PREVENTING PRESSURE SORES IN QUADRIPLEGICS USING FES

Andrews,B.J., Keating*,J.F., Smith,A.C.B., Delargy,M.**

Bioengineering Unit, University of Strathclyde, Glasgow
* Department of Orthopaedics, Victoria Infirmary, Glasgow
** West of Scotland Spinal Injuries Unit, Glasgow, UK

INTRODUCTION

Pressure sores are a major source of morbidity in patients with spinal cord injury. In one Scottish survey the prevalence of pressure sores in paraplegics was 23% and in quadriplegics 21%. Data from the USA confirm the high incidence of pressure sores in this group of patients (12). Treatment of established pressure sores often necessitates hospital admission and is time-consuming and costly. Surgical intervention is frequently required but is associated with high recurrence rates (14).

It is hardly surprising therefore that prevention is considered to be of vital importance in the management of pressure sores. There have been two main approaches to prevention: the use of specially adapted seating surfaces and pressure relieving exercises performed by the patient. Although specially developed cushions undoubtedly contribute to pressure sore prevention they are not a complete answer - there is an unacceptable incidence of pressure sores even with the best available surfaces (5). There is some evidence to suggest that sub-ischial pressures tend to be higher in patients with spinal cord injury and that the variability in these pressures is less than that in normal seated subjects (9,10).

It has been standard practice to teach the patient to augment the benefit of the cushion by pressure relieving "push- ups" using their upper limbs (6). Patients have been recommended to perform a push-up every 15 minutes (13,1). This form of prevention has two drawbacks - the variable level of compliance encountered in the patient population (11); and the inability of some quadriplegic patients to independently perform pressure reliefs.

We have recently investigated the use of functional electrical stimulation (FES) to automate ischial pressure reliefs in tetraplegic patients. Our initial experiments consisted of the application of bilateral simultaneous quadriceps stimulation to seated patients with ankle restrictions (2). Since our initial report, we have conducted further tests and present our current experience with development of the system.

PRINCIPLE OF OPERATION

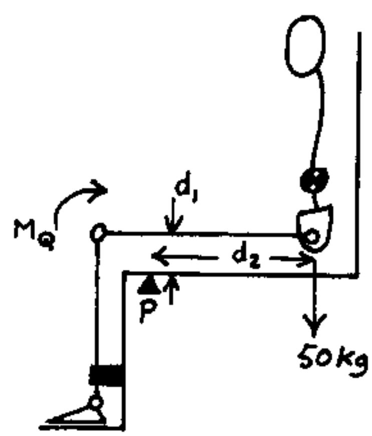
It was our aim in this study to produce an ischial pressure relief using electrical stimulation applied to the quadriceps muscles. We postulated that if the knees were prevented from extending by restricting the ankles to the wheelchair, then pivoting about the posterior thigh region would occur during quadriceps contraction. If sufficient quadriceps force is exerted, this should lead to elevation of the buttocks from the cushion surface resulting in ischial pressure relief. The quadriceps muscle was chosen for two reasons; tissues of the anterior thigh are convenient for the placement of surface electrodes, and are not at risk of pressure sores since they sustain only minimal pressures compared with the gluteal musculature, for example.

The force required to produce ischial pressure relief by quadriceps stimulation can be estimated by a biomechanical model (fig.1).

For a pressure relief to occur then the moment exerted by the quadriceps must at least equal that exerted by the body weight around the pivot point. If we assume the subject is of height 1.85m and mass 72kg and the pivot point is one-fifth the thigh length the following anthropometric data can be estimated (4):

Total length of thigh = 0.453m
d_1 = 0.09m
d_2 = 0.36m
mass of body = 50kgs

excluding lower limbs. We wish to estimate the magnitude of quadriceps force (F_{quads}) required. Taking moments about pivot point P :



$$2F_{quads}*d_1 = M*g*d_2$$

if both quadriceps are stimulated

$$2F_{quads}0.09m = 50kg*9.81m/s^2*0.36m$$
$$0.18m*F_{quads} = 176Nm$$
$$F_{quads} = 977N$$

or the quadriceps moment about a pivot point P is then:

$$F_{quads}*d1 = 977N*0.09m$$
$$= 88Nm$$

This level of quadriceps force can be achieved using FES in some patients with spinal cord injury following muscle conditioning. By extension of the analysis it can be shown that increasing the angle of the shank to thigh and body to thigh the force required is reduced further.

METHODS AND MATERIALS

In order to test the above biomechanical model, trials were carried out in 2 patients with spinal cord injury. Both were male patients with complete lesions at levels C6 and T7 respectively. Both patients had been subjects in FES gait studies and had well-conditioned muscles. Initial evaluation of the patients included measurement of quadriceps moment using a dynamometer.

For the purposes of the test an adapted wheelchair was used. This was fitted with shoe and ankle restraints. A standard foam cushion was used for the tests. Pressure measurements were made with the Oxford Pressure Monitor Mk2 (Talley Medical Ltd). This monitor employs sealed plastic air bags as sensors, linked to a pump. The pump increases pressure in the sensor bag and when the sensor walls part the pressure is recorded. This process is repeated cyclically for each sensor at rates not less than 2Hz (3). A matrix of 4 sensors (radius 1.25cm) was utilised under each ischium to record pressure. A point on the posterior thigh adjacent to the anterior edge of the cushion was also monitored during tests.

