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Partial weight bearing after surgery for fractures of the lower extremity – is it achievable?

Attila Vasarhelyi[a,*], Tobias Baumert[a], Christoph Fritsch[b], Werner Hopfenmüller[c], Georg Gradl[a], Thomas Mittlmeier[a]

[a]*Abteilung für Unfall- und Wiederherstellungschirurgie Klinik und Poliklinik für Chirurgie, Universität Rostock, Schillingallee 35, 18055 Rostock, Germany*
[b]*Novel GmbH, München, Germany*
[c]*Institut für Medizinische Informatik, Biometrie und Epidemiologie, Charité-Universitätsmedizin Berlin, Germany*

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Abstract

Partial weight bearing is a generally accepted principle of rehabilitation following trauma or reconstructive surgery of the lower extremity. Individual dynamic loads during partial weight bearing to a given load level of 200 N were compared in 23 patients who had sustained a fracture of the lower extremity and 11 healthy volunteers using dynamic sole pressure measurements. Excessive dynamic loading compared with the statically pre-tested 200 N level was observed in all groups. Maximum force levels were up to 690 N in young patients and up to 580 N elderly patients beyond the prescribed static load. None of the healthy volunteers was able to keep within the given load of 200 N. The set load level was exceeded by at least 38 N (119%) in the elderly patient group. In comparison, elderly patients showed statistically significantly higher maximum forces than young patients during the first two test days ($p = 0.007$ and 0.013). On the 3rd test day the maximum ground contact forces were on average 71 N higher than in the young patients group. Analysis of the force time integrals (impulses transferred to the ground) displayed higher values in the older again than in young patients. The differences were statistically significant during the first two test days ($p = 0.006$ and 0.037).

This study implies that the conventional concept of postoperative partial weight bearing starting from 200 N and a stepwise increase of the load level until full weight bearing is not valid during clinical practice.

Keywords: Partial weight bearing; Fractures of the lower leg; Rehabilitation; Gait analysis; Dynamic plantar pressure distribution

1. Introduction

Partial weight bearing is a common principle of postoperative treatment during the rehabilitation phase after fractures or reconstructive surgery of the lower limb employing modern concepts of stable fracture fixation. Weight bearing begins on the first postoperative day and increases stepwise until full weight bearing is achieved [1]. Full weight bearing in the early postoperative phase is believed to endanger the stability of the reconstruction and the surgical result [1]. Some authors have recommended other post-operative regimes. Mandracchia et al. preferred an immobilisation of about 2 weeks postoperatively before starting partial weight bearing [2]. DiStasio et al. found that patients treated with non-weight bearing for 6 weeks with removable orthoses and physical therapy had better subjective scores than the comparable group with a short leg cast and non-weight bearing [3]. Others have suggested early postoperative weight bearing of the operated limb [4–8]. Early movement from the first postoperative day leads to higher functional scores and the possibility to return to work much faster than after postoperative immobilisation [9]. Tropp and Norlin [10] showed that early mobilisation 1–2 weeks after surgery with a brace brought better results of the range of motion and less

* Corresponding author. Tel.: +49 1773003471; fax: +49 3814946052.
E-mail address: attila.vasarhelyi@med.uni-rostock.de (A. Vasarhelyi).

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impaired muscle torque than postoperative immobilisation in a cast for 6 weeks.

The clear advantage of weight bearing versus postoperative immobilisation is that early mobilisation increases the bone turn over metabolism [11]. The consequences of immobilisation for the bone metabolism were examined by several authors [12–15]. Immobilisation causes an increase of bone resorption whereas exercise training stimulates bone growth [14,15]. It was shown experimentally that proliferation of human osteoblasts is stimulated by optimal cyclic stretching in cell culture which leads to the assumption that physical activity or stress on the bone increases osteoblast counts [16]. To date there are no valid data documenting gait phases during rehabilitation after fracture fixation in the lower extremity. The research question of our study was to determine if patients were able to load the affected leg to 200 N following fracture fixation. Particular attention was paid to pain experienced by the subjects during postoperative partial weight bearing.

2. Patients and methods

2.1. Subjects

Twenty-three patients were investigated. All had fractures of the lower extremity and their details and injuries are shown in Tables 1 and 2.

