Physiological evaluation of sleep surfaces in healthy volunteers and patients with acute-upon-chronic lower back pain

Submitted for the degree MSc. (Med) Exercise Science

by

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DEDICATION

To my parents for the wonderful example you set me, for your endless love, support and encouragement during my years of study.

To Pete, your love and support I will cherish forever.

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DECLARATION

I, *Bronwyn Leigh Hulse*, do hereby declare that the experiments presented in this thesis were conceived and executed by myself and apart from the normal guidance received from my supervisor, I received no assistance.

Neither the substance nor any part thereof has been submitted in the past, or is being, or is to be submitted for a degree at this or any other University.

This thesis is presented in fulfilment of the requirements for the degree of MSc. (Med) Exercise Science.

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Date

ABSTRACT

Studies have documented that the use of a lumbar support while in the sitting position results in reduced back and leg pain, centralisation of pain and reduced erector spinae muscle activity in patients with lower back pain (LBP). While the positive effects of a lumbar support in sitting have been studied, few researchers have attempted to document the value of such a support in the supine position. Since many patients with LBP suffer from insomnia and nocturnal discomfort, it may be possible that the use of a foam surface overlay could positively influence their symptoms. Several foam surface overlays are currently used as a popular form of management for patients presenting with LBP. These include the convoluted foam surface ("egg box" shape), which to my knowledge has not been scientifically studied and the lumbar body support, the value of which has only recently been reported. That study found that patients with chronic LBP have decreased electromyographic (EMG) activity of the erector spinae muscles, lower heart rates (HR) and decreased perception of discomfort (ROD) when lying on this locally designed, triple density, contoured, lumbar body support system (LBS) compared with a conventional flat innerspring mattress (CM).

Accordingly the aim of this thesis was to measure the EMG activity, heart rate response, perception of comfort and pattern of pressure distribution after lying on a variety of different surfaces, thus endeavouring to determine a mechanism of action of the LBS.

In the first study of this thesis, ten patients with LBP were exposed to a random order, 30 minute period on three sleep surfaces: Lumbar body support on top of a conventional mattress (LBS + CM), 60 mm convoluted foam surface on top of a conventional mattress (CFS + CM), and a conventional mattress (CM) alone. Each patient acted as his/her own control. Recordings of EMG activity, HR and ROD were measured for each patient.

Average HR over the 30 minute period was lower after acute exposure to the LBS + CM (60 ± 11 b/min) compared to the CM (66 ± 10 b/min, $p < 0.05$; LBS + CM vs. CM). Although average HR response to the LBS + CM was lower compared to CFS + CM (64 ± 9 b/min), this difference was not significant. ROD reported after acute exposure to the LBS + CM was improved (1.9 ± 0.7 units), compared to the CFS + CM (3.9 ± 1.0 units) and CM (4.7 ± 2.2 units; $p < 0.05$). Average EMG activity was lower after 30 minutes on the LBS + CM (2.68 ± 1.1 mv) compared to the CFS + CM (4.46 ± 2.7 mv) and CM (4.19 ± 2.4 mv; $p < 0.05$). These results suggest that patients with LBP have reduced EMG activity and HR measurements with lower ROD when lying on a LBS + CM compared with a CM and CFS + CM.

The second series of experiments involved a further ten patients with lower back pain, who were required to lie supine in random order on the LBS + CM, on a polystyrene mould (PM) (identical to the shape of the LBS) and on a CM. Recordings of EMG activity, HR and ROD were measured for each patient. Average HR over the 30 minute period was lower on the LBS + CM (60 ± 7 b/min) vs. PM + CM (66 ± 10 b/min) and CM (68 ± 9 b/min; $p < 0.01$). Average ROD was improved when patients lay on the LBS + CM (1.8 ± 0.6 units) vs. PM + CM (5.7 ± 2.5 units) and CM (4.1 ± 1.8 units; $p < 0.05$). Furthermore, average EMG activity was significantly reduced after lying on the LBS + CM (2.5 ± 1.0 mv) vs. PM + CM (4.3 ± 1.9 mv) and CM (4.6 ± 1.8 mv; $p < 0.01$).

The findings of this study mirror our initial findings. The elevated EMG activity, heart rate and perception of discomfort after lying on a PM suggests that it could be a combination of both the correct density and the correct contour features that is important in reducing muscle spasm in patients with acute-upon-chronic lower back pain.

In the third study of this series, the pattern of surface interface pressure distribution in persons lying on a range of different surfaces (Base, HM, CM, 60 mm CFS, 90 mm CFS, TD, PM, Base + LBS, HM + LBS, CM + LBS and TD + LBS) was recorded by means of an Ergocheck ® pressure measuring device. Ten healthy patients without history of back pain were recruited.

The aim of this study was to establish the pattern of pressure distribution on the body after lying on the range of surfaces and to compare the differences after adding the LBS to certain of these surfaces.

The values for maximum pressure, average pressure and size of the area under pressure were measured for each surface. Maximum pressure recorded was significantly reduced when the LBS was placed on top of the four surfaces (CM + LBS, 23.6 ± 2.2 mmHg; HM + LBS, 25.0 ± 3.1 mmHg; base + LBS, 25.5 ± 3.0 mmHg and TD + LBS, 23.3 ± 2.1, $p < 0.01$), compared to when these surfaces were tested without the LBS (CM 38.7 ± 7.2 mmHg; HM 38.8 ± 7.0 mmHg and base 84.6 ± 23.3 mmHg). Furthermore, the HM and CM were significantly different to the PM (30.0 ± 3.1 mmHg), TD (29.4 ± 4.0 mmHg) and 90 mm CFS + CM (29.1 ± 3.6 mmHg; $p < 0.05$). Average pressure recordings mirrored the maximum pressure responses with exception of the 60 mm CFS + CM. Average pressure after lying on the 60 mm CFS + CM (11.1 ± 0.6 mmHg) was significantly different to the 90 mm CFS + CM (9.9 ± 0.6 mmHg) and LBS placed on top of each surface (Base + LBS, 9.7 ± 0.4 mmHg; HM + LBS, 9.7 ± 0.5 mmHg; CM + LBS, 9.6 ± 0.6 mmHg and TD + LBS, 9.3 ± 0.5 mmHg, $p < 0.05$). The area of pressure distribution was significantly greater when the LBS was placed on top of four surfaces (CM + LBS, 61.2 ± 5.8 dm^2; HM + LBS, 58.8 ± 6.5 dm^2; TD + LBS, 58.3 ± 7.0 dm^2 and base + LBS, 57.4 ± 7.1 dm^2), compared to the HM (44.8 ± 4.4 dm^2; $p < 0.05$). Furthermore there was a significant difference between the CM + LBS and the CM (47.8 ± 5.4 dm^2; $p < 0.05$). These results indicate that the pattern of pressure distribution in persons lying on the lumbar

body support is altered and pressures are more equally distributed when compared to the pressure distribution of the other surfaces measured, without increases in pressure at any point on the body. Similar average and peak pressure results were obtained for the 90 mm CFS + CM and LBS. Since these results were not mirrored by the 60 mm CFS, the thickness of a foam surface possibly plays a role in reducing pressure.

The data of these three separate studies could have implications in the adjunctive treatment of i)low back pain and ii) pressure sores.

Firstly, the results of this thesis suggest that the use of a 60 mm foam overlay may not be the optimum form of management for patients presenting with paraspinal muscular spasm. Further, it is postulated, that the density and contour features of the lumbar body support are likely to play a role in reducing EMG activity and heart rate, while improving perception of comfort compared to the flat surfaces (CM and 60 mm CFS), which offer little support to the lumbar region of these patients.

Secondly, either the LBS or 90 mm CFS are likely to reduce the incidence of pressure sores in patients required to lie supine for prolonged periods, due to the reduction in peak and average pressures. In view of the contoured surface, it is unlikely that pressure sores could develop in patients lying on the LBS. This hypothesis needs to be confirmed in longer term studies in patients who are severely debilitated or paraplegic, as they are often most at risk for the development of pressure sores.

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REVIEW OF THE LITERATURE

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Introduction

Low back pain (LBP) has been a growing concern for mankind over the past few decades and although not life-threatening, remains one of the most costly benign conditions in westernised countries (Bigos et al., 1996; Wheeler et al., 1995, Nachemson, 1992). Approximately 80% of people will experience low back pain at some stage in their lives and a total of 80-90% of attacks will recover within six weeks (Waddell, 1987). Most experts agree that LBP results in significant loss of productive work time (Cooper, 1993, Andersson, 1981), increased expense (Nachemson, 1976) and early retirement from productive work (Andersson 1979). In the U.K. during 1993 approximately 16.5 million people experienced backache, 3-7 million consulted their general practitioners, 1.6 million people attended hospital OPDs, 1.5 million received x-rays, 1 million attended physiotherapy, 1/2 a million attended casualty departments, 100,000 were admitted to hospital, 30,000 were treated as day patients and 24,000 had surgical treatment (Smith, 1996).

