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High plantar force loading after Achilles tendon rupture repair with early functional mobilization

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1 **High plantar force loading after Achilles tendon rupture repair with early**
2 **functional mobilization**

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23 **Abstract**

24 **Background:** Mechanical loading is essential for tendon healing and may explain variability
25 in patient outcome after Achilles tendon rupture (ATR) repair. However, there is no
26 consensus regarding the optimal postoperative regime, and the actual amount of loading
27 during orthosis immobilization is unknown.

28 **Purpose:** The primary aim of this study was to assess the number of steps and the amount of
29 loading in a weight bearing orthosis during the first six weeks post-surgical ATR repair. A
30 secondary purpose was to investigate if the amount of loading was correlated to fear of
31 movement or/and pain.

32 **Study Design:** Case series; Level of evidence, 4.

33 **Methods:** Thirty-four patients, mean (SD) age 38.8 (8.7) years, with ATR repair were
34 included. Early functional mobilization was allowed postoperatively in an orthosis with
35 adjustable ankle range of motion. During the first two weeks postoperatively, patient-reported
36 loading and pain were assessed using visual analogue scale and step counts with a pedometer.
37 At the two- and six-weeks follow-up, a mobile force sensor was used for measuring plantar
38 force loading, and Tampa scale of Kinesiophobia questionnaire was used to examine fear of
39 movement.

40 **Results:** Between the first and second week a significant increase in the daily average number
41 of steps taken (2025-2753, $p < 0.001$) as well as increase in self-reported loading (20-53%,
42 $p < 0.001$) was observed. Patient self-reported loading was significantly associated with the
43 plantar force measurement ($\rho = 0.719$, $p < 0.001$). At six weeks loading was 88.2% on the
44 injured vs. uninjured limb. Fear of movement was neither correlated to pedometer data,
45 subjective loading, pain, nor to force data. Patients with less pain during activity, however,
46 reported significantly higher subjective load and were taking more steps ($p < 0.05$).

47 **Conclusions:** This is the first study to demonstrate the actual loading patterns during
48 postoperative functional mobilization in surgically repaired ATR patients. The quick
49 improvements in loading magnitude and frequency observed may reflect improved tendon
50 loading essential for healing. Pain rather than fear of movement was associated with the high
51 variability in loading parameters. The data of this study may be used to improve ATR
52 rehabilitation protocols for future studies.

53

54 **Key words:** *Early functional mobilization, loading, step counts, fear of movement*

55

56

57 **What is known about the subject:**

58 Mechanical loading plays an important role for tendon healing. Early weight bearing has
59 demonstrated improvement in patients' symptoms, function and satisfaction, but the actual
60 loading in these protocols is mostly unknown. Therefore, no consensus regarding the optimal
61 postoperative regime can be established.

62

63 **What this study adds to existing knowledge:**

64 This study establishes the actual loading pattern, in both magnitude and frequency and their
65 associated factors, during direct postoperative functional mobilization in surgically repaired
66 ATR patients. The early loading pattern depends on postoperative pain rather than fear of
67 movement.

68

69

70

71 **Introduction**

72 Achilles tendon rupture (ATR) is a common injury with a high variability in patient
73 outcome,^{2,20-23} which may depend on differences in mechanical loading.^{27,31} Thus, immediate
74 weight bearing after an Achilles tendon rupture is suggested to provide beneficial mechanical
75 loading for healing of the Achilles tendon.^{3,7,11,12,15,24} The optimal loading protocol, however,
76 is not known.

77

78 Although early weight bearing has resulted in greater improvement in symptoms, function and
79 patient satisfaction in surgically treated ATR patients,¹³ different postoperative protocols have
80 been used,⁸ making comparisons between studies difficult. Even the natural course of loading,
81 i.e how much the patient actually loads in an orthosis after ATR surgery, is not known.

82 To evaluate different early weight bearing protocols, the actual cumulative amount of loading
83 should first be assessed. Thus, both the frequency (steps taken per day) as well as the
84 magnitude of load on the injured leg must be registered daily during the orthosis mobilization.
85 Today, mobile plantar force sensors, pedometers and self-reported diaries are available for
86 assessments of frequency, magnitude and pattern of loading.

87

88 Even though ATR-patients use the same weight bearing protocol, large variations in outcomes
89 have been found.^{20,23} Thus, the factors regulating loading behavior are not fully known. Fear
90 of movement has been suggested as a confounding factor influencing the outcome.²¹

91 Therefore, it is of great interest to evaluate if fear of movement and/or pain are related to the
92 amount of loading early after ATR surgery.

