Ultrasound-Guided Early Weight-Bearing Accelerates Functional Recovery After Open Repair of Acute Achilles Tendon Rupture: A Retrospective Cohort Study

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Abstract

Background

The optimal rehabilitation strategy after acute Achilles tendon rupture (AATR) repair remains controversial. Although early weight-bearing (EWB) may promote functional recovery, the clinical implementation of such protocols is currently limited by a lack of objective criteria to guide progression. This study evaluated the safety and effectiveness of an ultrasound-guided early weight-bearing (USEWB) protocol following open repair of AATR.

Methods

This retrospective cohort study included 64 patients who underwent open repair for AATR between March 2025 and September 2025. Patients were divided into a USEWB group (n = 31) or a conventional rehabilitation (CR) group (n = 33) according to the postoperative rehabilitation protocol. Functional outcomes were evaluated at 2, 4, 6, 8, 12, and 16 weeks postoperatively. The calf circumference difference (CCD), Achilles tendon resting angle (ATRA), Achilles Tendon Rupture Score (ATRS), and postoperative complications were subjected to statistical analysis. Linear mixed-effects models were used for longitudinal analysis.

Results

In both the ITT and PP populations, USEWB significantly accelerated early functional recovery, demonstrating higher ATRS scores at 4, 8 and 12 weeks and smaller CCD at 8, 12, and 16 weeks postoperatively compared with CR. In the PP population, USEWB exhibited a significantly lower ATRA at 8 weeks postoperatively ($p = 0.017$). No significant differences were observed in complication rates between groups.

Conclusion

USEWB after open AATR repair appears to accelerate early functional recovery without increasing the risk of tendon elongation or postoperative complications. This strategy may provide a practical approach for individualized rehabilitation after Achilles tendon repair.

Introduction

Acute Achilles tendon rupture (AATR) is one of the most common sports injuries, with an annual incidence of 80–90 cases per 100,000 people[1]. Although both surgical and nonoperative treatments are widely used[2, 3], postoperative rehabilitation has been recognized as a critical determinant of functional recovery[4, 5].

Traditional rehabilitation protocols following surgical repair typically involve prolonged immobilization and delayed weight-bearing for at least 6 weeks[6]. However, increasing evidence suggests that early weight-bearing (EWB) may facilitate tendon healing and accelerate functional recovery by providing controlled mechanical loading[7, 8]. Nevertheless, excessive loading may compromise tendon integrity and increase the risk of re-rupture[9].

Therefore, a major clinical challenge is how to safely implement EWB while minimizing the risk of complications[10]. Ultrasonography (US), with its capability for real-time and dynamic assessment, enables visualization of continuity and changes of tendon[11, 12]. This technique may provide objective feedback to guide individualized rehabilitation and identify patients at risk of excessive tendon separation during loading[13].

This study aimed to evaluate the safety and effectiveness of an ultrasound-guided early weight-bearing (USEWB) strategy following open repair of AATR. We compared short term functional outcomes between patients undergoing USEWB and those receiving conventional rehabilitation (CR). We hypothesized that USEWB would accelerate early functional recovery without increasing the risk of complications.

Methods

Design and Population

This study is a single-center, retrospective cohort study. Patients with AATR who underwent surgical treatment at our hospital between March 2025 and September 2025 were consecutively enrolled. The diagnosis was confirmed preoperatively by US. Inclusion criteria: 1. age 18–60 years; 2. closed injury; 3. AATR (time from injury to surgery < 7 days). Exclusion criteria: 1. partial rupture; 2. recurrent rupture; 3. conditions potentially affecting functional outcomes (e.g., diabetes, neuropathy, or autoimmune disease); 4. Concurrent peri-ankle conditions (e.g., ankle osteoarthritis or other ligament injuries). A total of 87 patients were initially enrolled for screening. After excluding 23 cases, 64 patients were finally included in the study. Patients were allocated to either the USEWB group (n = 31) or the CR group (n = 33) according to the postoperative rehabilitation protocol. During the 16-week follow-up, 7 patients were lost to follow-up (USEWB: n = 3; CR: n = 4). The patient screening process is shown in Fig. 1.

Surgical Procedure

Patients were positioned prone, and surgery was performed under lumbar anesthesia with a tourniquet. A longitudinal incision was made at the level of the rupture, posterior to the midline of the tendon. After exposing the ruptured ends, the ankle was placed in a neutral position. The ruptured ends were repaired using a Krackow modified Kessler suture with non-absorbable sutures (Fig. 2). Subsequently, six “8” sutures were placed using absorbable sutures to reinforce the repair. All surgeries were performed by the same surgeon using a standardized technique.

Postoperative Rehabilitation and Data Collection

CR group: All patients were immobilized in a short-leg brace with the ankle in 30° of plantar flexion immediately after surgery. Gradual wedge reduction was performed over the first 2 weeks until a neutral position was achieved, during which weight-bearing was not allowed. Partial weight-bearing and ankle range-of-motion exercises were initiated at 3–4 weeks postoperatively. Weight-bearing and activity levels were progressively advanced thereafter, including heel-raise exercises at 7–8 weeks and return to jogging after successful single-leg heel raises. Detailed rehabilitation protocols are provided in Table 1.

Table 1

Postoperative rehabilitation protocols in the USEWB and CR groups. The USEWB group was stratified according to ultrasound findings into patients without signs of tendon separation and those demonstrating intolerance or a tendency toward separation. The CR group followed a standardized protocol with delayed weight-bearing. USEWB, ultrasound-guided early weight-bearing group; CR, conventional rehabilitation CAM, controlled ankle motion.

	USEWB group (n = 31)		**CR group (n = 33)**
	no separation tendency	**intolerance or separation tendency**	
0–2 weeks after surgery	Immobilization in 30° of plantar flexion with gradual adjustment to neutral Non–weight-bearing	Immobilization in 30° of plantar flexion with gradual adjustment to neutral Non–weight-bearing	Immobilization in 30° of plantar flexion with gradual adjustment to neutral Non–weight-bearing
3–4 weeks after surgery	Ankle mobilization Standing ≤ 1 h/day Protected walking less than 500 steps on flat ground with an inflatable CAM boot, cane or crutches as needed	Ankle mobilization Standing ≤ 1 h/day No walking permitted	Ankle mobilization Standing ≤ 1 h/day No walking permitted
5–6 weeks after surgery	Ankle mobilization Standing up for 2 h per day Deep squat Protected walking less than 1000 steps on flat ground with an inflatable CAM boot	Ankle mobilization Standing up for 2 h per day Deep squat Protected walking less than 500 steps on flat ground with an inflatable CAM boot, cane or crutches as needed	Ankle mobilization Standing up for 2 h per day Deep squat Protected walking less than 500 steps on flat ground with an inflatable CAM boot, cane or crutches as needed
7–8 weeks after surgery	Double-legged heel raises Walking less than 2000 steps on flat ground without CAM boot	Double-legged heel raises Protected walking less than 1000 steps on flat ground with an inflatable CAM boot	Double-legged heel raises Protected walking less than 1000 steps on flat ground with an inflatable CAM boot
9–10 weeks after surgery	One-legged heel raises	One-legged heel raises Walking less than 2000 steps on flat ground without CAM boot	One-legged heel raises Walking less than 2000 steps on flat ground without CAM boot