All patients had an isolated fracture of the lower extremity (Table 2). Patients with multiple fractures or injuries were excluded. Patients who had walking disturbances before and/or after the operative treatment of the injury and patients with relevant secondary disorders (e.g. cardiac insufficiency, reduced pulmonary function) affecting the gait were not included in the study. Results were compared with a control group of 11 healthy volunteers (six males and five females; median age 26 years, range 22–44 years; median body weight 71 kg, range 61–99 kg).

2.2. Measurements and data processing

The data were registered using an in shoe gait analysing tool (pedar-m system, novel$_{\text{GmbH}}$, 964 Grand Avenue, St. Paul, MN, 55105, USA). The pedar mobile system allows measurements of dynamic sole pressure distributions. It uses flexible and size adaptable insoles. Four different sizes of insoles were used. Each insole contains 99 homogeneous capacitive receptors (99 per insole). Data could be registered online with a mobile data set at 10.000 sensors/s corresponding to 50 images/s. (Fig. 1). Error rates are moderately low (<5%) [17]. The insoles' sensitivity were calibrated for low force peak range from 10–200 N before gait analysis. Data and statistical analysis were performed with specific software (novel database pro and SPSS Version 12.01 (SPSS Inc., 233 S. Wacker Drive, Chicago, IL 60606, USA)). Statistical significances were assessed with the Mann–Whitney test. The average of the parameters maximum force difference (Δmf [N]) and force time integral (fti [N s]) were analysed with the corresponding standard deviation of each measurement. A static weight of 200 N was subtracted from each measured maximum force during dynamic partial weight-bearing gait ($\Delta mf = mf_{\text{partial weight}} - mf_{\text{200 N weighing machine}}$ [N]) to

Table 2
Patients and their specific injury of the lower extremity

	Young patients (*n* = 12)	Elderly patients (*n* = 11)
Malleolar fracture		
Weber B	7	4
Weber C		1
Tibial shaft fracture	2	
Tibial head fracture	3	
Femoral shaft fracture		4
Femoral neck fracture		2

Fig. 1. A patient wearing pedar mobile system connected to a portable data set.

Table 1
Subject characteristics

	Healthy volunteers (*n* = 11)	Young patients (*n* = 12)	Elderly patients (*n* = 11)
Male	6	7	6
Female	5	5	5
Age (year, range)	22–44	18–51	60–83
Median age	26	42	70
Median weight (kg)	71.0	76.5	79.0

Table 3
Acquired gait cycles on three successive test days

	Healthy volunteers ($n = 11$)	Young patients ($n = 12$)	Elderly patients ($n = 11$)
Total no. of cycles	33	36	33

Analysis of each cycle was based on three measurements of 15 randomly selected steps of the investigated limb during 3 min of walking.

assess the maximum force difference as overload of the pre-tested static insole force of 200 N. Force time integrals represented total impulses transferred to the ground during dynamic gait cycles and were considered particularly helpful for interpretation of data since they referred to force and time of load application.

Two days postoperatively the patients started with mobilisation and the maintenance of 200 N partial weight bearing, supervised by a physical therapist, and regardless of the individual's body weight. They were trained to walk with two crutches practicing a three-point-gait-pattern. A weighing machine was used to train statically 200 N partial weight bearing of the involved limb before dynamic gait trials. As soon as the individual patient was able to walk about 50 m on flat ground the measurements were started, and on average on the third postoperative day.

To avoid variable pressure distribution by wearing different shoes on test days, patients wore an identical pair of shoes for all measurements. The insoles placed in the shoes were connected via a cable that was also attached to the patients' leg with a portable recording set. The data were collected on a flash card and could be read out to a computer for further analysis.

Data were recorded on three successive test days using the Pedar® mobile system. Each test day comprised measurements of three standardized cycles of partial weight-bearing gait (Table 3) after the subjects had performed a static test on the weighing machine. The range of motion of adjacent joints was recorded and the patients completed a visual analogue pain score from 0 (no pain) to 10 (worst pain). On the first test day the patient's physical activity was categorised using the Barthel Index [18]. The patients walked for about 3 min at their comfortable speed on even ground. During 3 min of walking 15 steps were recorded. This trial was repeated two times. As such, three cycles with 15 steps were available for analysis (Table 3).

Between the individual test records the subjects were not informed of the results to avoid any external influence of the examiner or the physical therapist. For comparison, 11 healthy volunteers underwent the same protocol.