93

94 The primary purpose of this study was to assess the number of steps as well as the amount of
95 loading in a weight bearing orthosis during the first six weeks post-surgical ATR repair. A

96 secondary aim was to investigate if loading was correlated to fear of movement and pain. We
97 hypothesized that direct weight bearing after ATR repair would result in an improved and
98 more symmetrical loading pattern during the early immobilization period. Furthermore, we
99 hypothesized that patients with a low degree of fear of movement would load their injured
100 side to a greater degree compared to patients with a high degree of fear of movement.

101

102 **Materials and Methods**

103 *Study design*

104 This study is a prospective cohort study of a subgroup of patients included in a larger
105 prospective randomized controlled trial. Ethical approval was obtained from the Regional
106 Ethical Review Committee in [Stockholm, Sweden \(Dnr: 2013/1791-31/3\)](#). The study was
107 additionally registered on [clinicaltrials.gov \(trial number NCT02318472\)](#).

108

109 *Patients*

110 Eligible for inclusion in the randomized controlled trial were patients between 18 – 75 years
111 with an acute unilateral Achilles tendon rupture if surgery was performed within one week
112 after the injury. The exclusion criteria to participate in the randomized trial was; current
113 anticoagulation treatment (including high dose acetylsalicylic acid), known kidney failure,
114 heart failure with pitting edema, thrombophlebitis, thromboembolic event during the previous
115 three months, known malignancy, hemophilia, pregnancy, other surgery during the previous
116 month, inability to follow instructions and planned follow-up at another hospital. All
117 participants received oral and written information about the study procedure and provided
118 written informed consent prior to surgery. Patients were randomized postoperatively using
119 consecutively-numbered sealed envelopes opened after surgery. A non-stratified block

120 randomization was used assigning the patient to either direct postoperative early functional
121 mobilization or immobilization and non-weight bearing.

122

123 To meet the purpose of this study, which was to assess loading and pedometer data, only
124 patient cases randomized to early functional mobilization were included in the present study.

125 An additional inclusion criterion was that the pair of insoles for force measurements needed to
126 fit in the patient's own shoes. Two patients could not be included due to technical errors with
127 the equipment. Between September 2016 and January 2018, a total of 34 patients meeting the
128 inclusion criteria were consecutively included in this study. Written consent was collected
129 from all patients at study inclusion.

130

131 *Surgical procedure*

132 A standardized surgical procedure was performed, using the modified Kessler suture
133 technique, on an outpatient basis as described earlier.¹⁰ The surgical procedures were
134 performed by orthopedic surgeons from one university hospital.

135

136 *Postoperative regime*

137 The early functional mobilization was initiated directly postoperatively. An orthosis
138 (VACO®ped, OPED GmbH, Germany) with adjustable range of motion of the ankle was
139 used. During the first two postoperative weeks, 15 to 30 degrees of plantar flexion was
140 allowed with a rocker sole. At two weeks postoperatively, this was increased to 5 to 30
141 degrees of plantar flexion for the remaining four weeks. Full weight bearing with crutches and
142 plantar flexion exercises were allowed directly after application of the orthosis. Non-weight
143 bearing plantar flexion exercises without the orthosis was recommended to be performed
144 daily for one hour during the first two weeks. The patients were informed to weight bear as

145 tolerated and that loading their injured leg directly in the orthosis was safe. For the remaining
146 four weeks in the orthosis, patients could take the orthosis off when not walking and perform
147 plantar flexion exercises several times per day.

148

149 *Self-reported diary*

150 At home, from the day after surgery, patients completed a self-reported diary on estimated
151 daily weight bearing load, number of steps/day with a pedometer for the first two weeks and
152 pain on a visual analogue scale (VAS) for the first week. Patients estimated their daily loading
153 on a VAS scale, ranging from 0 (non-weight bearing) to 100 (full weight bearing without
154 crutches). For analysis, the scale was converted to percent. The 2-week follow-up varied
155 between days 10–16 postoperatively. Patients received a pedometer (Yamax SW 200/LS2000,
156 Yamax Corporation, Japan) to register the number of steps/day. The pedometer was worn at
157 the hip. The Yamax SW-200 has been used as a gold standard pedometer in earlier validation
158 studies²⁸ and has shown to hold good validity ($r=0.80-0.90$) in a healthy population.^{4,18} Pain
159 was registered on a VAS scale ranging from 0 (no pain) to 100 (worst imaginable pain) for the
160 first week, both during rest and during activity.

