The Determinants of Posture in Paraplegics Standing using Lumbar Anterior Root Stimulation

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Abstract

We have measured the hip extension moment in a patient standing using anterior nerve root stimulation. We present a novel method for calculating the mass properties of the leg using a 3D laser scanner.

The joint moments when standing are not significantly different from those recorded in the recumbent posture. We asked the patient to alter the hip angle and present data that suggests that the poor standing posture of the patient may partly be due to a sharp increase in the flexion moment as the hip extends.

Only slight changes in both M-wave and non M-wave activity were seen in a number of muscles. As such we believe that the primary reason for the poor posture seen in this patient is biomechanical rather than neurophysiological in nature.

Keywords: LARSI, joint moments, laser scanning,

1.Introduction

One of the difficulties of using nerve root stimulation to restore leg function to paraplegics is the complexity of the responses to the stimuli, [3,7]. In the British project we have previously described a system for measuring 14 isometric leg joint moments whilst the patient is seated or recumbent, [2,10], the MMCS. Relating these measures to the standing posture is not easy.

The subject stands with excessive lordosis and carries a lot of weight through her hands. This occurs even when our best stimulation pattern is used. What can we do about this? Can we be confident that any future surgical procedure will improve the situation?

We hypothesised that there could be one or more causes for the poor posture; (1) the flexibility of the abdomen between the stimulated legs and the neurologically intact upper body, the subject is a T9 paraplegic; (2) that it is impossible for her to apply forces at the support handles so as to improve her posture; and (3) that there is non M-wave activity, both reflex and of other origin, within the paralysed muscles.

To investigate these possibilities, we calculated joint moments, measured joint angles and recorded EMGs, when standing and compared them to those obtained when recumbent.

2. Method.

2.1. The Subject.

Patient 1 in the British project has been described elsewhere, (see for example,[6]). She is a complete T9 paraplegic who had Lumbo-sacral Anterior Root Stimulator Implant, LARSI, implanted in December 1994. The roots L2-S2 bilaterally were placed in tripolar electrode books, [3]. Standing with the implant is not functional because of apparent excessive hip flexion and lordosis. However, passive standing using an Oswestry Standing Frame gives a good posture, indicating that there is no skeletal problem that prevents good standing. She has previously demonstrated the ability to take up to 24 steps in the laboratory (with assistance because of excessive adduction); also the ability to tricycle over 1km on road, [6]. We have previously demonstrated a significant innervation to the hip flexor muscles from roots used in the standing pattern in this patient using needle EMG, [7].

2.2. Calculation leg mass and centre of mass.

One of the besetting problems within biomechanics has been the accurate calculation of the mass and centre of mass of subjects' limbs. The traditional route to solve this problem has been the use of tabulated data from extensive surveys. Within each study there is good agreement upon the results, but there is poor agreement between studies, indicating that the selection of population is important. However, this method also has a problem when considering individuals. It assumes that people conform to the average population. When considering the disabled population this problem is accentuated. In fact studies have shown how poorly the disabled (SCI) population fit the existing tables, [8]. For the subgroup of patients who use FES, and are therefore unlike the "normal" disabled population in terms of leg mass and muscle bulk, an interesting question arises: will they be better served by a "disabled" model or a "normal" model? Since the differences in leg joint moments between the recumbent and standing positions are likely to be small, an accurate method of calculating the mass properties of the leg was needed. A previous study using two established methods has found estimates of the leg mass of this subject of 9.19kg and 11.75kg respectively, [9]. This size of error, (28%) is unacceptably large for this type of work.

If we could individually determine the mass of the leg and its centre of mass we would not have to rely upon sampled population data. To do this a fast, (at least for the patient), non-invasive technique is needed. The method we have chosen utilises a 3D near infra-red whole-body laser scanner[1] [4].

The use of such a technique is not entirely new, (cf Jones & Rioux [5]). However its use to calculate the mass properties, mass and centre of mass, of the leg is novel. To achieve steady standing subjects stand in a specially constructed mobile Oswestry Standing Frame, OSF. They therefore stand passively, not using FES.

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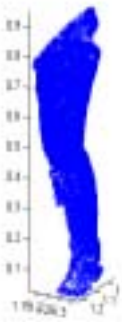

Figure 1. The reconstructed, sliced leg from the laser scanner data set.

