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TITLE PAGE

**SHORT FOOT EXERCISES HAVE ADDITIONAL
EFFECTS ON KNEE PAIN, FOOT BIOMECHANICS,
AND LOWER EXTREMITY MUSCLES STRENGTH IN
PATIENTS WITH PATELLOFEMORAL PAIN**

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51 **ABSTRACT**

52 **BACKGROUND:**

53 Patellofemoral pain (PFP) was reported as a common
54 knee problem. And the foot posture in a relaxed stance was
55 reported as distal factors of PFP. However, the effects of short
56 foot exercise (SFE) on the knee and functional factors have not
57 yet been investigated in patients with PFP.

58 **OBJECTIVE:**

59 This study aimed to investigate the additional effects of
60 SFE on knee pain, foot biomechanics, and lower extremity
61 muscle strength in patients with PFP following under the
62 standard exercise program.

63 **METHODS:**

64 Thirty patients with '*weak and pronated*' foot subgroup
65 of PFP were randomized to a control group (ConG, $n=15$) and a
66 short foot exercise group (SFEG, $n=15$) with concealed
67 allocation and blinded to the group assignment. The program of
68 ConG consisted of hip and knee strengthening and stretching
69 exercises. SFEG program consisted of additional SFE. Both
70 groups performed the supervised training protocol two times per
71 week for 6 weeks. Assessment measures were pain visual analog
72 scale (pVAS), Kujala patellofemoral score (KPS), navicular
73 drop test (NDT), rearfoot angle (RA), foot posture index (FPI),
74 and strength tests of lower extremity muscles.

75

76 **RESULTS :**

77 Both groups displayed decreases in pVAS scores, but it
78 was only significant in favor of SFEG. NDT, RA, and FPI scores
79 decreased in SFEG whereas they increased in ConG. There was
80 a significant group-by-time interaction effect in hip extensor
81 strength and between-group difference was found significant in
82 favor of SFEG.

83 **CONCLUSIONS:**

84 An intervention program consisting of additional SFE
85 had positive effects on knee pain, navicular position, and
86 rearfoot posture. An increase in the strength of the hip extensors
87 may also be associated with improved stabilization by SFE.

88

89 **Key words**

90 Patellofemoral Pain; Short Foot Exercises; Foot Core; Foot
91 Posture.

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101 **1. INTRODUCTION**

102 Patellofemoral pain (PFP) is characterized by increased
103 retropatellar or peripatellar pain with activity. The prevalence of
104 patellofemoral pain reported as 22.7% in the general population
105 (1). The etiology of PFP is widely accepted to be multifactorial,
106 with proximal, local, and distal factors. Distal factors such as
107 excessive and prolonged pronation of the rearfoot and increased
108 navicular drop values in relaxed stance have been reported as
109 important (2).

110 Unfortunately, it has been reported that despite the high
111 prevalence and positive short-term treatment outcomes 80% of
112 individuals who completed a rehabilitation program for PFP still
113 reported pain, and 74% had reduced their physical activity at a
114 5-year follow-up (3-6). The international consensus considering
115 the high failure rate for treatment of PFP suggests that a
116 paradigm shift towards identifying PFP subgroups and
117 delivering stratified care is required (2, 7, 8). Recently Selfe *et*
118 *al.* have taken the first step towards this by identifying 3 distinct
119 subgroups of patients with PFP one of these was “*Weak and*
120 *Pronated*” partially defined by having a score of Foot Posture
121 Index (FPI) of >6, however, they did not conduct any
122 intervention or investigate patient outcomes (9). Studies on the
123 effects of foot pronation on PFP have been limited to the
124 recommendation of foot orthoses. Mills *et al.* reported that
125 orthoses provided greater improvements in anterior knee pain

126 compared to a wait-and-see approach (10). Collins et al. reported
127 that foot orthoses are superior to flat inserts according to
128 participants' overall perception, but they do not improve
129 outcomes when added to physiotherapy (4).

130 Besides that current rehabilitation approaches adopt the
131 view that centers the patient and is based on the patient's active
132 participation. At this point, foot orthoses remain passive
133 methods and there is a need to investigate exercise therapies such
134 as the Short Foot Exercise (SFE) - Foot Core Paradigm in PFP
135 to assess whether they are capable of improving foot
136 biomechanics and reducing knee pain (11).

137 Limited numbers of studies have demonstrated that SFE is
138 effective in strengthening the biomechanical structure of the foot
139 (12-15). The pathomechanical effects of prolonged and
140 increased rearfoot pronation and increased navicular drop
141 measures on knee joint have been emphasized, according to the
142 results of previous studies, it can be considered that SFE may
143 also be effective in knee problems such as PFP.

144 The aim of this study was to investigate the additional
145 effects of SFE on knee pain, foot biomechanics, and muscle
146 strength in patients with PFP following under the standard
147 exercise program.

148

149

150

151 **2. MATERIAL AND METHODS**

152 A randomized controlled parallel-group trial was
153 performed in the outpatient clinic of Hacettepe University
154 Faculty of Physical Therapy and Rehabilitation. Diagnosis of
155 PFP (based on 2016 PFP consensus) was made by an orthopedic
156 surgeon and patients who consulted for physiotherapy were
157 recruited for this study between April and September 2017 (16).

158 Inclusion criteria were with no gender limitation being
159 25 to 55 years of age; having complaints of continuing knee pain
160 (for at least six months and without trauma) in the bilateral pre-
161 /retropatellar area, pain provoked by at least one activity from
162 prolonged sitting, squatting, kneeling, or stair climbing and
163 classifying as moderate (3.5-6.4) and severe (≥ 6.5) according to
164 pain-Visual Analogue Scale (pVAS), (17) and categorizing as
165 “*weak and pronated*” foot which defined by having a score
166 from FPI of >6 according to Selfe *et al.* (9) . Patients were
167 excluded if they had a history of previous knee surgery, trauma,
168 patellar dislocation or subluxation, tendinitis or bursitis, any
169 other non-surgical interventions in the previous 6 months if they
170 had intra-articular problems; involvement of ligaments or
171 meniscus; knee pain or joint effusion due to rheumatic diseases
172 and pregnancy, pain or tenderness of plantar fascia and foot or
173 history of plantar fasciitis (18-20).

