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Original article

Three-Dimensional computed tomography tunnel assessment of allograft anatomic reconstruction in chronic ankle instability: 33 cases

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ABSTRACT

Introduction: Although clinical results of anatomic reconstruction using allograft are reportedly good, studies on how accurately the tunnel has been made after surgery are very rare. The purpose of this study was to analyze the postoperative locations of the tunnels through 3-dimensional computed tomography (3D-CT) after anatomic ligament reconstruction and to evaluate its clinical results.
Hypothesis: We hypothesized that anatomic lateral ligament reconstruction could lead to excellent results in clinical outcomes by repositioning anterior talofibular ligament (ATFL) and calcaneofibular ligament (CFL) accurately.
Materials and methods: Thirty-three special forces of soldiers who were diagnosed as chronic ankle instability (CAI) were included. Visual analogue scale (VAS), American orthopaedic foot and ankle society (AOFAS) ankle-hind foot functional scores, and Tegner activity scale were comparatively analyzed before the surgery and at final follow-up. The locations of the talar, fibular and calcaneal tunnels were evaluated with 3D-CT taken after the surgery. Talar tilt and anterior drawer displacement were measured on stress radiographs.
Results: The mean follow-up period was 26.8 ± 3.6 months. The VAS decreased from 6.9 ± 1.6 to 1.7 ± 1.3, AOFAS ankle-hindfoot functional score increased from 61.3 ± 14.8 to 88.7 ± 9.2, and Tegner activity scale improved from 5.3 ± 1.2 to 6.4 ± 1.3 ($p < 0.001$). Talar tunnel for ATFL was located about68% of the way from the lateral talar process, and fibular tunnels for ATFL and CFL were approximately 52% and 20% of the way from the fibular tip. The calcaneus tunnel was approximately 17 mm posterosuperior from the peroneal tubercle on 3D-CT. Talar tilt decreased from 15.8 ± 4.8 to 3.9 ± 2.1 degrees ($p < 0.001$). There were excellent inter-observer agreements for CT evaluation (Kappa values were from 0.83 to 0.92). There was no relapse of lateral instability.
Discussion: Anatomic reconstruction of the lateral ligaments using allograft and the interference screw for CAI showed good results in postoperative stability and subjective clinical evaluation by repositioning the location of ATFL and CFL accurately on radiological determination.
Level of evidence: IV, Case-series.

1. Introduction

Ankle sprain is mostly the injury of lateral ligaments, and it was reported that among them, the cases where only anterior talofibular ligament (ATFL) was damaged account for 80% while those accompanied by the damage of calcaneofibular ligament (CFL) were 20% [1]. Although most of ankle sprains respond well to conservative treatment, 20–40% of severe ankle sprains develop into chronic ankle instability (CAI) [2]. These patients need surgical treatments, and while various surgical methods including open anatomical repair or reconstruction of ATFL and/or CFL have been suggested for CAI, ideal surgical treatment is still under debate [3–6].

Although the modified Brostrom procedure that repairs ligaments directly has been used widely, it has been reported that

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anatomic reconstruction using autograft or allograft is useful in case that ligament damage is severe due to excessive and repeated damage, and high intensity of labor or sporting activity is required [6,7]. Surgical procedures that reconstruct ATFL and CFL preferably anatomically have been suggested, but most of them could not reproduce the anatomical location of lateral ligaments or did not provide sufficient fixing power [3–5,8,9]. Recently, less invasive arthroscopic ligament reconstructions are attempted, but their clinical results have been very rarely reported [4].

It is important to determine the anatomical location of ligaments accurately in order to perform anatomic reconstruction that can be completed by a simple process in a short time [9–11]. Since it has been found that the function of not only ATFL but also CFL is important, a procedure through surgical dissection could reconstruct damaged lateral ligaments more identical to anatomical location and direction [7–13]. Even though clinical results of anatomic reconstruction using allograft and interference screws are reportedly good, studies on how accurately the tunnel has been made after surgery are very rare [6–13]. If the post-operative location of the tunnel is analyzed and can be compared with the footprint center of ATFL and CFL revealed in the previous cadaver studies, clinicians can implement more anatomically accurate reconstruction through feedback [10–14].

The purpose of the current study was to analyze the postoperative locations of the tunnels through 3-dimensional computed tomography (3D-CT) after anatomic reconstruction of ATFL and CFL using allograft tendon, and subsequently to evaluate its clinical results. The hypothesis of this study was that anatomic lateral ligament reconstruction could lead to excellent results in post-operative stability and subjective clinical evaluation by repositioning ATFL and CFL accurately.

