



Effects of custom-made insole on gait pattern of patients with unilateral displaced intra-articular calcaneal fracture: evaluation with computerized gait analysis

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Objective: The aim of this study was to investigate whether use of custom-fabricated insoles improves the gait pattern in patients with displaced intra-articular calcaneal fractures.

Methods: Fourteen patients (7 female, 7 male; mean age: 39±12 years) and 11 healthy individuals (mean age: 42±13 years) were included in the study. Treatment protocol included conservative treatment involving immobilization, with or without closed reduction, active exercises, wear of a custom-fabricated insole and prospective follow-up. All patients were evaluated by physical examination, axial and lateral radiographs, computerized tomography, and computerized gait analysis.

Results: The use of custom-made insoles significantly improved step and stride lengths and the peak values of fore-aft component in the involved foot and tended to increase plantarflexor moment and total ankle power. The majority of patients (71%) continued to have substantial mechanical abnormalities by computerized gait analysis. Plantar flexion moment, total ankle power, vertical component of ground reaction forces (GRFs), and total sagittal plane excursion were significantly decreased in the involved foot when compared to the uninvolved foot. Plantar flexion moment, total ankle power, vertical, fore-aft and mediolateral components of GRFs were significantly decreased in the involved foot when compared to the healthy control group.

Conclusion: Use of a custom-made insole improves advancement of limb and weight-bearing in patients with a displaced intra-articular calcaneal fracture. Nevertheless, mechanical abnormalities persist in the affected limb, which does not appear to recover a gait pattern similar to that of normal walking.

Key words: Calcaneus fracture; conservative treatment; gait analysis; insole.

The management of displaced intra-articular calcaneal fractures remains controversial.^[1-4] Both operative and conservative treatment methods have been investigated in several comparative studies. Although operative

treatment has been advocated in many reports,^[5-13] a high percentage of unsatisfactory outcomes based on the long-term results have been documented. Among patients treated conservatively or surgically, 15 to 50%

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continue to have complaints of persisting pain, loss of joint mobility, and functional disability.^[14-21] Conservative treatment frequently leads to severe functional impairment with considerable disability.^[18] In our previous study, we demonstrated significant deviations even with conservative treatment in the lower extremity biomechanics of the ankle and knee joints in patients with severely comminuted intra-articular calcaneal fractures.^[15]

Conservative treatment usually involves elevation, ice, early mobilization, cyclic compression of the plantar arch and bracing. Custom-fabricated insoles have been suggested to improve gait pattern in patients with calcaneal fractures by restoring the height of the heel and longitudinal arch, decompressing the peroneal tendons, and providing an anatomic position for the insertion of the tendo calcanei.^[17-21] Despite the extensive research on conservative treatment, there is no consensus regarding the use of insoles within the context of conservative treatment.

We hypothesized that the affected limb would recover a gait pattern similar to that of normal walking with the use of a custom-fabricated insole during conservative treatment. Thus, the primary aim of this study was to investigate whether the use of a custom-fabricated insole improves the gait pattern in patients with displaced intra-articular calcaneal fracture. The secondary aim was to identify mechanical abnormalities in gait pattern persisting after calcaneal fractures.

Materials and methods

Fourteen patients (7 female, 7 male; mean age: 39±12 years; mean weight 74.4±8.6 kg) with displaced intra-articular calcaneal fractures who were treated conservatively from March 2003 to May 2003 and 11 healthy individuals (mean age: 42±13 years; mean weight: 71.8±11.5 kg) were included in the study. Patients did not undergo surgery due to marked soft tissue injury, patient refusal, and lack of reimbursement.

Treatment protocol included immobilization in a brace or cast, with or without closed reduction. The cast or brace was removed six weeks post-injury and a physiotherapy program was begun in cases of subsided edema. Weight-bearing was allowed after 8 weeks. The exercise program included rising on the toes with the feet internally rotated, pointing straight ahead, and externally rotated and isometric contractions of the dorsiflexor muscles of the ankle. Each exercise was to be performed in a series of ten repetitions, three to five times a day.

Each patient was evaluated by physical examination, axial and lateral radiographs, computerized tomography, and computerized gait analysis in the final follow-up visit. Clinical outcome was evaluated using the Kaikkonen score and the 100-point ankle-hindfoot score, which includes level of pain, limitations of activity, use of support, restriction of motion, and alignment. Ankle joint range of motion in the sagittal plane was measured with the patient in the prone position, using a goniometer at the level of malleolus. Subtalar range of motion in the frontal plane was measured with the patient kneeling and holding the ankle in neutral flexion-extension. After marking the bisection of the heel, angular deviation of the calcaneal axis was calculated from the neutral position in maximum inversion and eversion.

