Is early weight bearing resumption beneficial after total hip replacement?

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KEYWORDS
Rehabilitation; Postural balance; Total hip replacement; Weight-bearing

Summary
Objective. — Current rehabilitation protocols of patients following total hip replacement recommend weight bearing on the operated extremity as early as possible. This strategy is likely to induce specific consequences on postural balance control; this study seeks to highlight these reactions to early loading.

Materials and methods. — Eight men and six women, ranging in age from 57 to 85 years, volunteered enrolling this study on their arrival at our rehabilitation center. This study assessed their postural behavior using a system composed of two separate force platforms under two loading situations; in the course of these tests they were required to minimize their body sway as much as possible by keeping their eyes open. In the natural uncontrolled situation, the subjects adopted a comfortable body weight distribution. In the imposed (IMP) situation, they had to load their operated extremity more than in regular natural conditions in order to distribute their body weight more evenly. Three successive 32-s trials (sampled at 64Hz) with intermediate recovery periods of equivalent duration were performed allowing period of rest between each trial. The balance strategies were evaluated through a frequency analysis of the resultant and plantar centers of pressure (CPRes) of each foot and of the estimated trajectories of the vertical projection of the center of gravity (CG), and from the difference CPRes−CG.

Results. — No difference was found for the plantar CP trajectories in the situation where body weight is spontaneously distributed, whereas loading the implanted extremity induced increased CPRes, CG, and CPRes−CG trajectory amplitudes along the mediolateral axis. No effect was observed along the anteroposterior axis. Finally, when comparing the two limbs for each testing condition, the statistical analysis demonstrated greater displacements along the ML axis for the trajectories measured under the healthy leg than under the implanted extremity.
Discussion. — Loading the operated extremity early in the rehabilitation process leads to less stability (an increase in the CG movements) and to increased energy expenditure (an increase in the CPRes—CG movements). These postural behavior alterations can be explained by various factors including a loss of muscle strength, residual apprehension due to the disuse of this limb, and persistent pain, all of which are increased by limb loading. These features should be taken into consideration when elaborating the rehabilitation protocol for these patients.

Level of evidence: Level III. Decision analyses study.

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Introduction

Every year, more than 100,000 people in France (generally older than 50 years) undergo a total hip arthroplasty. Replacing the damaged joint with an artificial joint eliminates pain and recuperates good joint function, flexibility, and stability. A more negative point is that following this type of operation, patients encounter a substantial sensorimotor deficit on the side of the operated lower limb. In the rehabilitation that follows surgery, a current practice is to solicit the opposite side as early as possible. As shown by Rao et al. [1] and Boden and Adolphson [2], loading the leg with the prosthesis makes it possible to accelerate the rehabilitation of muscle and joint functions and to limit demineralization resulting from immobilizing the segment. The objective of rehabilitation, now widely followed, is to make patients aware of their abilities at this level. Nevertheless, the question is raised of whether it is relevant in terms of the effects it has on motor coordination. For this reason, an objective measurement of performance in a standardized task should provide an evaluation of these effects.

It is within this context that this study was undertaken to quantify the effects induced by loading the leg with the prosthesis. The task retained was a balance task consisting of standing upright as still as possible. Other than the high reproducibility of this measurement, this balance task is the very example of a complex sensorimotor system that involves the peripheral sensory organs (providing proprioceptive, vestibular, and visual information) of the integration structures, the motor pathways, and the feedback structures. Carrying out the task successfully depends on the physical need to continue projecting the center of gravity (CG) to the ground inside the base. The struggle against gravity and the body’s substantial inertia in this upright position most often lead to nonalignment of the vertical projection of the CG (CGv) and of the resultant center of pressure (CPRes) position, which corresponds to the crude product of the neuromuscular system. In this organization that Silferi et al. [3] described step by step, the CPRes movements make it possible to check the CG movements. In other words, a CPRes displacement can be observed by either playing on one or the other or on both limbs. Recently [5], the extent to which these plantar and resultant trajectories correlate was detailed. Although there is indeed a correlation along the AP axis, the correlation is considerably reduced along the ML axis. The AP displacements of the CPRes therefore depend essentially on the variations in the pressures exercised under each limb, whereas the displacements measured from left to right (ML) first depend on the loading—unloading actions. This also confirms Winter’s conclusions [6] on the involvement of the calf muscles (triceps surae) in AP regulation and of the abductor—adductor pair in ML regulation of the body’s movements.