[1] Hamastua's Body Lines Scanner. Japan,

Several scans are taken and the data set is output as a text file. The images are visually inspected and rotated to ensure completeness and absence of movement artefact. Each scan takes just 10 seconds, short enough to allow a paraplegic to stand steadily in an OSF for several scans at a time.

The mass properties are calculated by numerical integration and using published densities for soft tissue and for bone. The size of the bones is estimated from the female data in the Visible Human Project[2]. This is digitally re-scaled to fit the x-ray image and scan size of the patient.

2.3 Standing experiments.

The subject had surface EMG electrodes applied to muscles on the right side: Paraspinals, Glutei, Rectus Femoris, Hamstrings, Gastrocnemius and Adductors. Muscle activity during stimulation with the standing pattern, whilst the subject is extended on a physiotherapy plinth, was recorded. EMG is also recorded whilst the subject stood without stimulation in an OSF.

Figure 2. A photo of subject 1 standing during the experiment. The LEDs and EMG electrodes can be clearly seen. This figure is represented in figure 3. Note the deflections on the handles indicating the amount of force being carried by the arms.

[2]URL:http://www.dhpc.adelaide.edu.au/projects/vishuman2/index.html

A position-measuring system, Selspot, is used to record the patient's posture in 3D space. Infra-red LEDs were placed over the leg joints and the spine of the subject. The positions marked were; T2, (a) and L2, (b) vertebrae, the front, (d) and back, (c) of iliac crests, the greater trochanter, (e), knee, (f), ankle, (g), (lateral malleoli) and the little toe, (h) on the right. All of the stands using FES were performed with the same stimulation pattern. This has been selected on the basis of the joint moments recorded in the MMCS. The primary consideration is to obtain the maximum knee extension to hip flexion ratio, that is the maximal amount of knee extension with the least amount of hip flexion, and without unwanted responses, e.g. inversion, [7].

During these tests the patient stands with each leg on a force platform[3]. The patient uses handles for support, which contain six-axis load cells, as described by Donaldson and Yu [1].

2.4. Results analysis.

EMG records were sampled at 1kHz (passband 16Hz-300Hz). Forces and moments from the handles were also sampled at 1kHz. The force plate and position data was sampled at 50Hz. The two recording computers were synchronised to within 2ms over the test period. The force data was plotted using Matlab[4] and displayed as a "movie" to allow a visual inspection of the changes in the forces and the posture to be seen. Joint moments were calculated at typical periods for each stand. The handle reaction vectors, [1], and the ground reaction vector for the right leg were plotted on the same axes as the positions of the LEDs.

Visual analysis of the EMGs was carried out to prevent loss of non-time locked data through averaging.

3. Results.

3.1 Biomechanical results.

The validation of the laser scanning method for determining mass centres will not be presented here. The worst case error in calculating the hip joint extension moment using the laser scanner, force plate and Selspot system is less than 4Nm.

The patient carries a large proportion of her body weight through her arms. The right arm carries significantly more than the left, which corresponds to a clinical finding that the left leg is less flexed than the right. The right GRV only has just enough vertical force in it to correspond to the mass of the leg, suggesting that the rest of the ½ body weight is carried through her arms. This explains why the patient gets tired very quickly when standing

[3] Kistler force plates. Kistler Instrumente AG Winterthur CH.

[4] The Maths Works inc. supplied by Cambridge Control Ltd, Cambridge, UK.

When the joint moments are calculated, they are very similar to those seen in measurements taken in the MMCS. Three out of the previous 4 tests with this pattern have given a joint moment of between 10 and 15Nm of hip flexion. The exception came during a test in which it was noted that the subject was extremely fatigued.

The hip angle in figure 4 is the angle between the vectors **fe** and **ed** in figure 3. An angle of around 35° would be expected for full hip extension in a normal standing posture.