2. Methods

2.1. Patients

The current study is a retrospective study on the special forces of the soldiers who were diagnosed as CAI and underwent anatomic ligament reconstruction using semitendinosus allograft and interference screws from June 2012 to February 2014. Ligament reconstruction was conducted on the following cases: In all patients, ATFL and CFL damage are identified by magnetic resonance imaging (MRI) and damaged ligament is changed unable to perform repair. Talar tilt angle more than 10 degrees compared to the opposite side or absolute talar tilt angle more than 15 degrees in the varus test with subjective lateral ligament instability, relapse after previous surgery, very thin AFTL due to chronic injuries on magnetic resonance imaging (MRI) with a complaint of severe instability, obesity (body mass index > 25 kg/m^2), and generalized laxity. Exclusion criteria were surgeries on both ankles, concomitant fractures, additional procedures due to cartilage lesion or prominent bony spur, and hind foot varus. Among a total of 42 patients, 33 who have undergone post-operative 3D-CT, and been observed at least for 2 years were included to the present study. The study protocol was approved by the Institutional Review Board of Armed Forces Medical Command (AFMC-16058-IRB-16-046).

2.2. Surgical technique and postoperative rehabilitation

Our surgical technique of lateral ligament reconstruction was modified by the method of Jung et al. [13] (Fig. 1). Surgery was performed under hemostasis using pressure bandage while patients were fixed at the lateral position under general or epidural anesthesia. Skin incision was performed in a U shape around the tip of fibula from posterior border of fibula 5 cm proximal from the tip of fibula, passing the tip of fibula in the direction of sinus tarsi, and then the insertion and running course of the talus and fibula of ATFL and CFL were dissected to determine the condition of ligaments. After confirming that ATFL and CFL were worn, becoming thin and scarring, reconstruction using allograft with a diameter of 4.5 mm that had been frozen, irradiated and stored at −40 °C was finally decided.

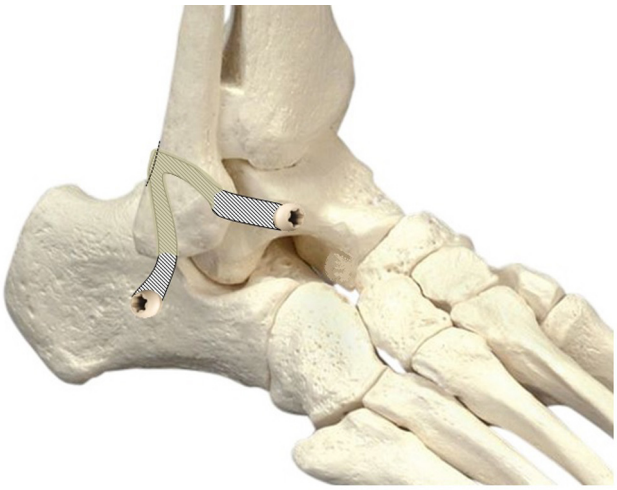

Fig. 1. The surgical technique lateral ligament reconstruction of ankle.

ATFL and CFL were incised to leave the residual tissue of 5 mm from the insertion of fibula, and dissection was performed up to the ATFL insertion of the junction between the body and neck of the talus to find the insertion of the talus. When incising the joint capsule to reach the insertion of talus, it was performed in a T shape, followed by tagging suture at the tip so that direct repair could be performed after reconstruction. After identifying the anatomical insertion by finding the residual ATFL tissue left at the insertion of talus, the tarsal tunnel with a diameter of 5.5 mm and length of 20 mm was drilled in the posterosuperior direction under the C-arm fluoroscopic guide, and the semitendinosus tendon was passed through the tunnel. Subsequently, in the pull-out state outside of the tunnel, the semitendinosus tendon was firmly fixed with a 5.5-mm-sized interference screw (Arthrex Inc., Naples, FL, USA) (Fig. 2). When it was difficult to identify the insertion of talus of ATFL, the talar tunnel was drilled targeting the location at 60–70% of the way along the anterior margin of the talar lateral articular facet from the apex of lateral talar process with the apex of lateral talar process and anterolateral corner of the trochlea as osseous landmarks (Fig. 3) [11–14].

After identifying the peroneal tendon sheath, and securing a space where peroneal tendon could be dissected from the posterior margin and bent back, two parallel tunnels with a diameter of 4.5 mm in consideration of allograft of 4.5 mm thickness were made to maintain the 3-6 mm gap at the anatomic insertion of ATFL and CFL at the distal part of fibula. When it was difficult to identify the anatomical insertion of ATFL and CFL, two fibular tunnels were drilled targeting the location at 50% and 20%, respectively, of the way along the anterior margin of fibular from the inferior tip of the lateral malleolus with the inferior tip of the lateral malleolus and fibular anterior tubercle as osseous landmarks (Fig. 4) [11–14].