	USEWB group (n = 31)		CR group (n = 33)
	no separation tendency	intolerance or separation tendency	
2 weeks after performing one-leg heel raises	Jogging	Jogging	Jogging
4 weeks after performing jogging	More vigorous training	More vigorous training	More vigorous training

USEWB group: Two weeks postoperatively, after brace removal, the patient's foot was positioned in a neutral resting position and suspended over the edge of the examination table to allow unrestricted motion. A linear transducer was placed over the Achilles tendon proximal to the calcaneal tuberosity to obtain longitudinal images of the tendon fibers in the neutral position, as well as images of the rupture site. US findings of the postoperative Achilles tendon primarily consisted of acoustic shadowing at the suture zone (Fig. 3a); in some patients, hypoechoic areas surrounding the sutures were also observed (Fig. 3c). Image was subsequently acquired in maximal dorsiflexion. The sonographer visually assessed whether the acoustic shadowing or the hypoechoic areas at the surgical site increased compared with the neutral position.

If no significant expansion of these areas was observed, the patient was transitioned to an inflatable walking controlled ankle motion boot. This boot has a window over the Achilles tendon (Fig. 4a) to allow probe placement, and US imaging was repeated during standing. If the acoustic shadowing or hypoechoic areas still showed no significant expansion, the patient was instructed to walk slowly while the sonographer manually held and guided the transducer to follow the patient's movement for dynamic ultrasound assessment (Fig. 4b-c). If no significant changes were observed (Fig. 3b), the patient proceeded to ankle range-of-motion exercises and was allowed to ambulate on level ground for no more than 500 steps per day during weeks 3–4 postoperatively. The rehabilitation protocol was subsequently advanced by approximately 2 weeks. If any increase in the gap was detected during the above assessments (Fig. 3d), a tendency toward tendon separation was assumed, and the examination was terminated. Patients who were unable to complete the walking assessment or demonstrated signs of separation followed the CR protocol (Table 1). All US examinations were performed by a sonographer with 15 years of experience, using a 9–15 MHz linear array transducer (HIVISION, G0201500101431, China).

Follow-up and Assessment Criteria

Patients were followed at 2, 4, 6, 8, 12, and 16 weeks postoperatively. All assessments were performed by the same surgeon. Calf circumference was measured 10 cm below the tibial tuberosity with the patient seated and legs hanging naturally, and calf circumference differences (CCD) were calculated between the injured and contralateral sides. Achilles tendon resting angle (ATRA) was measured using a handheld goniometer with the patient in the prone position and the knee flexed at 90°. Side-to-side differences were calculated. A negative relative ATRA value indicates dorsiflexion of the injured ankle, whereas a positive value indicates plantarflexion[14]. Achilles tendon total rupture score (ATRS) was used to evaluate the patient's functional status[15]. Postoperative complications, including re-rupture, deep vein thrombosis (DVT), and infection, were recorded.

Statistical Analysis

Statistical analysis for this study was performed using R software (version 4.3.3). Intergroup comparisons of complication rates were performed using Fisher's exact test. Repeated-measure variables were analyzed using linear mixed-effects models (LMM). Model diagnostics, including Q-Q plots and residual plots for conditional residuals, confirmed no severe violations of normality or homoscedasticity for the linear mixed-effects models. Each model included a random intercept for subjects to account for within-subject correlation, and fixed effects for group, time, and the group × time interaction. No additional covariates were included due to the balanced baseline characteristics and limited sample size. The models were fitted using the *lme4* package and parameters were estimated using the restricted maximum likelihood method. Degrees of freedom and *p*-values were calculated using the Satterthwaite approximation via the *lmerTest* package. Post-hoc pairwise comparisons at specific time points were performed using the *emmeans* package to derive estimated marginal means (EMMs) and estimated marginal mean differences (EMMD) between groups, with p-values adjusted via the Bonferroni correction to control for Type I error. The primary analysis was conducted in the intention-to-treat (ITT) population. Missing data were handled within the LMM framework under the assumption of missing at random, and no imputation was performed. A sensitivity analysis was conducted in the per-protocol (PP) population by excluding patients who deviated from the assigned rehabilitation strategy. Results are presented as EMMs ± standard errors (SE) for each group, and EMMD between groups at specific time points, accompanied by their 95% confidence intervals (CI). All statistical tests were two-sided, with $p < 0.05$ considered statistically significant.

Language Model Usage

Limited use of a large language model (OpenAI GPT-5.3) was employed solely for language editing purposes (including grammar and sentence structure refinement). All scientific content, interpretations, and conclusions were generated and critically reviewed by the authors. All large language model assisted outputs were revised to ensure accuracy.

Results

Study Population and Baseline Characteristics

A total of 87 patients were screened, of whom 64 met the inclusion criteria and were included in the analysis (USEWB: n = 31; CR: n = 33). During the 16-week follow-up, 7 patients were lost to follow-up

(USEWB: n = 3; CR: n = 4).

Baseline demographic and clinical characteristics are summarized in Table 2. There were no significant differences between groups in age, gender, side, body mass index, operation time, or distance from the rupture site to the Achilles tendon insertion (all $p > 0.05$).

Table 2
Baseline demographic and clinical characteristics of the study population. CR, conventional rehabilitation; USEWB, ultrasound-guided early weight-bearing; BMI, body mass index; OT, operation time; DRSTI, distance from the rupture site to the Achilles tendon insertion.