3. Results

3.1. Maximum force differences

Neither healthy volunteers nor patients were able to perform the prescribed partial weight bearing of 200 N during the dynamic measurement on all three test days. The statically pre-tested 200 N of partial weight bearing were substantially exceeded during dynamic measurements on three test days and in all three investigated groups (Fig. 2). Maximum total ground contact forces were up to 690.9 N in the younger group, 580.1 N in the elderly group and 570 N

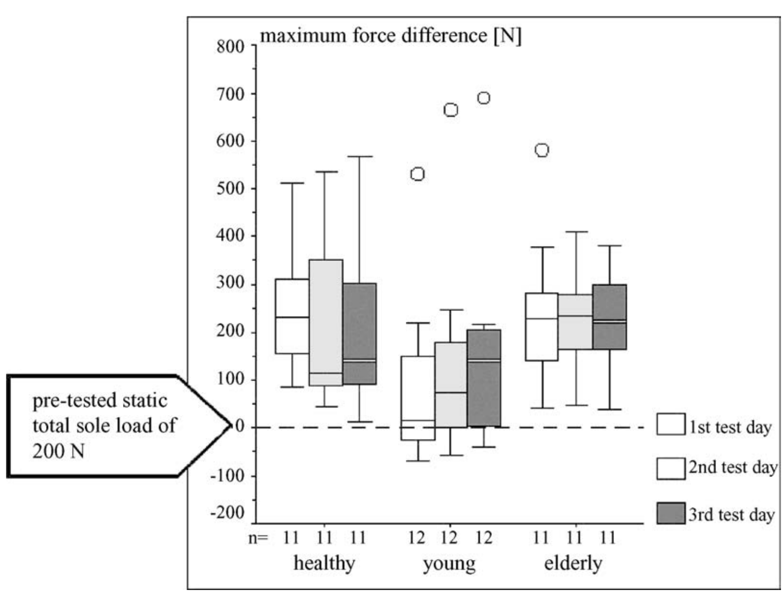

Fig. 2. The overload of the pre-tested static total insole load of 200 N for healthy volunteers, young and elderly patients on three successive test days. Two young patients kept within the given load level of 200 N only (see Table 5).

in the control group. One young patient reached maximum total ground contact forces of 530–690 N at his partial weight-bearing limb on each test day. Neither healthy volunteers (minimum force difference = 13.8 N on the third test day) nor elderly patients (minimum force difference = 38.5 N (119%) on the third test day) were able to keep within the given load level of 200 N (Fig. 2). In the whole group including the healthy volunteers the mean values of the maximum force differences counted approximately 200 N which meant an excess of 100% over all three measured gait cycles on three successive days (Table 4).

As shown in Fig. 2 the mean values of the maximum force differences did not change in the elderly patient group from test day 1 to test day 3 (234.6, 233.1, 218.8 N) significantly. The younger patients walked with much lower load on their operated limb (Figs. 3 and 4) but, with a noticeable increase of the mean maximum force differences: 80.4 N (1st test day 1), 125.7 N (2nd test day) and 147.5 N (3rd test day). The healthy volunteers had mean maximum force differences comparable to elderly patients (1st test day = 254.6 N, 2nd test day = 220.9 N, 3rd test day = 221.5 N) with a slight non-significant decrease from the 1st test day to the 2nd test day. The overload of the pre-tested static total sole load of 200 N is demonstrated in Fig. 2.

There were no significant differences in maximum force between the control and elderly groups nor was there a discernable learning effect from the first to the third test day in any group.