161

162 **Follow-up evaluations**

163 *Patient-reported outcome measures (PROM)*

164 Tampa scale of Kinesiophobia (TSK-SV)¹⁶ and Physical Activity Scale (PAS)²⁵ were
165 completed at two and six weeks postoperatively prior to the gait evaluation. TSK-SV is
166 comprised of 17 items and evaluates fear of movement and pain on a 4-point Likert scale with
167 scoring alternatives ranging from “strongly disagree” to “strongly agree.” The scale ranges
168 from 17 to 68, a total sum is calculated, and a high score indicates a high degree of
169 kinesiophobia. Kinesiophobia has been defined as present when the value is more than 37 in

170 patients with low back pain. ¹⁶ PAS was used to evaluate the patient physical activity before
171 the injury and was completed at the 2-week follow-up. It is scored from 1 (no physical
172 activity) to 6 (heavy physical exercise several times/week). ²⁵

173

174 *Plantar force loading*

175 A mobile force sensor, the Loadsol® insoles (Novel GmbH, Munich, Germany) was used for
176 measuring plantar force loading. The insoles were connected through Bluetooth to an iPod
177 touch device and were calibrated to body weight before use. The measurement was done with
178 the insoles in the patient's normal shoe on the healthy side and in the orthosis on the injured
179 side. The patients were instructed to walk in a flat corridor in the orthosis at a self-selected
180 speed for three minutes. Crutches were allowed if needed. The orthosis is provided with a
181 wedged sole externally, so make the insoles lie flat in the orthosis.

182

183 For plantar force measurements three patients were excluded due to technical errors and two
184 patients were measured only at one occasion. Pedometer assessment was missing from one
185 patient. For analysis of force data, the maximal force (peak force) in Newton, the average
186 peak force over three minutes walking in Newton, stance phase (single and double support) in
187 % of the total gait cycle and the cadence (step frequency) was recorded and used for analysis.
188 The insoles have been tested for validity and reliability in healthy during walking, running
189 and hopping. ⁹

190

191 *Patient characteristics in relation to outcome measures*

192 In order to assess whether the outcome data (self-reported loading, pedometer data, TSK-SV,
193 PAS, plantar force loading) were correlated to patient characteristics (age, gender, BMI,
194 nicotine usage) these variables were analyzed statistically with correlation analyses. The

195 analyses demonstrated no significant correlations between patient characteristics and outcome
196 data ($p>0.05$).

197

198 **Statistics**

199 Data were processed in the Loadpad Analysis® software and Microsoft Excel.

200 Descriptive data were reported as mean, median, standard deviation and frequency.

201 Nonparametric statistics were used for ordinal data and for data that were not normally

202 distributed. Wilcoxon signed ranked test was used to compare differences between injured

203 and uninjured side and for differences between follow-up occasions. Spearman's rank

204 correlation was used to analyze relationship between patient-reported outcomes and gait

205 parameters as well as understanding the relationship between self-reported subjective load to

206 plantar force measurement. The Limb symmetry index (LSI) was used to compare differences

207 in loading between the two- and six-week follow-up. The LSI value was defined as the ratio

208 between the injured limb and the uninjured limb, expressed as a percentage (LSI,

209 injured/uninjured $\times 100$). All data were analyzed in SPSS (IBM SPSS, Version 25.0. Armonk,

210 NY, USA). The level of significance was $p<0.05$ for all analyses.

211

212 **Results**

213 *Patients*

214 In total, 34 patients who had sustained an acute Achilles tendon rupture were enrolled (Table

215 1).

216

217

218

219

220 Table 1. Demographic data n=34

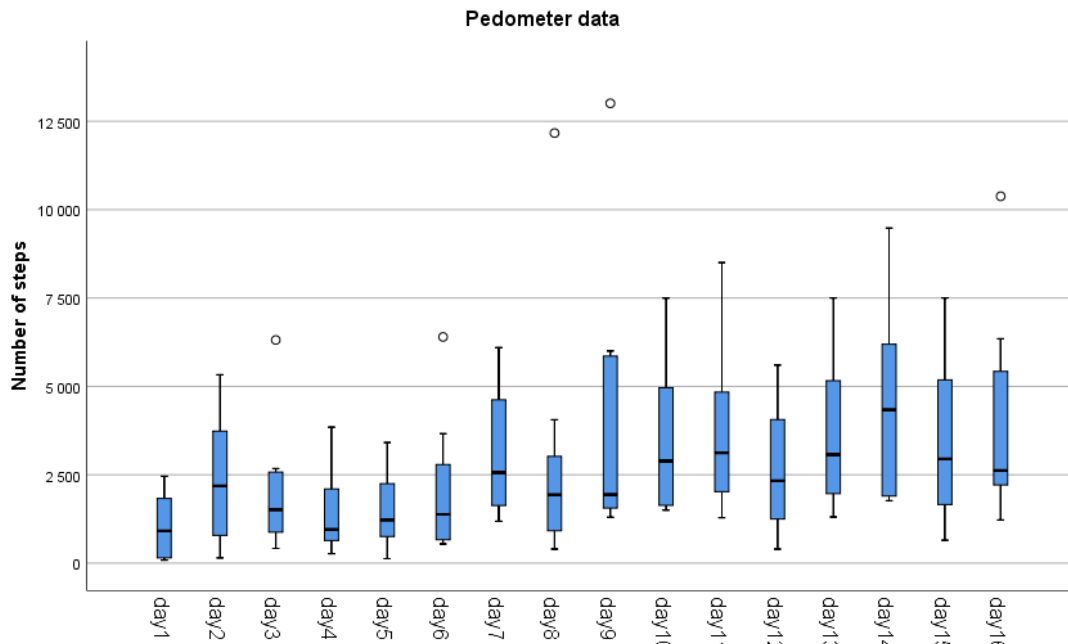
Age (years) mean (SD)	38.8 (8.7)
Gender (M/F) n (%)	28/6 (82/18)
Height (cm) mean (SD)	177.7 (8.3)
Weight (kg) mean (SD)	81.0 (10.8)
BMI (kg/m²) mean (SD)	25.6 (2.7)
Nicotine (smoker/snuff/no) n (%)	0/8/26 (0/23/77)
Injured side (L/R) n (%)	17/17 (50/50)
PAS before injury median (range)	5 (2-6)