The benefits that could result from greater loading of the operated leg should be discussed in terms of certain biomechanical properties. On the one hand, such great postural asymmetry is a potential source of deficit in balance control because of a tendency for plantar CP displacements to increase under the two limbs [7]. It can therefore be hypothesized that decreasing this asymmetry of distribution can at least partially erase the deficit that is classically reported [8]. On the other hand, the sensorimotor deficit related to implanting a prosthesis greatly alters the control of the operated limb. As shown by the calculation formula (cf. Analysis methods chapter), since the percentage of the body weight applied to one limb amplifies the effects of the plantar movements on CPRes displacements, it does not seem appropriate to overload a limb that is insufficiently controlled.

Based on measurements taken in patients who had recently undergone total hip replacement surgery, our objective was to study their balancing strategies and thereby the effects of early loading on the operated limb. This study is also original in that it measured the two limbs separately using a system made up of two force platforms. This study is part of a series of studies published recently by Belaid et al. [9] and Rougier et al. [10].

Material and methods

Subjects

This study conducted in a physical medicine and rehabilitation center investigated 14 consenting subjects (eight men and six women; 57—85 years old; weight: 71.3 ± 13.1 kg [mean ± standard deviation]; height: 1.66 ± 0.07 m) who had had a total hip replacement. All of them originally suffered from coxarthrosis (joint wear or deformation caused

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Table 1  Clinical assessment of patients’ postural abilities.

<table>
<thead>
<tr>
<th>Muscle strength&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Gluteus medius</th>
<th>Gluteus maximus</th>
<th>Hamstrings</th>
<th>Quadriceps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adductors, abductors</td>
<td>3.14 (0.53)</td>
<td>3.07 (0.27)</td>
<td>3.64 (0.50)</td>
<td>3.86 (0.53)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Range of movement&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Flexion/extension</th>
<th>Adduction/abduction</th>
<th>Internal/external rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>81.07 (12.12)</td>
<td>33.93 (7.38)</td>
<td>22.86 (6.42)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Proprioception&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Pain&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Functional independence&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tactile sense 1.93 (0.27)</td>
<td>Kinesthesia 1.93 (0.27)</td>
<td>Pallesthesia 1.71 (0.61)</td>
</tr>
<tr>
<td></td>
<td>Level of intensity 4.07 (1.33)</td>
<td>Level of independence 95.50 (5.37)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Mean (standard deviation).

Manual measurement of muscle strength on a scale from 0 (no strength) to 5 (normal strength).

Measurement of joint range of motion using a goniometer.

Evaluation of sensitivity (tactile sense, kinesthesia, pallesthesia) on a scale from 0 (no sensitivity) to 2 (normal level of sensitivity).

Evaluation of pain level on a visual analogic scale from 0 (no pain) to 10 (unbearable pain).

Evaluation of functional autonomy (MIF) using different daily tasks on a scale from 0 (dependence) and 126 (independence).

by osteoarthritis). From a surgical point of view, 11 had been operated on using a posterior exterior approach and three via the anterior approach.

These patients’ functional abilities were evaluated using clinical tests (Table 1). The tactile sense was assessed based on the patients’ ability to discriminate prick and touch in the toes, kinesthesia was assessed by the patient’s sensitivity to discriminate the high and low positions of the toes, and pallesthesia by the patient’s sensitivity to vibration explored using a tuning fork applied to the malleoli. The exclusion criteria were the following: age over 85 years, inability to maintain upright standing for at least 1 min, presence of a neurological or orthopedic pathology that could disturb balance, orthopedic or traumatic sequelae in the lower limbs, a replacement in the contralateral hip and/or an ipsilateral or contralateral knee, joint or muscle deficit that precluded standing, and incomprehension of the instructions given.