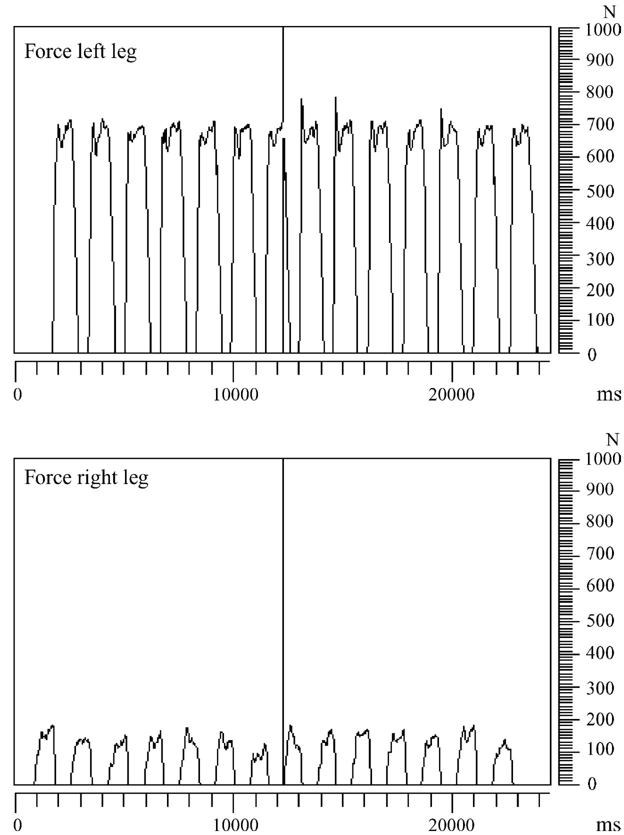

Fig. 3. Loading curves of the intact leg (above) and the injured leg (below) of a young male patient on his 5th postoperative day after surgical treatment of a fracture of the right tibia. The average of dynamic load of his right insole counted 200 N.

3.2. Force time integrals

Both in the control and in the elderly patient group the mean force time integral values (Table 5) showed a decrease from test day 1 to test day 3. There was no significant increase of the mean impulse rates in the younger patients group. The range of force time integral values varied highly in the elderly patient group and in the other groups.

The force time integral values for all three groups are shown in Table 5. Healthy volunteers presented significantly

Table 4
Maximum force differences from the pre-set load level of 200 N in healthy volunteers, young and elderly patients

Δmf [N] and test day	Healthy volunteers	Young patients	Elderly patients	Whole group
Δmf 1				
Mean	254.6	80.4*	234.6+	186.6
S.D.	140.0	168.8	154.1	170.4
Max.	511.7	530.0	580.1	580.1
Min.	84.2	−68.6	39.8	−68.6
Δmf 2				
Mean	220.9	125.7	233.1×	191.2
S.D.	178.8	193.3	107.4	167.5
Max.	533.2	664.4	409.7	664.4
Min.	44.0	−54.7	47.3	−54.7
Δmf 3				
Mean	221.5	147.5	218.8	194.5
S.D.	190.3	199.1	105.5	169.7
Max.	570.0	690.9	380.6	690.9
Min.	13.8	−42.0	38.5	−42.0

Δmf, maximum force difference, S.D., standard deviation, max., absolute maximum, min., absolute minimum.
* $p = 0.006$ vs. healthy volunteers.
+ $p = 0.007$ vs. young patients.
× $p = 0.013$ young patients.

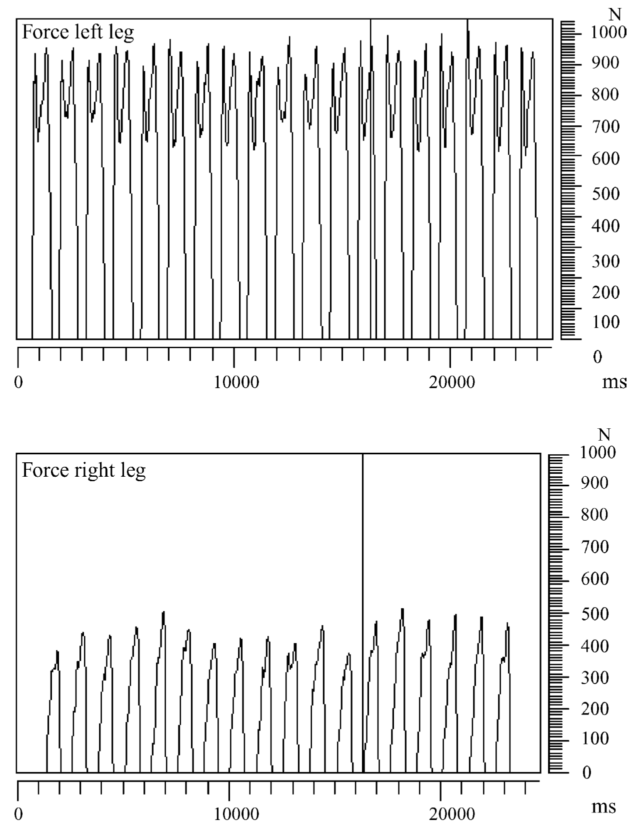

Fig. 4. The impulse rates (force time integral values) as a function of the time-depending ground reaction for healthy volunteers, young and elderly patients on three successive test days. Elderly patients had tendentially higher impulse rates than younger patients and healthy volunteers (see Table 6).