221 PAS= Physical Activity Scale, BMI= Body mass index

222

223 *Pedometer data*

224 Patients significantly increased the daily average number of steps taken between week one
 225 and two ($p < 0.001$). The number of steps taken daily was, median (range), during week one
 226 2025 (174 – 14687) and during week two 2753 (305 – 13085) (Figure 1).



227

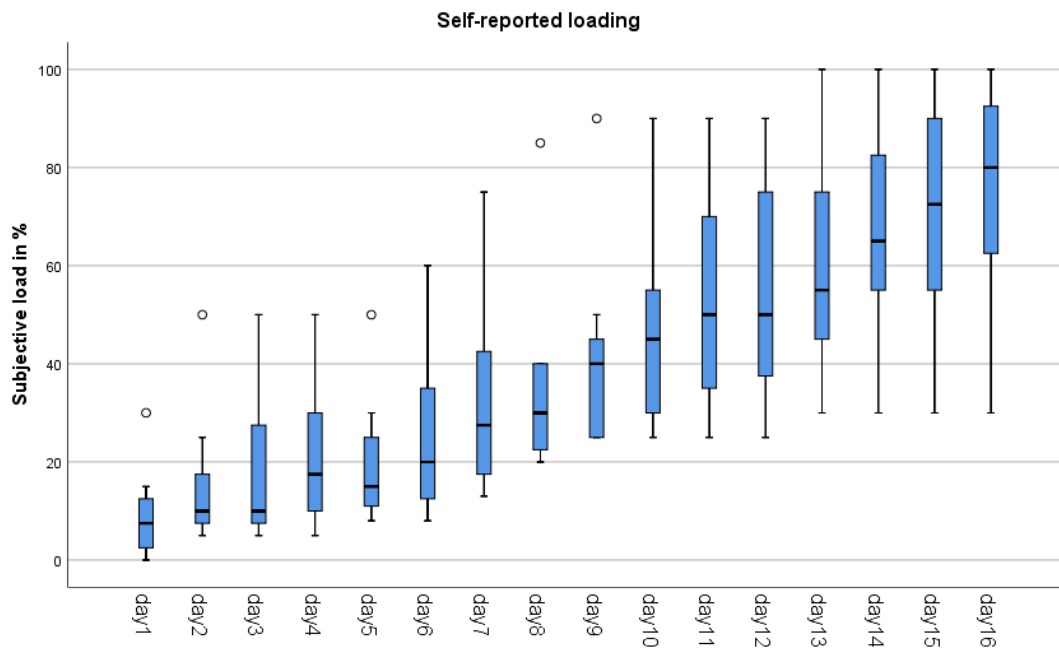
228 Figure 1. Boxplot of daily step counts during the first two weeks postoperatively

229

230 *Self-reported loading*

231 There was a significant increase in the average patient-reported loading between week one
 232 and two ($p < 0.001$). The patient-reported loading was, median (min-max), during week one 20
 233 (5-90) % and during week two 52.5 (20-100) % (Figure 2).

