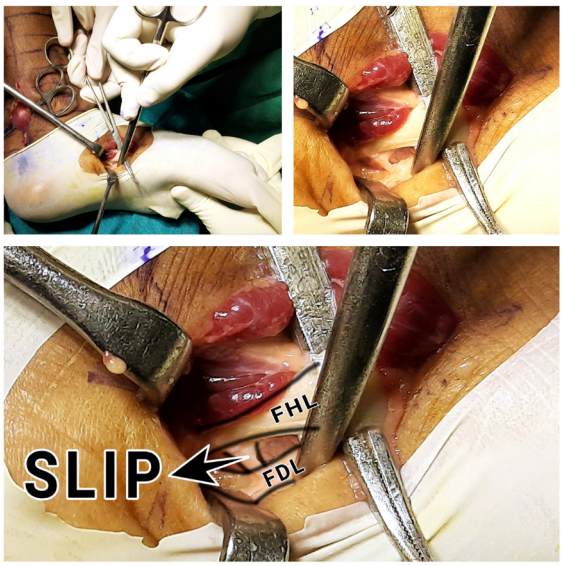

Figure 1. Soft tissue dissection and isolation of FHL tendon through 1st incision, Type I anatomical variation of Master Knot of Henry.

Statistical analysis

All the statistical analysis was done using SPSS (ver. 21.0) for Windows. Repeated measure ANOVA test was used to compare the values over subsequent follow-ups.

Result was considered statistically significant if P-value < 0.05. In this study the most important findings obtained are the significant improvement of Mean AOFAS Ankle-Hindfoot scores, Mean ATRS scores and Mean Modified RUPP Scores. The improvement of AOFAS Hallux MTP-IP Joint scores and Mean Heel Rise Height Index are also found to be significant. Type I variation in MKH was found in 90.9% of the patients while 9.1% patients showed Type II variation. There was only 1 patient who had infection at the heel site and no patients had any donor site morbidity.

RESULTS

This study had 22 patients who underwent FHL Tendon Transfer using 2 incision technique and followed up for 6 months postoperatively.

The mean age group of study population was 50.7 ± 11.1 years and having a male preponderance (63.6%). Left side was predominantly affected (63.6%). Majority of the patients were farmers (40.9%) by occupation and the most common mechanism of injury was slip and fall in the fields (72.7%). The mean delay in presentation following the injury was 18.5 ± 13.4 weeks and history of steroid injection was present in half of the study population (54.5%). The mean defect as measured in USG was 5.23 ± 1.34 cm.

The Heel rise height index (HRHI) which was defined as the Heel-rise height of affected side divided by the heel

rise height of un-injured side showed significant improvement from 7.16 ± 6.93% to 63.36 ± 9.87% ($p < 0.0001$, repeated measure ANOVA test) and calf circumference on the injured side showed significant improvement ($p < 0.01$) at the end of 6 months follow-up. There was significant improvement in AOFAS ankle-hindfoot scores from 43.91 ± 4.63 pre-operatively to 89.68 ± 4.95 ($p < 0.0001$), ATRS Scores from 19.55 ± 2.81 preoperatively to 79.05 ± 2.95 ($p < 0.0001$), AOFAS hallux MTP-IP Scores from 65.18 ± 4.17 preoperatively to 96.27 ± 4.68 ($p < 0.0001$) at the end of 6th month follow-up. The improvement seen in Modified RUPP Scores were significant at the end of 6th month follow-up ($p = 0.008$, McNemar Test).

Regarding the intra-operative findings, the mean total duration of surgery was found to be 93.41 ± 13.92 mins and the mean time required to find Master Knot of Henry (MKH) and release was found to be 20.82 ± 5.88 mins. It was deduced that a mean of 22.13 ± 3.90% of the total duration of surgery is needed for finding and release of MKH. One of the patients had intra operative tourniquet malfunction, because of which the duration of surgery was way more than the mean due to obvious reason of not obtaining a relatively bloodless field to visualize, identify and work with the tendons. The mean height and width of the FHL tendon graft was found to be 8.09 ± 0.63 cm and 7.57 ± 0.54 cm respectively.

We could identify only 2 variations in the anatomy of MKH. Type I variation: single slip from FHL proximally to FDL was seen in 20 (90.9%) of the study population, while other 2 (9.1%) had Type II variation: 1 slip from FHL proximally to FHL and another slip from FDL proximally to FHL (6).