The matrix was positioned under the ischium with the patient positioned in the left lateral position, with knees and hips flexed to 90°. The bony point of the ischium was determined by palpation and the matrix secured to the skin by adhesive tape. The quadriceps was activated by a computer-controlled stimulator developed in our unit. Stimulation was carried out at a frequency of 25Hz, pulse width 300μs, with the regulated current output ramped up from 0mA to 120mA. Each test period lasted for one hour. Both quadriceps were stimulated simultaneously for 10s at intervals of 5 minutes.

RESULTS

Both patients could produce a mean quadriceps moment of 65Nm (range 40-91Nm) when stimulated at the above parameters. Both patients were seated in the test wheelchair with the back- rest inclined at 10° to the vertical and the leg-rests angled at 20° to the vertical. The mean seating pressures under the ischium were 67mmHg (+/-5.7mmHg) and 70mmHg (+/-4.9mmHg) respectively prior to application of stimulation. Mean posterior thigh pressures were 13mmHg (+/-2.0mmHg) and 11.8mmHg (+/- 2.0mmHg).

During application of stimulation seating pressures dropped to a mean of 34mmHg (+/-4.77mmHg) and a mean of 40mmHg (+/- 5mmHg) in the ischial area in both subjects. Correspondingly, the mean posterior thigh pressures rose to 30mmHg. No fatigue was observed at the duty cycle used for test sessions of 60 minutes. The mean ischial pressure illustrating a fall during quadriceps stimulation is plotted against time in fig.2.

	Subject A	Subject B
Resting Pressure	66 mmHg (+/-5.5 mmHg)	70 mmHg (+/-4.9 mmHg)

Ischial Relief	34 mmHg (+/-4.7 mmHg)	40 mmHg (+/-5.2 mmHg)
Thigh Pressure	11.8 mmHg (+/-2.0 mmHg)	13 mmHg (+/-2.2 mmHg)

Table 1. Results of FES Ischial Pressure Relief

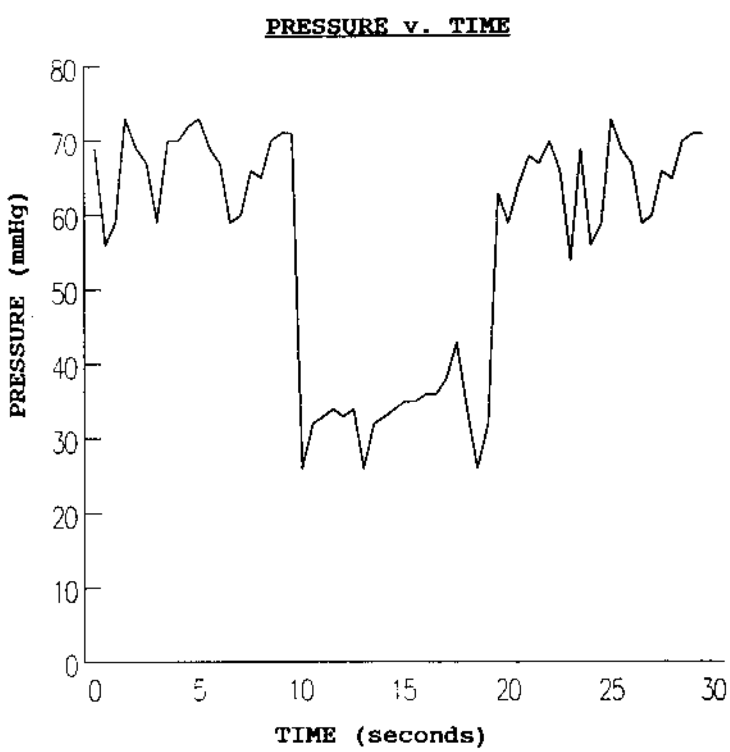


Figure 2. Graph of Ischial pressure against time showing fall when electrical stimulation is applied to quadriceps.

DISCUSSION

The concept of using FES as a possible means of pressure sore prevention is novel and has only been explored to a limited extent. Levine et al (1989) have attempted to modify seating pressures using stimulation of the gluteal musculature. Although this has met with some success, the pressure alterations achieved have been small, usually of the order of 10mmHg.

The use of the quadriceps muscles has some advantages over gluteal stimulation. They are more accessible for electrode placement and consequently can be more conveniently conditioned. This is more difficult to do with the gluteal musculature. In addition, in the studies of Levine et al, the indifferent electrode was placed on the skin of the sacrum, a common site for pressure sore formation. We consider this is best avoided. The results in this series of tests supports the use of the quadriceps as a more appropriate alternative to the gluteal muscles.

An automatic FES-pressure relief system may be a potentially valuable addition to current methods of prevention. The pressure relief would occur at regulated intervals and would not require any intervention on the part of the patient. This would overcome the compliance problem in paraplegic patients. For tetraplegic patients with weak or absent triceps power, the system would provide an independent method of pressure relief.

It is our intention to evaluate and develop the system with a larger group of patients. We will be evaluating the most practical wheelchair geometry and the effect of fatigue over more prolonged periods of time.

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