174 All patients read and signed an informed consent form
175 approved by Hacettepe University Non-interventional Clinical

176 Research Ethics Board (Number: GO17/168-17) prior to
177 participation. The trial was registered on clinicaltrials.gov (ID:
178 NCT03099512).

179

180 **2.1. Sample Size Analysis**

181 A sample size calculation (*GPower 3.1.9.2*) based on the
182 average knee pain while prolonged sitting, ascending and
183 descending stairs (the more complained of all) (using $\alpha: .05$, $\beta:$
184 $.20$ (*power: 80%*)) was conducted from a pilot study (pVAS
185 scores of prolonged sitting; with mean (standart deviation
186 (SD))= -2.12 (2.85) in short foot exercise group (SFEG) and .66
187 (2.16) in control group (ConG), ascending stairs; with mean
188 (SD)= -3.75(2.43) in SFEG and 2.16 (2.74) in ConG, descending
189 stairs; with mean (SD)= 2.62 (2.44) in SFEG and 2.16 (2.85) in
190 ConG). Based on the results, 22 patients with PFP were needed
191 to adequately power the study for variables of interest.

192 Therefore, to allow for potential dropouts (expected as
193 %25) 30 patients were recruited for the study. In total, 45
194 patients were assessed for eligibility. Thirty-five of them
195 randomized and at the end of intervention 30 participants had
196 completed the study (Figure 1).

197

198 **2.2. Randomization and blinding**

199 In this study, concealed allocation was conducted and
200 patients with PFP were divided into 2 groups with *Random*

201 *Allocation Software (version 1.0)* in a single block format.
202 Randomization was performed after the baseline assessment,
203 and the patients were blinded to group allocation by ensuring
204 that they were unaware of the exercises performed by the other
205 group. To maintain the blinding, the intervention sessions were
206 delivered separately to members of each treatment group.

207

208 [Figure1 near here]

209

210 **2.3. Outcome Measures**

211 Participants were assessed at baseline and at the end of
212 the 6-week intervention. The initial clinical examination
213 (baseline) consisted of observation and palpation of the knee
214 joint, patella, and peripatellar soft tissue. All assessments were
215 performed by the same physiotherapist who had at least 2 years
216 of experience in these procedures.

217 Participants' self-report of pain intensity was assessed by
218 using pVAS, with the minimal clinically important difference
219 being ≥ 2 cm (21, 22). Participants were asked to rate their
220 response based on the average knee pain, which located around
221 or behind the patella while performing walking, prolonged
222 sitting, climbing stairs, squatting activities, and nocturnal pain
223 during the previous week. Besides pain intensity, other common
224 symptoms were investigated with the Kujala Patellofemoral
225 Scale (KPS) , with the minimal clinically important difference

226 being 10 to 13 points (23). The KPS is a 13-item self-reported
227 questionnaire the maximum possible score of 100 indicates a
228 normal, painless and fully functioning knee.

229 *Navicular drop (ND)* was assessed to determine the
230 flexibility of the medial longitudinal arch (MLA) and the
231 position of the navicular bone in both feet (14). The participant's
232 knee was stabilized while nonweightbearing (sitting) (NWB)
233 and the subtalar joint neutral position (STJN) was manually
234 determined. In this position, the navicular tuberosity was marked
235 and the floor-distance was measured with a digital caliper (*Neiko*
236 *01408A, Neiko Tools USA*). Subsequently, all procedures
237 (except STJN) were repeated in symmetrical bilateral
238 weightbearing (standing) (WB) and the differences between the
239 two measures were noted for both feet as *Navicular drop test*
240 (*NDT*) score.

241 *Rearfoot angle (RA)* was measured to determine the
242 position of the rear foot (calcaneal eversion/inversion) and noted
243 as the angle between distal midline of the Achilles tendon and
244 the midline of the calcaneus. A standard universal goniometer
245 was used and rearfoot angle measurements were repeated in both
246 NWB and WB positions.

247 The *six item-Foot Posture Index (FPI)* with good inter
248 item reliability (*Cronbach's $\alpha = 0.83$*) was used to evaluate foot
249 posture. Items include: talar head palpation, curves above and
250 below the lateral malleoli, calcaneal inversion/eversion,

251 talonavicular bulging, MLA, rearfoot abduction/adduction. Each
252 item is scored between -2 (supinated) and +2 (pronated) and 0
253 for neutral position (total score between -12 (highly supinated)
254 and +12 (highly pronated)) (24).

255 *Isometric strength* of hip extensors and abductors, knee
256 flexor and extensors, ankle dorsi (DF) and plantar flexors (PF),
257 flexor hallucis longus (FHL) muscles were quantified by using a
258 hand-held dynamometry-*Laffayette Manual Muscle Tester*
259 (*Laffayette Instrument, 47903, USA*). All measurements were
260 performed in standard clinical muscle test positions and the *make*
261 *test* method was applied and, to avoid the effect of examiner's
262 strength and stabilize the dynamometer a strap was used to hold
263 dynamometer(25, 26). The center of the force pad on the
264 dynamometer was placed approximately midpoint of the area
265 between two neighbour joints (*for instance, the force pad was*
266 *placed at the midline of the femur for hip extensors*). Participants
267 held the contractions for 5 seconds, and 3 trials were performed
268 with a 30 seconds rest between each trial (27) mean strength
269 values were recorded in Newton (N).

270

271 **2.4. Intervention**

272 Participants from both groups performed the training
273 protocol two times per week for 6 weeks, with at least one day
274 between intervention sessions. All individual sessions were
275 supervised by the same physiotherapist and performed as one set

276 (containing 10 repetitions per exercise) once a day. Sessions on
277 the other days were performed as a home program according to
278 the same protocols. And, no medication was prescribed as part
279 of their treatment.