ATFL was reconstructed by passing the allograft from the anterior to posterior of fibular proximal tunnel using the Nitinol suture passer (Arthrex Inc., Naples, FL, USA), and under the condition of 0° of ankle extension and 10° eversion under maximum tension, the passed graft at the entrance of fibular tunnel was sutured on the fibular periosteal tissue. While tension was maintained, the residual graft was allowed to pass from the posterior to anterior

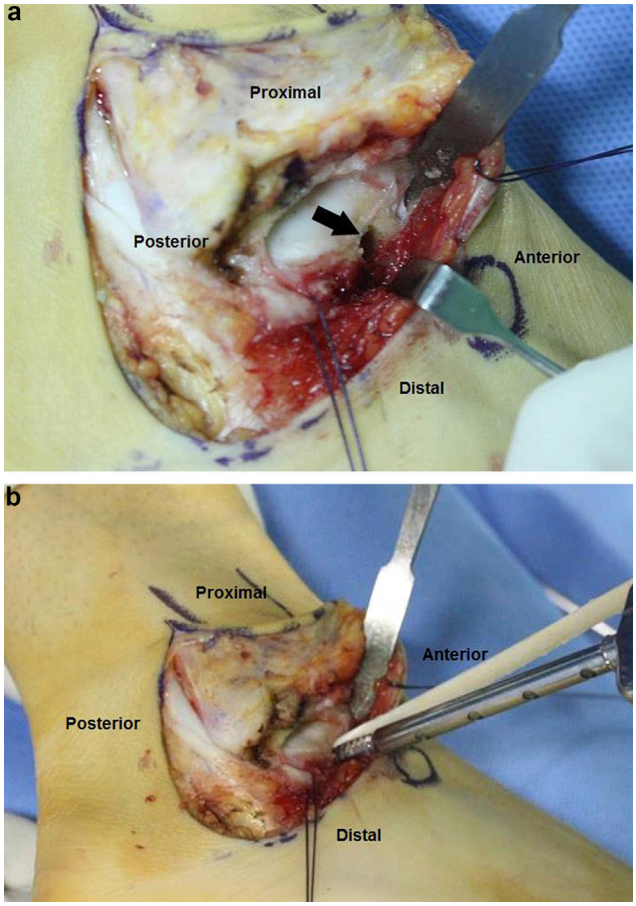

Fig. 2. The anatomic tarsal tunnel with a diameter of 5.5 mm and length of 20 mm is made in the posterosuperior direction in right ankle. Black arrow represents the anatomic tarsal tunnel for anterior talo-fibular ligament reconstruction (a). While pulling out the semitendinosus tendon allograft, itis firmly fixed with a 5.5-mm-sized interference screw (b).

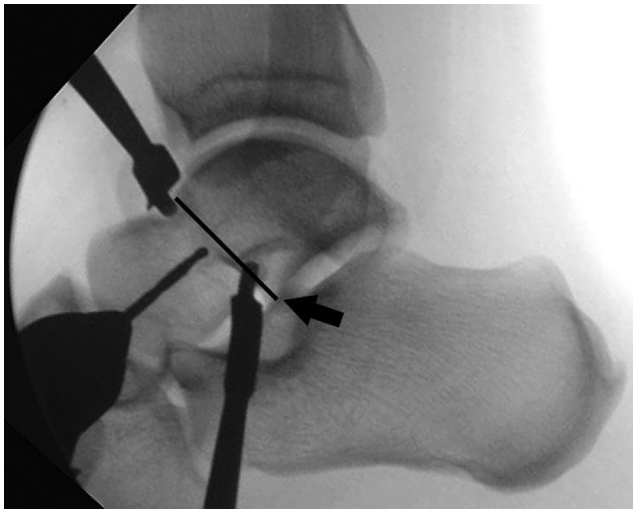

Fig. 3. The talar tunnel is drilled targeting the location at 60–70% of the way along the anterior lateral malleolar line (ALML) from the apex of lateral talar process with the apex of lateral talar process and anterolateral corner of the trochlea as osseous landmarks. Black line shows the ALML and black arrow represents the lateral talar process.

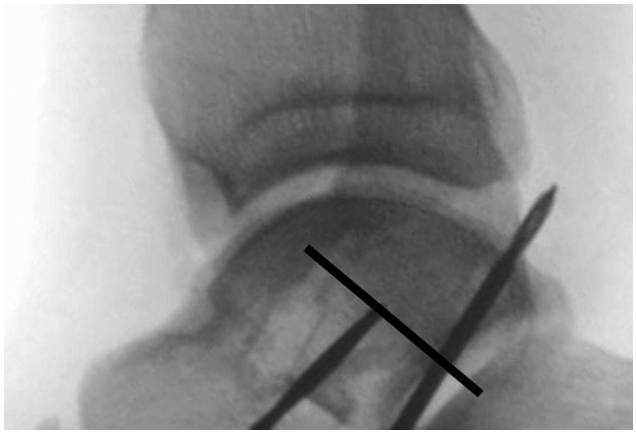

Fig. 4. Two fibular tunnels are drilled targeting the location at 50% and 20%, respectively, of the way along the anterior distal fibular line (ADFL) from the inferior tip of the lateral malleolus with the inferior tip of the lateral malleolus and fibular anterior tubercle as osseous landmarks. Black line shows the ADFL.