Insoles were a modified form of the (University of California Biomechanics Laboratory) UCBL orthosis and individually fabricated to fit the involved foot of each patient. First, both feet were wrapped in plaster in such a way as to cover the malleoli. The patient was then instructed to stand on his/her feet until the plaster was completely firm and the calcaneus and metatarsal heads was checked for proper placement. The plaster was removed upon complete hardening and a negative model was obtained. Liquid plaster was poured into the negative model to obtain a positive model which was then filed to maintain the subtalar joint in neutral position. Polyethylene thickness was adjusted between 3-4 mm in accordance with the patient's weight. The polyethylene material was molded on the positive model in a special kiln at 180 °C. The mold was trimmed depending on the characteristics of each patient's foot (Fig. 1). The medial arch was filled with poliform to increase stability and the heel was wedged into a cup to avoid axial drift of the calcaneus. The insole was worn inside a sneaker with heel of a minimum of 2 cm and a front rocker to assist push-off and plantar flexion.

Computerized gait analysis was conducted at the Biomechanics Research Laboratory of the Mechanical Engineering Department of the Middle East Technical University, Ankara, Turkey. The gait analysis system consisted of 6 Ikegami (Ikegami Tsushinki Co. Ltd., Tokyo, Japan) charge-coupled device cameras and 2 Bertec (Bertec Corp., Columbus, OH, USA) force plates. The force plates were inserted in a staggered pattern in the middle of a 5-m walkway. To capture motion at 50 Hz, markers covered with retro-reflective material and specially developed infrared light probes were mounted on the cameras. To obtain kinematic data,



Fig. 1. (a, b) Final views of the custom-made insole. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

retro-reflective markers were placed onto the anatomic landmarks of both the lower extremities at the following points: anterior superior iliac spine, posterior midline of the pelvis, thigh, knee, mid-tibia, ankle, and second metatarsal (Fig. 2).

Each gait analysis session started with calibration of the kinematic recording system. During data acquisition, patients walked at a self-selected velocity on a level 5-m walkway under two conditions: (1) unbraced shoe, (2) shoe with the custom-fabricated insole. All patients wore the insoles for a minimum of 2 weeks prior to testing to establish familiarity. Practice trials were performed by each subject until they were able to consistently and naturally contact both of the force plates. A minimum of three successful trials were recorded for each subject. During these trials, the 3-dimensional trajectory coordinates for each of the 13 markers and the mutually perpendicular 3 force and 3 moment components on each force plate were recorded simultaneously. Patients were encouraged to rest between trials as often as necessary. All subjects in the control group were instructed to walk at a self-selected speed along the walkway.

Spatiotemporal (step length, stride length, step time, stride time, cadence, and percentages of stance ratio, single-limb and double-limb support) and kinematic parameters (ankle dorsiflexion at heel strike and terminal stance, ankle plantar flexion at push-off, total sagittal plane excursion) were calculated. Ground reaction forces (GRFs) in the vertical, fore-aft and medial-lateral directions were determined. Peak values of the vertical (F1, F2, F3), fore-aft (F4, F5, F6) and mediolateral (F7, F8, F9) components of the resultant force between the floor and the foot were calculated (Fig. 3).

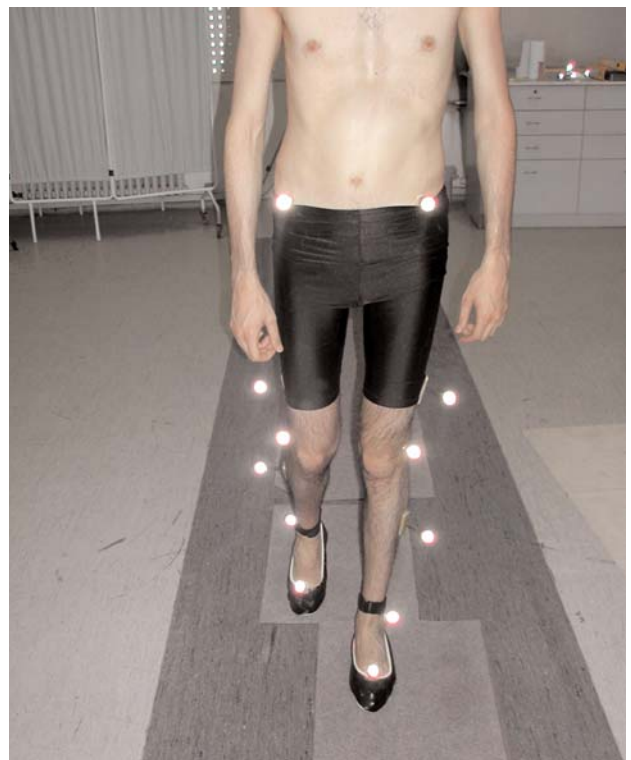


Fig. 2. Subject with markers in the laboratory. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