Experimental equipment

The experimental dual force platform used (PF02 Equi+, Aix-les-Bains, France) allowed us to record the center of pressure displacements separately under each limb while the patient maintained the standing position, and then, with a calculation provided by the software, to determine the positions of the point where the resultant reaction (CP<sub>Res</sub>) was applied. Both rectangular force platforms (35 x 20 cm) were positioned side by side. They were made of wood slabs sufficiently thick to be considered nondeformable. Each platform was mounted on four vertical dynamometric uniaxial sensors (measurement range, 0–150 daN). The analog signals from these cells were then amplified, converted from analog to digital form using a 14-bit acquisition card, and then recorded with a 64-Hz frequency. The instrument error, evaluated by placing an inert object matching the mean patient weight, was less than 0.7 mm for plantar and resultant CP displacements.

Experimental procedure

The 14 patients took the posturographic tests as soon as they were admitted to the rehabilitation center (12 ± 3 days after surgery). The tests were conducted in a quiet place so that the patients’ attention would not be disturbed. They were instructed to remain as stable as possible in a standardized upright position: barefoot, heels 9 cm apart, 30° angle between the feet, arms hanging along the body, and eyes open (with a vertical line drawn on the opposite wall).

Two conditions were randomly proposed: spontaneous (SPO) (no instructions as to how to distribute the body weight) and imposed (IMP) (instructions to load the body weight on the operated limb). Whereas in the first condition (SPO), patients generally distributed their weight asymmetricaly, for the second condition, they approached symmetry in weight distribution. A recording session included three 32-s sessions with 15-s of rest between each trial. The rest period consisted in remaining upright on the double platform with the possibility of leaning on a walker placed in front of the patient. All of these instructions for the experimental procedure were given visually on the computer screen and orally through loudspeakers, using the Equi+Prog02 software (Aix-les-Bains, France).

Analysis methods

Center of pressure trajectories

First, the displacements of each of the centers of pressure of the right and left legs (CP<sub>R</sub> and CP<sub>L</sub>) were recorded along the ML and AP axes. These trajectories were then used to calculate the CP<sub>Res</sub> displacements using the following formula [6]:

\[
CP_{Res} = \frac{CP_R \times R_R}{(RR + RL)} + \frac{CP_L \times R_L}{(RR + RL)}
\]

where \( R_R \) and \( R_L \) represent the vertical forces applied under the right foot and the left foot, respectively.

When maintaining the upright position, the sum of the mean vertical forces corresponds to the individual’s weight. The variable \( R_R \text{ or } R_L / (R_R + R_L) \) corresponds to how much the right or left vertical force intervenes, approximately 0.5 in an orthostatic standing situation for a normal subject. Since all patients had not been operated on the same side, the plantar CP trajectories were characterized not as left and right load but as healthy leg \( (CP_{hl}) \) and implant leg \( (CP_{il}) \).

Estimation of the movements involved in the vertical projection of the center of gravity

As seen above, the plantar CP movements \( (CP_{hl} \text{ and } CP_{il}) \) determine the \( CP_{res} \) displacements and therefore the CG movements. These \( CP_{res} \) trajectories reflect both the vertical projection displacements of the CG \( (CG_s) \), controlled by the \( CP_{res} \) trajectories, and the horizontal accelerations that are communicated to CGv through the CP—CGv difference \( [11] \); these two components must be differentiated \( [12] \). Simply stated, the CG, movements can be deduced from the \( CP_{res} \) movements using a biomechanical relation \( [3,13,14] \). This relation, based on Newtonian mechanics and the exterior forces applied to the human body, expresses the relative amplitude of the CGv variations in position depending on the frequency of the \( CP_{res} \) displacements.

As reported by Silferi et al. \( [3] \), the principle multiplies the different amplitudes of the \( CP_{res} \) frequency spectrum, resulting from a Fourier transform, by the \( CGv/CP_{res} \) filter, thereby determining the frequency spectrum of CGv. If need be, an inverse Fourier transform can return to the temporal domain.

Parameters used

To represent the spatial characteristics of the \( CP_{res} \), CGv, \( CP_{hl} \), and \( CP_{il} \) displacements, several classical parameters were calculated: the mean positions along the ML and AP axes, the ellipsis surface calculated with a 90% confidence interval \( [15] \), and the mean velocity. Absolute values for the mean positions were used because the patients’ implants were not all on the same side.

These different movements were then described from a spatiotemporal point of view using frequency analysis, i.e., two parameters: the root mean square (RMS) and the mean power frequency (MPF). The RMS has the advantage of evaluating the mean amplitude independently of the frequencies. The MPF corresponds to the frequency spectrum’s center of gravity and provides information on any possible sliding, i.e., the most widely used displacement frequencies.

