We assessed the unloading effect of the patellar tendon-bearing (PTB) cast in five healthy volunteers using a new system for analysis of dynamic plantar pressure. We devised a method to improve the unloading effect of the PTB cast, and tested this using the same system.

Our findings showed that the conventional PTB cast only achieved unloading of 30% of the body-weight and that the part of the cast on the leg had a more important role in the unloading than that which was in contact with the patellar tendon. When the depth of the free space under the foot inside the PTB cast was 1, 2 and 3 cm, the unloading effect was 60%, 80% and 98%, respectively.

The unloading effect of the conventional PTB cast was disappointing at only 30% of body-weight. It was improved by producing a space between the sole of the foot and the cast, and was adjustable by altering the depth of this space.

The F-SCAN system (Tekscan Inc, South Boston, Massachusetts) is a pressure-sensitive insole with 960 individual points on its surface. Since it is thin (0.18 mm) and flexible, it can fit any size or shape of foot. The software is designed to display, compare, store and print data collected from the sensor. The peak pressure/centre-of-force display is used to summarise the data from a single gait cycle and record the peak pressure at each individual sensing cell over the time period of the stride.

The unloading effect was assessed by measuring the weight borne by the whole surface of the sole when wearing the PTB cast using the F-SCAN system. The cast was applied unilaterally. An extension shoe was worn on the contralateral foot to compensate for the discrepancy in leg-length due to the heel on the cast.

A sensor sheet was placed over the sole inside the PTB cast to determine the changes in the plantar pressure during weight-bearing and to compare them with the corresponding region of the contralateral free foot. The sensor sheets were set on each foot with no variation in sensitivity between the right and left feet. Both sheets were exchanged after each experiment to avoid any possible decrease in sensitivity with multiple use. Before measurements were taken the right and left sheets were calibrated under identical conditions, and placed in contact with the whole sole.

In each experiment, ten sets of measurements were taken, with all subjects wearing a similar cast and walking on a flat surface indoors. Recordings were made of five cycles of steady gait, excluding the first step and the one before stopping. Thus data were obtained for 50 gait cycles per experiment.

The unloading effect of the cast was measured by calculating the peak pressure (the maximum loading in kg) of the side without the cast. The load removed was calculated as the peak pressure on the side with the cast minus the peak pressure on the side without the cast, and then this load was divided by the peak pressure on the side without the cast to obtain the unloading rate (Fig. 1). Mean values and

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**Patients and Methods**

The patellar tendon-bearing (PTB) cast described by Sarmento has been widely used for the treatment of below-knee fractures. There have, however, been few reports of its unloading effect. We have used a new dynamic plantar monitoring system (F-SCAN) to evaluate this and have developed a new method for improving the degree of unloading. We have investigated the unloading effect of the PTB cast, the contribution of each part of the cast to the overall effect, and the relationship between the depth of the free space under the plantar region inside the PTB cast and unloading.
standard deviations were computed, and mean values compared using the Wilcoxon rank-sum test.

The subjects were five healthy men with a mean age of 37 years (33 to 47), a mean weight of 72.8 kg (65 to 80) and mean height of 173.2 cm (168 to 180). PTB casts were prepared using Scotch cast material (3M Company, St Paul, Minnesota) and each was fitted with a 3.5 cm heel. All the casts were applied by the same orthopaedic surgeon who was well versed in the technique.

Experiment 1. We determined the unloading effect for a conventional PTB cast with the walking heel placed on the sole at the level of the navicular bone.

Experiment 2. A soft sponge pad 1 cm thick was placed under the foot within the conventional PTB cast and the unloading effect was measured (Fig. 2a).

Experiment 3. The contribution of each part of the PTB cast to the overall unloading effect was assessed by means of stepwise removal of the same cast. The effect was measured after removal of the part for patellar tendon support, then removal of the part for anterior condylar support, and finally removal of the proximal two-thirds of the cast. In this experiment we used a free-sole PTB cast with a soft sponge insole 1 cm thick as in experiment 2.

Experiment 4. We measured the unloading effect of the PTB cast with a space under the foot within the cast, and noted the changes (Figs 2b and 2c). The space under the sole of the foot was produced using a bellows bag made of rubber with thin metal plates on the upper and lower surfaces to maintain its form. The thickness of the bag was altered by inflation and deflation through a valve at the front. Before casting, the sensor sheet was placed on the bag, which was inflated to the maximum and placed under the foot of each subject. After the cast had hardened, the amount of air was adjusted using the valve to alter the

Fig. 1

The unloading effect of the PT cast. A is the peak pressure (maximum loading in kg) on the side without the cast. B is the peak pressure with the cast. C is the unloading rate (C = A-B). The unloading ratio is C/A.