280

281 *Control Group (ConG)*. The treatment program consisted of hip
282 and knee strengthening and stretching exercises, considered as
283 standard exercise therapy approach (Appendix).

284 *Short Foot Exercise Group (SFEG)*. The SFEG physiotherapy
285 program was similar to ConG. Additionally; participants in
286 SFEG performed short foot exercises (SFE). SFE is described as
287 targeting isolated contraction of the plantar intrinsic muscles.
288 The foot is 'shortened' by using the intrinsic plantar muscles to
289 pull the metatarsal heads towards the calcaneus (when the
290 metatarsal heads on the ground and the toes neither flexed nor
291 extended) as the MLA is elevated (28). For progression; SFE is
292 performed from sitting to bipedal, to unipedal-with minimal
293 support and to unipedal-without support (Appendix).

294 To exclude the confounding effects, the patients were
295 asked not to change their shoes and not use orthoses during the
296 treatment. Appropriately designed orthoses were recommended
297 for severe cases who completed the intervention program and
298 were in need.

299 **2.5. Statistical Analyses**

300 Statistical analyses were performed using the “*Statistical*
301 *Processing for The Social Sciences Software (SPSS 22.0 Inc.,*
302 *Chicago, Illinois)*”. The variables were investigated using
303 *Shapiro-Wilk’s test* to determine the normality. Data for
304 variables were reported as mean (X), standard deviation (SD)
305 and 95% confidence interval (95%CI). Outcome measures were
306 compared before and after the treatment using a two-way (group-
307 by-time) mixed-model analysis of variance (ANOVA), with
308 time (baseline and postintervention) as the repeated measure.
309 Partial Eta-squared was cited as a measure of effect size (29).
310 When significant group-by-time interactions were found, the
311 main effects of time and group were reported and also planned
312 pairwise comparisons with *paired samples t-test* was used to
313 determine whether the ConG or SFEG group had changed over
314 time, and the *independent samples t-test* was used to determine
315 between-group differences. Because data were normally
316 distributed parametric tests were used. In the absence of a
317 significant interaction term, the main effects of time and group
318 were reported only. For all analyses, the alpha level was set at
319 .05.

320

321

322 **3. RESULTS**

323 The demographic characteristics of the groups were
324 similar and summarized in at Table.1. No adverse effects were

325 reported but 5 patients dropped out due to other reasons
326 (Figure.1). The tenderness of lateral retinaculum has been
327 palpated in all participants and 24 (80%) of all with tenderness
328 along the medial patellar facet; 27 (90%) participants with the
329 tenderness of distal to the dorsal patellar tendon, indicating
330 patellar tendinopathy; 3 (10%) participants with tenderness
331 either side and proximal pole of the patella, indicating
332 quadriceps tendon and peripatellar soft tissues inflammation.
333 And also mild swelling was observed in 3 (10%) of all
334 participants.

335

336 [Table.1 near here]

337

338 There was a significant group-by-time interaction for the
339 average knee pain around or behind patella while prolonged
340 sitting, ascending stairs, squatting activities and nocturnal pain
341 values (*respectively* $p=.002$; *effect size* (ES): $.291$, $p=.007$; ES:
342 $.235$, $p=.041$; ES: $.141$, $p=.027$; ES: $.164$). This means that
343 groups were changed over time but in different ways. The main
344 effect of time for all were significant, in other words the groups
345 did change over time and both groups were getting less pain
346 (*respectively* $p=.001$; ES: $.335$, $p<.001$; ES: $.541$, $p<.001$; ES:
347 $.443$, $p=.027$; ES: $.164$). No significant main effect of group was
348 found (*respectively* $p=.547$; ES: $.013$, $p=.873$; ES: $.001$,
349 $p=.546$; ES: $.013$, $p=.439$; ES: $.022$). The group-by-time

350 interaction term for the average knee pain around or behind
351 patella while descending stairs values was near the threshold of
352 statistical significance ($p=.051$; $ES: .129$), but there was a
353 significant main effect of time ($p<.001$; $ES: .496$). And no
354 significant main effect of group was found ($p=.461$; $ES: .020$).

355 The group-by-time interaction and the main effect of
356 group for the average knee pain around or behind patella while
357 walking did not meet the significance threshold (*respectively*
358 $p=.131$; $ES: .080$, $p=.124$; $ES: .083$). However a significant
359 main effect of time was found ($p=.008$; $ES: .225$). No
360 statistically significant group-by-time interaction and main
361 effect of group was observed for KPS (*respectively* $p=.601$; $ES:$
362 010 , $p=.836$; $ES: .002$) but main effect of time was significant
363 ($p<.001$; $ES: .502$). This means that both groups had similar
364 changes for the average knee pain while walking and KPS values
365 (Table 2).

366 pVAS scores decreased in both groups but planned
367 pairwise comparisons (between-group differences) showed that
368 a significant difference in terms of prolonged sitting, ascending
369 and descending stairs, squatting activities and nocturnal pain
370 between the 2 groups ($p=.02$, $p=.007$, $p=.05$, $p=.041$, $p=.027$)
371 (Table 2).