Descriptive statistics were provided for continuous variables using mean and standard deviation. The involved, uninvolved and control foot were compared using the Wilcoxon, Student's *t* and Mann-Whitney *U* tests for numeric variables. GRFs were normalized by percent body weight to allow comparison. Statistical

analyses were done using SPSS 9.0 (SPSS Inc., Chicago, IL, USA) software. Statistical significance was set at 0.05.

Results

Nine patients had right-side fractures and five left-side fractures. Average duration of follow-up was 32 (range: 21 to 44) months. Mean subtalar joint range of motion was $14.4^{\circ} \pm 4.6^{\circ}$ for inversion (range: 5° to 20°) and $3.2^{\circ} \pm 5.6^{\circ}$ for eversion (range: -10° to 12°) on the involved ankle. According to the 100-point ankle-hindfoot score, clinical results were good in one patient (7%), fair in three patients (21%) and poor in ten patients (71%). According to the ankle score defined by Kaikkonen et al.,^[22] the mean score of the patients assessed at the sixth month was 71.8 ± 32.6 (range: 15 to 100).

Gait analysis after the use of custom-fabricated insole revealed a significant increase in step and stride lengths (Table 1). There were no significant changes in kinematic parameters. Analysis of the GRFs yielded inconsistent changes except for a significant increase in the peak values of fore-aft component (F4, F6) (Table 2 and Fig. 3).

There were no significant differences in ankle plantar flexion at push-off, ankle dorsiflexion at heel strike and terminal-stance between the involved foot with insole

and the uninvolved feet (Table 1). The total sagittal plane excursion was significantly lower in the involved foot. There were no significant differences in the percentages of stance phase, single-limb and double-limb support. The plantar flexion moment, total ankle power, and vertical (F3) component of GRFs were significantly lower in the involved foot (Table 2 and Fig. 3).

Cadence, step length, stride length, and percentage of single-limb support were significantly lower in the patient group in comparison to the control group (Table 1). The patient group had higher step and stride time values and lower total sagittal plane excursion plantar flexion moment, total ankle power, vertical (F3), fore-aft (F5, F6) and mediolateral (F7) components of GRFs in the involved foot (Table 2 and Fig. 3).

Discussion

Patients with traumatic heel injury usually have a tendency to use the forefoot more frequently for initial foot strike to avoid pain, which can lead to plantar flexion during initial foot contact.^[23] However, this toe-walking pattern was not observed in any of our patients. The majority of patients (71%) in our study had low values of ankle-hindfoot scores, which suggests a residual functional impairment. This was confirmed by the

Table 1. Analysis of spatiotemporal, kinematic and kinetic parameters in patients and control subjects.

Parameters	Patients with a calcaneal fracture			Control subjects (n=14)
	Involved foot		Uninvolved foot	
	w/o insole (n=14)	w/insole (n=14)	(n=14)	
Walking speed (m/s)	0.93±0.24	0.96±0.28 [‡]	0.95±0.28	1.24±0.18
Step length (m)	0.54±0.09*	0.56±0.08 [‡]	0.53±0.12	0.65±0.07
Stride length (m)	1.05±0.19*	1.09±0.20 [‡]	1.09±0.20	1.29±0.13
Step time (s)	0.60±0.10	0.60±0.09 [‡]	0.58±0.08	0.52±0.03
Stride time (s)	1.17±0.16	1.19±0.15 [‡]	1.20±0.15	1.06±0.07
Cadence (step/min)	103.07±12.17	101.57±11.60 [‡]	101.00±11.20	113.91±7.14
Single-limb support (%)	77.98±3.23	78.13±3.41 [§]	78.22±4.17	80.54±2.09
Double-limb support (%)	21.93±3.46	21.96±4.04	21.87±4.10	19.46±2.09
Stance phase (%)	63.92±1.62	63.66±3.38	63.58±1.84	62.17±1.68
Ankle DF ¹ (deg)	-1.39±5.61	-1.83±6.33	-2.10±6.47	-0.73±5.76
Ankle DF ² (deg)	11.32±3.99	11.08±4.27	11.59±5.35	13.41±5.29
Ankle PF ¹ (deg)	-6.08±6.49	-6.87±8.31	-10.60±8.48	-10.65±5.10
Ankle excursion (deg)	18.35±4.58	19.43±3.85 ^{††}	23.90±5.19	24.07±5.09
Ankle PF moment (Nm/kg)	84.29±23.28	87.19±21.61 ^{†§}	107.89±16.54	110.7±17.77
Total ankle power (Watt/kg)	140.98±62.25	142.55±55.60 ^{††}	198.94±53.44	247.6±60.65