The values of the different parameters measured for each of the movements \( (CP_{hl}, CP_{il}, CP_{res}, CGv, CP—CGv) \) and for each of the conditions, SPO and IMP, were compared using a nonparametric statistical test for matched samples, the Wilcoxon rank test. The same procedure was followed to compare the values measured under the healthy limb \( (CP_{hl}) \) and the implant limb \( (CP_{il}) \). In both cases, the significancy threshold retained was \( p < 0.05 \).

Results

In the SPO condition, the results show an asymmetry in the distribution of body weight, with the operated leg less loaded \( (0.429 \pm 0.06) \) than the healthy leg \( (0.571 \pm 0.06) \). This asymmetry was greatly decreased in the IMP condition \( (healthy \text{ leg, } 0.487 \pm 0.019; \text{ operated \ leg, } 0.513 \pm 0.019) \), which showed a distribution that was close to symmetry. The statistical comparison of the distributions indicated a statistically significant difference \( (T = 5, p < 0.01) \).

The absolute values of the mean positions of the plantar CP trajectories \( (CP_{hl} \text{ and } CP_{il}) \) along the ML and AP axes were not significantly different between the two conditions, SPO and IMP. Conversely, a large effect was observed on the \( CP_{res} \) and CG trajectories, which in principle have the same mean positions. However, this effect was not found along the ML axis, where the mean absolute values of the

![Figure 1](image_url)  
**Figure 1** Spectra and diagrams representing, for both spontaneous (SPO) and imposed (IMP) conditions, the RMS and MPF values for plantar CP: CP_{hl} (healthy leg) and CP_{il} (implant leg), along the ML and AP axes.
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Figure 2 Spectra and diagrams representing, for both spontaneous (SPO) and imposed (IMP) conditions, the RMS and MPF values for the resultant trajectories (CP, CGv, CP–CGv), along the ML and AP axes. Indicates a significant difference.

positions was reduced in the IMP condition (7.20 mm ± 3.84) compared to the SPO condition (17.62 mm ± 10.35). This substantial decrease showed a statistically significant effect (T = 9, p < 0.01). To complete these results, we report the, as yet, unpublished results [16] recorded on healthy subjects of comparable age, who were requested to remain standing with no specific instructions given on how to distribute their body weight. They showed a mean distribution of 0.516–0.484 (±0.034) and a mean position of CPRes movements equaling 5±8 mm.

As shown in Fig. 1, which combines the frequency spectra of the CPn and CPil plantar movements, loading the operated limb did not result in any real effect on these movements. This was true for both the ML and AP axes, as for the two typical RMS and MPF parameters. On the other hand, appreciable differences were observed in the resultant trajectories of the CPres, the CGv, and the CP–CGv differences (Fig. 2) only on the ML axis. Statistically significant differences were found in the IMP condition of the CPres movements (T = 20, p < 0.05), CGv (T = 24, p < 0.05), and CP–CGv (T = 16, p < 0.01). These increases, found for all the frequency bands studied, did not result in any effect on the MPF. It should be noted that this sizable increase in amplitudes (RMS) and CP–CGv on the ML axis alone is sufficient to obtain statistically significant differences for the surface, which increased in the IMP condition (T = 25, p < 0.05).

Finally, we compared the parameters of the trajectories of the two plantars CP (CPn and CPil) for each of the two conditions, SPO and IMP. The statistical analysis brought out only a single significant effect on the RMSs along the ML axis, which, in the IMP condition, was greater for the healthy leg (0.25 mm ± 0.12) than for the operated leg (0.20 mm ± 0.09) (T = 22, p < 0.05). Consequently, this means that the mediolateral displacements of the plantar CP were greater in this condition than under the healthy leg.

Discussion

To avoid systematically relying on crutches, many physical therapists request their patients to acclimatize to bearing weight on their operated leg. The rehabilitation of these patients is now greatly simplified because it is mainly based on muscle toning and therefore on nearly immediate weightbearing of the operated leg. In this study, distribution asymmetry was typically attenuated in the IMP condition.