372 [Table.2 near here]

373

374 A significant group-by-time interaction was found for
375 right side NDT (*right* $p=.007$; *ES*: .230), RA-NWB (*right*
376 $p=.034$; *ES*: .151, *left* $p=.001$; *ES*: .348, and WB (*right* $p=.004$;
377 *ES*: .257, *left* $p<.001$; *ES*: .424) and FPI (*right and left* $p<.001$;
378 *right ES*: .534, *left ES*: .547). This means that groups were
379 changed over time but in different ways. The group-by-time
380 interaction term for the left side NDT was near the threshold of
381 statistical significance ($p=.054$; *ES*: .126). The main effect of
382 time for all were significant, in other words the groups did
383 change over time and both groups' foot posture changed (*NDT*
384 *right* $p=.013$; *ES*: .201, *left* $p=.017$; *ES*: .064, RA-NWB *right*
385 $p=.014$; *ES*: .075, *left* $p=.001$; *ES*: .348, and WB *right and left*
386 $p<.001$; *right ES*: .420, *left ES*: .424, FPI *right and left* $p<.001$;
387 *right ES*: .534, *left ES*: .547). And no significant main effect of
388 group was found (*NDT right* $p=.307$; *ES*:.037, *left* $p=.228$;
389 *ES*:.228, RA-NWB *right* $p=.218$; *ES*:.054, *left* $p=.416$; *ES*:.024,
390 and WB *right* $p=.600$; *ES*: .023, *left* $p=.336$; *ES*:.033, FPI *right*
391 $p=.241$; *ES*: .049 and *left* $p=.400$; *ES*:0.025).

392 NDT, RA, and FPI scores decreased in SFEG whereas
393 they increased in ConG. Planned pairwise comparisons
394 (between-group differences) showed that a significant difference
395 in terms of all parameters between the 2 groups (*NDT right*
396 $p=.007$, *left* $p=.054$; RA-NWB *right* $p=.040$, *left* $p=.001$; RA-WB
397 *right* $p=.004$, *left* $p<.001$; FPI *right and left* $p<.001$) (Table 3).
398 These indicate that the participants in the SFEG had more and

399 statistically significant improvements compared to the
400 participants in the ConG after the interventions.

401

402 [Table.3 near here]

403

404 *Hip muscles (extensors and abductors) group:*

405 Statistically significant group-by-time interaction effect was
406 observed for hip extensors (*right* $p=.028$; *ES*: .161, *left* $p=.037$;
407 *ES*: .280), however no statistically significant group-by-time
408 interaction effect was observed for hip abductors (*right* $p=.298$;
409 *ES*: .0039, *left* $p= .727$; *ES*: .004), suggesting that both groups
410 had similar changes. For the main effect of time significant
411 improvements in both groups were observed. This means that the
412 groups did change over time and both groups gained strength
413 ($p<.001$; *extensors*; *right* *ES*:.0,572, *left* *ES*:.490, *abductors*;
414 *right* *ES*:.344, *left* *ES*:.399). No significant main effect of group
415 was found (*extensors*; *right* $p=.172$; *ES*:.065, *left* $p=.241$;
416 *ES*:.049, *abductors*; *right* $p=.875$; *ES*:.001, *left* $p=.958$;
417 *ES*:.000).

418 As there was a significant group-by-time interaction
419 effect in the extensors a planned pairwise comparison was
420 performed, between-group difference was found significant in
421 favor of SFEG (*right* $p=.028$, *left* $p=.037$) (Table 4).

422

423 [Table.4 near here]

424

425 *Knee muscle group:* There were no significant group-by-
426 time interactions for the knee musculature (*flexors right* $p=.741$;
427 *ES:.004*, *left* $p=.299$; *ES:.038* and *extensors right* $p=.466$;
428 *ES:.020*, *left* $p=.347$; *ES:.033*). This showed that both groups
429 had similar changes. No significant main effect of group was
430 found (*flexors right* $p=.458$; *ES: .020*, *left* $p=.889$; *ES: .001* and
431 *extensors right* $p=.368$; *ES: .030*, *left* $p=.374$; *ES:.029*).
432 However a significant main effect of time was found (*flexors and*
433 *extensors right* $p<.001$; *flexors right* *ES: .397*, *left* *ES: .531* and
434 *extensors right* *ES: .437*) except left side extensors ($p=.078$;
435 *ES:.111*) (Table 4).

436 *Ankle muscle group and FHL:* The group-by-time
437 interaction and the main effect of group for the ankle muscle
438 group and FHL did not meet the significance threshold (*DF right*
439 $p=.936$; *ES:.000*, *left* $p= .365$; *ES:.029*, *PF right* $p=.178$;
440 *ES:.064*, *left* $p=.777$; *ES:.003*, *FHL right* $p=.758$; *ES:.003*, *left*
441 $p=.267$; *ES:.045*, *DF right* $p=.400$; *ES:.025*, *left* $p=.184$;
442 *ES:.062*, *PF right* $p=.414$; *ES:.024*, *left* $p=.518$; *ES:.015*, *FHL*
443 *right* $p=.809$; *ES:.002*, *left* $p=.273$; *ES: .044*). The results
444 suggest that both groups had similar changes. No significant
445 main effect of time was found for FHL (*right* $p=.075$; *ES:.109*,
446 *left* $p=.875$; *ES:.001*). However for the main effect of time,
447 significant improvements were observed in ankle musculature

448 strength (*DF right* $p=.001$; *ES:.324*, *left* $p<.001$; *ES:.472*, *PF*
449 *right* $p<.001$; *ES:.395*, *left* $p=.002$; *ES:.002*) (Table 4).

450

451 **4. DISCUSSION**

452 The overall aim of this study was to investigate the
453 efficiency of SFE. Specifically, we focused on the knee pain,
454 foot biomechanics, and muscle strength in patients with '*weak*
455 *and pronated*' foot subgroup of PFP. The results of this study
456 show that patients with '*weak and pronated*' foot subgroup of
457 PFP who performed SFE in addition to hip and knee
458 strengthening and stretching exercises experienced greater knee
459 pain reduction and clinically higher functional improvements
460 compared to patients who performed only hip and knee
461 strengthening and stretching exercises. The result of this study
462 demonstrated that SFE has significant effects on foot
463 biomechanics and knee pain.

464 Our results are similar to others that have found
465 improvements in pVAS and KPS (30, 31). pVAS scores
466 decreased in both groups but it was significantly in SFEG's
467 favor. And improvements in all pain related domains for SFEG
468 were approximately ≥ 2 cm which was indicated as minimal
469 clinical important difference (32). Although there is no
470 difference between overall scores in KPS, in more detail, we
471 observed that KPS-climbing stairs, squatting, prolonged sitting
472 and walking scores were clinically higher in the SFEG.