The values are given as mean±SD. The moments are given as percent bodyweight. DF¹: Dorsiflexion at heel strike, DF²: Dorsiflexion at late stance, PF: Plantar flexion during push-off. *The difference in the involved foot after use of insole is significant (p<0.05); †The difference is significant compared with uninvolved foot (p<0.05); ‡The difference is significant compared with control feet (p<0.01); §The difference is significant compared with control feet (p<0.05).

Table 2. Analysis of ground reaction forces in patients and control subjects.

	F1	F2	F3	F4	F5	F6	F7	F8	F9
Patients									
Uninvolved foot	104.9±8.0	79.0±7.3	105.8±4.5	3.5±1.5	15.3±1.5	16.7±3.8	3.7±1.5	6.5±1.1	7.4±2.2
Involved foot									
w/o insole	102.0±8.5	82.7±4.1	99.4±6.5	2.5±2.3	13.0±2.6	13.4±2.8	4.0±1.3	7.2±1.3	7.7±2.5
with insole	103.5±7.0	80.4±4.1	99.3±5.1	4.3±2.6	14.7±2.6	15.1±3.0	3.1±1.8	7.3±1.2	7.8±1.8
Control subjects									
Control foot	107.1±9.8	74.9±8.3	106.1±7.2	4.0±3.9	16.9±5.3	18.2±3.1	5.3±2.7	6.5±1.2	6.9±1.4
P value									
Involved foot compared with uninvolved foot	0.441	0.314	0.011 [†]	0.678	0.208	0.214	0.208	0.086	0.441
Involved foot after the use of insole	0.260	0.110	0.953	0.018 [*]	0.086	0.050 [*]	0.208	0.953	0.594
Involved foot compared with control foot	0.453	0.064	0.010 [†]	0.749	0.356	0.020 [†]	0.021 [†]	0.113	0.135

The values are given as the mean±SD. The moments are given as percent bodyweight. *The difference in the involved foot after use of insole is significant (p<0.05); [†]The difference is significant compared with uninvolved foot (p<0.05); ^{*}The difference is significant compared with control feet (p<0.05).

findings of the gait analysis which revealed significantly slowed gait speed and decreased stride length, cadence, percentage of single-limb support and sagittal plane excursion in the involved foot. Kitaoka et al.^[24] described a tendency for a decreased proportion of single-limb support and limitation of ankle motion in the injured ankle. They found a decrease in motion in all planes in walking on level ground. Remarkably, these changes were sustained for an average of 6 years, which indicates permanent functional impairment. Although our findings were similar, we cannot interpret them as permanent functional impairment due to the limited follow-up time.

GRF components and temporal distance factors usually change following calcaneal fractures as patients attempt to unload the involved side during the stance phase to compensate for the difference. GRF abnormalities we found reflected a less vigorous walking pattern on the involved side. During the gait analysis, the most remarkable findings were the reduction of the plantarflexor moment and total ankle power of the injured ankle immediately following heel contact. These kinetic changes reflect an impaired weight acceptance during loading response and can be attributed to pain and instability. Losch et al., on the other hand, explained these changes as an adapted and internalized motion pattern caused by pain and resting behavior at any point during the mobilization phase.^[25]