Age	**CR (n = 33)**	**USEWB (n = 31)**	***p***
	34.7 ± 7.5	**36.4 ± 6.2**	**0.267**
Gender			0.667
male	31 (94%)	28 (90%)	
female	2 (6.1%)	3 (9.7%)	
Side			0.622
Left	15 (45%)	16 (52%)	
Right	18 (55%)	15 (48%)	
BMI	25.5 ± 2.6	25.3 ± 3.3	0.882
OT (min)	36.8 ± 4.0	38.2 ± 4.5	0.329
DRSTI (cm)	4.7 ± 0.9	4.4 ± 1.3	0.514

Functional Recovery Outcomes

Functional recovery was assessed using CCD, ATRA, and ATRS at 2, 4, 6, 8, 12, and 16 weeks postoperatively (Fig. 5). Results from the ITT are reported in Table 3, and sensitivity analyses based on the PP are shown in Table 4.

Table 3

Comparison of functional recovery outcomes between the USEWB and CR groups in the ITT population. A negative CCD value indicates smaller circumference on the injured side. A negative ATRA value indicates dorsiflexion of the injured ankle, whereas positive indicates plantarflexion. Mean difference= USEWB group minus CR group. Adjusted *p* values were Bonferroni-corrected for multiple comparisons. *$p < 0.05$. CR, conventional rehabilitation; USEWB, ultrasound-guided early weight-bearing; EMMs, estimated marginal means; SE, standard error; EMMD, estimated marginal mean differences; CI, confidence intervals; CCD, calf circumference difference; ATRA, Achilles tendon resting angle; ATRS, Achilles tendon total rupture score; ITT, intention-to-treat.

	Time (weeks)	CR (EMMs ± SE)	USEWB (EMMs ± SE)	EMMD (95% CI)	Adjusted *p* value	Global group × time interaction *p* value
CCD (cm)	2	-0.761 ± 0.058	-0.723 ± 0.059	0.038 (-0.125 to 0.201)	0.646	0.254
	4	-1.487 ± 0.060	-1.410 ± 0.060	0.077 (-0.091 to 0.245)	0.367	
	6	-1.274 ± 0.060	-1.155 ± 0.059	0.119 (-0.048 to 0.286)	0.162	
	8	-1.029 ± 0.059	-0.807 ± 0.063	0.222 (0.052 to 0.392)	0.011*	
	12	-0.875 ± 0.058	-0.582 ± 0.063	0.293 (0.125 to 0.462)	<0.001*	
	16	-0.704 ± 0.061	-0.503 ± 0.063	0.201 (0.029 to 0.374)	0.022*	
ATRA (°)	2	7.573 ± 0.353	7.087 ± 0.365	-0.486 (-1.484 to 0.513)	0.340	0.163
	4	4.413 ± 0.371	4.590 ± 0.371	0.177 (-0.855 to 1.208)	0.736	
	6	2.987 ± 0.371	2.158 ± 0.365	-0.829 (-1.851 to 0.194)	0.112	
	8	0.713 ± 0.365	-0.304 ± 0.384	-1.016 (-2.058 to 0.025)	0.056	
	12	-6.478 ± 0.359	-5.771 ± 0.384	0.707 (-0.327 to 1.740)	0.180	
	16	-6.800 ± 0.377	-6.732 ± 0.384	0.068 (-0.991 to 1.126)	0.900	

ATRS	2	20.909 ± 1.570	19.710 ± 1.620	-1.199 (-5.637 to 3.238)	0.595	<0.001*
	4	29.325 ± 1.644	34.095 ± 1.646	4.771 (0.194 to 9.347)	0.041*	
	6	51.126 ± 1.644	52.645 ± 1.62	1.519 (-3.022 to 6.059)	0.511	
	8	65.338 ± 1.618	71.408 ± 1.702	6.070 (1.451 to 10.69)	0.010*	
	12	72.026 ± 1.594	84.052 ± 1.702	12.025 (7.439 to 16.612)	<0.001*	
	16	88.639 ± 1.672	88.899 ± 1.702	0.260 (-4.433 to 4.953)	0.913	

Table 4

Sensitivity analysis of functional outcomes between the CR and USEWB groups in the PP population. The PP population excluded patients who deviated from the assigned rehabilitation strategy. A negative CCD value indicates smaller circumference on the injured side. A negative ATRA value indicates dorsiflexion of the injured ankle, whereas positive indicates plantarflexion. Mean difference= USEWB group minus CR group. Adjusted *p* values were Bonferroni-corrected for multiple comparisons. $^{*}p < 0.05$. CR, conventional rehabilitation; USEWB, ultrasound-guided early weight-bearing; EMMs, estimated marginal means; SE, standard error; EMMD, estimated marginal mean differences; CI, confidence intervals; CCD, calf circumference difference; ATRA, Achilles tendon resting angle; ATRS, Achilles tendon total rupture score; PP, per-protocol.

	Time (weeks)	CR (EMMs ± SE)	USEWB (EMMs ± SE)	EMMD (95% CI)	Adjusted *p* value	Global group × time interaction *p* value
CCD (cm)	2	-0.761 ± 0.058	-0.712 ± 0.066	0.049 (-0.124 to 0.222)	0.578	0.354
	4	-1.487 ± 0.061	-1.404 ± 0.067	0.083 (-0.096 to 0.262)	0.361	
	6	-1.274 ± 0.061	-1.119 ± 0.066	0.154 (-0.023 to 0.332)	0.087	
	8	-1.029 ± 0.060	-0.800 ± 0.069	0.229 (0.049 to 0.409)	0.013*	
	12	-0.875 ± 0.059	-0.571 ± 0.069	0.304 (0.126 to 0.483)	<0.001*	
	16	-0.704 ± 0.062	-0.517 ± 0.070	0.188 (0.003 to 0.372)	0.047*	
ATRA (°)	2	7.573 ± 0.356	7.312 ± 0.401	-0.261 (-1.316 to 0.794)	0.626	0.034*
	4	4.413 ± 0.373	5.000 ± 0.409	0.587 (-0.503 to 1.676)	0.290	
	6	2.987 ± 0.373	1.981 ± 0.401	-1.006 (-2.084 to 0.072)	0.067	
	8	0.713 ± 0.367	-0.625 ± 0.418	-1.338 (-2.432 to -0.244)	0.017*	
	12	-6.478 ± 0.361	-5.742 ± 0.418	0.736 (-0.350 to 1.823)	0.183	
	16	-6.800 ± 0.380	-6.496 ± 0.427	0.304 (-0.819 to 1.428)	0.595	

ATRS	2	20.909 ± 1.557	19.154 ± 1.754	-1.755 (-6.370 to 2.859)	0.455	<0.001*
	4	29.325 ± 1.631	34.704 ± 1.788	5.379 (0.618 to 10.140)	0.027*	
	6	51.127 ± 1.631	52.462 ± 1.754	1.334 (-3.378 to 6.046)	0.578	
	8	65.337 ± 1.605	72.817 ± 1.824	7.481 (2.701 to 12.260)	0.002*	
	12	72.027 ± 1.580	86.228 ± 1.824	14.202 (9.454 to 18.950)	<0.001*	
	16	88.641 ± 1.658	89.245 ± 1.862	0.604 (-4.301 to 5.510)	0.809	