473 The findings of the current study indicate that a
474 significant improvement occurred in the ND and RA values in
475 the SFEG. However, in the ConG, a slight increase in the ND
476 and RA values was recorded and this indicated an increased
477 tendency to pronated foot posture. At this point, although the
478 baseline values of the two groups seem to be different to consider
479 the laterality of the NDT and RA, the difference in baseline
480 values due to random allocation of the patients into the groups.
481 Although the baseline values of the patients randomly included
482 in the SFEG show lower MLA and more pronated rearfoot
483 posture than ConG, both groups remained within the norm
484 values.

485 As a result, findings from this study can be interpreted as
486 progressive SFE, in addition to hip and knee strengthening
487 exercise is effective in increasing the activity of the foot intrinsic
488 muscles and reducing foot pronation by providing arch control
489 in patients with '*weak and pronated*' foot subgroup of PFP.

490 The main mechanism of arch control is the 'Windlass
491 mechanism'. The winding of the plantar fascia around the
492 metatarsal heads, via dorsiflexion during the propulsive phase,
493 elevates the MLA and as a result, the foot forms a rigid lever arm
494 (33). In this way, the plantar flexor torque is transferred to the
495 ground effectively. Intrinsic muscles are thought to affect this
496 active mechanism (33).

497 Although it was beyond the scope of this study,
498 consistent with Nguyen and Boiling (34), the ND- subtalar joint-
499 knee valgus connection was also demonstrated and an exercise
500 approach was suggested.

501 Another noteworthy finding of the current study was an
502 improvement in foot pronation assessed with FPI in SFEG. With
503 these results add to the findings of current study, it was
504 concluded that SFE should be taken into consideration to
505 maintain foot posture. Although there is a consensus that foot
506 orthoses are effective only in patients with PFP with excessive
507 pronation, foot orthoses are commonly demonstrated as first
508 treatment option for foot pronation in PFP (35-37). In addition,
509 FPI was demonstrated as a useful assessment for foot posture
510 and orthoses (36). This indicates patients with PFP who may
511 benefit from orthoses will have scores of 10 points and over
512 defined as '*highly pronated*' according to FPI. In line with Selfe
513 et al., in this study, patients were defined as '*pronated*' (in the
514 range of 6-7 points) according to the FPI (38). Therefore the
515 results of this study also offers preliminary evidence to suggest
516 that as part of a stratified care approach SFE may be a useful
517 targeted intervention to use for the weak and pronated foot group
518 of patients with PFP.

519 Muscle strength imbalance is stated as one of the most
520 important factors to predispose PFP. In particular, knee and hip
521 extensor, hip abductor muscles weakness has been emphasized

522 in previous studies (39-41). It is reported that the weakness of
523 hip and knee muscles could increase femoral adduction and
524 medial rotation, leading to excessive knee dynamic valgus
525 during functional activities (42). Also the inhibition of the load
526 response ability results in the greater transmission of shock to
527 the supporting foot structures and acceleration of the lower
528 extremity pronation (43, 44). In other words, the weakness of the
529 hip and knee muscles can lead to poor shock absorption and
530 decreased pronation control. Furthermore, previous reports show
531 that this lack of control could result in dynamic postural balance
532 instability (40). Current literature indicates increased muscle
533 strength and improvements after various exercise treatments
534 (isometric, isotonic or isokinetic) (35). However, the foot, which
535 is the distal-end element of the lower extremity kinematics, foot
536 biomechanics, foot muscles training and their effects remain
537 relatively unclear.

538

539 Similar to literature, the strength of all tested lower
540 extremity muscle groups increased in both groups after exercise
541 programs (45, 46). However, in more detail, it was generally
542 observed that the muscle strength in SFEG increased slightly
543 more. In particular, we believe that the increase in strength of the
544 hip extensors may have occurred due to the additional support of
545 the SFE to postural stability. This additional support is explained
546 with the sensory contributions of the foot intrinsic muscles via

547 neural subsystem according to the concept of foot core system
548 (47-49). This sensory contribution is believed due to the
549 stimulation of proprioceptors on the sole. As a result of the
550 increasing afferent input to the spinal cord, voluntary muscle
551 activation was enhanced and the standing stability was improved
552 (50).

553 On the other hand, it has been known that muscle
554 strength affects posture, posture also affects muscle strength and
555 is an important component of maximum gain in strength training
556 (51). We believe that the combination of these two, may explain
557 the difference in the strength of the hip extensors in SFEG. In
558 other words, foot posture improved via the SFE may have lead
559 gaining more from strengthening exercises in the SFEG by
560 providing the alignment of the entire lower extremity posture.

561

562 **4.1. Study Limitations**

563 These results of this study need to be considered in the
564 context of several limitations. First of all, SFE is an exercise
565 protocol based on intrinsic muscle training and the most
566 prominent marker of effective treatment will be recording the
567 intrinsic muscles activity. Because of the limited evaluation
568 methods in the literature and the need for special devices, we
569 could not include this evaluation in our study.

570 Secondly, this study seems like as gender-specific study
571 because of the high proportion of the female participants (more

572 than %80). But it was reported that females were 2-3 times more
573 likely develop PFP compared with males (52). As a result,
574 female participants were included in higher proportion compared
575 with males.

576 The clinical picture of PFP emphasizes the importance of
577 dynamic situations compared to static positions. Unfortunately
578 only static evaluations could be included in this study. However,
579 if we could obtain data on plantar pressure distribution
580 dynamically, we believe that the improvements with SFE could
581 be more objectively expressed.