It is not possible for this review to focus on all aspects of LBP, hence in reading this review, other important factors should not be excluded. These include the muscle weakness/tightness pattern around the pelvic and shoulder girdles (Norris, 1995), postural correction and muscle imbalance (Janda, 1994; Kendall et al., 1993), adequate lower limb muscular strength and endurance, cardiovascular fitness (Schramm et al., 1995; Lahad et al., 1994; Battie, 1991), co-ordination (Johannsen et al., 1995), psychological status (Croft et al., 1996; Gatchel et al., 1995; Rose et al., 1995), sport and daily living activities, as well as education (Lahad et al., 1994). Furthermore, there is evidence to provide support for the efficacy of multidisciplinary rehabilitation programs for the long term outcomes of treatment (Lanes et al., 1995).

Conservative management strategies of LBP have been thoroughly described in a number of recent reviews (Bigos et al., 1996; Rodriquez et al., 1992; Lahad et al., 1994; Vivian, 1991). This review will not attempt to re-analyse the findings of all the studies documented in those reviews, but rather to focus on literature which is of specific relevance to the aims of this thesis.

Definition of low back pain

The precise aetiology of low back pain has been a challenge for medical researchers over the past few decades. Indeed in 85% of patients a precise cause for the backache cannot be found, despite sophisticated imaging technology.

In general terms, LBP can be subdivided into three classes (Burton et al., 1989).
1. Transient LBP - occasional "twinges" of LBP.
2. Acute LBP - episodes of pain of relatively short duration, of varying intensity and frequency, where the symptoms last for between 0-6 weeks.
3. Chronic LBP - pain lasting longer than six weeks which can lead to long term disability.

Further, three general diagnostic categories can be used: simple back pain, serious spinal pathology and nerve root pain. Simple backache refers to pain of musculo-skeletal origin, which varies with physical activity. Possible sources of the pain include soft tissues such as skeletal muscle, ligaments, intervertebral disc and bone. Serious spinal pathology can present as backache including spinal cord compression (cauda equina), tumours, infection, inflammatory disease (ankylosing spondylitis) and structural deformity (scoliosis). Nerve root pain occurs due to nerve root impingement by soft-tissue (herniated intervertebral discs) or bone (osteophytes). Pain often radiates below the knee.

For the purposes of the studies described in this thesis, acute (simple back pain) and nerve root pain are the primary focus. A clear knowledge of spinal function is required in order to understand the aetiology of low back pain.

1. Pain sensitive structures and function of the lower back

The spinal stabilising system

To accomplish the three important mechanical functions of the spinal column, namely to carry large loads to allow movements between head, thorax and pelvis and to protect the neural elements, it is necessary that the spine is a mechanically stable system (Panjabi 1994).

According to Panjabi (1992; 1994), the spinal stabilising system consists of three interrelating subsystems, namely the passive (spinal column), and active (muscular) with sensory feedback from both systems resulting in co-ordination via neural control mechanisms. When the stability provided by one system is compromised, other systems will compensate.

1.1. The Spinal Column

This can be divided into four components, namely the intervertebral discs, apophyseal joints, ligaments and vertebrae.

The intervertebral disc

The intervertebral disc is composed of two main areas, namely the central, semi-fluid nucleus pulposus and the surrounding concentric layers of fibrous tissue, the annulus fibrosis. Each intervertebral disc acts a hydraulic "shock absorber", helping to uniformly distribute load from one vertebra to another. Most of the pain sensitive area of the disc exists in the fibrous tissue of the annulus fibrosis. The orientation of the annular fibres varies from +30 degrees to -30 degrees in relation to the central disc, therefore enabling the spinal column to resist loads in both positive and negative directions (Panjabi, 1994). The production of an axial

load will compress the fluid nucleus resulting in a lateral expansion which in turn places the annulus fibres under stretch (Norris, 1995). Continual loading results in a rise in pressure leading to fluid loss of as much as 10% of the water within the disc (Kraemer et al., 1985). This fluid can be resorbed via pores within the vertebral end plates once the compressive force subsides.

If subjected to continual mechanical overload, the discs begin to lose their viscoelastic properties and hence the ability to absorb shock which results in degeneration. In addition, age related changes occur whereby the nucleus is unable to build sufficient central fluid pressure due to destruction of the protein matrix. The reduced central pressure results in peripheral distribution of load onto the pain sensitive annular fibres, causing them to develop cracks. The annulus could become painful due to mechanical irritation of it's peripheral nerve fibres and will progressively deform as a consequence of reduction of disc spaces. Tears in the annular fibres develop in response to the stress of movement producing mechanically, (distortion of the nerve endings) or chemically, (leakage of the nuclear material into the peripheral annulus) mediated pain (Vivian, 1991). This can lead to herniation of the nucleus pulposus whereby the nuclear material breaks down and moves through the annular tear, leading to nerve root impingement. Such an injury to the disc will influence the mechanics of the spinal column.

The apophyseal joints (facet joints)

The second component of the spinal column, are the apophyseal joints (facet joints). These articular surfaces are surrounded by a joint capsule, which is richly innervated, therefore playing an important role in pain production.
Due to the alignment of the apophyseal joints (superior/inferior), the joint surfaces glide past each other during axial loading. Thus during axial movement of the lumbar spine the joint surfaces are displaced resulting in an impaction (Norris, 1995). Although the articular facets are primarily arranged in a vertical

plane, they gradually change from sagittal to frontal from L1/L2 to L5/S1 hence enabling motion primarily in the sagittal plane.

In instances when there is severe disc degeneration, inferior articular processes impact on the lamina of the inferior vertebra resulting in an increased compressive force on the inferior articular surfaces which is then aggravated with movement. During flexion, anterior sagittal rotation and anterior translation takes place, which causes the facets to move apart, opening the joint space and placing pressure on the joint capsule as well as the posterior spinal ligaments.

In contrast extension of the lumbar spine produces tension on the anterior elements, thus compressing the posterior structures, depending on the range of motion. The inferior articular processes move downwards impacting on the articular process below, causing a posterior movement resulting in a possible over stretching or damaging of the joint capsule (Yang et al., 1984). This could lead to erosion of the lamina (Oliver et al., 1991), impaction of the joint capsule at the site of the compression as well as structural abnormalities which could occur, causing pain.

During lateral flexion when the trunk movement is slow, spinal tissues will be prevented from over stretching due to tissue tension which is felt at this end range, however, rapid movements build up considerable momentum, hence exerting stress on the spinal tissues. Further, the facet joints tend to hypertrophy as the spine degenerates (Panjabi, 1994), as the load shared by the facets increases with respect to the discs. This can predispose to facet joint arthritis later in life.

The ligaments

The third constituent of the spinal column are the longitudinal ligaments, which extend the entire length of the spine linking the vertebrae together. The anterior

longitudinal ligament supports the anterior aspects of the vertebral column, including the vertebral discs, while the posterior longitudinal ligament provides the posterior support to the vertebral bodies and forms part of the anterior wall of the vertebral canal. Other ligaments include ligamentum flavum, (which lies between the laminae of adjacent vertebrae), the supraspinous ligament (longitudinal fibres run over the spinous processes), ligamentum nuchae, (triangular, midline, fibroelasticseptum), interspinous ligaments, (between adjacent vertebral spines) and intertransverse ligaments (connect adjacent transverse processes) (Palastanga et al., 1989).

An important function of these ligaments is to provide spinal stability. There are important elements to consider in terms of ligament function which could predispose one to injury. These include; ligament cross sectional area, ligament length, distance of the ligament from the centre of rotation, and orientation of the ligament with respect to spinal motion direction (Panjabi, 1994).

Although pathology can occur in isolation to either the intervertebral discs, the apophyseal joints or the ligaments, it is likely that pain could derive from a combination of pathology or injury from the different anatomical sites.

The vertebrae

Finally, micro fractures of the trabeculae in the subchondral bone due to vertical compressive loading e.g. equestrian activities can lead to end plate fractures in the vertebrae. Repetitive hyperextension could lead to fracture of the pars interarticularis or vertebral transverse process all of which result in pain.

1.2 The Skeletal Muscles

Skeletal muscle trigger points have been proposed as one of the sources of pain reported by patients with lower back pain. It has been suggested that trigger points are often situated in the iliocostalis lumborum and the longissimus

thoracic muscles of these patients (Travell et al., 1983). However the intertester reliability in determining the presence of trigger points has been questioned (Nice et al., 1992).

The skeletal muscles play a crucial role in the stabilising system of the spine. Two important components of these muscles are their length and strength. Imbalances between these elements is likely to lead to pain. Muscular attachment to the lumbar spine will affect pelvic tilt either actively through contraction or passively through increased muscular tone. The pelvis can be considered as a see saw balanced on the hip joints. Anterior tilting of the pelvis occurs when the anterior part of the pelvis drops downwards, posterior tilting is the reverse action, with the anterior pelvis moving upwards. For example: anterior tilting increases the lumbar lordosis due to lengthening of the abdominals and possible tightness in the hip flexors (Norris, 1995).