In this study the mean wound healing time found was 13.09 ± 3.49 days. One patient had wound complication of surgical site infection at the heel site, due to which the wound healing was delayed. This is the same patient who had intra operative tourniquet cuff malfunction, and a tag suture was applied with a gauze at the heel site as an additional reinforcement. This is the site which got infected on 10th post operative day, for which antibiotic bead insertion was done and the wound went on to heal well by 28th post operative day. This patient was also found to have comparatively decreased functional outcome compared to the other patients at last follow-up.

There were no re-ruptures throughout the follow-up period. There was no donor site morbidity, great toe deformities, or any paresthesia due to iatrogenic sural nerve injury. All the patients had absent flexion of IP (interphalangeal) joint of great toe, but this did not translate to any functional deficiencies as in walking or activities of daily living.

The mean Heel Floor Distance (HFD) was found to be 7.45 ± 1.53 cm on the normal side while on the injured side, it was found to be 0.59 ± 0.59 cm. The minimum and maximum HFD on the Normal side was 5 cm and 11 cm, respectively, while on the injured side it was 0 cm and 2 cm, respectively. The mean heel floor distance was 7.45 ± 1.53 cm with a minimum measurement of 5 cm and maximum of 11 cm on the normal side and 0.59 ± 0.59 cm with a mean range 0-2 cm on the injured side.

The heel rise height index (HRHI) was 7.16 ± 6.93% pre-operatively, 42.06 ± 9.72% at 3 months and 63.36 ± 9.87% at 6 months. The improvement was found to be significant with $p < 0.0001$ calculated by repeated measure ANOVA.

The mean calf circumference was 40.05 ± 1.3 cm in normal side and 39.2 ± 1.28 cm in affected side pre-operatively. The mean calf circumference on normal side was 40.02 ± 1.34 cm at 6 weeks, 40.10 ± 1.32 cm at 3 months and 40.2 ± 1.38 cm at 6 months. The Mean calf circumference on injured side was 39.27 ± 1.32 cm at 6 weeks, 39.44 ± 1.17 cm at 3 months and 39.61 ± 1.24 cm at 6 months (**table I**).

The calf circumference of the injured side as a percentage of the normal side was calculated and the mean was found to be 97.87 ± 1.3% pre-operatively, 98.16 ± 2.43% at 6 weeks, 98.38 ± 2.02% at 3 months and 98.55 ± 1.31%. This was found to be statistically insignificant with $p = 0.3$ by repeated measure ANOVA test.

The mean AOFAS Ankle-Hindfoot Scores improved from 43.91 ± 4.63 pre-operatively to 54.59 ± 7.2 at 6 weeks, 78.59 ± 5.4 at 3 months, to 89.68 ± 4.95 at 6 months (**figure 2**). This was found to be statistically significant with $p < 0.0001$ with repeated measure ANOVA Test.

The mean ATRS Scores improved from 19.55 ± 2.81 pre-operatively to 38.95 ± 3.12 at 6 weeks, 70.82 ± 3.55 at 3 months, to 79.05 ± 2.95 at 6 months (**table II**). This was found to be statistically significant with $p < 0.0001$ with Repeated Measure ANOVA test.

The mean AOFAS hallux MTP-IP scores improved from 65.18 ± 4.17 at 6 weeks to 83.18 ± 3.46 at 3 months and to 96.27 ± 4.68 at 6 months (**table III** and **figure 3**). This was found to be statistically significant with $p < 0.0001$ by repeated measure ANOVA test. There was no deformity

Table I. Calf circumference.

Calf circumference (cm)	Mean ± SD
Normal side Pre-Op	40.05 ± 1.30
Injured side Pre-Op	39.20 ± 1.28
Normal side at 6 weeks	40.02 ± 1.34
Injured side at 6 weeks	39.27 ± 1.32
Normal side at 3 months	40.10 ± 1.33
Injured side at 3 months	39.44 ± 1.17
Normal side at 6 months	40.20 ± 1.38
Injured side at 6 months	39.61 ± 1.24

Repeated Measure ANOVA; $p < 0.01$.

Table II. Comparison of ATRS Scores preoperatively and during follow up period.