CCD

The longitudinal analysis of CCD revealed no statistically significant global interaction between group and time in either the ITT population ($p = 0.254$) or the PP population ($p = 0.354$). There was no significant difference in CCD between the two groups at 2 weeks postoperatively in ITT ($p = 0.646$) and PP population ($p = 0.578$). In the ITT population, the USEWB group exhibited a significantly smaller CCD compared with the CR group at 8 weeks postoperatively ($p = 0.011$) and at 12 weeks postoperatively ($p < 0.001$). This significant inter-group difference was sustained at 16 weeks postoperatively ($p = 0.022$). Sensitivity analysis within the PP population corroborated these longitudinal trends, confirming a significantly reduced CCD in the USEWB group from 8 weeks through 16 weeks postoperatively (all $p < 0.05$).

ATRA

In the ITT population, the global group × time interaction was not statistically significant ($p = 0.163$). Conversely, the PP population revealed a statistically significant global group × time interaction ($p = 0.034$). There was no significant difference in ATRA between the two groups at 2 weeks postoperatively in ITT ($p = 0.340$) and PP population ($p = 0.626$). In the ITT population, no significant differences were tracked between the groups at any specific follow-up interval (all $p > 0.05$), although the difference at 8 weeks postoperatively approached statistical significance ($p = 0.056$).

In the PP population, the USEWB group exhibited a significantly lower ATRA compared with the CR group at 8 weeks postoperatively ($p = 0.017$), indicating that the injured ankle tended to be in a more dorsiflexed position in the USEWB group. Subsequently, the between-group difference gradually diminished, with no significant differences observed at 12 weeks ($p = 0.183$) and 16 weeks ($p = 0.595$) postoperatively.

ATRS

The ATRS demonstrated significant improvements over the 16-week follow-up period in both groups, backed by a significant global group × time interaction in both the ITT ($p < 0.001$) and the PP population ($p < 0.001$). There was no significant difference in ATRS between the two groups at 2 weeks postoperatively in ITT ($p = 0.595$) and PP population ($p = 0.455$).

In the ITT analysis, the USEWB group had a significantly higher ATRS at 4 weeks ($p = 0.041$), 8 weeks ($p = 0.010$), and 12 weeks ($p < 0.001$) postoperatively. By 16 weeks postoperatively, the ATRS between the two groups equilibrated ($p = 0.913$). This prominent trend of accelerated functional recovery was also reinforced by the PP population analysis, where significantly higher ATRS was observed in the USEWB group at 4, 8 and 12 weeks postoperatively.

Complications

Postoperative complications are summarized in Table 5. One patient in each group experienced a re-rupture (3.0% in CR vs. 3.2% in USEWB, $p > 0.999$). DVT occurred in three patients (9.1%) in the CR group and one patient (3.2%) in the USEWB group, but the difference was not statistically significant ($p = 0.614$). Superficial infection was reported in two patients in each group (6.1% in CR vs. 6.5% in USEWB, $p > 0.999$). The overall complication rate was 18% in the CR group and 13% in the USEWB group ($p = 0.734$). No significant differences were found for any individual complication or for the composite outcome.

Table 5
Comparison of postoperative complications between the CR and USEWB groups.

Re-rupture	**CR (n = 33)**	**USEWB (n = 31)**	***p***
	1 (3.0%)	**1 (3.2%)**	**> 0.999**
DVT	3 (9.1%)	1 (3.2%)	0.614
Infection	2 (6.1%)	2 (6.5%)	> 0.999
Total complication	6 (18%)	4 (13%)	0.734

CR, conventional rehabilitation; USEWB, ultrasound-guided early weight-bearing; DVT, deep vein thrombosis.

Discussion

The present study demonstrates that a USEWB strategy after open Achilles tendon repair accelerates early functional recovery without increasing the risk of re-rupture or tendon elongation. However, this advantage was not sustained during mid-term follow-up, suggesting that EWB primarily facilitates faster recovery rather than improving ultimate functional outcomes.

While mechanical loading has been shown to promote tendon healing by enhancing collagen alignment[16], excessive loading may compromise tendon integrity[17]. In this study, patients in the USEWB group demonstrated less muscle atrophy and improved early functional recovery. Although the global group × time interaction for CCD did not reach statistical significance in either the ITT or the PP population, post-hoc analysis revealed that the USEWB group achieved a significantly smaller CCD starting at 8 weeks postoperatively, indicating a more effective preservation of calf muscle volume. We speculate that the non-significant global interaction is primarily attributable to our relatively modest sample size, which constrained the global statistical power. EWB can mitigate disuse-related changes in the calf muscles, including muscle atrophy and impaired neuromuscular control[18]. The disappearance of this advantage at later time points suggests that EWB does not appear to change the final healing outcome of the tendon but may accelerate functional recovery.

Safety concerns, particularly the risk of re-rupture, remain the primary consideration for EWB protocols[19]. Although the timing of weightbearing differs, previous studies have also demonstrated the safety of EWB protocols[7, 20]. In the present study, no significant difference in re-rupture rates was observed between groups, supporting the safety of EWB when guided by US. However, given the low incidence of re-rupture[21], the study may be underpowered to detect small differences. The concern of re-rupture may influence patients' acceptance of EWB[22, 23]. To some extent, visual feedback from US may improve patients’ understanding of rehabilitation progression and facilitate adherence to postoperative protocols. Although this study did not quantitatively assess psychological factors, imaging-supported rehabilitation may improve patient engagement during the rehabilitation process—a hypothesis that warrants further investigation.

Achilles tendon elongation is another critical concern, as excessive elongation can impair plantar flexion strength and functional performance[24]. In the present study, although no significant global group × time interaction for ATRA was observed in the ITT population, the PP analysis demonstrated that the USEWB group exhibited a significantly lower ATRA difference at 8 weeks postoperatively, indicating that the injured ankle tended to be in a more dorsiflexed position in the USEWB group. However, this difference disappeared at the subsequent 12- and 16-week follow-ups. We speculate that EWB may have alleviated postoperative Achilles tendon stiffness rather than caused pathological tendon elongation, which was further supported by the higher ATRS scores observed in the USEWB group. This is consistent with previous literature demonstrating that EWB does not induce pathological tendon lengthening[25–27]. Nevertheless, ATRA is not a surrogate for direct measurements of elongation[28]; therefore, future studies incorporating quantitative imaging and strength assessments are needed to better elucidate the relationship between EWB and tendon remodeling.