It appears that the length of the abdominal muscles is more important than the strength of these muscles for decreasing lumbar lordosis. No correlation has been found between abdominal muscle strength and pelvic tilt (Walker et al., 1987). A positive correlation has been shown between abdominal muscle length and lordosis (Toppenberg et al., 1986).

Therefore one can relate pelvic tilt to muscular length rather than to strength. Hence, it is essential for maintenance of correct length of the muscles attached to the pelvis to prevent injury (Norris, 1995).

Recently, Richardson et al., (1990) proposed that the components for spinal stability can be augmented by facilitating a co-contraction of the musculature surrounding the spinal column, specifically the transversus abdominis, oblique abdominals, erector spinae and multifidus. A study by Hides et al., (1994) has shown that lower back pain results in marked asymmetry of multifidus cross

sectional area (CSA), with gross muscular atrophy ipsilateral to the symptoms and isolated to a single vertebral level, at the site of the pathology. Hides et al., suggest that the mechanism of wasting was not as a result of disuse atrophy or spinal reflex inhibition, but rather inhibition as a consequence of perceived pain via a long loop reflex, aimed at the vertebral level of pathology to safeguard damaged tissues from movement. The muscle wasting was rapid (less than 14 days in 20 of the total 26 patients studied), which the authors suggest is illustrative of a metabolic effect of reduced circulation caused by substantial skeletal muscle spasm.

Change in multifidus fibre type has been reported in patients with low back pain (Biedermann et al., 1991). This could result from a shift in recruitment patterns of the motor units in the paraspinal muscles due to injury. This could account for the reduced ratio of slow twitch to fast twitch fibres in the multifidus, as fast twitch motor units are recruited before the slow twitch units.

1.3 Neuromuscular control unit

Very briefly, the vertebral column is supplied by two sets of nerves: 1) the sensory branches from the dorsal primary rami, and 2) the sinu vertebral nerves.

The dorsal primary rami innervate the articular joint capsule, ligamentum flavum and the interspinous ligaments. The sinu vertebral nerves innervate the vertebral body, the adjacent intervertebral discs, the posterior longitudinal ligament, the internal vertebral plexus, the epidural tissue and the dura mater (Stanish, 1987). Sensory motor reflex pathways are considered to produce spasms of the skeletal muscles of the spine.

As the aetiology of low back pain is unknown, one can hypothesise that a certain percentage of patients may have dysfunction of the neuromuscular control system (Panjabi, 1994). To my knowledge, only three studies exist that have

investigated this aspect of low back pain. In the first two studies, the researchers found differences in the sway measurements of patients compared with normal subjects when required to perform proprioceptive tasks (Hanai et al., 1988; Byl et al., 1991). In the third study, both age and injury were documented as influential factors of proprioceptive function (Parkhurst et al., 1994).

Although progress has been made in the understanding of pain, much remains poorly understood about the neurotransmitters and neuromodulators in LBP which are known to play a role in what is ultimately experienced as pain and which are beyond the scope of this review.

1.4. The spine and night pain

Current treatment of LBP includes avoiding prolonged bed rest and early activity. However, we can spend up to one third of our lives sleeping, hence the importance of an appropriate sleep surface.

Lack of sleep for extended periods of time can lead to reduced endurance, impaired co-ordination, and an overall decline in emotional and physical well being. Muscle activity during sleep is minimal, therefore the forces acting on the musculoskeletal system are limited to those provided by gravitational pull on the body mass as it is supported by flat beds of variable hardness (Gracovetsky, 1987).

Sleep and rest are as essential for the musculoskeletal system as they are for the central nervous system. Gracovetsky, (1987) describes a conceptual framework for the response of the spine during sleep and rest. When the body is supported by a mattress, there is minimal active force due to relaxation of the muscles. Other forces may alter the shape of the soft tissues of the musculoskeletal system due to the effect of gravity on the body mass. For example, when one lies on one's side, the hip and shoulder joint make contact

with the mattress, causing a lateral curvature of the spine. The result is stress on the spinal structures.

There is a close association between sleep and pain (Closs, 1992). Deprivation of sleep as a result of pain could lead to further undesirable consequences such as negative mood states and impaired tissue repair. Closs, (1992) reported that pain was the most commonly reported cause of sleep disruption and that the control of nocturnal pain requires further attention in order to optimise pain control and promote sleep. Furthermore they found that analgesics helped more patients return to sleep than any other form of intervention.

A comprehensive study by Boissonnault et al., (1996) focused on detailed pain descriptions for patients with low back pain referred to physical therapy. With specific reference to night pain the authors found that despite 50% of patients reporting an increase in pain complaint in the prone and supine positions, only two patients claimed that a recumbent position was the source of their worst pain. They noted that specific recumbent positions could, however stress the spine to a level which increased symptom intensity. Furthermore, 56% of patients experienced pain nightly and only one patient revealed that night pain was the most intense pain experienced. Lying prone increased symptoms in 48 of 98 patients (49%) as opposed to lying supine with hips and knees flexed which resulted in an increase in pain complaint in only seven patients (7%). The authors concluded that non weight bearing positions were the most effective means for relief of pain, including the supine and side lying positions, however no mention was made about the type of mattress used, and not all patients experienced pain relief from these recumbent positions.

Factors affecting LBP

Historically, back pain, specifically lumbar disc protrusion was uncommon amongst the native inhabitants of countries such as Malaysia, Indonesia, India and Thailand. In contrast, the sedentary lifestyles adopted by western society predispose one to a greater incidence of degenerative disk disease (Fahrni, 1975).

LBP is influenced by many factors including (i) time spent in the sitting posture (Pietri et al., 1992; Fahrni, 1975; Magora, 1972; Kroemer et al., 1969), (ii) lifting heavy loads (Nachemson, 1976), (iii) increased number of working hours spent sitting (Knuttson 1966), (iv) non-orthopaedic items such as beds and chairs (Fahrni, 1975) and (v) reduction in physical activity (Kelsey et al., 1979), with subsequent reduction in skeletal muscle strength.

According to Andersson (1981), jobs involving manual labour, frequent bending and twisting, lifting, repetitive movement, vibration and a static work posture have been associated with low back symptoms.

2.1. Lumbar lordosis

One of the controversies in management of low back pain is whether to advocate maintenance of increased or decreased lumbar lordotic curves during sitting, standing or lifting (McKenzie, 1981; Williams et al., 1991).

Adams et al., (1985) have proposed the reduction of the lumbar lordosis while lifting heavy objects and sitting as this is mechanically and nutritionally advantageous in healthy subjects. Fahrni, (1975) has suggested that the lordotic curve plays a causative role in degenerative change.

Williams, (1974) suggest that LBP is likely to occur due to lumbar lordosis placing excessive stress on the posterior bony and soft tissue structures of the

spine. The advantages of a flexed posture include: reduced stress at the apophyseal joints, decreased compressive stress on the posterior annulus and improved transport of metabolites. However, there are also disadvantages including, higher compressive stress on the anterior annulus and increased hydrostatic pressure on the nucleus pulposis at low load levels (Adams et al., 1985).

A contrasting view exists whereby the maintenance of a lumbar lordosis during sitting McKenzie, (1981) and lifting (Delitto et al., 1992) is advocated. McKenzie maintains that this posture could have a profound effect on the decrease in pressure on the pain sensitive structures in the neural foramen as a consequence of anterior displacement of the nucleus pulposis. This contrasting view suggests that the normal lumbar lordosis should be maintained during sitting (Williams et al., 1991).

A lumbar support reduces intradiscal pressure and erector spinae musculature myoelectrical activity (Andersson et al., 1975), prevents pelvic rotation and preserves lordosis (Keegan, 1953). Furthermore, abnormally high stress on both the facet joint cartilage and collagen elements of the intervertebral discs can be avoided when the lumbar lordosis is maintained (Twomey et al., 1988). Thus a lumbar support which maintains the lumbar lordosis during sitting has been advocated by many researchers (Williams et al., 1991; Twomey et al., 1988; Grandjean 1987; Pope et al., 1984; McKenzie, 1981; Andersson et al., 1975).

2.2. Chair design

Mandal (1976), in agreement with Keegan (1953) claimed that by increasing the thigh-trunk angle a normal lordosis would be achieved, thereby aiding in the reduction of tension on the posterior elements of the spine. According to Keegan, (1953) a thigh-trunk angle of 135 degrees is necessary for a physiologically neutral position of the lumbosacral curve. A forward tilting-chair

brings the hips closer to this neutral position compared to the standard upright chair.

Bennett et al., (1989) described the influence of chair design on LBP. They established that the conventional flat back chair promotes a flattening of the lumbar curvature, when compared to a Balans® Multichair where the lumbar curvature was greater. This could contribute to the adjunctive treatment of LBP.