ATRS Scores	Mean ± SD	Minimum	Maximum
Pre-Op	19.55 ± 2.81	15.00	25.00
6 weeks	38.95 ± 3.12	35.00	46.00
3 months	70.82 ± 3.55	66.00	78.00
6 months	79.05 ± 2.95	74.00	84.00

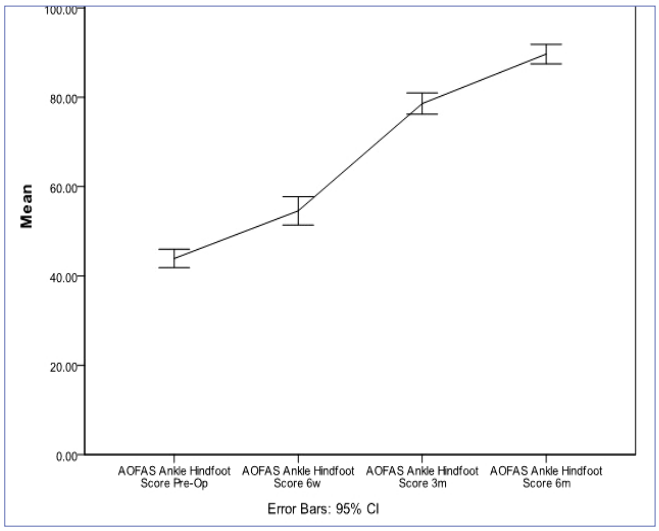

Figure 2. AOFAS Ankle-Hindfoot Scores.

seen in the great toe post operatively. Interphalangeal joint flexion was absent with presence of normal 1st MTP joint flexion in all the patients which did not translate into any clinical/functional weakness or any difficulties in performing activities of daily living and did not affect the satisfaction outcome of the patient.

Modified RUPP scores improved from poor at 3 months follow-up to fair at 6 months (**table IV**). 1 patient had scored fair at 3 months which improved to good at 6 months follow-up. At the end of 6 months follow-up, total of 13 patients (59.1%) had excellent scores (**table V**). The improvement from 3 months to 6 months was found to be statistically significant with p = 0.008 done using McNemar Test. In this study, the mean total duration of surgery was found to be 93.41 ± 13.92 mins while the mean time required to find MKH, and release was 20.82 ± 5.88 mins. The mean time

Table III. AOFAS hallux MTP-IP Scores.

AOFAS Hallux MTP-IP Scores	Mean ± SD	Minimum	Maximum
6 weeks	65.18 ± 4.17	50.00	72.00
3 months	83.18 ± 3.46	74.00	87.00
6 months	96.27 ± 4.68	87.00	100.00

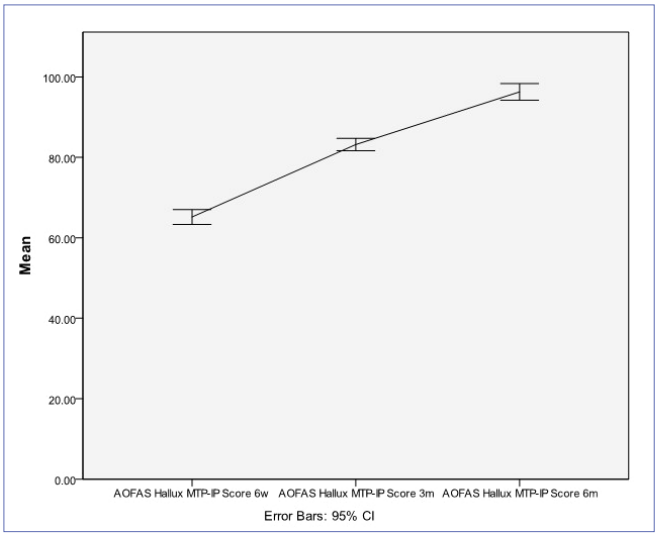

Figure 3. AOFAS Hallux MTP-IP Scores.

required to find MKH, and release was found to be 22.13 ± 3.9% of the total duration of surgery. One of the surgeries took about 135 mins, the delay was attributable to the malfunctioned tourniquet cuff intra-op which led to difficulty in achieving a bloodless operative field.

The mean length of the FHL graft obtained was 8.09 ± 0.63 cm measured from the musculotendinous junction to the distal tip (**figure 4**). The mean thickness of the FHL graft obtained was 7.57 ± 0.54 cm as measured using graft sizer.

In this study, Type I variation of MKH: a single slip from FHL proximally to FDL distally was found in 20 patients (90.9%) and Type II variation: slip from FHL proximally to FDL distally and another slip from FDL proximally to FHL distally was seen in 2 patients (9.1%). There were no other variations found. The Mean Wound Healing time was found to be 13.09 ± 3.49 days with a minimum of 11 days and

Table IV. Modified RUPP Scores.