From a practical perspective, US-guided rehabilitation may help surgeons identify patients who tolerate EWB without excessive tendon separation, allowing earlier mobilization. This strategy may help selectively accelerate rehabilitation after AATR repair.

Several limitations should be acknowledged. First, this was a single-center, retrospective study with a relatively small sample size. Further validation is required through large-scale, multicenter, prospective randomized controlled trials. The assessment of tendon separation trends via US relies primarily on the subjective interpretation, which may be a source of diagnostic variability. More standardized and objective ultrasound evaluation criteria need to be developed in the future. Additionally, US evaluation was performed at a single time point only, limiting continuous monitoring of tendon healing. The development of wearable ultrasound devices in the future could enable a more comprehensive evaluation of the entire rehabilitation process. The follow-up period was insufficient to assess long-term efficacy; particularly regarding potential elongation, longer-term longitudinal studies are necessary to fully characterize the timeline of postoperative recovery.

Conclusion

USEWB after open AATR repair appears to accelerate early functional recovery without increasing the risk of tendon elongation or postoperative complications. This strategy may provide a practical approach for individualized rehabilitation after Achilles tendon repair.

Abbreviations

AATR acute Achilles tendon rupture, EWB early weight-bearing, US Ultrasonography, USEWB ultrasound-guided early weight-bearing, CR conventional rehabilitation, CCD calf circumference differences, ATRA Achilles tendon resting angle, ATRS Achilles tendon total rupture score, DVT deep vein thrombosis, LMM linear mixed-effects models, ITT intention-to-treat, PP per-protocol, CAM controlled ankle motion, BMI body mass index, OT operation time, DRSTI distance from the rupture site to the Achilles tendon insertion

Declarations

Ethics approval and consent to participate: This study was reviewed and approved by the Ethics Committee of Peking University Third Hospital (M20250533). All procedures were performed in accordance with the ethical standards of the 1964 Declaration of Helsinki and its later amendments. Informed consent was obtained from all patients for participation.

Consent for publication: Informed consent was obtained from all patients for the publication of this study.

Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no conflicts of interest.

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Authors' contributions: Z C: Conceptualization; data curation; formal analysis; investigation; methodology; visualization; writing—original draft. B Z: Investigation; methodology; resources; writing—review and editing. A S: Data curation; investigation; validation. Y C: Data curation; investigation. G S: Data curation; investigation. J F: Software; validation. S G: Software; validation. Z W: Software; visualization. H C: Project administration; supervision. F Z: Project administration; supervision. YB L: Conceptualization; methodology; validation; supervision; writing—review and editing. Y L: Conceptualization; project administration; supervision; writing—review and editing. All authors read and approved the final manuscript.

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References

1. Bergamin F, Civera M, Reinoso MR, Burgio V, Ruiz OG, Surace C. Worldwide Incidence and Surgical Costs of Tendon Injuries: A Systematic Review and Meta-Analysis. Mltj-Muscles Ligaments Tendons J. 2023;13(1):31–45.
2. Acevedo D, Garcia JR, Grewal RS, Vankara A, Murdock CJ, Hardigan PC, et al. Comparison of rerupture rates after operative and nonoperative management of Achilles tendon rupture in older populations: Systematic review and meta-analysis. J Orthop. 2024;52:112–8.
3. Lameire DL, Ramelli L, Halai M, Wasserstein D, Park SSH. Outcomes of operative and nonoperative management of myotendinous Achilles tendon ruptures: a systematic review. BMC Musculoskelet Disord. 2025;26(1).
4. Yan XJ, Zhang WH. Enhanced recovery after surgery protocols for minimally invasive treatment of Achilles tendon rupture: Prospective single-center randomized study. World J Orthop. 2024;15(12).
5. Coopmans L, Amaya Aliaga J, Metsemakers WJ, Sermon A, Misselyn D, Nijs S, et al. Accelerated Rehabilitation in Non-operative Management of Acute Achilles Tendon Ruptures: A Systematic Review and Meta-analysis. J foot ankle surgery: official publication Am Coll Foot Ankle Surg. 2022;61(1):157–62.
6. Gould HP, Bano JM, Akman JL, Fillar AL. Postoperative Rehabilitation Following Achilles Tendon Repair: A Systematic Review. Sports Med Arthrosc Rev. 2021;29(2):130–45.
7. Deng Z, Li Z, Shen C, Sun X, Wang T, Nie M, et al. Outcomes of early versus late functional weight-bearing after the acute Achilles tendon rupture repair with minimally invasive surgery: a randomized controlled trial. Arch Orthop Trauma Surg. 2023;143(4):2047–53.

8. Dold AP. Acute Achilles Tendon Ruptures: An Update on Current Management Strategies. J Am Acad Orthop Surg. 2024;33(16):881–9.
9. Irfan SA, Ahmed S, Ashkar A, Heyes G, Khan MW, Ahsan Nawaz SM, et al. Comparative effectiveness of weight-bearing strategies on functional recovery in acute Achilles tendon rupture: A network meta-analysis. Foot ankle surgery: official J Eur Soc Foot Ankle Surg. 2025;31(7):561–9.
10. Pisano A, Boxler M, Gambuti E, Falco F, Trierweiler M, Vinci A, et al. Open surgical repair as gold standard for acute Achilles tendon ruptures: Systematic review and network meta-analysis. Knee surgery, sports traumatology, arthroscopy. official J ESSKA. 2025;33(7):2664–83.
11. Gitto S, Draghi AG, Bortolotto C, Draghi F. Sonography of the Achilles Tendon After Complete Rupture Repair: What the Radiologist Should Know. J ultrasound medicine: official J Am Inst Ultrasound Med. 2016;35(12):2529–36.
12. Chianca V, Zappia M, Oliva F, Luca B, Maffulli N. Post-operative MRI and US appearance of the Achilles tendons. J Ultrasound. 2020;23(3):387–95.
13. Cao Y, Gao S, Zhao B, Li X, Pan XN, Lv Y, et al. The short-term clinical effects of accelerated rehabilitation following open surgery for acute Achilles tendon rupture based on ultrasonography monitoring: a retrospective cohort study. J Orthop Surg Res. 2025;20(1):865.
14. Carmont MR, Grävare Silbernagel K, Brorsson A, Olsson N, Maffulli N, Karlsson J. The Achilles tendon resting angle as an indirect measure of Achilles tendon length following rupture, repair, and rehabilitation. Asia-Pacific J sports Med Arthrosc rehabilitation Technol. 2015;2(2):49–55.
15. Nilsson-Helander K, Thomeé R, Silbernagel KG, Thomeé P, Faxén E, Eriksson BI, et al. The Achilles tendon Total Rupture Score (ATRS): development and validation. Am J Sports Med. 2007;35(3):421–6.
16. Li ZJ, Yang QQ, Zhou YL. Biological and Mechanical Factors and Epigenetic Regulation Involved in Tendon Healing. Stem cells Int. 2023;2023:4387630.
17. Hsu JE, Horneff JG, Gee AO. Immobilization After Rotator Cuff Repair: What Evidence Do We Have Now? Qld Gov Min J. 2016;47(1):169–77.
18. Marusic U, Narici M, Simunic B, Pisot R, Ritzmann R. Nonuniform loss of muscle strength and atrophy during bed rest: a systematic review. Journal of applied physiology (Bethesda, Md: 1985). 2021;131(1):194–206.
19. Ochen Y, Beks RB, van Heijl M, Hietbrink F, Leenen LPH, van der Velde D, et al. Operative treatment versus nonoperative treatment of Achilles tendon ruptures: systematic review and meta-analysis. BMJ (Clinical Res ed). 2019;364:k5120.
20. Gillissen S, Halperin I, Balesar V, Gorter E, Greeven A. Functional and early weight-bearing protocol for achilles tendon ruptures: a retrospective study. Eur J trauma Emerg surgery: official publication Eur Trauma Soc. 2021;47(6):2049–54.
21. Laboute E, Thoreux P, Beldame J, Caubere A, Giunta JC, Coursier R, et al. Re-ruptures and early outcomes after surgical repair of acute Achilles tendon ruptures: prospective, comparative multicenter study. Int Orthop. 2023;47(7):1855–61.