582 To our knowledge, this is the first study investigate the
583 use of SFE in patients with PFP. In the current study, the
584 improvement observed in terms of knee pain in both groups,
585 revealed that exercise contributes to PFP rehabilitation.
586 However we believe that the results support the use of SFE as an
587 important component of a stratified care approach for the
588 rehabilitation of PFP patients with a FPI in the region of 6/7. The
589 findings indicate that SFE will positively influence navicular
590 position, rearfoot posture and valgus stress on the knee.
591 Although it was away from the primary purposes, FPI should be
592 considered as an evaluation in patients with PFP in terms of
593 concordance with NDT and RA. And also the results of this
594 study suggest that the increase in strength of the hip extensor
595 muscles may also be due to the additional support to the
596 stabilization with SFE. Further research about SFE in patients

597 with PFP is warranted to clarify the long-term effects of SFE,
598 training during dynamic activities and performance.

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600

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847 **7. TABLES**

848 **Table 1. The demographic characteristics of the groups**

ConG (n=15) X (SD) (Min/Max)	SFEG (n=15) X (SD) (Min/Max)	<i>p</i>
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Age (years)	43.60 (7.76) (25/52)	39.60 (8.87) (25/55)	0.199
Height (cm)	165.14 (7.59) (153/182)	167.66 (12.15) (150/192)	0.693
Weight (kg)	68.36 (10.66) (54/86.5)	71.34 (16.25) (47.7/99)	0.760
BMI (kg/m²)	25.09 (3.77) (19.13/32.56)	25.36 (5.19) (18.25/34.18)	0.896
<i>BMI: Body Mass Index, ConG: Control Group, SFEG: Short Foot Exercise Group, X: Mean, SD: Standard deviation, Min.: Minimum value, Max.: Maximum value, * p<0.05.</i>			

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867 **Table 2. Pain intensity before and after treatment**

Outcome/Time	ConG (n=15) X (SD) (95% CI)	SFEG (n=15) X (SD) (95% CI)	Between- group differences X (95%CI)
Walking pain			

Baseline	4.13±3.22 (2.34, 5.92)	3.66±2.28 (2.39, 4.93)	
6th week	3.46±2.99 (1.80, 5.12)	1.40±1.54 (0.54, 2.25)	1.60 (-0.50, 3.70)
<i>Within-group change</i>	0.66±3.49 (-1.27, 2.60)	2.26±1.90 (1.21, 3.32)	
Sitting pain			
Baseline	3.13±3.13 (1.39, 4.87)	4.93±2.46 (3.56, 6.29)	
6th week	3.00±3.22 (1.21, 4.78)	2.33±1.87 (1.29, 3.37)	2.46 (0.97, 3.95)
<i>Within-group change</i>	0.13 ±1.95 (-0.95, 1.21)	2.60± 2.02 (1.47, 3.72)	
Stair-up pain			
Baseline	4.46±2.87 (2.87, 6.05)	5.80±2.11 (4.63, 6.96)	
6th week	3.30±2.38 (1.97, 4.62)	2.20±1.52 (1.35, 3.04)	2.43 (0.73, 4.13)
<i>Within-group change</i>	1.16±2.21 (-0.06, 2.39)	3.60±2.32 (2.31, 4.88)	
Stair-down pain			
Baseline	4.86±3.02 (3.19, 6.53)	5.06±1.75 (4.09, 6.03)	
6th week	3.63±3.00 (1.97, 5.29)	2.26±1.22 (1.58, 2.94)	1.56 (-0.006, 3.13)
<i>Within-group change</i>	1.23±2.09 (0.07, 2.39)	2.80±2.11 (1.63, 3.96)	
Squatting pain			
Baseline	5.20±3.23 (3.40, 6.99)	6.73±2.28 (5.46, 7.99)	
6th week	4.00±3.25 (2.19, 5.80)	3.53±1.76 (2.55, 4.51)	2.00 (0.08, 3.91)
<i>Within-group change</i>	1.20±3.05 (-0.49, 2.89)	3.20±1.93 (2.12, 4.27)	
Nocturnal pain			
Baseline	1.80±2.65 (0.33, 3.26)	3.60±3.35 (1.74, 5.45)	
6th week	1.80±2.65 (0.33, 3.26)	1.33±1.83 (0.31, 2.35)	2.26 (0.28, 4.25)
<i>Within-group change</i>	0.00±2.56 (-1.41, 1.41)	2.26±2.73 (0.75, 3.78)	
Kujala Patellofemoral Scale			
Baseline	63.86±10.07 (58.28,69.44)	62.06±14.16 (54.22,69.91)	
6th week	72.60±12.14 (65.87,79.32)	72.73±11.39 (66.42,79.04)	1.93 (-5.55, 9.41)
<i>Within-group change</i>	-8.73±8.13 (-13.23, -4.22)	-10.66±11.57 (-17.07, -4.25)	
<i>Walking pain: pain after 30 minute walking, Sitting pain: pain after 1 hour sitting, Stair-up pain: pain at ascending stairs, Stair-down pain: pain at descending stairs, Squatting pain: pain while squatting, ConG: Control Group, SFEG: Short Foot Exercise Group, X: Mean, SD: Standard deviation, CI: Confidence of Interval.</i>			

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871 **Table 3. Navicular drop test, rear foot angle values and foot**