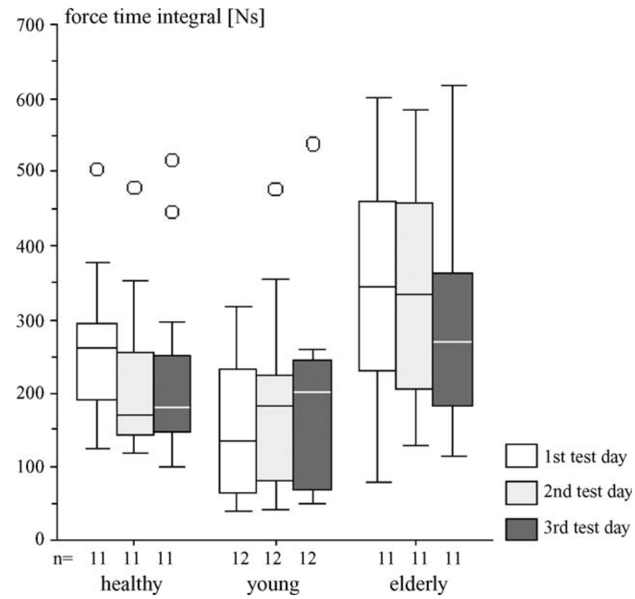

Fig. 5. Loading curves of the intact leg (above) and the injured leg (below) of an elderly female patient on her 6th postoperative day after surgical treatment of a fracture of the right ankle. The average of dynamic load of her right sole counted 450 N corresponding to 80% of her body weight.

higher force time integrals than young patients at their injured leg on the 1st test day ($p = 0.016$). Elderly patients showed significantly higher impulse rates than the young patients on test days 1 and 2 (1st test day: $p = 0.006$ and 2nd test day: $p = 0.037$). Force time integrals of the elderly patients were higher during all three test days than those of the two other groups (Fig. 5).

3.3. Pain score and Barthel Index

There was a decrease of the pain score level from test days 1–3 in both patient groups (Table 6). The median pain score of the young patients on the 1st test day was 3 and decreased to 2 on the 3rd test day while elderly patients had an initial median pain score of 4 which decreased to

Table 5
Force time integral values in healthy volunteers, young and elderly patients

Fti [N s] and test day	Healthy volunteers	Young patients	Elderly patients	Whole group
Fti 1				
Mean	268.8	154.5[*]	346.1[+]	253.5
S.D.	105.6	92.4	177.0	149.1
Max.	503.8	316.8	602.4	602.4
Min.	124.8	39.5	79.0	39.5
Fti 2				
Mean	220.3	188.5	330.9[×]	244.9
S.D.	112.7	126.9	154.1	142.3
Max.	479.7	476.5	583.2	582.2
Min.	117.6	41.6	128.5	41.6
Fti 3				
Mean	231.1	192.0	295.1	238.0
S.D.	135.4	135.9	149.9	142.8
Max.	517.2	537.7	616.2	616.2
Min.	100.1	50.6	114.1	50.6

Fti, force time integral, S.D., standard deviation, max., absolute maximum, min., absolute minimum.
[*] $p = 0.016$ vs. healthy volunteers.
[+] $p = 0.006$ vs. young patients.
[×] $p = 0.037$ young patients.

Table 6
Scores of pain from VAS of test days 1–3 and Barthel Index of both patient's groups

	1st test day	2nd test day	3rd test day	Barthel Index
Young patients	3 (range 0–5)	3 (range 0–5)	2 (range 0–4)	90 (range 80–95)
Elderly patients	4 (range 0–5.5)	2 (range 0–9.5)	1.5 (range 0–6.5)	70 (range 55–95)

VAS, visual analogue scale, median values, range in brackets.

1.5 on the 3rd test day. The median Barthel Index was lower in the elderly patient group compared with the younger group.

4. Discussion

4.1. Partial weight-bearing controversy

Partial weight bearing is an integral component of postoperative rehabilitation after fracture treatment of the lower extremity. Few studies have demonstrated the limitations of the concept of partial weight bearing [19,20]. The methods applied varied from biomechanical testing to force platform data and animal experiments [12,16,19,21]. However, given loads of partial weight bearing have never been tested during dynamic gait phases. Mittlmeier et al. [22] have noted that gait analysis is superior to radiographic analysis in assessing functional outcome after surgical reconstruction.