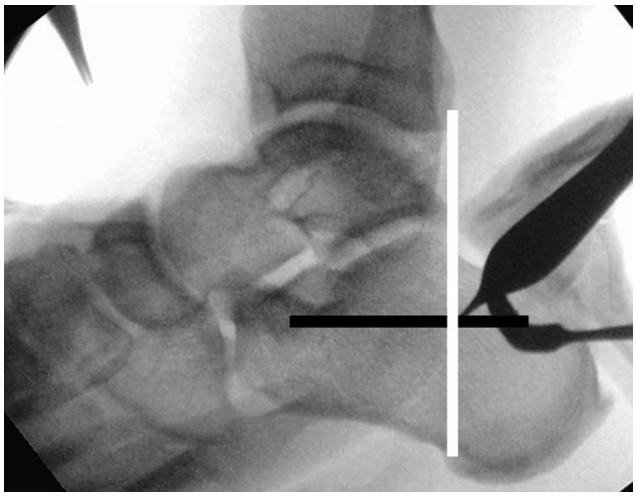

Fig. 5. The white vertical line is tangent to the posterior convexity of the talus and the black horizontal, perpendicular line is tangent to the deepest concavity of the sinus tarsi. This interconnection of two lines is the targeting point of the calcaneus tunnel for the calcaneo-fibular ligament reconstruction.

of the fibular distal tunnel, and so the origin of fibula insertion of calcaneofibular ligament was formed. With identifying and protecting the sural nerve by dissecting distal subcutaneous tissue of incised flap, CFL insertion adjacent to the peroneal tubercle of calcaneus was identified, and subsequently, a calcaneus tunnel with a diameter of 5.5 mm and length of 20 mm was drilled in parallel to the ankle joint under the C-arm fluoroscopic guide. If the insertion point of CFL was not identified clearly, the tunnel was drilled after identifying osseous landmarks with lateral fluoroscopic radiograph (Fig. 5) [10–14]. By dissecting the area between two peroneal tendons and calcaneal periosteal tissue, the allograft to reconstruct CFL was translocated under peroneal tendon up to the calcaneal insertion. By considering the length of 20 mm through which the distal end of the allograft would penetrate to the calcaneus tunnel, the allograft was cut out using the interlocking suture. The cut allograft was passed through and pulled out of the calcaneus tunnel. Subsequently, under the condition of 0° of ankle extension and 10° eversion under maximum tension, the allograft was firmly fixed using a 5.5-mm-sized interference screw (Arthrex Inc., Naples, FL, USA) (Fig. 6). The incised joint capsule was re-sutured, and by pulling extensor retinaculum to the distal

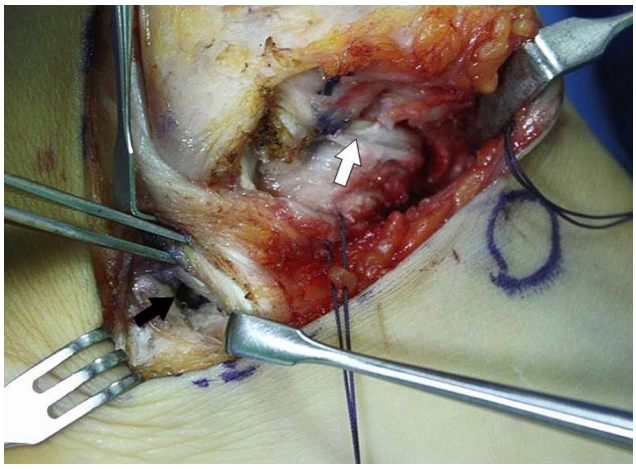

Fig. 6. The anterior talo-fibular ligament (ATFL) and calcaneo-fibular ligament (CFL) reconstruction is completed in right ankle. White and black arrows show the reconstructed anterior talo-fibular ligament and calcaneo-fibular ligament of the calcaneus tunnel, respectively.

part of fibula, the stability of the lateral soft tissue was reinforced with the pants-over-vest technique.

For 3 days after the surgery wound was treated under short leg splint, which was replaced by short leg cast at the third day after the surgery. Short leg cast was maintained for 6 weeks and a partial weight bearing was permitted. Then, 6–12 weeks after the surgery, total weight bearing was applied with an ankle brace on. After removing the cast at the 6th week from surgery, ankle joint and peroneal strengthening exercises were performed. After gradual neuromuscular exercise, the patients were allowed to return to sporting activities at the 4–6th month after surgery depending on the conditions.

2.3. Clinical evaluation

Visual analogue scale (VAS), American orthopaedic foot and ankle society (AOFAS) ankle-hind foot functional scores, and Tegner activity scale were comparatively analyzed before the surgery and at the final follow-up after the surgery.