Frey et al., (1986) compared lumbar curves whilst sitting on a Westnofa Balans® Multi-Chair (WBMC) to sitting on a conventional chair and to standing. They found that the lumbar lordosis whilst sitting on the WBMC better resembled the standing posture than when subjects sat on a conventional chair. The authors postulate that this chair would be suitable for patients when reduced flexion or slight extension of the lumbar spine is indicated during sitting.

Irving (1992), conducted a questionnaire study on surgeons at Groote Schuur Hospital using the Medac Upright Posture Chair (MUPC). This forward-tilting chair design was chosen in order to help maintain the normal lumbar lordosis (Bridger, 1985). Irving reported that the MUPC seemed to reduce LBP in both the sitting and standing positions.

Snijders et al., (1995) recorded EMG activity of the rectus abdomini and internal and external oblique muscles. EMG activity was measured in the supine position, during standing, during sitting in an office chair with the use of back and arm rests, and with and without crossed legs. They found that during sitting, the activity of the oblique abdominals is significantly lowered by the "crossed-leg" position, while rectus abdominis activity is not significantly altered by this position. These authors advocate that the design of the workplace should accommodate "leg-crossed" and "ankle-on-knee" postures, as the stability of the sacro-iliac joint (SIJ) may be improved by hip flexion and adduction.

2.3. Use of a lumbar roll as a lumbar support.

Williams et al., (1991) explored the use of a lumbar roll in reducing back and referred pain during sitting. These workers reported that alteration in sitting posture from kyphotic to lordotic, facilitated by a lumbar support, resulted in decreased back and leg pain and centralisation of pain.

Andersson et al., (1974) used fine wire electrodes to measure the myoelectric activity of the multifidi muscles at L1, L3 and L5 levels and iliocostalis at the L1 level. Surface electrodes were placed paravertebrally at L1, L3 and L5 in the seated position. In unsupported sitting, the highest level of muscle activity was found in anterior sitting and the lowest in posterior sitting. Four support parameters were studied namely: backrest inclination, seat inclination, lumbar support and thoracic support. These findings conclude that of the support parameters, back rest inclination was the most important, the activity decreasing with an increase in inclination.

2.4. Use of a lumbar support in supine postures

While studies have examined the effect of a lumbar support on LBP during sitting, very little research has focused on the use of a lumbar support for LBP in the supine position.

Recently, Beattie et al., (1994) conducted a study whereby the effect of lordosis on the position of the nucleus pulposis in subjects lying in the supine position was determined. They concluded that in young healthy females, the use of a lumbar roll in the supine position increased the distance from the posterior margin of the nucleus pulposis to the posterior portions of the vertebral bodies. Since many patients with LBP experience pain at night during sleeping, it may be possible that the use of a lumbar body support (LBS) would improve their symptoms.

Recent research conducted in this laboratory has indicated that the integrated electromyographic (iEMG) activity of the lumbar erector spinae muscles in patients with acute-upon-chronic LBP is decreased following lying on a LBS, compared to a conventional flat mattress (Derman et al., 1995). In addition, heart rates and ratings of pain and discomfort were also reduced in the patients following lying on the LBS compared with the flat surface. To our knowledge this is the only study at present focusing on the use of a lumbar support in the effect of postural correction on LBP in the supine position. However, further studies are required in order to validate this type of conservative treatment option, as a prophylactic measure for people debilitated as a result of pain.

Not only is equipment important for improvement of one's LBP, but so too is the beneficial effect of postural training of specific muscle groups to correct skeletal muscle imbalances.

3. Surface electromyography

3.1. Characteristics of the EMG signal

The EMG signal recorded from the skin is a combination of the physiological action that generates myoelectric energy and the multitude of factors that effect the characteristics of the recording. Interpretation of EMG activity is frequently subject to error, however with ample precision and care, the EMG signal can be a powerful and effective tool for both clinical evaluation and research (Kamen et al., 1996). Studies with EMG signals have been frequently criticised for failure to develop common guidelines with regard to instrumentation and selection of criterion measurement (Grossman et al., 1966).

3.2. Electromyography and paraspinal muscle activity in low back pain

Muscular spasm is often regarded as a common feature presenting in patients with low back pain, hence a great proportion the medical literature advocates the reduction of muscle tension in paraspinal muscles. However, researchers remain

divided as to the origin of low back pain. This is in part due to the lack of an appropriate model that can explain the seemingly inconsistent results presented throughout the literature on low back pain. According to recent reviews on neuromuscular activity and back pain, there are two etiologic models to account for myogenic causes of back pain. The reflex spasm model and the biomechanical (postural) model. Within the reflex spasm model, exist two contending hypotheses describing the etiological factors that produce low back pain, namely: the physical stressor (organicity) model and the psychosocial stress (emotional) model (Geisser et al., 1995).

3.2.1. The physical stressor (organicity) model

The model suggests that there is increased muscle activity in response to ligamentous strain or tissue inflammation with pain being produced as a result of irritation of pain sensitive structures resulting in paraspinal muscle spasm. A stressful physical event triggers a pain-spasm-pain cycle which produce more muscle spasms. The chronic pain problem then develops as more stressful events take place (Traue et al., 1992). One would expect a general increase in muscular activity during rest and during movement as part of the pain-spasm-pain cycle. However, reports in the literature are inconsistent, although some studies have observed higher *resting* levels of EMG in the lumbar region (Hoyt et al., 1981), in standing (Flor et al., 1989; Flor et al., 1985; Soderberg et al., 1983; Jayasinghe et al., 1978) and in sitting (Kessler et al; in submission). Others including Kravitz et al., (1981); Ahern et al., (1988); Miller (1985) and Collins et al., (1982) found no difference in resting EMG levels in patients with lower back pain and control groups. These discrepancies highlight the technical difficulties associated with EMG measurement.

In a study conducted by Kravitz et al., (1981), paralumbar muscle activity was measured in both patients with low back pain and in asymptomatic subjects, during periods of rest and during voluntary muscular contraction. The resting

state measurement was the same for both groups, but during an attempt to relax the lower back musculature whilst contracting other muscle groups, the patients with LBP displayed greater average measurement, compared to the pain free group. In contrast significantly higher resting state EMG recordings were documented in LBP patients compared to the pain free group (Grabel, 1973). According to his findings, Grabel suggests EMG feedback induced muscle relaxation training as an effective treatment modality. This is of particular relevance as Grabel used the same procedures for electrode placement and patient positioning as that of Kravitz et al., (1981). According to Kravitz, relaxation training of the lower back musculature is required during the activation of other muscle groups in order to reduce paralumbar muscular activity in LBP patients.

Roy et al., (1990), have shown the usefulness of a surface EMG measurement technique to identify low back pain and asymmetrical muscle function in rowers. They were able to distinguish rowers with lower back pain using EMG spectral parameters. Another important finding of the study was that the physical condition of the person may play an important role in determining if EMG fatigue indices are normal in an individual with lower back pain. De Luca, (1993) address the issue of spectral analysis for performance evaluation of back muscles. This is supported by Ng and Richardson, (1996) who have shown that EMG power spectral analysis is a reliable method to measure the fatigue rate of back muscles if measures to minimise cross talk are adhered to.

Jayasinghe et al., (1978) performed an EMG investigation of postural fatigue during erect standing in patients with lower back pain. These authors found an increase in the mean square value of the EMG as a function of time during standing whereas the non pain group showed an overall decrease in EMG with time. The authors claim that this increase of EMG activity could be related to muscle insufficiency or fatigue.

In contrast, Collins et al., (1982) found that EMG activity was similar or significantly greater in controls compared to patients with lower back pain during a 45 degree bend and forward pelvic tilt. In support of this, Miller, (1985) measured EMG activity during upright quiet sitting in a recliner chair, standing and during active sitting (unsupported). Similar levels of EMG activity in both LBP and non back pain groups were found, suggesting that the reflex muscle spasm was not present, therefore not a cause of LBP in subjects with lower back pain.

3.2.2. The psychosocial stress model

This model argues that the increased muscle activity is related to stressful events and will be found in a symptom specific response pattern of the suffering patient (Traue et al., 1992). In support of this model we would expect activation patterns during periods of emotional stress. The assumed causal relationship is that the patient has a physiologic response pattern to stress that is maximal in the paraspinal muscles. This persistent hyperactivity of these muscles leads to chronic low back pain.

Flor et al., (1985) found localised increases in EMG activity after personally relevant stresses such as the self report of pain. There was no evidence of overall arousal reflected by means of heart rate and skin conductance. However Collins et al., (1982), in a well controlled study did not support this model. Regardless of whether the initial damage was caused by physical or psychological factors, both hypotheses eventually agree that a reflex spasm develops. The crucial assumption is that changes in muscle activity are related to changes in experienced pain levels.

3.2.3. The biomechanical (postural) model

The prime emphasis of this model is on the stabilisers of the spine particularly the back musculature. In contrast to the previous two models, this model

causally relates abnormally low-levels of EMG activity to lower back pain. In addition asymmetrical muscular activation patterns enhance this biomechanical problem (Traue et al., 1992). There is a great deal of empirical data in the literature to support this model. Basmajian, (1978) found atypically low levels of EMG activity in back pain patients during a trial to determine the effects of cyclobenzaprine hydrochloride and diazepam on muscle spasm. Furthermore, patients who improved after drug therapy demonstrated enhanced EMG activity during movement.