234



235

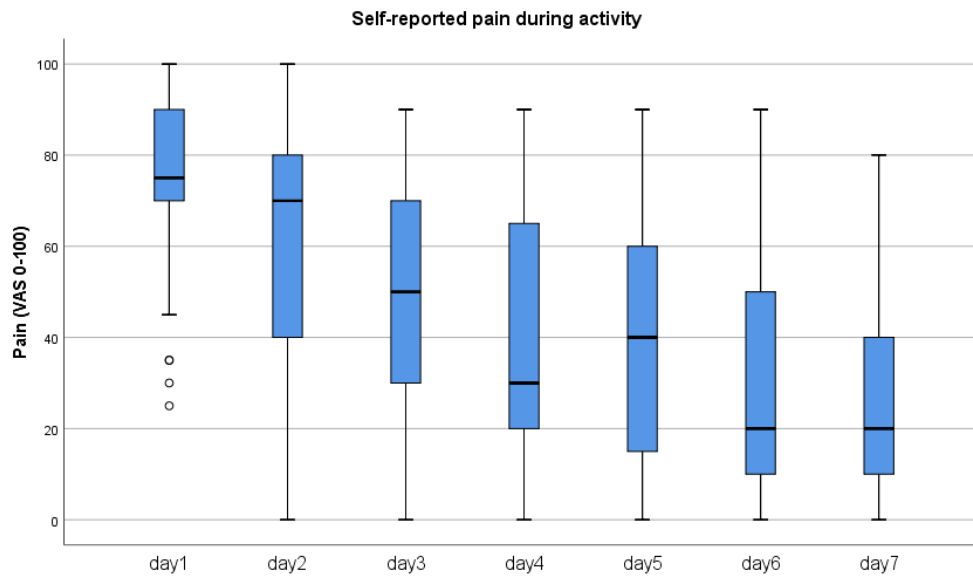
236 Figure 2. Boxplot of daily self-reported loading during the first two weeks.

237

238 *Self-reported pain*

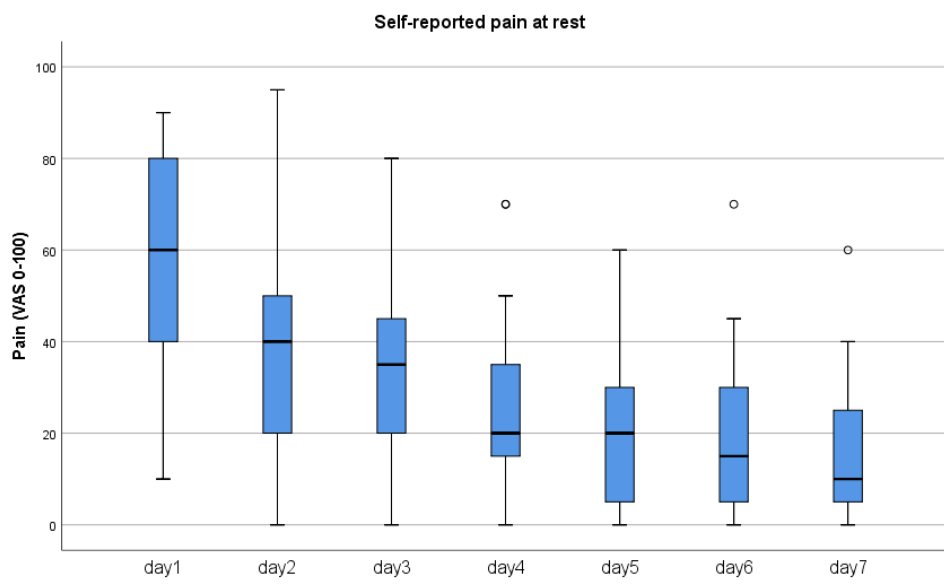
239 Self-reported pain assessment, VAS 0-100, during both activity and at rest decreased
 240 significantly during the first postoperative week ($p < 0.001$). Pain, mean (SD), was day one
 241 during activity 74 (21) and at rest 57 (24). Pain at day seven was during activity 27 (20) and at
 242 rest 15 (13) (Figures 3-4).

243



244

245 Figure 3. Boxplot of self-reported pain (VAS 0-100) during activity week one.



246

247 Figure 4. Boxplot of self-reported pain (VAS 0-100) at rest week one.

248

249 *Patient-reported fear of movement*

250 Patient-reported fear of movement did not change significantly between two, mean 35.5 (SD

251 7.0), and six weeks, mean 34.2 (SD 7.9). At two weeks 13/34 (38.2 %) reported a score >37,

252 which represents a high degree of fear of movement.

253

254 *Plantar force*

255 There were, at both two and six weeks, significantly lower plantar force load and less stance
 256 time on the injured- compared to the uninjured limb ($p<0.001$) (Table 2). The limb symmetry
 257 index (LSI) of both maximum force and average peak force increased significantly from two-
 258 to six weeks (Table 2). In addition, the stance time was more symmetrical at six weeks and
 259 cadence was increased (Table 2).