2.4. Radiological evaluation

The locations of talus, fibular and calcaneus tunnels were evaluated and analyzed with 3D-CT taken immediately after surgery using Picture Archiving and Communication Systems (PACS; Maroview ver. 5.4, MAROTECH Inc., Seoul, Korea) [14]. The position of talar tunnel was measured by selecting the view best showing the locational relationship between the entrance of talar tunnel, the apex of lateral talar process and anterolateral corner of the trochlea on 3D-CT, and subsequently calculating the percentage of the location of the tunnel entrance from the apex of lateral talar process relative to the total distance (the anterior lateral malleolar line of the talus; ALML) reaching the anterolateral corner of trochlea from the apex of lateral talar process along the anterior margin of the talar lateral articular (Fig. 7). In addition, how far the entrance of the tunnel was in the anteromedial direction from ALML was also measured (Fig. 8) [15]. The location of fibular tunnel was measured by selecting the view best showing the locational relationship between the entrance of fibula tunnel, inferior tip of lateral malleolus, and anterior fibular tubercle on 3D-CT, and subsequently calculating the percentage of the location of the tunnel entrance from the inferior tip of lateral malleolus relative to the total distance (the anterior distal fibular line; ADFL) reaching the anterior fibular tubercle from the inferior tip of lateral malleolus

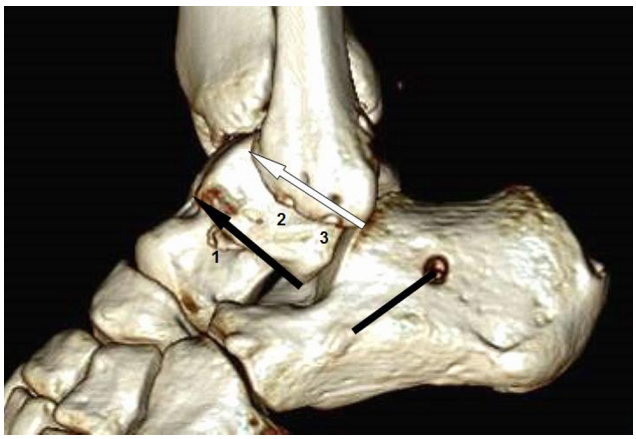

Fig. 7. The position of talar tunnel is measured by calculating the percentage from the lateral talar process relative to the total distance of the anterior lateral malleolar line (ALML). The locations of two fibular tunnels are measured by calculating the percentage from the fibular tip relative to the total distance of the anterior distal fibular line (ADFL). The long black arrows and white arrows represent the ALML and ADFL, respectively. The number 1, 2, and 3 show the talar tunnel of anterior talo-fibular ligament (ATFL), fibular tunnel of ATFL, and fibular tunnel of calcaneo-fibular ligament (CFL), respectively. Black line indicated the distance from the peroneal tubercle to the calcaneus tunnel of CFL.

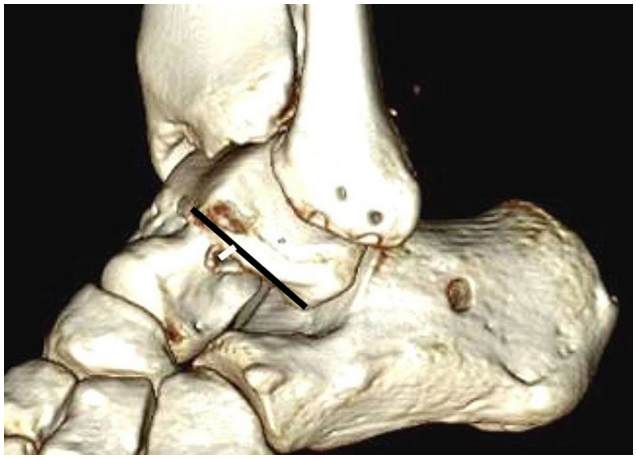

Fig. 8. The distance (white line) is measured from the anterior lateral malleolar line (ALML) to the talar tunnel Black line shows ALML.

along the fibular anterior border (Fig. 7). The location of the calcaneus tunnel was evaluated by selecting the view best showing the locational relationship between the entrance of calcaneus tunnel and the peroneal tubercle on 3D CT, and measuring the distance of the tunnel entrance in the posterosuperior direction from the posterior point of the peroneal tubercle (Fig. 7). The value was measured by one orthopaedic surgeon (D.W. Lee) and one radiologist (M.J. Kim) who had over 5 years of orthopaedic clinical experiences and musculoskeletal radiological experiences. The examiners were blinded to the information of the patients and the average of their values was used for the analysis.

In x-ray analysis, talar tilt angle upon a varus stress and anterior talar displacement were measured using telos device (Telos Medical, Austin, TX, USA) at 150 N, and comparatively analyzed before surgery and at the final follow-up more than 12 months after surgery [16].

2.5. Statistical analysis

Statistical analysis was performed by SPSS for Windows version 21.0 (SPSS Inc., Chicago, IL), and $p < 0.05$ was considered statistically

Table 1
Patient demographics ($n = 33$).

	Value
Age (yrs)	22.7 ± 4.1 (18.1–32.8)
Sex (n)	33 males
Body mass index (kg/m^2)	26.6 ± 5.3 (19.4–36.2)
Preoperative symptom duration (mo.)	32.5 ± 12 (12.9–53.5)
Follow-up duration (mo.)	26.8 ± 3.6 (24.1–40.3)

Allogenic semitendinosus grafts were used in all patient.

significant. Preoperative and postoperative parametric or non-parametric variables were compared by the paired t-test or Wilcoxon's signed-rank test. Kappa (κ)-values were measured to assess inter- and intra-reader agreement for determining the ALL injuries on MRI, and the κ-values were classified as recommended by Landis and Koch, with values of 0.81–1.00 indicating excellent agreement, 0.61–0.80 substantial agreement, 0.41–0.60 moderate agreement, 0.21–0.40 fair agreement, and 0–0.21 slight agreement [17].