Collins et al., (1982) showed that patients with LBP displayed reduced erector spinae EMG activity levels during dynamic movement, in comparison to a pain free control group. In another study of dynamic movement, Ahren and co-workers (1988), found reduced surface EMG activity in low back pain patients compared to controls. Other studies have produced similar findings (Wolfe et al., 1982; Wolfe et al., 1979). There are, however some methodological considerations that should be taken into account when analysing the data from the above studies. For example many of the subjects studied had undergone back surgery which could have resulted in structural alterations in the EMG recruitment patterns and range of motion. Most of the studies assessed subjects who had experienced a long history of pain thus confounding the EMG data with the pain process itself. Furthermore, in most cases only a single site was assessed, thus further compensatory patterns may have been overlooked in other regions. Similar to the reflex spasm model, the biomechanical model has produced some conflicting results. Ahern et al., (1988) did not find significant EMG asymmetries for back pain subjects during dynamic movements. Other studies contradict the biomechanical model and provide evidence for the reflex-spasm model.

In keeping with the above two models and in order to evaluate which theoretical framework would best explain the myogenic contributions to pain, Traue et al.,

(1992) conducted a study in order to analyse the relationship between postural EMG activation patterns and the self report of pain in a sample of patients with pre-chronic back pain. These researchers found that their results could not be explained by a single model as their data supported both the organicity and biomechanical models of pain. During unsupported sitting, EMG activity was negatively correlated with pain in the lumbar region (L3 site) which supports the biomechanical model of abnormally low levels of EMG activity (Wolf et al., 1979; Soderberg et al., 1983; Collins et al., 1982; Basmajian, 1976; Basmajian 1978).

In contrast, in the thoracic spinal region pain reports were positively correlated with the level of neuromuscular activity, which would support the organicity model of pain and therefore support muscle tension as a relevant factor for pain over the trapezius site. Traue et al., (1992) explain that the abnormally low levels of lumbar paraspinal EMG activity in the lumbar region are due to the lack of spinal stabilisation of the paraspinal musculature at this level, which would place stress on the surrounding connective tissue and fascia, thus irritating nerve endings resulting in the subjective pain experience very similar to the tension induced pain. However, this explanation presents a problem as it is not the erector spinae that are directly involved in spinal stabilisation, but rather the deeper intersegmental muscles including the multifidus.

In the past, the back extensor muscles have been considered as a single functional unit (Floyd et al., 1955). However more recent research has found functional differences between parts of the larger superficial back muscles, (erector spinae), and smaller deep back muscles (multifidus) (Jonsson, 1970). Multifidus is an intersegmental muscle designed to enhance the stability of the spine (Panjabi et al., 1989) in contrast to the erector spinae, which are designed for movement and to counterbalance external loads. Therefore in determining spinal stability it is necessary to utilise fine wire EMG recordings of the multifidus as opposed to surface EMG recordings of the erector spinae.

The histochemical fibre types suggest that multifidus has a greater role in spinal stability due to the predominance of slow twitch fibres as opposed to the erector spinae with a predominance of fast twitch fibres. This may explain the higher fatigue rates found in low back patients as the muscles have a greater proportion of fast twitch fibres (Type 2), which in turn fail to resist fatigue as well as muscles that contain predominantly more slow twitch fibres (Type 1) (Biedermann et al., 1991). These authors have begun to collect biopsy material from the multifidus in a selected group of normal volunteers in order to obtain more specific details on the histochemical structure of the paraspinal musculature.

In an attempt to determine potential causal relationships between muscle activity, physical activity, psychosocial stress and pain, Geisser et al., (1995) conducted a time series analysis approach to investigate both immediate and lagged associations between these variables. Their results suggest that patients with chronic pain are heterogeneous in terms of their make up and in factors that lead to development of pain. One possible explanation could be that patients with low back pain suffer from various disorders with different etiological causes, and are automatically lumped into one group. Most studies fail to specify the type of pain or pathology involved (Geisser et al., 1995).

A causal relationship was found between physical activity and pain, explaining that inconsistencies in previous research examining the relationship between EMG activity and pain could be due to sample differences. These findings are consistent with both the reflex spasm and the biomechanical models.

Recent research has shown that during dynamic trunk flexion and extension, patients with chronic LBP, showed hyperactivity of the back muscle when the muscles act as antagonist and decreased activity when the muscles act as agonist (Sihvonen et al., 1991). It is suggested that if chronic pain is present,

changes in motor output are likely to originate from the alterations in the firing pattern of segmental interneurons in the spinal chord or brainstem (Lund et al., 1991).

Many studies have focused on the role of EMG activity on the low back musculature during flexion/extension isokinetic lifting (Noe et al., 1992), axial torque (McGill 1991) and isometric contractions (Mannion et al., 1994; Shirado et al., 1995; McGill 1991). Although EMG activity of the lower back musculature has been well documented in the sitting and standing postures, to my knowledge, there has only been one study that has researched the influence of supine postures on EMG activity (Derman et al., 1995).

Studies utilising surface electrodes over the belly of the paraspinal musculature in normal subjects have shown that the raw paraspinal muscle EMG signal can be reliably and repeatedly measured if it is first rectified and then integrated, producing an integrated electromyographic signal (iEMG) (Lee et al., 1992). This technology has been used to compare patients with chronic LBP to control subjects during a standardised postural endurance test (Biering-Sorensen, 1984). iEMG increases were significantly greater in the LBP group compared to the control subjects. In an attempt to explain this phenomenon Cooper, (1993) claims the increased central drive found in patients with LBP is secondary to radiographically and histologically proved peripheral abnormalities found within the neuromuscular system. In order to optimise function, these patients may activate different parts or fibre-types of the same muscle, activate more groups of either fibre type, or activate more of the available muscles. He therefore concludes that paraspinal muscle dysfunction does take place in part due to disuse atrophy and denervation.

In the past it has been assumed that all patients with lower back pain have elevated levels of paraspinal activity, however paraspinal levels can either be

elevated or reduced in patients with chronic pain. This may be due to the difficulty in the diagnosis of lower back pain itself. Therefore the diagnosis should be limited to patients that have paraspinal muscle spasm which presents as lower back pain. In addition, potential correlation's between absolute changes in EMG activity with changes in magnitude of perceived pain should also be viewed with caution (Wolfe et al., 1982).

4. Effect of support surfaces in prevention of pressure sores and LBP

4.1. Support surfaces and pressure sores

Pressure ulcers are defined as "a localised area of tissue damage resulting either from direct pressure on the skin causing tissue ischaemia, or from shearing forces causing mechanical stress to the tissues" (Vohra et al., 1995). The pathophysiology of this condition continues to be poorly understood due to the lack of well conducted studies on support surfaces.

A variety of support surfaces have been developed in an endeavour to achieve an even distribution of pressure to the lumbar and thoracic areas, away from bony prominences. These include foam (Rosenthal et al., 1996; Bliss, 1995; Allen 1993), gel (Fletcher, 1996), air (Allen 1994; Cordell et al., 1995; Lowthian 1995; Rithalia, 1995), and sheepskin products.

Low pressure supports are soft in nature and aim for wide distribution of pressure as opposed to alternating pressure mattresses which are much firmer. They are adequately firm to provide support during the inflation and deflation of adjacent cells beneath the body which results in oscillation of pressure. This in turn mirrors the alternate high and low pressures that arise due to change in pressure in response to movement which re-oxygenates the tissues, thereby preventing ischaemic necrosis.

Of the pressure reducing devices, fluidising systems have been the most consistent in diminishing pressure over bony prominences. Additionally the low air loss beds provide safe pressure relief over these prominences (Wild, 1991).

Other important considerations when evaluating support surfaces, which are beyond the scope of this review include life expectancy of the surface, skin moisture control, skin temperature control, flammability, patient/product friction, product service requirements (Krouskop et al., 1995) and infection control (Orr et al., 1994).

There is confusion however regarding which product is best. Currently there is no evidence to suggest that any single pressure-reducing device is more effective than others in reducing risk of developing pressure ulcers over bony prominences (Wolf, 1995). Therefore, there is a need for further standardised studies to be conducted in an attempt to discover the best method of treatment for these patients, before the use of such support surfaces will be more widely accepted in the treatment of patients with tissue pressure ulceration.

4.3. Support surfaces and LBP

To my knowledge there has been only one clinical trial which has documented the use of specialised surfaces in reducing back pain in the supine position. The more recent study by Derman et al., (1995) was described in the section titled "*use of a lumbar support in supine postures*".

In a letter to the editor, a patient described how her backache was relieved by a polystyrene mattress (Hill 1973). The polystyrene mattress was judged to be superior to other pressure relieving devices as it allowed free circulation of air, comparing favourably with the water mattress and ripple bed (Van Laer, 1967).