260

261 Table 2. Plantar force assessment with the Loadsol® insoles

	<u>2 weeks (n=31)</u>	<u>6 weeks (n=32)</u>
Max force, N		
injured, mean (SD)	705.5 (288.3)*	968.3 (226.3)*
uninjured, mean (SD)	1167.7 (251.7)*	1114.1 (329.0)*
LSI max force, %		
mean (SD)	62.8 (28.5) ^b	88.2 (11.8) ^b
Average peak force, N		
injured, mean (SD)	514.2 (285.0)*	858.6 (200.3)*
uninjured, mean (SD)	986.9 (159.0)*	989.4 (312.2)*
LSI average peak force, %		
mean (SD)	53.6 (31.5) ^b	88.2 (11.5) ^b
Stance time, %		
injured, mean (SD)	65.6 (9.7)*	68.2 (6.3)*
uninjured, mean (SD)	77.7 (5.4)*	74.7 (5.5)*
Cadence, steps/min		
mean (SD)	79.6 (14.6) ^b	94.9 (9.0) ^b

262 N=Newton, LSI= limb symmetry index (injured/uninjured*100)

263 * significant side differences ($P<0.001$)

264 ^b significant differences between test occasions ($P<0.001$)

265

266 *Correlations between patient-reported outcome and pedometer data*

267 Patients reporting higher subjective loading were taking more steps per day during both the
 268 first- ($\rho=0.599$, $p<0.001$) (Figure 5) and second postoperative week ($\rho=0.383$, $p=0.030$).

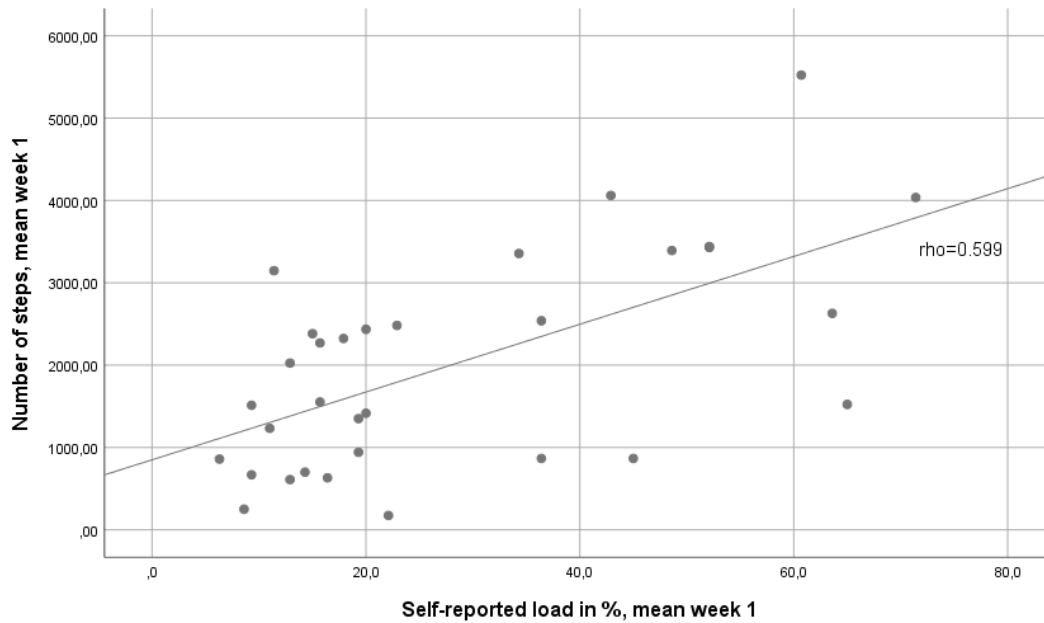
269 Patients with less pain during activity the first postoperative week reported a higher subjective

270 load ($\rho= -0.354$ - -0.483 , $p= 0.043$ - 0.004) and were taking more steps ($\rho= -0.366$ - 0.453 ,

271 $p= 0.036-0.008$). Patients experiencing more pain at rest the first two postoperative days
272 reported lower subjective loading ($\rho= -0.374--0.418$, $p= 0.016-0.032$).

273

274



275
276 Figure 5. Correlation between self-reported loading and pedometer data week one.