3. Results

Baseline demographic data are provided in Table 1. The mean follow-up period was 26.8 ± 3.6 months. The mean period of preoperative symptom manifestation was 32.5 ± 12 months, and the number of reoperation cases after Brostrom procedure was 6. The mean tourniquet time was 53.2 ± 9.4 minutes.

The mean VAS score for pain decreased significantly from 6.9 ± 1.6 before the surgery to 1.7 ± 1.3 ($p < 0.001$), AOFAS ankle-hind foot functional score increased significantly from 61.3 ± 14.8 before the surgery to 88.7 ± 9.2 at the final follow-up ($p < 0.001$). Tegner activity scale improved significantly from 5.3 ± 1.2 before the surgery to 6.4 ± 1.3 after surgery ($p < 0.001$) (Table 2).

In radiology, it was shown that talar tilt angle upon varus stress decreased significantly from 15.8 ± 4.8 before surgery to 3.9 ± 2.1 degrees after the surgery ($p < 0.001$), and the mean postoperative anterior translation on anterior drawer testing was 4.1 ± 1.7 mm (Table 2).

In the post-operative 3D-CT, the talus tunnel of ATFL was found at the mean location of 67.7 ± 5.2 (58.1–71.3)%, of the way from the apex of lateral talar process, and 3.6 ± 1.3 (1.8–5.2) mm antero-medially from ALML. Fibular tunnels of ATFL and CFL were found at the mean location of 52.1 ± 2.4 (41.3–60.5)% and 19.8 ± 2.7 (11.3–23.5)%, respectively, of the way on ADFL from the inferior tip of lateral malleolus. The calcaneus tunnel of CFL was found at the mean location of 16.8 ± 3.1 (11.8–21.6) mm posterosuperior from the posterior point of the peroneal tubercle (Table 3). There were excellent inter-observer agreements for CT evaluation (Kappa values were from 0.83 to 0.92).

4. Discussion

The main finding of the current study was that the anatomic reconstruction of ATFL and CFL using osseous landmarks already known in previous studies among carefully selected CAI patients has been shown to reposition ATFL and CFL accurately on postoperative 3D-CT, and has yielded good clinical results in postoperative stability and subjective clinical evaluation.

Although it has been known that most of CAI patients showed good results only with isolated modified Brostrom procedure, the ligament reconstruction has been found to be useful in the cases of the previous surgery failure, generalized laxity, obesity, athletes who have to perform high intensity activities, and insufficient ligament tissue for direct repair [6,7,13,18]. In the present study, all patients showed absence or insufficiency of the residual ATFL and CFL fibers. The ultimate purpose of ligament reconstruction is to recreate the course of injured ligaments that cannot be reinserted even with augmentation and it can overcome the limitations of repair techniques [19]. Non-anatomic ligament reconstructions have been mainly tenodesis using peroneus brevis, which sacrifices peroneus brevis, a dynamic stabilizer for the lateral part of the ankle, and cannot restore normal motility of the ankle and hind foot [20,21]. Moreover, there have been reports that more degenerative changes have been observed in the long-term follow-up surveys of non-anatomic reconstruction compared to anatomic reconstruction [20,21]. In contrast, it has been reported that anatomic reconstruction can restore the native joint biomechanics

Table 2
Comparison of preoperative and postoperative clinical and radiological outcomes.

	Preoperative	Postoperative	p-value
VAS	6.9 ± 1.6 (2–8)	1.7 ± 1.3 (0–3)	< .0001
AOFAS Ankle-Hindfoot Scale score	61.3 ± 14.8 (48–82)	88.7 ± 9.2 (77–100)	< .0001
Tegner activity scale	5.3 ± 1.2 (1–7)	6.4 ± 1.3 (4–9)	< .0001
Talar tilt (degrees)	15.8 ± 4.8 (10.7–24.4)	3.9 ± 2.1 (0.8–6.1)	< .0001
Anterior drawer displacement (mm)	Not performed	4.1 ± 1.7 (2.5–6.8)	–

VAS: visual analog scale for pain; AOFAS: American Orthopaedic Foot and Ankle Society.

Table 3
Comparison of Locations of ATFL and CFL on 3-D CT.

	Clanton et al. [14]	The current study
ATFL insertion on talus (%)(from lateral talar process along ALML)		68
Single	82	
Double		
Superior	66	
Inferior	34	
ATFL origin on fibula (%) (from fibular tip along ADFL)		
Single	50	52
Double		
Superior	55	
Inferior	30	
CFL origin on fibula (%) (from fibular tip along ADFL)	16	20
CFL insertion on calcaneus (mm) (from peroneal tubercle)	16	17

ATFL: anterior talo-fibular ligament; CFL: calcaneo-fibular ligmanet; ALML: anterior lateral malleolar line of the talus; ADFL: anterior distal fibular line.