22. Slagers AJ, Dams OC, van Zalinge SD, Geertzen JH, Zwerver J, Reininga IH et al. Psychological Factors Change During the Rehabilitation of an Achilles Tendon Rupture: A Multicenter Prospective Cohort Study. Phys Ther. 2021;101(12).
23. White G, Bright F, Rio EK, Chimenti RL, Murphy MC. Do Anxiety, Depression, Fear of Movement and Fear of Achilles Rupture Correlate with Achilles Tendinopathy Pain, Symptoms or Physical Function? J Clin Med. 2025;14(2).
24. Diniz P, Pacheco J, Guerra-Pinto F, Pereira H, Ferreira FC, Kerkhoffs G. Achilles tendon elongation after acute rupture: is it a problem? A systematic review. Knee surgery, sports traumatology, arthroscopy: official. J ESSKA. 2020;28(12):4011–30.
25. Valkering KP, Aufwerber S, Ranuccio F, Lunini E, Edman G, Ackermann PW. Functional weight-bearing mobilization after Achilles tendon rupture enhances early healing response: a single-blinded randomized controlled trial. Knee surgery, sports traumatology, arthroscopy. official J ESSKA. 2017;25(6):1807–16.
26. Eliasson P, Agergaard AS, Couppé C, Svensson R, Hoeffner R, Warming S, et al. The Ruptured Achilles Tendon Elongates for 6 Months After Surgical Repair Regardless of Early or Late Weightbearing in Combination With Ankle Mobilization: A Randomized Clinical Trial. Am J Sports Med. 2018;46(10):2492–502.
27. Okoroha KR, Ussef N, Jildeh TR, Khalil LS, Hasan L, Bench C, et al. Comparison of Tendon Lengthening With Traditional Versus Accelerated Rehabilitation After Achilles Tendon Repair: A Prospective Randomized Controlled Trial. Am J Sports Med. 2020;48(7):1720–6.
28. Larsson E, Helander KN, Falkheden Henning L, Heiskanen M, Carmont MR, Grävare Silbernagel K, et al. Achilles tendon resting angle is able to detect deficits after an Achilles tendon rupture, but it is not a surrogate for direct measurements of tendon elongation, function or symptoms. Knee surgery, sports traumatology, arthroscopy. official J ESSKA. 2022;30(12):4250–7.