277

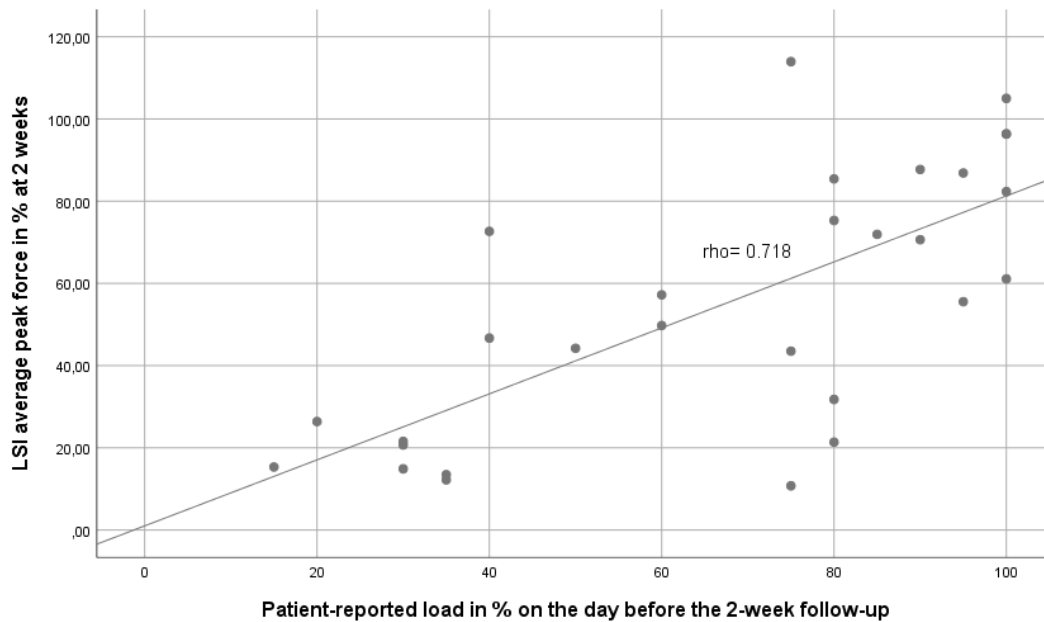
278 Fear of movement was in these patients neither correlated to pedometer data, subjective
279 loading data, pain, nor to force data ($\rho= -0.204-0.116$, $p=0.271-0.998$).

280

281 *Relationship between patient-reported subjective loading and force data*

282 Patient self-reported loading was significantly associated to the force measurement, LSI
283 average peak force, assessed at two weeks ($\rho= 0.719$, $p<0.001$) (Figure 6). At 2-weeks self-
284 reported loading on the injured leg was 52.5 (20 – 100) % and LSI average peak force was
285 53.6 (31.5) %.

286



287

288 Figure 6. Relationship between self-reported and objectively measured load at the 2-week
 289 follow-up

290

291 **Discussion**

292 The results of this study demonstrate for the first time the combined objective and subjective
 293 data of the frequency, magnitude and pattern of loading after acute Achilles tendon rupture
 294 repair. During the two first postoperative weeks with functional mobilization ATR patients
 295 increase the number of steps and the loading of the injured limb up to around 50% of normal
 296 values. Between weeks two and six post-surgery, loading of the injured- compared to the
 297 intact leg increased from 50% up to around 90%. Contrary to our hypothesis, this loading
 298 pattern did not relate to the patient-reported fear of movement, but rather to the experience of
 299 pain.

300

301 The most important finding of this study was the demonstration of a high combined increase
 302 in loading frequency as well as loading magnitude up to two weeks post ATR surgery using
 303 functional mobilization. The observed increase in loading frequency up to the second

304 postoperative week, with around 2700 steps taken daily would seem to represent around 50%
305 of the normal number of steps taken daily in an aged matched population (around 5400
306 steps).¹ The number of daily steps taken after ATR have been shown essential for the tendon
307 healing process²⁷ as well as for general health condition.¹

308

309 The minimum recommendation of daily number of steps in healthy adults is suggested to be
310 3000, 5 times a week, in line with the recommendation of 30 min moderate intensity walking
311 per day.^{17,30} There was a wide variation in number of steps per day but on a group level,
312 patients in this study were almost able to reach the minimum health recommendations in
313 terms of walking already at two weeks postoperatively. Thus, we can conclude that direct
314 weight bearing post ATR surgery in a functional orthosis allows for early increased loading
315 frequency.

316

317 The observation at two weeks post-surgery that the number of daily steps taken were 50% of
318 normal was paralleled with the finding that patients loaded 50% on the injured compared to
319 their intact limb. This observation would seem to reflect the finding that the recovery of
320 loading frequency and the recovery of loading magnitude are correlated to each other. The
321 loading magnitude, i.e. early tensional load, is crucial for improving the mechanical properties
322 of the healing Achilles tendon.^{27,31} The optimal combination of loading magnitude and
323 loading frequency for tendon healing and patient recovery, however, is unknown.

324 Earlier studies on early weight bearing protocols demonstrating earlier return to sporting
325 activity, better subjective patient outcomes¹⁹ and improved health-related quality of life²⁹
326 have not provided detailed reports of loading both magnitude and frequency. Therefore, to
327 optimize the postoperative regime of ATR we suggest that future studies provide data of both
328 magnitude and frequency of loading, similarly as performed in this study.