There is a gap in the current literature regarding the use of lumbar supports as an adjunctive treatment for patients with lower back pain. Therefore in order to expand the current knowledge, we deemed it necessary to conduct this research.

Overall summary and aim of this thesis:

It is clear that the treatment of lower back pain remains a complex challenge for medical practitioners and therapists alike. The difficulty in establishing an accurate diagnosis together with the non-specific nature of the problem makes lower back pain one of the most disabling and costly problems affecting Western Society. Furthermore, the many inconsistencies discussed in the review indicate that future research is required, with specific reference to recumbent postures.

Although there remains considerable controversy, there are sufficient studies to support a general conclusion that the use of a lumbar support in sitting reduces pressure from the posterior annulus, with reduction in intra discal pressure and erector spinae musculature myoelectrical activity. However there are insufficient studies to support this conclusion for supine postures.

Therefore, the aim of this thesis is to study the effects of the surface EMG activity, heart rate, perception of comfort and interface pressure between the lower back and selected sleep surfaces in patients with lower back pain and in healthy subjects.

Chapter two describes the surfaces used in this study while chapter three defines the general methods. Chapter four reports the acute cardiovascular and muscular response to lying supine on three different locally manufactured sleep surfaces, and chapter five includes discussion of an additional surface in an attempt to further explain the mechanism whereby reductions in heart rate and paraspinal muscular activity occurs. Measurement of interface pressure between the lower back and these surfaces is detailed in chapter six. The findings of these studies are summarised in chapter seven. Chapter eight lists the references used in this thesis and chapter nine contains the appendices.

CHAPTER TWO

A REVIEW OF THE SURFACES USED IN THE STUDIES

A REVIEW OF THE SURFACES USED IN THE STUDIES

Lumbar body support (LBS) (KBS 2000 international; *Klaas Vakie ® Cape Town, South Africa).* RSA Patent Nr. 94/9243.

The LBS is a polyurethane, pressure equalising body support, composed of specially contoured, quadruple density foam, which is placed on top of an ordinary flat mattress when used therapeutically. The densities of the foam vary according to the size of the lumbar body support, which is available in a small, medium, large and extra large, to accommodate people with different body sizes. Small, medium and large sizes were used in chapters four and six, while the medium size was utilised in chapter five. Convoluted foam is used for aesthetic purposes to cover the built-in components. Two built up regions are designed to accommodate the three natural spinal curvatures in the cervical, thoracic and lumbar regions (figure 2.1.). Thus, the natural spinal curvature can be maintained during sleep with the lumbar lordosis intact. The LBS was designed based on the concept that a flat surface causes pressure build up between the body and the surface area on which it is resting, concomitantly increasing the possibility of "bedsores" and back pain.

Figure 2.1. The lumbar body support (LBS) (KBS 2000).

***Sealy*® Posturepedic (conventional inner spring mattress; CM)**

The conventional mattress (CM) used in this thesis consisted of an inner spring unit, covered with an insulating pad followed by a layer of thick cotton wadding (density unknown; *Sealy*®). The surface was flat and rigid with internal supportive inner-spring components. Foam layers were placed above the cotton wadding to form the bulk of the mattress. A multi quilted fabric comprised of dakron formed the outer layer and covered the inner structures. This mattress was used as a control mattress in each set of experiments (figure 2.2.)

Base

The base used for testing in this thesis formed one of the components of the innerspring (*Sealy*®) mattress i.e. base of this mattress. This flat surface provided no contour for support and was very rigid when compared to the foam surfaces and the *Sealy*® mattress.

Figure 2.2. The conventional innerspring mattress and base

Hospital mattress (HM)

The hospital mattress which was used for the purposes of this study is shown in figure 2.3. This was a foam mattress covered with a washable outer cover made of cotton, which was placed on top of an innerspring mobile base (on wheels).

Figure 2.3. The hospital mattress (HM) used in this study.

Triple density (TD) foam mattress

A triple density flat foam surface (figure 2.4.), was placed on top of the conventional flat innerspring mattress (*Sealy*®; CM). This triple density foam surface consisted of the following dimensions: 192 cm in length and 91 cm in width.

Figure 2.4. The triple density foam mattress (TD)

60 mm convoluted foam surface (CFS)

This foam surface differed from the latter one in that it was composed of single density convoluted (egg-crate shape) foam (figure 2.5.). This flat foam surface was placed on top of the conventional flat innerspring mattress (*Sealy*®; CM), and consisted of the following dimensions: 60 mm thick, 91 cm in width and 192 cm in length.

90 mm convoluted foam surface (CFS)

This foam surface was made of convoluted single density foam (egg-crate shape), with the following dimensions: 90 mm thick, 91 cm wide and 192 cm in length. Once again, this flat foam pad was placed on top of the inner spring *Sealy*® mattress.

Figure 2.5. 60 mm convoluted foam surface (CFS)

Polystyrene mould (PM)

A precise mould of a medium size lumbar body support was produced in polystyrene for the purposes of this trial (figure 2.6). Hence in chapter five we used one LBS and one polystyrene mould both of medium sizes. The manufacturers ensured that the exact geometry of the LBS was mirrored in order to provide support in the same regions as the LBS so as to simulate the anatomic contours of the body in the supine position. Hence, whilst the polystyrene mould retained the same shape and contour as that of the LBS, its comfort was altered to form a very rigid, single density surface. The mould was placed on top of the conventional innerspring surface (*Sealy*$_{®}$) during tests.

A single cotton sheet was placed over each surface before subjects lay down, in order to standardise the testing procedure.

Figure 2.6. Polystyrene mould

List of abbreviations for the surfaces used in this study

CM	(conventional flat inner-spring mattress, *Sealy*®)
LBS	(lumbar body support; KBS 2000 *Klaas Vakie*®)
LBS + CM	(lumbar body support placed on top of the conventional mattress)
CFS	(convoluted foam surface - egg crate shape)
CFS + CM	(convoluted foam surface placed on top of the conventional mattress).
HM	(hospital mattress)
HM + CM	(hospital mattress placed on top of the conventional mattress)
TD	(triple density foam)
TD + CM	(triple density foam placed on top of the conventional mattress)
60 mm CFS	(60 mm convoluted foam surface)
60 mm CFS + CM	(60 mm convoluted foam surface placed on top of the conventional mattress
90 mm CFS	(90 mm convoluted foam surface)
90 mm CFS + CM	(90 mm convoluted foam surface placed on top of the conventional mattress)
PM	(polystyrene mould)
PM + CM	(polystyrene mould placed on top of the conventional mattress)
Base + LBS	(lumbar body support placed on top of the base)

CHAPTER THREE

GENERAL METHODS USED IN CHAPTERS FOUR AND FIVE

GENERAL METHODS USED IN CHAPTERS FOUR AND FIVE

The study protocols were approved by the Ethics and Research Committee of the Faculty of Medicine of the University of Cape Town, and performed according to the principles of the Declaration of Helsinki. All subjects provided written informed consent.

The methods described below apply only to chapters **four and five**, whilst methods for chapter six is described in detail in that chapter.

To be considered for inclusion into the study, patients obtained a diagnosis of conditions presenting with acute-upon-chronic lower back pain. This was determined by a physician during a physical examination. Patients were included only if palpation of the erector spinae musculature elicited tenderness on physical examination. The patient was then referred to the back rehabilitation programme at the Sports Science Institute of South Africa (SSISA) by the medical practitioner where they were recruited for the study.

Each patient was required to report to a laboratory at the SSISA. Standard medical and surgical histories were recorded for each patient, as were past and present symptoms, intensity of discomfort, onset of discomfort, physical activities, present medication, relieving and aggravating factors. Patients were requested not to consume any caffeine in addition to prescribed or over the counter medication three hours prior to testing.

Height, weight and trochanteric diameters (Td) were recorded for each patient. In chapter four each individual was fitted to the appropriate size LBS (small; Td of below 87 cm, medium; Td of 87-99 cm, or large; Td of 100-109 cm). In chapter five patients with a Td of 87-99 cm (medium) were used in order to make accurate scientific comparisons with the medium size polystyrene mould.

Patients were required to lie supine, in random order on three different surfaces (LBS+CM, 60 mm CFS+CM and CM) (refer to chapter two for abbreviations). The position of the head was controlled my placing a pillow beneath the neck when patients lay on the flat surfaces.

Electromyographic (EMG) measurements, heart rate, and perception of discomfort were documented in response to lying on each surface. Subjects lay supine on the test surface for a 5-minute period before data were recorded, and for a further 30 minutes thereafter. After a 10-minute break, the exact testing procedure was replicated on a different test surface. Patients were tested in the same room each time where testing conditions (room temperature, investigator, noise levels) were constant for inter and intra test surface.

Measurement of EMG activity

Prior to resting on each surface in randomised order, the EMG electrodes were attached to the patients' back. The erector spinae muscles were chosen as the muscle groups to be used for EMG assessment.