Figures

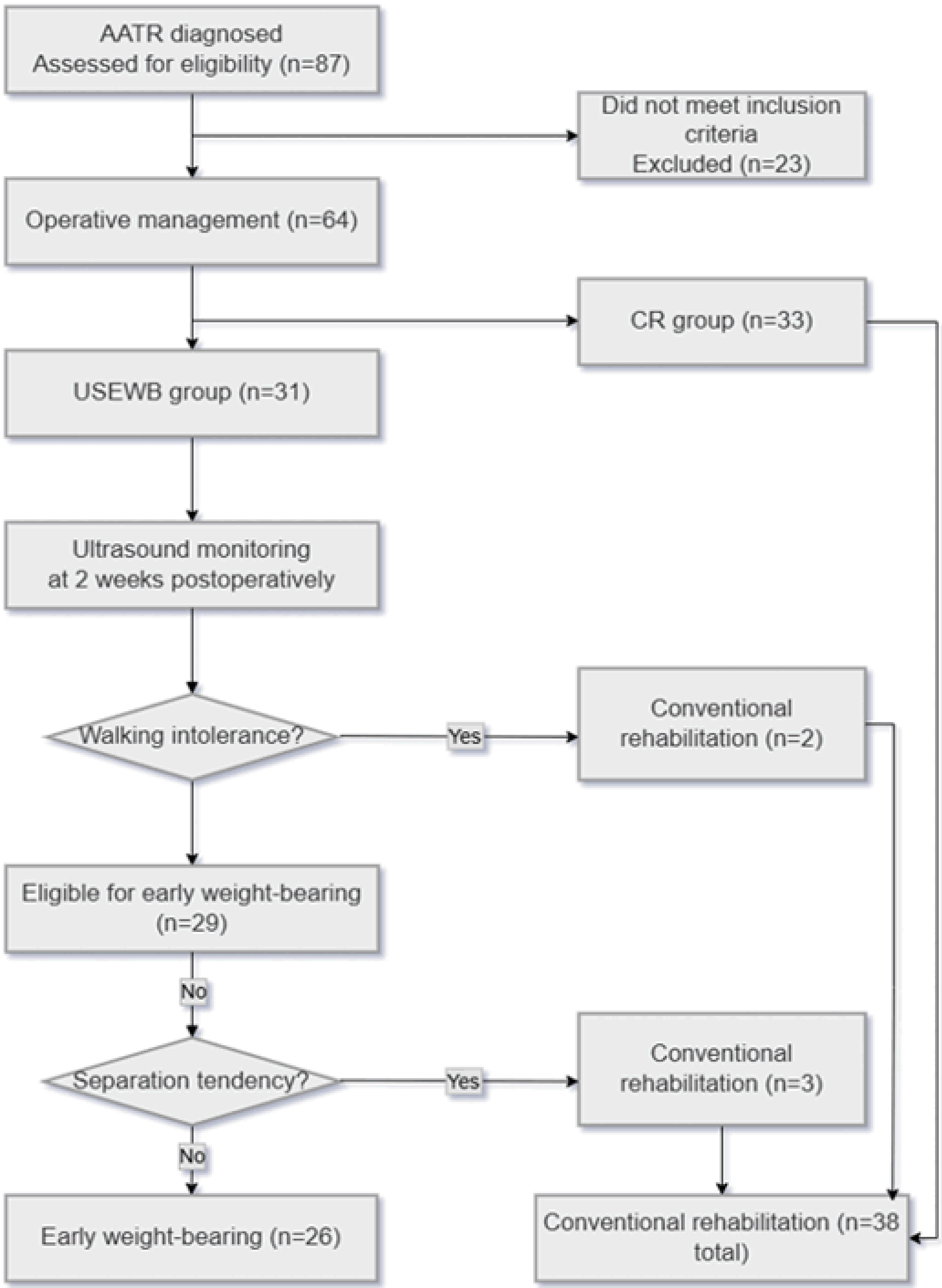

Figure 1

Flow diagram of patient selection and study enrollment.

AATR, Acute Achilles tendon rupture; USEWB, ultrasound-guided early weight-bearing; CR, conventional rehabilitation.

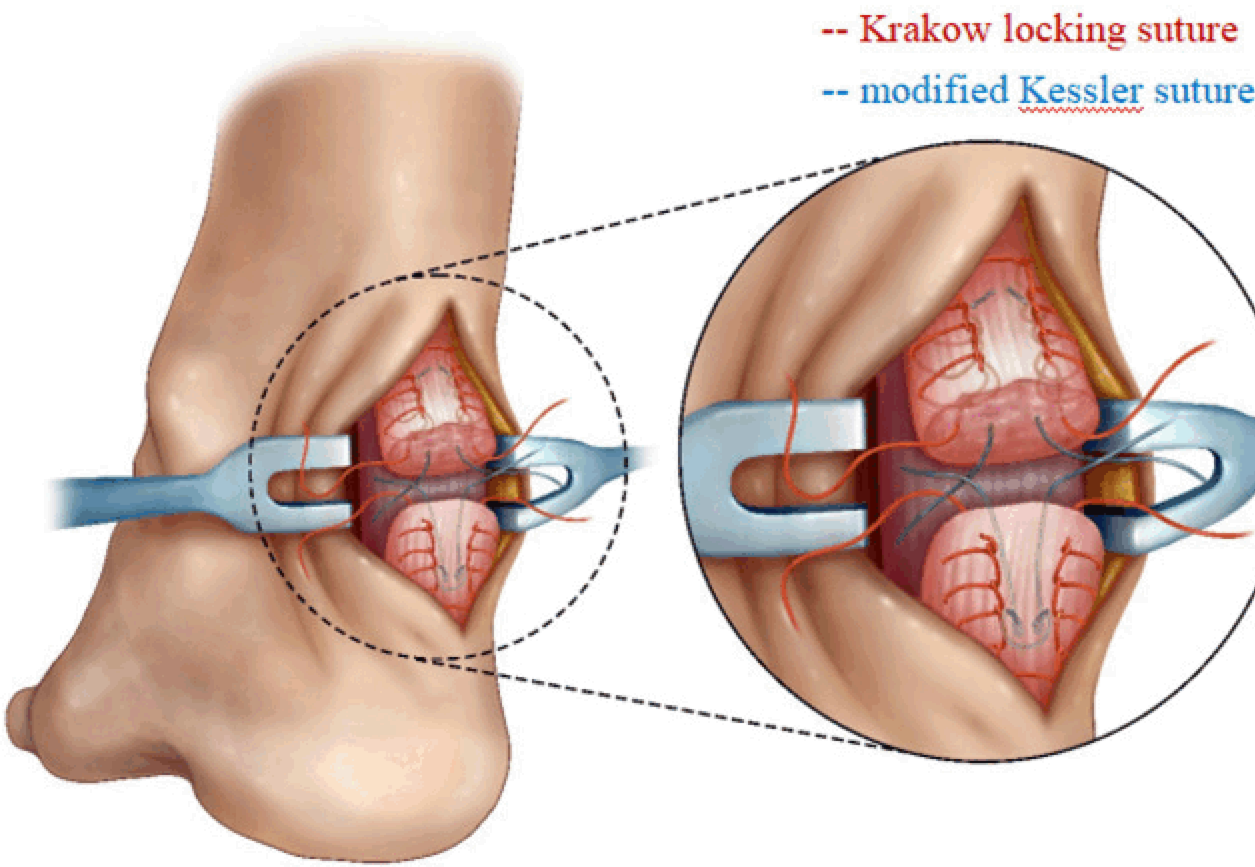

Figure 2

Diagram of suture technique. Reprinted from Reference [13].

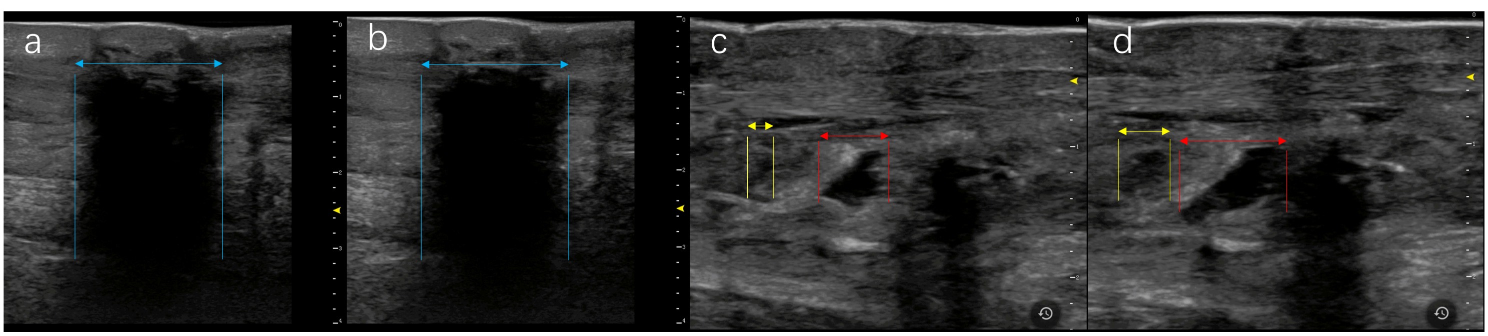

Figure 3

US assessment of the Achilles tendon at two weeks postoperatively. (a) Longitudinal US image in the neutral position showing prominent acoustic shadowing at the suture zone. (b) Dynamic US imaging during walking, demonstrating no significant expansion of the acoustic shadowing compared to the neutral position. (c) Longitudinal US image revealing two distinct anechoic areas at the surgical site. (d) Dynamic US imaging during walking, showing marked expansion of the anechoic areas relative to the resting state, suggesting potential weak zones within the tendon and evident deformation during functional loading.