Modified RUPP Scores	Count	Percentage (%)
3 months		
Excellent	8	36.4
Good	12	54.5
Fair	1	4.5
Poor	1	4.5
6 months		
Excellent	13	59.1
Good	8	36.4
Fair	1	4.5

Table V. Comparison and improvement of Modified RUPP Scores.

		Modified RUPP Scores 6 months				
		Excellent	Good	Fair	Poor	Total
Modified RUPP Scores 3 months	Excellent	8 (100%)	0(0.0%)	0 (0.0%)	0 (0.0%)	8 (36.4%)
	Good	5 (41.7%)	7 (58.3%)	0 (0.0%)	0 (0.0%)	12 (54.5%)
	Fair	0 (0.0%)	1 (100.0%)	0 (0.0%)	0 (0.0%)	1 (4.5%)
	Poor	0 (0.0%)	0 (0.0%)	1 (100.0%)	0 (0.0%)	1 (4.5%)
	Total	13 (59.1%)	8 (36.4%)	1 (4.5%)	0 (0.0%)	22

McNemar Test; p = 0.008.

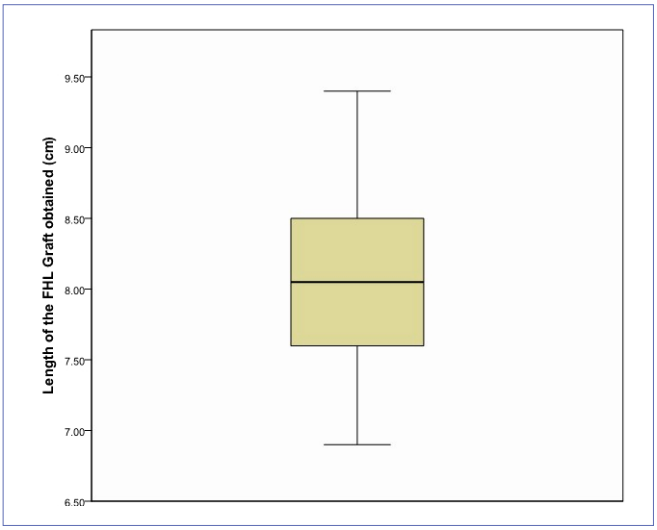

Figure 4. Length of FHL Graft obtained.

maximum of 28 days. One patient had Surgical Site Infection at Heel site due to which wound healing was delayed. 1 case (4.5%) had surgical site infection at the heel site, for which the corrective secondary procedure performed was antibiotic bead insertion following which the wound healed completely by 28 days. As a result, this patient had a comparatively decreased functional outcome at the last follow-up. There were no re-ruptures in the study throughout the follow-up of the patients. None of the patients had paresthesia in the operated side due to iatrogenic sural nerve injury.

DISCUSSION

There are various procedures documented for the management of chronic Tendoachilles tears and each of them yield satisfactory outcomes. In the most recent systematic review done, they concluded that both FHL and PB tendon transfers show good results for treatment of chronic TA tears and incorporated Visual Analogue Scale, AOFAS and ATRS scores (9).

In this study the procedure adopted is FHL tendon transfer using 2 incision technique, which differs slightly from most of the procedures done in various studies with respect to exposure of Tendoachilles. Tendoachilles was neither visualized nor debrided. There was no augmentation done in the form of suturing the FHL to the residual Tendoachilles while the other studies done documented suturing of FHL to the residual Tendoachilles. In one study, a minimally invasive 3 incision procedure was adopted in treating chronic TA tears using Peroneus brevis tendon where the gap was less than 6 cm (10). Another study shows good results for Chronic TA tears using Peroneus brevis in a minimally invasive surgical procedure with no complications (11). In our study of 22 patients, the mean age of patients was 50.7 ± 11.1 years, with majority of patients below the age of 50 years (40.9%). The study done by Mahajan and Dalal had slightly older patients with mean age of 70 years while that done by Nagakiran *et al.* had patients with a mean age of 52.3 years (12, 13). This study had a male preponderance with a total of 14 male patients (63.6%) and 8 female patients (36.4%). The study done by Nagakiran *et al.* also had male preponderance with 20 males (74%) and 7 females (26%) (13). However, the study done by Suttinark and Suebpongsiri had a female preponderance with 3 males (33.3%) and 9 females (66.7%) (14). This study population consisted predominantly of farmers (40.9%) followed by manual laborers (31.8%) and home makers (27.3%). The most common mechanism of injury in this study was found to be slip and fall (72.7%) attributable to field injuries and very commonly toilet seat injuries. This was described in the study by Dar TA *et al.* as the Indian commode is in level with the surrounding floor, making the foot easily slip into the commode following which the foot reflexively causes to go into plantar flexion when the patient tries to get out (15). During this, the taut Tendoachilles hits the toilet rim violently causing an injury/tear to the Tendoachilles. In this study, the mean time of presentation following the injury was 18.5 ± 13.4