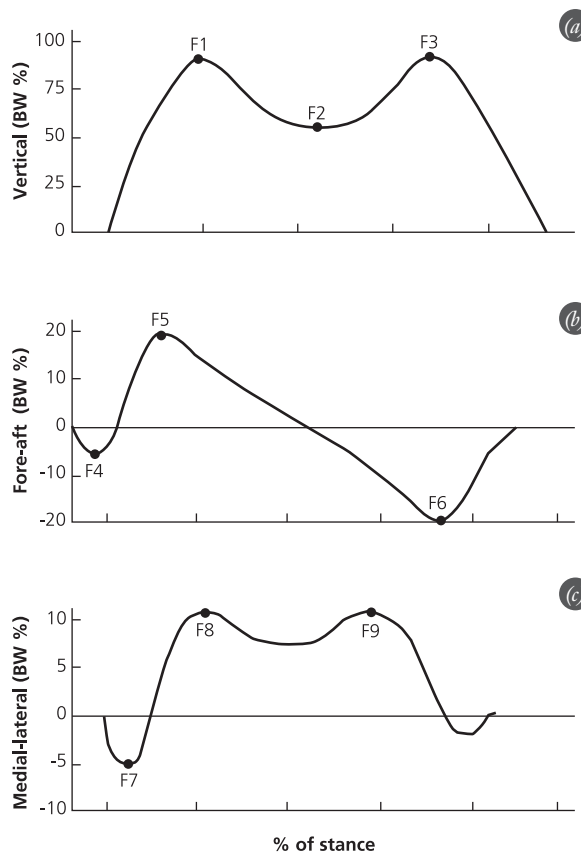


Fig. 3. Schematic representation of the (a) vertical, (b) fore-aft and (c) medial-lateral GRFs.

In the kinetic analysis, the vertical component of the ground reaction force (F3) was significantly lower in the involved foot than in the uninvolved and control feet. Similarly, Kitaoka et al.^[24] found F3 to be significantly lower in the involved foot than the uninvolved foot. A flattening of the vertical GRF curve together with a decrease in F3 component can be interpreted as the inadequate transmission of body weight to the forefoot during the terminal phase.

Conservative treatment of displaced intra-articular calcaneus fractures can result in chronic heel pain and functional impairment. This may be due to subtalar incongruity, joint osteoarthritis, decrease in calcaneus height, nerve or other soft tissue, a valgus or varus hindfoot, flattening of the longitudinal arch, smashed heel-pad syndrome, or widened heel with calcaneofibular abutment and/or impingement of the tendon.^[15,17-21]

Theoretically, after non-operative treatment and early mobilization of intra-articular fractures, custom-fabricated insoles can restore the height of the heel and longitudinal arch, decompress the peroneal tendons and bring the insertion of the tendo calcanei into an anatomic position. We found a significant increase in step and stride lengths and peak values of fore-aft components (F4, F6) with the use of custom-fabricated insole. This suggests an improvement in the transmission of body weight to the forefoot, probably allowing for adequate weight-bearing. Although not statistically significant, the use of custom-fabricated insoles tended to increase plantarflexor moment and total ankle power in our study. This might reflect greater energy storage during initial contact and more power generation during toe-off, provided that the knee, hip and pelvis joints were also analyzed.

There are some limitations that need to be addressed when interpreting these findings. First, the relatively low sample size can decrease the power of the study. The insignificant changes observed in some gait parameters should be interpreted carefully in terms of Type 2 error. Thus, our results need to be validated by further studies with a larger sample size. Second, we did not reevaluate the patients over the long term with computerized gait analysis. This gives rise to questions about the longevity of the beneficial effects provided by the insole. Third, the current study was designed to reveal the immediate effects of the insole on gait parameters. The question of whether the useful mechanical effects provided by the insole will persist over the medium term or carry over into an individual level (i.e. disability, quality of life) remains unanswered.

In conclusion, while current results suggest that use of a custom-fabricated insole improves advancement of limb and weight-bearing, mechanical abnormalities persist as long as 2.5 years after injury and the affected limb does not recover sufficiently to develop a gait pattern similar to that of normal walking.

Conflicts of Interest: No conflicts declared.