Table 4
Variable functional and radiological results of lateral reconstruction of ankle in chronic instability patients.

Reports	Material & technique	Patient no. (ankles)	Mean follow-up period		Functional results			Radiological results	
					Preoperative	Postoperative		Preoperative	Postoperative
Caprio et al. [26] (2006)	Allo-semiT Single tunnel	11 (11)	14.1 M ($p < 0.001$)	AOFAS	29.6 ± 15.6	55.4 ± 13.6			
				SF-12 (Physical)	35.6 ± 9.14	49.3 ± 8.7			
Ellis et al. [3] (2011)	Allo-TA Double tunnel	11 (12)	3.5 ± 1.7 Y (1.2–5.0)	FAOS					
				Pain	85.2 ± 19.2				
				Symptom	80.4 ± 21.2		T-T tilt ($p < 0.01$)	20.2	4.6
				Daily activity	93.4 ± 10.5				
				SF-36v2 (Physical)	50.4 ± 8.2		ATT (mm)	–	6.5
				Karlsson	82.3 ± 19.9				
				BHJMI	2.6 ± 2.8				
				VAS	VAS 1.8				
Hua et al. [5] (2012)	Allo-semiT Double tunnel	35 (36)	37.9 M (24–54)	AOFAS ($p = 0.000$)	42.3 ± 4.9	90.4 ± 6.7	MST	34 out of 36	Stable
				Karlsson($p = 0.000$)	38.5 ± 3.2	90.1 ± 7.8			
Jung et al. [6] (2012)	Allo-semiT Double tunnel	27 (28)	19.0 M (12.0–26.0)	AOFAS ($p < 0.05$)	63 ± 21.5	91 ± 9.5	T-T tilt ($p < 0.05$)	17.8 ± 7.7	6.7 ± 6.3
				Karlsson	55 ± 22.5	80 ± 19.5	ATT($p < 0.05$)(mm)	10 ± 9.4	4.5 ± 4.3
				VAS	6.0 ± 3.0	2.0 ± 2.0			
Xu et al. [27] (2014)	Auto & Allo-semiT Single tunnel								
	Auto	32 (32)	33.5 ± 6.7 M	AOFAS ($p < 0.0001$)	62.3 ± 8.2	95.1 ± 7.5	T-T tilt	14.0 ± 3.2	3.8 ± 1.2
							ATT	12.3 ± 3.2	4.6 ± 1.2
	Allo	36 (36)	28.5 ± 6.7 M		60.2 ± 8.4	94.8 ± 5.5	T-T tilt	13.0 ± 3.5	3.6 ± 1.4
							ATT	11.5 ± 2.3	4.3 ± 1.5
Current study	Allo-semiT Double tunnel	33 (33)	26.8 ± 3.6 M(24.1–40.3)	VAS	6.9 ± 1.6	1.7 ± 1.3	T-T tilt	15.8 ± 4.8	3.9 ± 2.1
				AOFAS	61.3 ± 14.8	88.7 ± 9.2	ATT	–	4.1 ± 1.7
				TAS	5.3 ± 1.2	6.4 ± 1.3			

AOFAS: American Orthopedic Foot and Ankle Score; FAOS: Foot and Ankle Outcome Score; BHJMI: Beighton and Horan Joint Mobility Index; VAS: Visual Analogue Scale; TAS: Tegner activity scale; T-T tilt: Tibiotalar tilt; ATT: Anterior talar translation; MST: Manual stress test.

by repositioning damaged ligaments in the accurate anatomic sites, and its clinical results are good [6,7,13,22].

The reason that relatively constant results at similar locations to the insertion of ATFL and CFL found in previous cadaver experimental research could be obtained on the postoperative 3D-CT assessment in the present study was because the tunnel was targeted at the anatomic location after clearly exposing the insertion sites of ATFL and CFL during surgery [11–14]. Clanton et al. [14] emphasized that surgically relevant osseous landmarks should be used as references, and subsequently reported that single banded ATFL was located approximately 82% of the way from the apex of lateral talar process in talus and approximately 50% of the way from the inferior tip of the lateral malleolus in fibula in cadaver studies. They also reported that double banded ATFL was located approximately 66% and 34%, respectively, of the way from the apex of lateral talar process in talus, and approximately 55% and 30%, respectively, of the way from the inferior tip of the lateral malleolus in fibula while CFL was located approximately 16% of the way from the inferior tip of the lateral malleolus in fibula and approximately 16 mm posterosuperior from the posterior point of the peroneal tubercle in calcaneus. Similar results were obtained in the current study, and the present authors also used a percentage measurement to exclude the individual variations as much as possible. As a result, it was shown that ATFL was located approximately 68% of the way from apex of lateral talar process in talus, and approximately 52% of the way from the inferior tip of the lateral malleolus in fibula while CFL was located about 20% of the way from the inferior tip of the lateral malleolus in fibula and approximately 17 mm posterosuperior from the posterior point of the peroneal tubercle in calcaneus. Until 2 bundle-reconstruction of ATFL has not been popularized, and the current authors conducted reconstruction targeted to single banded ATFL or superior band of double banded ATFL revealed in previous cadaver studies since it was known that superior ATFL band has anatomically larger diameters than inferior band, and the ankle plays a more important role when it is damaged under plantar flexion and inversion condition [9–14]. Since it is often difficult to see and identify the insertion of CFL and the peroneal tubercle known as a reproducible and consistent osseous landmark when the calcaneus tunnel is drilled, the method that uses the sinus tarsi and the posterior convexity of the talus as references in a lateral view as suggested by Best et al. [10] has been always used in the present study.