EMG activity was detected by triode surface electrodes (Thought Technology Triode™ MIEP01-00, Montreal, Canada) and positioned over the belly of the erector spinae muscles in the area that the patient experienced the most tenderness to palpation. If both sides were equally painful, the electrodes were placed on the right side of the spine. Surface electrodes are appropriate for detecting signals generated from the superficial back muscles such as the erector spinae (Kamen et al., 1996).

Prior to placement of each electrode, the skin overlying the muscles was carefully prepared. Hair was first shaved off, the outer layer of epidermal cells abraded, and the oil and dirt removed with an alcohol pad. The leads were

further stabilised with micropore adhesive tape to prevent electrode movement. To prevent cross talk, the inter electrode distance, measured in the longitudinal direction of the muscle fibres, was kept constant, as described by De Luca, (1994). Care was taken not to place electrodes on the identified motor points to avoid unwanted signal effects related to the innervation zone of the muscle (Roy et al., 1986). Therefore the electrode was placed in the middle of the muscle between the origin and insertion point, as the outside edges of the muscle are susceptible to detecting crosstalk signals from adjacent muscles. To ensure that the electrode placement remained constant throughout the trials, subjects were asked not to remove electrodes between tests.

The Triode electrodes were linked up via a fibre-optic cable to the Flexcomp/DSP EMG apparatus (Thought Technology, Montreal, Canada) and customised software programme (FlexComp™ Version 1.51B). A 50 Hz notch filter was applied to the EMG data throughout testing to prevent electrical interference. There is no significant movement artefact in supine bed rested subjects, therefore no further filtering was used (Derman et al., 1995).

The EMG signals were sampled 31 times per second over 5-minutes, thus yielding raw signals and then displayed on a computer screen at the end of each 5-minute period. A toggle switch was activated at the beginning of each test so as to mark the start point of the test procedure. Temporal normalisation of the data was based on the toggle-switch data and by expressing the EMG as a function of the 5-minute time period. This ensured that the identical number of data points was collected from each muscle group tested to allow for comparisons between groups.

Values were converted into root mean square (RMS). An average value was obtained for each lead over the five minute period. RMS EMG, dependent on the area, number and firing rate of the motor unit action potential was advocated by

Basmajian et al., (1985) as the most appropriate method for signal analysis. Consequently, RMS EMG was the method of data analysis employed in this study.

Measurement of heart rate

Heart rate was measured continuously each minute and the recordings were averaged over five minute intervals using a Polar Favour heart rate monitor (Polar Electro, Finland). The start button on the heart rate monitor was depressed at the same time as the toggle switch for recording EMG activity.

Rating of discomfort

Perception of discomfort was recorded on a scale of 1 to 10 (Table 3.1) at the end of each 5 minute period. The identical scale to that which was used in the study by Derman et al., (1995) was applied in this thesis.

Table 3.1. Scale used to measure perception of comfort/discomfort

1 = Extremely comfortable
2 = Very comfortable
3 = Moderate comfort
4 = Comfort
5 = Minimal discomfort
6 = Mild discomfort
7 = Moderate
8 = Severe discomfort
9 = Extreme discomfort
10 = Unbearable discomfort

Statistical analysis

The significance of differences between experimental variables were analysed using a multifactor analysis of variance (ANOVA), with two main effects (time and group), with repeated measures. This analysis determined the main effect and the interaction effects between groups over time for changes in heart rate and EMG activity. Data were further analysed by calculating the mean area under the curve for heart rate vs. time. A one way analysis of variance was used to determine significant differences between groups including mean area under the curve for heart rate vs. time and average heart rate over time. A Scheffe's post hoc test was used where significant values were found. A Friedman two way analysis of variance was used for non parametric measures (rating of comfort, scale of one to ten). Statistical significance was established at the $p < 0.05$ level. The statistical procedures were performed on the Statgraphics software package (Statgraphics, version 6, Graphics Corp; USA). The EMG data from one patient in chapter four and one individual in chapter five was excluded from the statistical analysis due to poor EMG signal recording. Therefore in the EMG statistical analysis 9 patients were used and in the heart rate and rating of discomfort analysis 10 volunteers were used.

CHAPTER FOUR

PHYSIOLOGICAL EVALUATION OF THE LUMBAR BODY SUPPORT, CONVOLUTED FOAM SURFACE AND CONVENTIONAL FLAT MATTRESS IN PATIENTS WITH ACUTE-UPON-CHRONIC LOWER BACK PAIN

PHYSIOLOGICAL EVALUATION OF THE LUMBAR BODY SUPPORT, CONVOLUTED FOAM SURFACE AND CONVENTIONAL FLAT MATTRESS IN PATIENTS WITH ACUTE-UPON-CHRONIC LOWER BACK PAIN

Introduction

The use of a lumbar support during sitting is frequently advocated (Williams et al., 1991; Grandjean 1987; McKenzie 1981; Pope et al., 1984; Twomey et al., 1988). Such a device helps to maintain the lumbar lordosis, prevent pelvic rotation (Keegan 1953), with reduction in intradiscal pressure and erector spinae musculature myoelectrical activity (Andersson et al., 1975). Furthermore, abnormally high stresses on both the facet joint cartilages and collagenous elements of the inter vertebral discs can be avoided when the lumbar lordosis is maintained (Twomey et al., 1988).

Williams et al., (1991) explored the use of a lumbar roll in reducing back and referred pain in the sitting posture. They found that alteration in sitting posture from kyphotic to lordotic, facilitated by a lumbar support, resulted in decreased back and leg pain and centralisation of pain. McKenzie (1981) describes the centralisation phenomenon as a change in distribution of referred symptoms from a distal to a more central location.

While studies have examined the effect of a lumbar support on lower back pain during sitting, minimal research has focused on the use of a lumbar support for lower back pain in the supine position. Since many patients with lower back pain suffer from insomnia and nocturnal discomfort (Boissonnault et al., 1996), it may be possible that the use of a lumbar body support (LBS) may positively influence these symptoms.

Muscle spasm and increased myoelectric activity of the lumbar erector spinae muscles are recognised findings in lower back pain (Roy et al., 1990). Although EMG activity of the lower back musculature has been well researched in the sitting and standing postures, to my knowledge, there has only been one study that has focused on the effect of EMG activity in the supine posture (Derman et al., 1995).

This study indicated that the EMG activity of the lumbar erector spinae muscles in patients with acute-upon-chronic lower back pain is decreased following lying on a LBS, compared to a conventional flat mattress (CM) (Derman et al., 1995). In addition, decreased lumbar skeletal muscle activity, heart rates and ratings of pain and discomfort were reduced in the patients following lying on the LBS compared with a flat surface. Other surfaces were not however tested.

A convoluted foam surface (egg - box shape) (CFS) which is soft, but does not offer any lumbar support is one popular form of management for patients with lower back pain. As the CFS is predominantly flat, it resembles the conventional surface mattress and when placed on top of a conventional mattress, the patients' comfort may be improved due to increased softness. However, it is postulated that without maintenance of the lumbar lordosis, the CFS is likely to be without effect on heart rate and EMG activity of the posterior paraspinal musculature.

The aim of this study is therefore to determine if there is a difference in EMG measurement, heart rate response and perception of comfort in patients with acute-upon-chronic lower back pain, after lying on three different surfaces: lumbar body support placed on top of the conventional flat surface (LBS+CM), 60 mm convoluted flat surface placed on top of the conventional flat surface (CFS+CM) and conventional flat mattress alone (CM).

Patient selection and recruitment

Ten patients presenting with localised acute-upon-chronic lower back pain of various causes, were referred to the back rehabilitation programme at the Sport Science Institute of South Africa, (SSISA). A medical practitioner referred each patient after diagnosis during a physical examination. Each patient presented with lower back pain at time of entry to the study. For a patient to be included into the study, deep palpation of the lumbar erector spinae muscles or the spinous processes had to elicit discomfort. Individuals with a history of lower back pain who were currently pain free were excluded.

Methods and statistical analysis

The methods and statistical analysis used in this study is described in more detail in chapter 3.

Results

Table 4.1. provides detail of the patients used in this study (Mean age; 38.8 yrs, height; 1.72 m, Td; 85.2 cm and mass; 71.3 kg). Additionally the clinical diagnoses are listed.

Table 4.1. Characteristics and clinical diagnoses of patients with acute-upon-chronic LBP.

Patient no.	Gender	Age (yrs)	Height (m)	Td (cm)	Mass (kg)	Clinical diagnosis
1	F	28	1.73	109.0	96.3	Vertebral compression fracture L_4
2	F	58	1.69	70.0	58.3	Mechanical lower back pain
3	F	48	1.65	78.3	68.5	Facet joint arthritis
4	F	36	1.76	74.4	59	Scoliosis
5	F	26	1.65	71.5	60.5	Osteoporosis, mild scoliosis
6	M	47	1.75	86.1	76	Disc prolapse L_4/L_5
7	M	21	1.73	87.3	72	Disc prolapse L_3/L_4; L_4/L_5
8	F	46	1.60	87.0	69	Disc prolapse L_4/L_5
9	M	33	1.86	89.4	73	Iliolumbar ligament strain
10	M	45	1.80	99.0	80	Mechanical lower back pain
Ave		38.8	1.72	85.2	71.3	

Abbreviations: no, number; yrs, years; m, meters; Td, trochanteric diameter; kg, kilograms; Ave, average.