329

330 The second main finding of this study was the significant increase in the magnitude of loading
331 from the second up to the sixth postoperative week. Thus, the observed increased loading
332 from 50% up to around 90% on the injured- compared to the intact leg may reflect vital
333 tensional loading on the healing Achilles tendon, which is important for achieving improved
334 patient-reported outcome. These specific data can also be used by health care personnel, who
335 want to provide their ATR patients with information about weight bearing in an orthosis
336 postoperatively.

337

338 The finding at two weeks, that the magnitude of loading was around 50% was supported not
339 only from the self-reported loading assessment but also from the plantar force measurements,
340 may have clinical implications. Thus, the observation of a significant relationship between the
341 subjective and objective loading measurements suggests that the patient-reported assessments
342 may be a good estimation of loading. Since objective measurement devices of loading
343 parameters are rarely available in the clinic patient assessments may be used instead.

344

345 The finding in our study showing that patients with less activity-related pain, walked more
346 steps and reported higher load on their injured leg suggest that the patient's experience of pain
347 is one of the determining factors for both loading frequency and loading magnitude.

348 Therefore, patient information and pain control post-surgery may be important factors in
349 regulating loading- frequency and magnitude, and thereby possibly also patient-reported
350 outcome.

351

352 Contrary to our hypothesis, step counts did not relate to patient fear of movement, but rather
353 to pain. This finding would seem to be in contrast with the findings of Olsson et al ²¹, who

354 assessed fear of movement 12 weeks after ATR and found that fear of movement was
355 correlated with physical activity, patient-reported symptoms, and general health. In the
356 present study, however, there were no relationships between fear of movement and pain or
357 loading parameters. A possible explanation for this discrepancy between studies are different
358 time points of assessment. The perception and willingness to be active when out of the boot
359 and returning to activity may not be relevant while still in the boot. Moreover, most patients
360 in this study did not experience pain at two weeks postoperatively, which is one of the main
361 factors in the pain-related fear of movement/injury survey.

362

363 There are some potential limitations in this study. Three-dimensional gait analysis is the
364 golden standard to objectively assess forces during gait. Though, this method is expensive and
365 not usually available for clinical use. Also, this method is not suitable when wearing an
366 orthosis due to the difficulty of marker placement on bony landmarks. Different types of
367 insoles have shown good reliability and validity in both healthy and patients^{5,6,14} and wireless
368 insoles may be a useful tool for evaluate forces during gait. Sandberg et al²⁶ used an insole
369 device to measure plantar flexion moments and found that patients after ATR repair was not
370 activating the calf muscles during gait in an orthosis.²⁶ A possible limitation in the present
371 study is that the used measures of plantar load might not be directly translated into load on the
372 Achilles tendon and further, we do not know if the patients loading activated the triceps surae
373 muscles.

374

375 Another limitation is that the pedometer (Yamax SW-200) used, has been suggested to be less
376 accurate at slower gait speeds¹⁸, which may cause a possible underestimation of steps during
377 the first week, as patients are not walking in their normal gait speed with crutches. In the
378 study by Sandberg et al,²⁶ they found that walking speed was reduced four weeks

379 postoperative after ATR repair but seemed to have normalized at seven weeks
380 postoperatively. We did not assess gait speed, however at the six weeks follow-up, patients
381 were walking more symmetrical and with a higher cadence than at two weeks.

382

383 Despite these potential limitations, this is the first study to quantify cumulative tendon load
384 using a combination of laboratory and field-based tools. Since tendon healing and patient
385 recovery is affected by magnitude and frequency of loading, the total amount of weight
386 bearing steps during the early rehabilitation phase may account for the variation in recovery
387 of the patients.

388

389 **Clinical Relevance**

390 Mobile plantar force sensors are a feasible technology to objectively quantify loading early
391 after surgery in patients with Achilles tendon rupture. Reliable and practical methods to assess
392 the actual loading during mobilization are of importance for future studies determining the
393 effect of the rehabilitation protocols on outcome in this patient population. The patients'
394 subjective assessment of weight bearing, however, seems as a practical and easy method for
395 weight bearing estimation when more objective measurements are lacking.

396

397 **Conclusions**

398 This study demonstrated relatively high plantar forces in surgically treated ATR patients
399 already at two weeks postoperatively when treated with early functional mobilization in a
400 dynamic orthosis. There was a significant increase in plantar forces between two and six
401 weeks, with the patients loading around 90% on the injured compared to the healthy side.
402 Pain, rather than fear of movement, was associated with both loading frequency and
403 magnitude.

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