weeks with majority (36.4%) of them presenting before 10 weeks. Similar results were reported in the study done by Mahajan and Dalal, which reported a delay in mean of 15 weeks from the injury to the time of surgery, while that done by Nagakiran *et al.* showed a mean delay of 5.6 weeks. In this study, left side was injured in 14 (63.6%) of the patients. The study done by Nagakiran *et al.* also showed similar observations. A study done by Chang *et al.* also had similar results, and they attributed this to right hand dominant individuals having a more frequent left foot push off (16). Despite this, other studies show a preponderance for right sided injuries. About 12 patients (54.5%) in our study give a history of receiving local steroid injection to the wound, a practice still persistent in the peripheral health centers, especially for Retrocalcaneal bursitis. Various studies show the greater incidence of TA tears in patients having history of local steroid infiltration. Mahajan and Dalal's study had 22% patients with a history of local steroid injection. A study done by Vallone shows the importance of using USG guidance for local steroid infiltration in their study of Complete TA tears after local infiltration of corticosteroids in the treatment of deep retrocalcaneal bursitis (17).

The mean defect as measured under USG guidance was 5.23 ± 1.34 cm in this study pre-operatively. The study done by Wegrzyn *et al.* reported 7.4 cm as the average defect in TA ruptures, while that done showed 6.00 ± 0.64 cm as the average gap after debridement and excision of fibrosis (18). The study done by Mubark *et al.* showed no significant correlation of the tendon gap as measured by USG to the final ATRS Scores (19). The patients in this study were almost unable to do heel rises on the affected side at presentation. The mean heel floor distance on the unaffected side was 7.45 ± 1.53 cm. The Heel Rise Height Index (HRHI) was calculated as heel rise in the affected side as a percentage of the uninjured side and the improvement of HRHI over follow-ups was found statistically significant in this study. At the last follow-up of 6 months, patients had a mean of 63.4 ± 9.87% in this study. Comparable results were reported in the study done by Carmont *et al.*, where patients were followed up for 12 months at the end of which they obtained mean HRHI of 82 ± 16% (20). In this study, there was an overall very minimal increase in the mean calf circumference in the affected side, from 39.2 ± 1.28 cm to 39.61 ± 1.24 cm. These findings are consistent with the study done by Suttinark and Suebpongsiri in which they reported some calf hypertrophy in most of the patients (14). The study done by Daniel K. Wilcox *et al.* showed reduction of mean circumference to 96% of the normal side (21). In this study, calf circumference of the injured side was calculated as a percentage of the normal side, and the improvement in this percentage was found to be insignificant in this study.

The mean AOFAS Ankle-Hindfoot score in this improved from 43.91 ± 4.63, pre-operatively, to 89.68 ± 4.95 at the last follow-up, *i.e.*, 6 months. Similar results were reported in the study done by Nagakiran *et al.* which showed improvement from 39.79, Pre operatively, to 91.14 at 6 months follow-up (13). Similarly, the study done by Suttinark and Suebpongsiri showed improvement from 54.6 to 92.9, but this was at the end of 22 months of follow-up (14). Previous study showed improvement from a mean of 69 to 88 at end of 12 months (12). These minimal variations could also be attributable to the variation in the procedure of surgery followed in these various studies.

In this study, the mean ATRS scores improved from 19.55, pre-operatively, to 79.05 at the end of 6-month follow-up. This was comparable to the study done by Nagakiran *et al.* which showed improvement from 19.64 to 81.14 at the end of 6 months (13). A study done by Oksanen *et al.* showed that the mean ATRS score came to 70.3 following a mean follow-up of 27 months (22).