872 **posture index scores before and after treatment**

	ConG (n=15) X±SD (95% CI)	SFEG (n=15) X±SD (95% CI)	Between-group differences X (95%CI)
NDT (mm)			
<i>Right side</i>			
Baseline	8.61±3.12 (6.88, 10.34)	11.19±3.48 (9.26, 13.12)	
6th week	8.74±2.65 (7.27, 10.21)	8.21±2.95 (6.58, 9.84)	-3.10 (-5.30, -0.90)
<i>Within-group change</i>	-0.12±3.45 (-2.04, 1.78)	2.97±2.30 (1.69, 4.25)	
<i>Left side</i>			
Baseline	8.35±4.43 (5.90, 10.81)	11.29±4.23 (8.94, 13.64)	
6th week	8.76±4.22 (6.42, 11.10)	9.09±3.13 (7.35, 10.83)	-2.60 (-5.25, 0.47)
<i>Within-group change</i>	-0.40±2.73 (-1.91, 1.11)	2.19±4.19 (0.12, 4.52)	
RA (NWB) (degree)			
<i>Right side</i>			
Baseline	2.53±5.28 (-0.39, 5.46)	1.40±6.34 (-2.11, 4.91)	
6th week	2.93±5.31 (-0.007, 5.87)	-0.66±4.32 (-3.05, 1.72)	2.46 (0.12, 4.80)
<i>Within-group change</i>	-0.40±1.18 (-1.05, 0.25)	2.06±4.11 (-0.21, 4.34)	
<i>Left side</i>			
Baseline	2.13±5.44 (-0.88, 5.15)	4.86±4.74 (2.23, 7.49)	
6th week	2.13±5.13 (-0.71, 4.97)	2.13±2.66 (0.65, 3.61)	2.73 (1.26, 4.20)
<i>Within-group change</i>	0.00±1.25 (-0.69, 0.69)	2.73±2.43 (1.38, 4.08)	
RA (WB) (degree)			
<i>Right side</i>			
Baseline	8.60±1.80 (7.60, 9.59)	7.33±3.43 (5.43, 9.23)	
6th week	8.06±1.86 (7.03, 9.10)	4.40±2.64 (2.93, 5.86)	-2.40 (-3.97, -0.82)
<i>Within-group change</i>	0.53±1.45 (-0.27, 1.34)	2.93±2.60 (1.49, 4.37)	
<i>Left side</i>			
Baseline	7.93±3.30 (6.10, 9.76)	9.00±3.22 (7.21, 10.78)	
6th week	7.93±2.34 (6.63, 9.23)	4.86±3.27 (3.05, 6.67)	-4.13 (-5.99, -2.27)
<i>Within-group change</i>	0.00±2.03 (-1.12, 1.12)	4.13±2.87 (2.54, 5.72)	
FPI			
<i>Right side</i>			
Baseline	6.53±3.77 (4.44, 8.63)	6.13±3.04 (4.45, 7.82)	
6th week	6.53±3.77 (4.44, 8.63)	4.00±2.87 (2.41, 5.59)	-2.13 (-2.94, -1.32)
<i>Within-group change</i>	-	2.13±1.45 (1.32, 2.94)	
<i>Left side</i>			
Baseline	6.73±3.88 (4.58, 8.88)	7.00±2.03 (5.87, 8.12)	
6th week	6.73±3.88 (4.58, 8.88)	4.53±2.32 (3.24, 5.82)	-2.46 (-3.37, -1.55)
<i>Within-group change</i>	-	2.46±1.64 (1.55, 3.37)	

NDT: Navicular Drop Test, **RA:** Rear foot Angle, **NWB:** Non-weight Bearing Position (sitting), **WB:** Weight Bearing Position (standing), **FPI:** Foot Posture Index, **ConG:** Control Group, **SFEG:** Short Foot Exercise Group, **X:** Mean, **SD:** Standard deviation, **CI:** Confidence of Interval, **negative (-):** Varus for rear foot angle, **positive (+):** Valgus for rear foot angle.

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896 **Table 4. Lower extremity muscle strength before and after**
 897 **treatment.**

Muscle Strength (N)/Time	ConG (n=15) X±SD (95% CI)	SFEG (n=15) X±SD (95% CI)	Between-group differences X (95%CI)
Hip Joint Abduction			
<i>Right Side</i>			
Baseline	35.40±5.19 (32.46, 38.24)	34.71±6.27 (30.89, 38.54)	
6th week	38.44±4.31 (35.99, 40.89)	39.52±4.70 (36.67, 42.36)	-2.35 (-6.89, 2.18)
<i>Within-group change</i>	-3.06±5.68 (-6.17, 0.11)	-5.39±6.27 (-8.92, -1.86)	
<i>Left Side</i>			
Baseline	31.96±4.70 (29.32, 34.51)	32.65±5.58 (29.22, 36.08)	
6th week	35.99±4.51(33.44, 38.44)	36.77±3.92 (34.32, 39.22)	-0.71 (-4.88, 3.44)
<i>Within-group change</i>	-4.02±4.41 (-6.47, -1.47)	-4.70±6.47 (-8.33, -1.07)	
Hip Joint Extension			
<i>Right Side</i>			
Baseline	33.63±3.92 (31.47, 35.79)	34.22±3.53 (32.06, 36.38)	
6th week	36.57±4.41 (34.12, 39.03)	40.50±4.31 (37.85, 43.14)	-3.60 (-6.80, -0.41)
<i>Within-group change</i>	-2.94±3.53 (-4.90, -0.98)	-6.57±4.80 (-9.21, -3.82)	
<i>Left Side</i>			
Baseline	32.55±4.80 (29.81, 35.20)	34.12±6.47 (30.20, 38.04)	
6th week	37.26±4.90 (34.51, 40.01)	40.10±4.60 (37.26, 42.95)	-1.98 (-6.53, 2.55)
<i>Within-group change</i>	-4.70±4.70 (-7.35, -2.05)	-6.66±7.06 (-10.68, -2.74)	
Knee Joint Flexion			
<i>Right Side</i>			
Baseline	33.34±5.78(30.10, 36.48)	35.69±4.02(33.24, 38.14)	
6th week	37.95±7.25 (33.93, 41.97)	40.59±5.88 (37.06, 44.12)	-0.78 (-5.57, 4.01)
<i>Within-group change</i>	-4.60±7.15 (-8.53, -0.58)	-5.39±5.49 (-8.43, -2.35)	
<i>Left Side</i>			
Baseline	32.65±5.88 (29.32, 35.89)	35.20±5.00 (32.16, 38.24)	
6th week	39.03±5.00 (36.18, 41.87)	39.22±6.37 (35.30, 43.05)	2.02 (-1.89, 5.94)
<i>Within-group change</i>	-6.37±5.88 (-9.61, -3.13)	-4.31±4.41 (-6.86, -1.86)	
Knee Joint Extension			
<i>Right Side</i>			
Baseline	25.00±2.54 (23.63, 26.47)	25.49±3.23 (23.53, 27.55)	
6th week	27.36±2.35 (25.98, 28.63)	28.83±2.94 (27.06, 30.69)	-0.88 (-3.35, 1.57)
<i>Within-group change</i>	-2.25±2.74 (-3.88, -0.68)	-3.13±3.53 (-5.19, -1.07)	
<i>Left Side</i>			
Baseline	24.81±4.60 (22.26, 27.36)	24.90±3.72 (22.65, 27.16)	
			-7.04 (-22.06, 8.06)