4.2. Study limitations

This study was designed to assess the concept of partial weight bearing in an early phase after surgery using an in-shoe gait analysing system. A high degree of accuracy, reliability and repeatability of the in-shoe system used has been confirmed previously [19,23–25]. The main advantages of the insole system are its practicability and portability and it does not require a specialised area for its use. The patients were trained as early as possible after surgery to use two forearm crutches for partial weight bearing of the operated limb. Patients were told to walk at their comfortable speed as it has been shown that increasing speed would steadily increase the ground reaction forces and other variables [25,26] and Kernozek et al. [25] have shown that a minimum of eight steps are needed to achieve excellent reliability.

None of the participants of the present study was able to perform the prescribed partial weight of 200 N immediately postoperatively. The patients who were 60 years old or more had more difficulties with the task than younger participants. This was reflected in the reduced scores of the Barthel Index in older patients. Reduced mental awareness, will and muscle power as well as reduced peripheral sensory feedback [27] could explain this difference between the older and younger participants. Partial weight bearing is a non-symmetric gait and appears to be a complex task in the postoperative period. The visual analogue scale of pain slightly decreased in young patients suggesting that increasing levels of load bearing might be a function of postoperative pain. But, in the older patients, substantial decreases of the pain level did not reflect a variance in the magnitude of load bearing during the three successive test days. Thus the pain score pain does not necessarily indicate partial weight bearing in older patients.

4.3. Dynamic loads and its practicability

During first test day measurements statistically significant differences were found between healthy volunteers and young patients concerning maximum force differences and force time integrals. But, respectively in single gait cycles, two young patients reached total sole forces of 891 and 864 N. In these two cases the maximum load meant full load bearing on the operated limb. In general, 200 N means approximately 20–30% of body weight. But, as Li et al. [28] have noted it appears more difficult for volunteers to support one leg with 10% (and 90%) than with 50% of their corresponding body weight [29]. This was also reflected by the measurements of healthy volunteers in the present series which tended to exceed the prescribed load level of 200 N.

The investigation interval in the present study included three successive days after surgery and the results did not differ essentially from those found by Tveit and Karrholm [19]. The latter investigated the concept of partial weight bearing in long-term follow-up of 15 patients after total hip replacement. None of these patients managed to load the operated limb with 30% of body weight. They stated that to monitor the partial weight bearing phase it would be necessary to develop an "easy-to-use portable system" to control the load level. This appears questionable from the standpoint of effectiveness and comfort and does not address the importance of postoperative partial weight bearing.

The functional and biological importance of strict partial weight bearing is controversial. Firstly, it is thought to protect and relatively unload healing bone thus supporting the stability of the reconstruction and the surgical result in the early postoperative phase. Six patients with tibial osteotomies stabilized with external ring fixators could not reliably reduce loading of the healing zone during partial weight bearing in three dimensional interfragmentary movement measurements with reflective markers [21]. The authors concluded that partial weight bearing was only helpful to prevent patients from extreme loading such as a stumbling which might cause a major increase in ground contact forces. Harager et al. consequently recommended immediate full weight bearing after fixation of ankle fractures [20].

4.4. Clinical relevance

A more individualized rehabilitation with pain-adapted partial weight bearing or early full weight bearing might lead to more rapid rehabilitation and avoid endangering the surgical result. Instead of using a defined load for partial weight patients might benefit from becoming more aware of the possibility of affecting the surgical result by an unexpected fall and this could be evaluated in future studies.

5. Conclusion

Early joint mobilisation and partial weight bearing represent accepted principles of postoperative treatment and previous studies have shown a clear advantage of immediate partial weight bearing versus immobilisation after surgery. The present study has shown that the conventional concept of partial weight bearing during routine rehabilitation and strictly supporting the operated limb with a 200 N load was not feasible or predictable with regard to measured load levels. The clinical consequence is that a more individualised postoperative loading regime controlled by dynamic measurements such as plantar pressure measurements for only those patients with critical stability of their osteosynthesis might be appropriate. This novel concept may help to avoid the long-lasting loss of muscle mass observed during strict partial weight bearing and an accelerated return to normal gait.

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