The improvement of mean AOFAS hallux MTP-IP scores seen in this study, from 65.18 preoperatively to 96.27 at 6 months follow-up was comparable to the study done by Coull *et al.* and others, where the mean AOFAS Hallux MTP-IP scores was found to be 97 at the end of mean follow-up of 43.6 months (23). The results were also consistent with another study done by Richardson *et al.* which showed the mean AOFAS Hallux MTP-IP score was 96.4 with a mean follow-up of 28 months (24). There was absent plantar flexion in interphalangeal joint of great toe in all the patients, while the plantar flexion of 1st MTP joint was preserved in all the cases in this study. This absence of IP joint flexion did not cause any clinical/functional deficiencies in the patient, nor was there any decrease in the patient satisfaction outcome in this study. They did not have any difficulty in walking as a result of the absent dorsiflexion of Interphalangeal joint. These reports are consistent with other studies which showed absent IP joint flexion which did not affect the gait of the patient.

A study done by Hahn *et al.* showed a significant reduction in the active flexion of IP and MTP joints of hallux and a slightly extended hallux in more than 35% of their cases (25). However, there was no such complication in this study. The modified RUPP Scores in this study showed statistically significant improvement from 3 months to 6 months and about 13 (59.1%) patients had excellent scores. This was comparable to those obtained in the study done by Tawari *et al.* where PB brevis was used, and they had about 50% patients had excellent scores (26).

The mean total duration of surgery was 93.41 mins, out of which the mean time required to find, isolate and release MKH was noted to be 20.82 mins. So, the mean percentage of total duration of surgery was found to be 22.13%. A study done by Rahm *et al.* showed similar results with mean of 99 mins where Modified Wapner technique was used (27). 2-incision technique was used in this study, and the mean length of the graft obtained was 8.09 ± 0.63 cm. This is comparable to the results in the study done on cadavers by Beger *et al.*, which had a mean length of 7.03 ± 0.86 cm obtained by the same 2-incision technique, while that obtained using single incision technique was 5.75 ± 0.63 cm (7).

In this study, the anatomical variation in the MKH had 20 (90.9%) Type I (Single slip from FHL proximally to FDL distally) and 9.1% had Type II (Slip from FHL proximally to FDL and another slip from FDL proximally to FHL). There were no other variations found. These findings were consistent with the study done on cadavers by Mao *et al.*, which had similar two variations only, *i.e.*, Type I found in 96.9% cadavers and Type II found in 3.1% cadavers with no other variations (6). All these studies have been done on cadavers, which allows for extensive dissection and better understanding of these variations. However, this work attempted to study these variations intra-operatively. This knowledge of variations is important for the surgeons to carry out the transfers and expect the functional outcome. In this study the mean wound healing time calculated by the post-operative day when suture removal was carried out was 13.09 ± 3.49 days. This study had only 1 patient who had wound complication at the heel site. This occurred in that same patient who had tourniquet cuff malfunction intra-operatively which subsequently led to increased duration of surgery because of a relatively bloody field of surgery. For this case, also due to unsatisfactory fixation in the calcaneal tunnel, tag suture was applied with a gauze at the heel site. This was the one which developed Infection at the heel site, and it gradually healed with the help of antibiotic bead insertion by the end of 28 days. Hence this experience also re-emphasizes the well-known fact that the shorter duration of surgery can also probably decrease the incidence of wound complications. There were no other complications noted in this study including re ruptures, paresthesia following iatrogenic nerve injury, deformities, or any donor site morbidities.

CONCLUSIONS

FHL tendon transfer using 2-incision technique had good functional outcome as detailed in this study. Though there are other autologous donor grafts like FDL and PB, FHL has the advantages of being isophasic, stronger than FDL and PB and has the same axis of contraction as that of Tendoachilles. The procedure of surgery done in our study is slightly different from those done in most of the other studies, wherein the procedure done in this study had no exposure of the Achilles tendon/muscle belly, which helps in further reducing the incidence of wound complications. This procedure is technically more demanding as thorough knowledge of the anatomy is essential for the surgeon, especially at the 2nd incision, required for harvesting the FHL graft, more so a longer one. An attempt was made to classify the anatomical variations in Master Knot of Henry intra-operatively, despite previous studies being done only in cadavers. Very minimal donor site morbidity (in the form of absent IP joint flexion in great toe) was noted with no clinical/functional deficiencies, residual deformities in the hallux, gait problems and patient satisfaction outcome, even though there was absent Hallux Interphalangeal joint flexion with preserved Hallux MTP joint flexion.

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DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

SV: conceptualization, writing. AR: study execution. VCS: data collection, writing.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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