6th week	28.04±4.11 (25.69, 30.40)	35.79±29.81 (17.75, 53.83)	
<i>Within-group change</i>	-3.13±3.04 (-4.90, -1.47)	-10.19±28.34 (-26.57, 6.08)	
Ankle Dorsi Flexion			
<i>Right Side</i>			
Baseline	22.65±4.02 (20.39, 24.90)	23.33±2.64 (21.77, 25.00)	
6th week	24.71±3.43 (22.75, 26.67)	25.69±2.94 (23.83, 27.45)	0.09 (-2.47, 2.28)
<i>Within-group change</i>	-2.05±3.53 (-4.02, -0.07)	-2.15±2.64 (-3.62, -0.68)	
<i>Left Side</i>			
Baseline	22.75±2.45 (21.37, 24.12)	24.12±2.54 (22.65, 25.69)	
6th week	25.39±2.05 (24.22, 26.57)	25.98±2.15 (24.61, 27.26)	0.83 (-1.01, 2.69)
<i>Within-group change</i>	-2.64±2.74 (-4.21, -1.07)	-1.76±2.05 (-3.02, -0.67)	
Ankle Plantar Flexion			
<i>Right Side</i>			
Baseline	30.59±5.78 (27.36, 33.83)	30.10±5.29 (26.87, 33.34)	
6th week	33.53±5.78 (30.30, 36.67)	31.67±4.90 (28.63, 34.61)	1.41 (-0.67, 3.51)
<i>Within-group change</i>	-2.84±2.84 (-4.51, -1.27)	-1.47±2.64 (-2.96, 0.004)	
<i>Left Side</i>			
Baseline	26.08±5.88 (22.84, 29.41)	25.49±4.02 (22.94, 27.94)	
6th week	29.22±6.57 (25.59, 32.85)	28.24±3.62 (25.98, 30.49)	0.47 (-2.89, 3.83)
<i>Within-group change</i>	-3.04±5.00 (-5.88, -0.28)	-2.54±3.82 (-4.70, -0.50)	
FlexorHallucis Longus			
<i>Right Side</i>			
Baseline	21.57±2.25 (20.29, 22.84)	21.77±2.05 (20.49, 23.04)	
6th week	22.26±2.74 (20.69, 23.83)	23.04±2.25 (21.57, 24.41)	-0.27 (-2.13, 1.56)
<i>Within-group change</i>	-0.68±2.25 (-1.96, -0.59)	1.27±2.61 (-2.35, 0.47)	
<i>Left Side</i>			
Baseline	25.10±14.41 (17.06, 33.14)	20.69±2.25 (19.31, 22.06)	
6th week	22.35±2.94 (20.79, 24.02)	22.84±2.05 (21.57, 24.12)	-4.77 (-13.42, 3.86)
<i>Within-group change</i>	2.64±15.49(-5.78, 11.27)	-2.04±2.96 (-3.76, -0.33)	
<i>N: Newton, ConG: Control Group, SFEG: Short Foot Exercise Group) X: Mean, SD: Standard deviation, CI: Confidence of Interval.</i>			

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904 8. FIGURE CAPTIONS

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906 **Figure.1.** CONSORT Flow Chart (*Abbreviations: ConG;*
907 *Control group, SFEG; Short Foot Exercise Group*)

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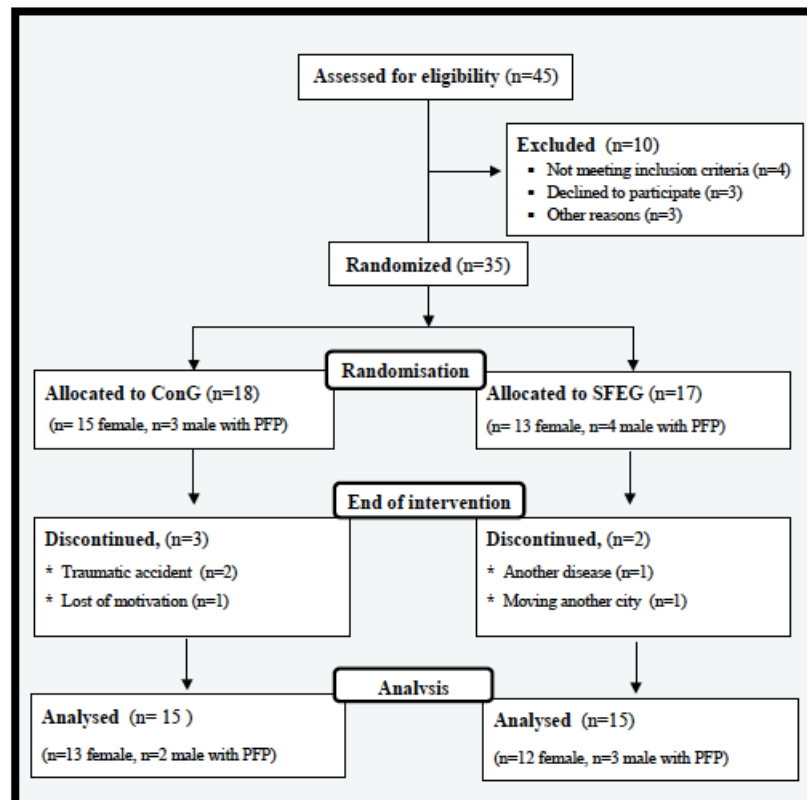
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913 9. FIGURES



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