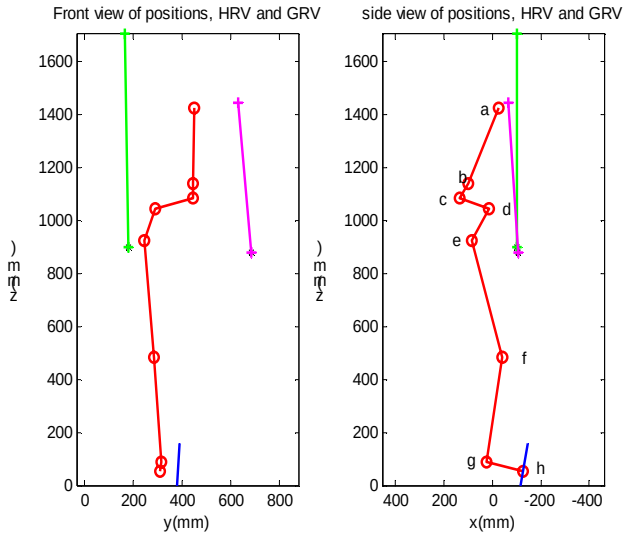

Figure 3. A plot of the posture of the patient (o-), and the ground reaction vector and the two handle reaction vectors. Note only one GRV is plotted. The scale for the GRV and the HRVs are 0.5N/mm.

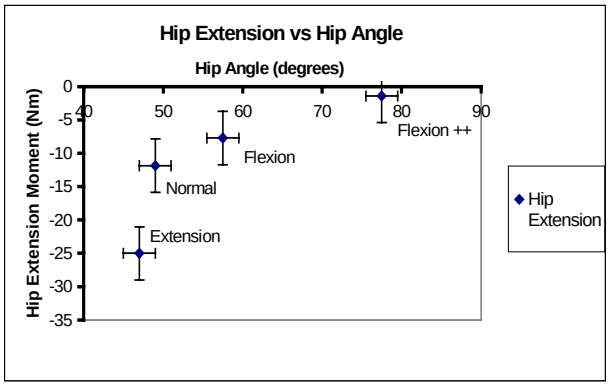

Figure 4. Plot of the Hip angle against the Hip Extension Moment. Note that all the moments are negative, meaning that the moment is flexing the hip. Error bars give the max and min measured result, with the mean as the point, samples of 3 for each angle, with a corresponding moment.

The hip flexion moment (figure 4) decreases as the amount of hip flexion increases. The gradient gives the change in moment per degree change in hip angle. To the right of the "normal" standing posture this is 0.36Nm/°. This compares with a value of 0.29Nm/° recorded in the MMCS. However when the patient tries to extend her hips beyond "normal" the amount of flexion moment increases dramatically, by about 10Nm. Such an increase would significantly hinder her ability reaching a better posture, but it should be noted that this is the result of only one experiment.

3.2. Electrophysiological results.

Some minor and some subtle differences were seen with the change from lying to standing. Minor differences may have been due to movements of the electrodes with respect to the underlying muscle or changes in the muscle lengths. Some subtle effects may have been due to posturally driven spinal reflexes. In particular an extra 10Hz reflex in the adductors appears to be dependent upon standing posture.

4. Conclusions.

At present the subject stands less well than she did at one time with the implant. We expect that this is due to a reduced time spent exercising. Nevertheless we wish to find the origin of the poor posture and to see if any medical or surgical intervention might effect an improvement.

Her short standing endurance and poor standing posture are accompanied by a significant right hip flexion moment. However, we have found that this moment is not greater than we measure in the MMCS while she is recumbent. Furthermore, we saw no significant non-M-wave EMG activity in Rectus Femoris or in Iliacus (at an earlier experiment, not reported here) which would have caused greater hip flexion moment. We therefore conclude that the third hypothesis, listed in the Introduction, is untenable: the cause of her poor posture is essentially biomechanical rather than physiological in nature. We will use this data to investigate the first two hypotheses.

The rapid increase in hip flexion moment, seen only in this experiment, is very significant, if true, and we hope to corroborate it. What muscle could be responsible for the rapid rise in moment with angle remains a matter of conjecture.

The method of laser-scanning, to find the leg mass properties of individuals is valuable and avoids a long-standing difficulty in experimental biomechanics. While the laser scanner equipment is at present quite expensive (circa £40,000), they are likely to become significantly cheaper as they are adopted by bespoke tailors.

Acknowledgements.

We would like to acknowledge the time and effort that our subject and her husband put into carrying out this experiment, and thank her husband for taking the photographs during the experiment. We would also like to thank Jon Marsden and Celia Coutinho of the HMBU for providing practical support during the experiment. J. Norton is supported by a Graduate School Research Scholarship from University College London. Some of the support came from the NHS Executive; the views expressed here are those of the authors and not necessarily those of the NHS Executive.

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