Overall, the results of this study show that patients with a hip implant maintain a specific behavior. When these patients are standing in the position they find most comfortable, they basically show an asymmetry in the distribution of their weight over the two limbs (to the detriment of the operated leg) but no real asymmetry in the actions of each limb. This asymmetry results naturally from greater weightbearing on the healthy limb. As was shown previously in the healthy subject [7], simply distributing body weight unequally over the two limbs leads to an increase in the CPres displacements and therefore the CG movements. Basically, it seems clear that the equilibration strategies adopted spontaneously by patients with a hip implant result from a compromise between using a limb that is deficient from a sensorimotor point of view (the operated leg) and a healthy one.
limb. These strategies restrain the role of the deficient limb because of residual pain and/or problems with daily living [17]. It could also be suggested that these strategies are adopted so as to limit postural deterioration. According to the formula used to calculate the $C_{\text{Res}}$, explained in Material and methods, we know that the $C_{\text{Res}}$ displacements depend on the $C_{\text{P}}$ and $C_{\text{P}}$ plantar displacements weighted by the load that is applied to each. Patients with hip pain (before or after implantation) instinctively load the healthy leg more than the pathological leg, which has become a deficient support. In this study, the $C_{\text{Res}}$ and CG displacements observed were greater in the IMP condition, which indicates a clear alteration of postural performance. This could also be considered to be related either to an adaptation begun well before surgery, which has allowed the patient to become accustomed to this asymmetrical weight distribution and therefore a relative optimization of the equilibration strategies. This may contribute to the patient’s ability to maintain balance during the IMP condition.

Requiring patients to attempt a balanced distribution of their weight on both limbs may be a means to provide better balancing, greater stability, and therefore a lower risk of falling. Yet the results of this study do not argue in favor of this conclusion. The RMS values along the ML axis show that the increased $C_{\text{Res}}$ amplitudes did not result in increasing the plantar displacements, but instead they showed a deficit in their ability to control the loading—unloading mechanisms on the two legs. It is known that the abductor and adductor muscles of the hips control the $C_{\text{Res}}$ displacements along the ML axis [6]. Therefore, patients’ instability may stem from the sensorimotor deficit of the hip joint. Moreover, it is very difficult to ask patients to load the operated side more because people who have just undergone this type of surgery greatly apprehend resuming weightbearing on the operated lower limb for fear of falling. In addition, residual pain can only reinforce this type of behavior. Immediately after the prosthesis has been implanted, patients do not have the necessary muscle strength to exaggerate the weightbearing on their operated leg because the neighboring joint muscles have been damaged.

It is also important to take into consideration the mean age of the patients studied here [18,19]. Aging is an inevitable and natural process accompanied by alterations in one’s ability to control posture and balance [20] and necessarily a reduction in the ability to contract the postural muscles, including those of the hip joint. It is therefore reasonable to think that these patients’ ability to bear weight on one leg is inevitably reduced. Although loading the implanted limb more could be a potential means for patients to establish better balance and therefore limit the risk of falling, this study clearly shows that this deficient limb should not be loaded for several reasons: muscle capacity that is not totally recovered (and we assume that this phenomenon is amplified in older patients), apprehension caused by the habit of not bearing weight on this limb, and residual pain amplified by overloading this limb.

This study may have presented other results for younger patients able to recuperate full use of the muscles around the hip joint in what can be assumed to be a shorter period of time. Similarly, if the experiment had been conducted at another stage during rehabilitation, and not immediately after the patients arrived in the rehabilitation center, the study may also have found differing results.

This study demonstrated that the current practices in rehabilitation subsequent to total hip arthroplasty was in need of a challenge and an adjustment according to the sensorimotor abilities of each patient. Rapidly using this joint may in the end cause loss of balance and even a fall. It could be hypothesized that movements increase to a greater extent along the ML axis, thus improving the dynamic conditions of gait initiation and consequently counteract a potential loss of balance. The reduced abilities of these patients associated with their aging presents limits the stability required to maintain balance in the upright stance. In optimal rehabilitation conditions, it seems vital to first aim for improving strength and flexibility in the deficient joint before attempting to apply a load, which may actually increase this deficiency.

The present study’s results and conclusions should be relativized, however. Generalizing to other standardized motor tasks such as locomotion remains to be demonstrated. Finally, here we deliberately attempted to favor balance control with visual information. The reproducibility of the results in nonvision conditions also remain to be demonstrated.

References

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