Fig. 2a – Diagram of the position of the sensor sheet. It was placed on the sole of the foot and a sponge pad 1 cm thick was then set on the other side, distally beyond the sensor sheet. Figures 2b and 2c – Diagram to show the mechanism of the bellows bag. Using the air valve, the bellows bag is allowed to expand (b) and to contract (c).
thickness of the bag. Measurements were made with the space between the sole of the foot and the sensor sheet set at 0, 1, 2 and 3 cm.

Results

Experiment 1. The mean unloading rate of the conventional PTB cast with the heel set under the navicular bone was only 30% (23.1 to 38.9).

Experiment 2. The height of the soft sponge pad was reduced by loading on the foot which slid down in the cast. The mean unloading rate of the free-sole PTB cast with a soft sponge pad was improved to 56% (36.0 to 69.9).

Experiment 3. When the patellar tendon support was removed, the unloading rate decreased to 46% (32.1 to 65.6). It was reduced to 36% (24.4 to 53.0) by removal of the part supporting the anterior condyle and further decreased to 11% (4.8 to 16.4) by removal of the proximal two-thirds of the cast (Fig. 3).

The contribution of each part of the free-sole PTB cast to overall reduction of weight was determined to be 18% for the patellar tendon support, 17% for the anterior condylar support, 46% for the proximal two-thirds excluding the patellar tendon and condylar supports, and 19% for the distal one-third including the ankle (Fig. 4).

Experiment 4. When the bag was inflated maximally so that there was no space under the foot, the PTB cast showed a mean unloading rate of 30% (25.6 to 37.3). This was similar to that of a conventional PTB cast and showed that the bag did not affect the loading rate. When the bag was partly deflated to produce a space of 1 cm under the sole (i.e., 1 cm between the top of the bellows bag and the bottom of the sole of the foot) within the cast, the mean unloading rate increased to 60% (40.5 to 69.0). With spaces of 2 cm and 3 cm, when the bag was fully deflated, the unloading rate was 80% (72.4 to 85.2) and 98% (96.1 to 100), respectively. There was a significant correlation between the depth of the clear space and the unloading rate (Fig. 5).

Discussion

After the original report of Sarmiento,1 the unloading effect of the PTB cast was measured by a number of investigators.7-9 Using hydraulic measurement Sakurai et al7 found that a load of 40 kg led to a pressure of 9 kg (22.5%) on the patellar tendon. Svend-Hansen et al8 measured the unloading effect using a pressure transducer on the sole of the foot and found no difference in the unloading rate between a below-knee cast, a PTB cast and an above-knee cast. Other authors also found that the unloading effect of the PTB cast was disappointing.7-9 The pressure transducers which they used only detected changes at the sites of placement and the number of measuring sites was limited. This presented a problem when attempting to assess the load borne by the entire plantar region.
Our study, using the F-SCAN, has shown that the weight-bearing of the whole plantar region is 70% in the conventional PTB cast, and that the unloading rate is only 30%. This was attributed to the sole of the foot coming into contact with the bottom of the cast because the leg slid downwards on loading. We considered that when a PTB cast has a space between the sole of the foot and the bottom of the cast to prevent plantar pressure from below, an improvement of the unloading effect might be expected. Accordingly, we have investigated the unloading effect of the PTB cast with a soft sponge pad 1 cm thick between the foot and the bottom of the cast. The role of the sponge pad was not only to cushion, but also to produce the space between the foot and the cast. The results showed that the sponge pad was markedly compressed because the leg slid downwards. The unloading effect, however, improved to 56% compared with the 30% of the conventional PTB cast. Experiment 3 (Figs 3 and 4) showed that the cast enclosing the calf was more involved in unloading than the part supporting the patellar tendon. Sarmiento et al\textsuperscript{13} considered that this effect of the part of the cast for the leg was due, not only to a simple unloading, but also to the dynamic effect of the hydraulic container theory, and emphasised the importance of fitting the cast closely to the shape of the leg. The leg slides downwards on loading in the conventional PTB cast with a soft sponge insole until the sole of the foot comes into contact with the bottom of the cast. This results in suspension of the leg by the inner region of the cast.

According to Sarmiento’s theory,\textsuperscript{1} the effect of suspension by the cast increases the unloading effect. We therefore studied the correlation between the unloading effect and change in the depth of the space under the foot. It was impossible to produce an accurate height and to change the height of the space with a soft sponge pad in the cast. The space was produced using a bellows bag the thickness of which could be easily altered by inflation. The unloading effect was significantly improved according to the depth of the space under the foot, and with a space of 3 cm was approximately 100%. These results indicated that the leg was completely suspended by the inner region of the cast (Fig. 6).

During treatment of a fracture of the leg, excessive weight-bearing can cause shortening or displacement at the site of the fracture while prolonged non-weight-bearing can cause bone atrophy. Adequately controlled loading promotes bone union. The application of a cast with unloading
and adjustable weight-bearing is therefore of value for the
treatment of a below-knee fracture.

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