US, Ultrasonography

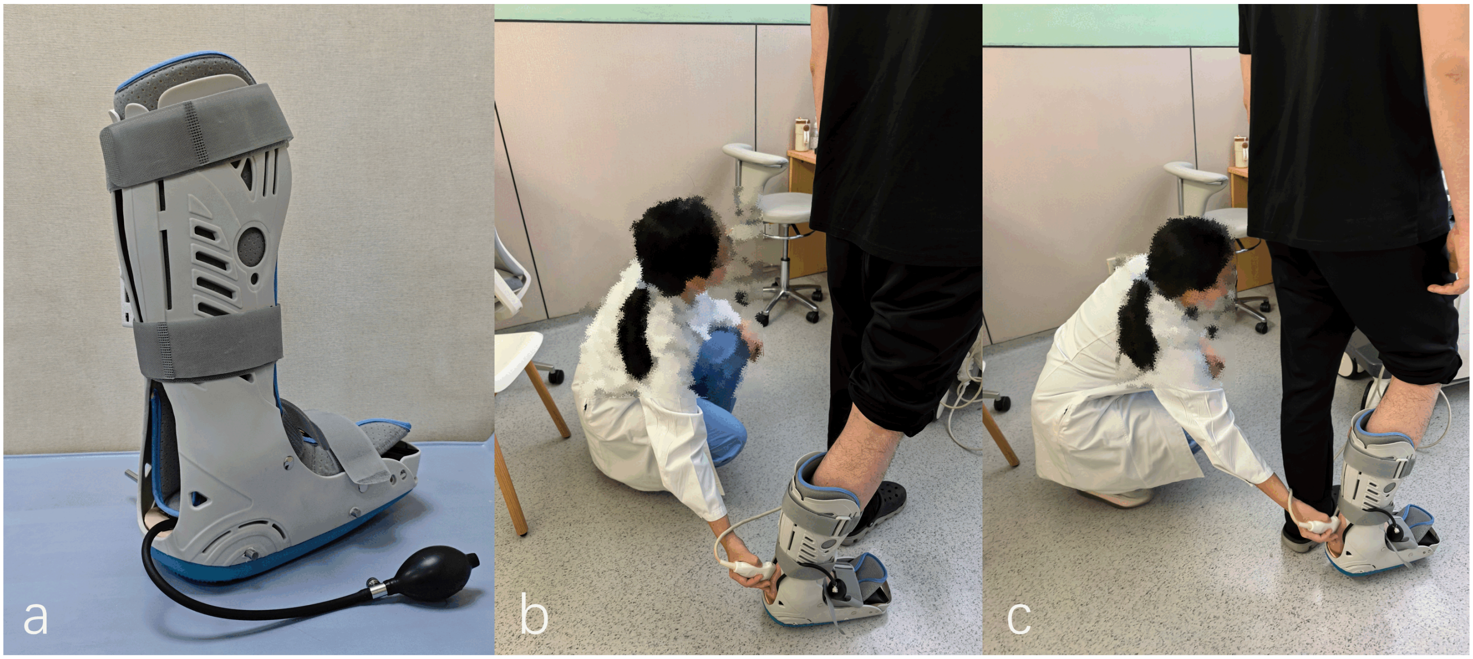

Figure 4

(a) An inflatable walking controlled ankle motion boot with a window over the Achilles tendon to facilitate ultrasound probe placement; (b–c) Dynamic ultrasound assessment of the Achilles tendon during the gait cycle.

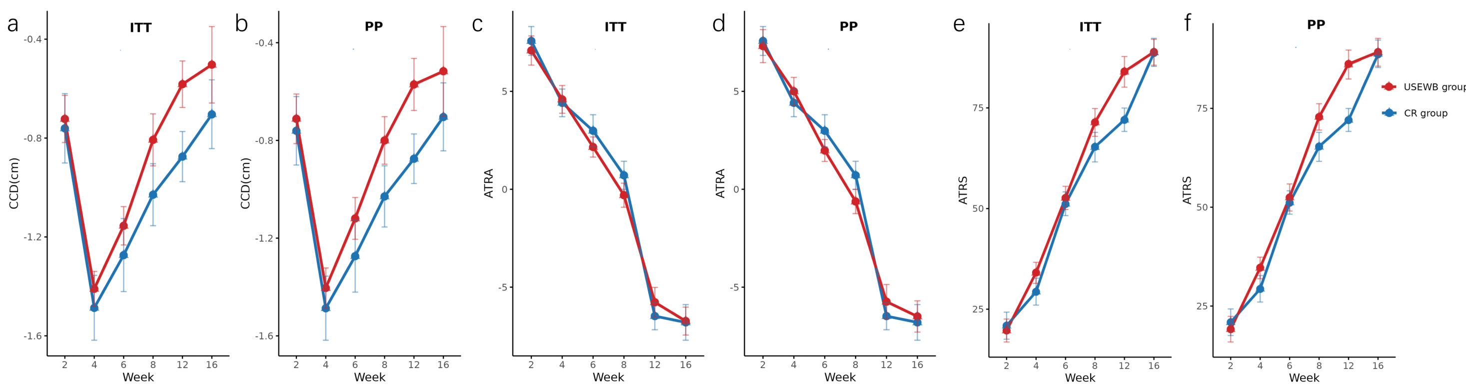

Figure 5

Longitudinal changes in functional recovery outcomes in the USEWB and CR groups. Comparison between USEWB and CR groups regarding trajectories of (a–b) CCD, (c–d) ATRA, and (e–f) ATRS in both ITT and PP populations.

USEWB, ultrasound-guided early weight-bearing; CR, conventional rehabilitation; CCD, calf circumference difference; ATRA, Achilles tendon resting angle; ATRS, Achilles tendon total rupture score; ITT, intention-to-treat; PP, per-protocol.