Another key to be able to reconstruct the ligament as identically to the anatomical location and direction of the lateral ligament as possible in the current study was sufficient incision. Somewhat large incision is needed when exposing the anatomical insertion of ATFL and CFL in talus, fibula and calcaneus, and nerve injury may be prevented if sural nerve is well identified and protected from damage during dissection by incising in a U-shape avoiding the course of sural nerve. In the present study, a symptom of post-operative sural nerve neuralgia was shown in 2 cases, which however was naturally recovered within 6 months after the surgery. Recently while the minimal invasive techniques were introduced through a percutaneous procedure or arthroscopy, each author had a different preferred location including talar neck, junction of neck and body, and talar body, and most did not specify the precise location of the tunnel [4,18,23,24]. Dierckman et al. [7] reported that an excellent results of approximately 4 degrees and 5 mm in the postoperative varus and anterior stress tests were obtained over the minimal open reconstruction by Youn et al. [18] when traditional open anatomical reconstruction was performed, and emphasized that anatomic reconstruction should not be too compromised to less invasive techniques since its main purposes are the recovery of function and stability of ankle and hind foot.

Michels et al. [25] suggested that invasion into the ankle joint could be prevented without breaking the opposite cortex if a tunnel with a diameter of 5 mm and length of 20 mm was made in the direction of the most posterior point of medial malleolus when drilling a tarsal tunnel, but the posteromedial neurovascular bundle may be damaged if a guide pin was penetrated. In the present study, the tarsal tunnel has been drilled targeting the most distal point of medial malleolus in order to prevent invasion into the ankle joint as much as possible without damaging the posteromedial neurovascular bundle.

Technically speaking, many authors have proved the successful clinical and even radiological outcome of lateral ankle reconstruction using allogenic tendon graft [26,27] (Table 4). Reconstruction using allograft free tendon has the advantage that the donor site problems do not occur leading to reduction of pain and muscle weakness of the patient after the surgery since it does not require an additional incision in the knee compared to the method using autograft tendon. In addition, disease transmission and immune problems from the use of allograft have been rarely reported in recent studies, and an adequate fixation can be obtained with the use of the relatively long ligament tissue compared to autograft [7,8,13,28]. Although there can be disadvantages of delayed remodeling, graft-bone incorporation and cost increase, firm fixation was obtained by the use of the interference screw that has been proven to be more biomechanically excellent than suture anchor or bone-patellar tendon graft [6,29,30]. In addition, the treatment was free since it was the obtained injury during military service.

Strengths of this study were that robust ligament reconstruction was performed to the anatomical location using allograft and the interference screw, and relatively consistent results were demonstrated in the postoperative 3D-CT assessments. Moreover, the patients were all the special forces of the soldiers who require high level activities and there was no relapse of lateral instability.

The weaknesses of this study are as follows. First, there can be difference due to the measurement software program since 3D-CT results were comparatively analyzed after the surgery based on the results of previous cadaver studies, and the number of cases was relatively small. Second, we targeted anatomical tunnel position based on previous studies and comparison between plan X-ray and 3D CT scan. But, Variation to the previous studies are reported. In addition, Things reported in anatomical study and X-ray, CT based research can be different. Third, the anterior displacement test was not conducted before the surgery. Since the anterior displacement test may show the only limited level of anterior displacement if deltoid ligament or posterior talofibula ligament is intact, and it is known that the varus stress test better reflects the complex lateral ankle instability of the anterior talofibula and calcaneofibular ligament, only the varus stress test was conducted.

It is possible that this study shows good result because of short-term follow-up duration. So, it is considered that analysis of more cases and long-term accumulated studies are needed, and more in-depth anatomical and biomechanical studies need to be performed for two or three bands of ATFL in the future.

5. Conclusion

Anatomic reconstruction of the lateral ligaments using allograft and the interference screw for CAI patients showed good results in postoperative stability and subjective clinical evaluation by repositioning the location of ATFL and CFL accurately on radiological determination.

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Authors' contribution

Dhong Won Lee (Surgery & manuscript writing), In Keun Park (Data collection & manuscript edition), Min Jeong Kim (Radiologic assessment), Woo Jong Kim (Statistics), Min Soo Kwon (Data collection), Sung Jin Kang (Data collection) Jin Goo Kim (Manuscript edition), Young Yi M.D (Supervision & manuscript revision).

All authors have read and validated the final script before submitted.

Disclosure of interest

The authors declare that they have no competing interest.

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