References

1. Barei DP, Bellabarba C, Sangeorzan BJ, Benirschke SK. Fractures of the calcaneus. *Orthop Clin North Am* 2002;33: 263-285.263-85.
2. Eastwood DM, Phipp L. Intra-articular fractures of the calcaneum: why such controversy? *Injury* 1997;28:247-59.
3. Sanders R. Displaced intra-articular fractures of the calcaneus. *J Bone Joint Surg Am* 2000;82:225-50.
4. Sanders R. Intra-articular fractures of the calcaneus: present state of the art. *J Orthop Trauma* 1992;6:252-65.
5. Barla J, Buckley R, McCormack R, Pate G, Leighton R, Petrie D, et al.; Canadian Orthopaedic Trauma Society. Displaced intra-articular calcaneal fractures: long-term outcome in women. *Foot Ankle Int* 2004;25:853-56.
6. Bèzes H, Massart P, Delvaux D, Fourquet JP, Tazi F. The operative treatment of intraarticular calcaneal fractures: indications, technique, and results in 257 cases. *Clin Orthop Relat Res* 1993;(290):55-9.
7. Hutchinson F 3rd, Huebner MK. Treatment of oscalcis fractures by open reduction and internal fixation. *Foot Ankle Int* 1994;15:225-32.
8. Paul M, Peter R, Hoffmeyer P. Fractures of the calcaneum. A review of 70 patients. *J Bone Joint Surg Br* 2004;86:1142-5.
9. Randle JA, Kreder HJ, Stephen D, Williams J, Jaglal S, Hu R. Should calcaneal fractures be treated surgically? A meta-analysis. *Clin Orthop Relat Res* 2000;(377):217-27.
10. Rodriguez-Merchan EC, Galindo E. Intra-articular displaced fractures of the calcaneus: operative vs non-operative treatment. *Int Orthop* 1999;23:63-5.
11. Sanders R, Fortin P, DiPasquale T, Walling A. Operative treatment in 120 displaced intra-articular calcaneal fractures. Results using a prognostic computed tomography scan classification. *ClinOrthopRelat Res* 1993;(290):87-95.
12. Tennent TD, Calder PR, Salisbury RD, Allen PW, Eastwood DM. The operative management of displaced intra-articular fractures of the calcaneus: a two-centre study using a defined protocol. *Injury* 2001;32:491-6.
13. Aşık M, Şen C, Bilen FE, Hamzaoğlu A. Surgical management of intraarticular calcaneus fractures. [Article in Turkish] *Acta Orthop Traumatol Turc* 2002;36:35-41.
14. Bajammal S, Tornetta P 3rd, Sanders D, Bhandari M. Displaced intra-articular calcaneal fractures. *J Orthop Trauma* 2005;19:360-4.
15. Bozkurt M, Kentel BB, Yavuzer G, Öçgüder A, Heycan C, Tonuk E. Functional evaluation of intraarticular severely comminuted fractures of the calcaneus with gait analysis. *J Foot Ankle Surg* 2004;43:374-9.

16. Catani F, Benedetti MG, Simoncini L, Leardini A, Giannini S. Analysis of function after intra-articular fracture of the os calcis. *Foot Ankle Int* 1999;20:417-21.
17. Crosby LA, Fitzgibbons T. Intraarticular calcaneal fractures. Results of closed treatment. *Clin Orthop Relat Res* 1993;(290):47-54.
18. Kitaoka HB, Schaap EJ, Chao EY, An KN. Displaced intra-articular fractures of the calcaneus treated non-operatively. Clinical results and analysis of motion and ground-reaction and temporal forces. *J Bone Joint Surg Am* 1994;76:1531-40.
19. Lim EV, Leung JP. Complications of intraarticular calcaneal fractures. *Clin Orthop Relat Res* 2001;(391):7-16.
20. Pozo JL, Kirwan EO, Jackson AM. The long-term results of conservative management of severely displaced fractures of the calcaneus. *J Bone Joint Surg Br* 1984;66:386-90.
21. Salama R, Benamara A, Weissman SL. Functional treatment of intra-articular fractures of the calcaneus. *Clin Orthop Relat Res* 1976;(115):236-40.
22. Kaikkonen A, Kannus P, Järvinen M. A performance test protocol and scoring scale for the evaluation of ankle injuries. *Am J Sports Med* 1994;22:462-9.
23. Tang SF, Chen CP, Hong WH, Chen HT, Chu NK, Leong CP. Improvement of gait by using orthotic insoles in patients with heel injury who received reconstructive flap operations. *Am J Phys Med Rehabil* 2003;82:350-6.
24. Kitaoka HB, Crevoisier XM, Harbst K, Hansen D, Kotajarvi B, Kaufman K. The effect of custom-made braces for the ankle and hindfoot on ankle and foot kinematics and ground reaction forces. *Arch Phys Med Rehabil* 2006;87:130-5.
25. Losch A, Meybohm P, Schmalz T, Fuchs M, Vamvakakis F, Dresing K, et al. Functional results of dynamic gait analysis after 1 year of hobby-athletes with a surgically treated ankle fracture. [Article in German] *Sportverletz Sportschaden* 2002;16:101-7.