Average heart rate response

Average heart rate response after lying on each of the three surfaces over a 30 minute period is documented in table 4.2. and figure 4.1. There was a significant difference between groups (group effect) on average heart rate during the 30 minute period. Average heart rate measured over 30 minutes on the LBS+CM (60 ± 11 b/min) was significantly lower than average heart rate measured on the CM alone (66 ± 10 b/min, $p < 0.05$). Although the average heart rate response to the LBS+CM (60 ± 11 b/min) tended to be lower compared to the CFS+CM (64 ± 9 b/min), this difference was not statistically significant. There was no significant change over time, from the initial five to the last five minutes of the 30 minute period (time effect) for either of the three surfaces. However, when data were expressed as area under the curve of heart rate vs. time, a value of $p < 0.49$ for between group measures was obtained [LBS (1507 ± 72 beats) vs. CFS (1584 ± 72 beats) and CM (1629 ±72 beats)].

Rating of discomfort during the test

Average rating of discomfort (scale of 1-10) is presented in table 4.3 and figure 4.2. Patients reported a significantly lower average rating of discomfort on the LBS+CM (1.9 ± 0.7 units), compared to the CFS+CM (3.9 ± 1.0 units) and the CM (4.7 ± 2.2 units; $p < 0.05$; LBS+CM vs. CFS+CM and CM). At the end of the 30 min period perception of discomfort was greatest on the CM (5.6 ± 2.7 units) followed by the CFS (4.3 ± 0.9 units) and LBS (1.4 ± 0.5 units) (table 4.3.).

Table 4.2. Changes in heart rate during 30 minutes in the supine position on the conventional mattress, the lumbar body support placed on top of the conventional mattress and convoluted foam surface placed on top of the conventional mattress.

Minute	Average HR (LBS+CM)	Average HR (CFS+CM)	Average HR (CM)
5	65 ± 11	67 ± 10	67± 12
10	62 ± 10	64 ± 10	64 ± 10
15	61 ± 9	62 ± 9	65 ± 10
20	59 ± 11	62 ± 8	65 ± 9
25	58 ± 12	63 ± 8	66 ± 9
30	56 ± 11	64 ± 9	66 ± 8
Average	60 ± 11*	64 ± 9	66 ± 10

Abbreviations and units: HR, heart rate (b/min); LBS, lumbar body support; CFS, convoluted foam surface; CM, conventional mattress. * = LBS+CM vs. CM ($p < 0.05$). Data expressed as values ± SD.

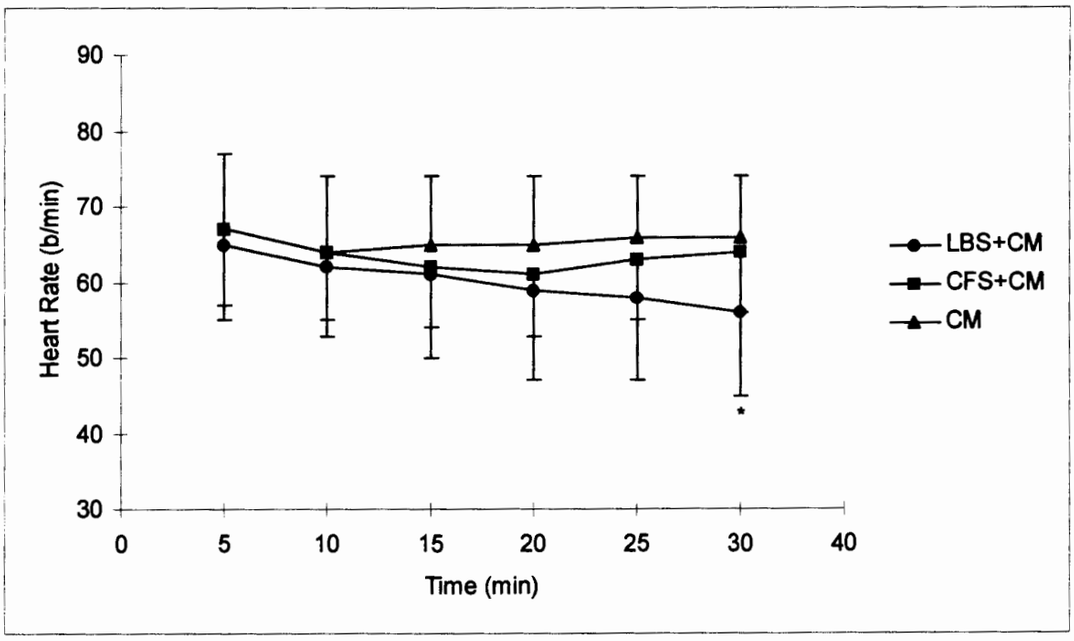

Figure 4.1. Average heart rate response in the supine position over a 30 minute period after resting on the lumbar body support placed on top of the conventional mattress, the convoluted foam surface placed on top of the conventional mattress and the conventional mattress alone. * = LBS+CM vs. CM ($p < 0.05$). Data expressed as means ± SD. Abbreviations: LBS+CM, lumbar body support placed on top of the conventional mattress; CFS+CM, convoluted foam surface placed on top of the conventional mattress; CM, conventional mattress.

Table 4.3. Rating of discomfort during 30 minutes of lying supine on the conventional mattress, the lumbar body support and convoluted foam surface placed on top of the conventional mattress.

Min	Average ROD (LBS+CM)	Average ROD (CFS+CM)	Average ROD (CM)
5	2.5 ± 1.0	3.5 ± 1.1	3.1 ± 0.7
10	2.1 ± 0.7	3.8 ± 1.0	4.3 ± 2.3
15	1.9 ± 0.6	3.7 ± 1.1	4.7 ± 2.4
20	1.7 ± 0.7	3.8 ± 1.0	5.0 ± 2.4
25	1.6 ± 0.7	4.0 ± 0.8	5.2 ± 2.5
30	1.4 ± 0.5	4.3 ± 0.9	5.6 ± 2.7
Average	1.9 ± 0.7 *	3.9 ± 1.0	4.7 ± 2.2

Abbreviations: Min, minute; ROD, rating of discomfort (scale 1-10); LBS+CM, lumbar body support + conventional mattress; CFS+CM, convoluted foam surface + conventional mattress; CM, conventional mattress. * = LBS+CM vs. CFS+CM and CM ($p < 0.05$). Data expressed as values ± SD.

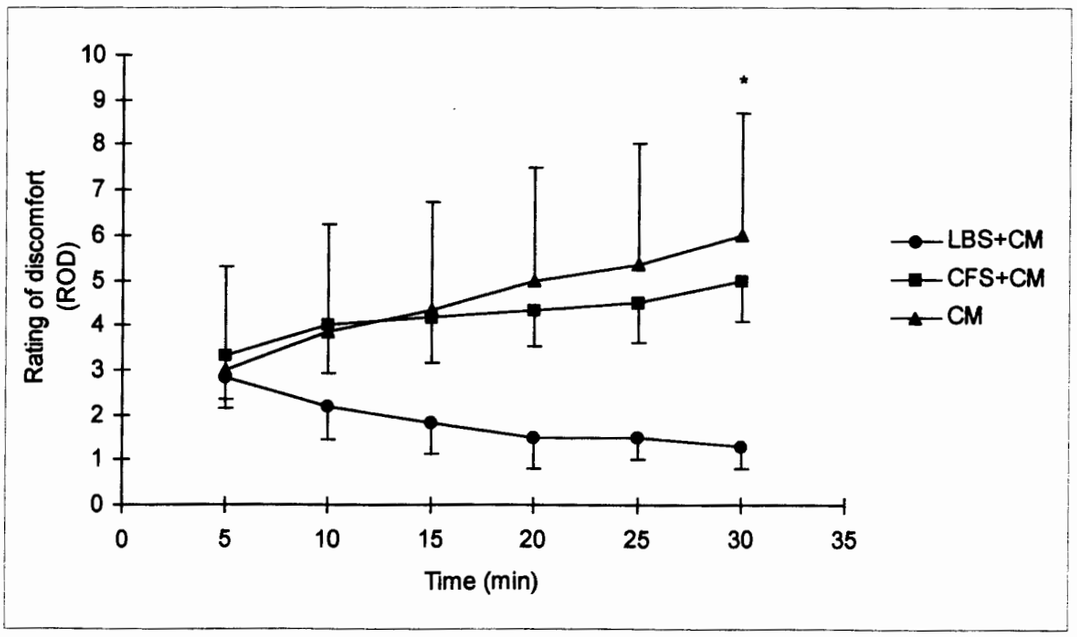

Figure 4.2. Average perception of comfort (10 point scale) during 30 minutes of lying supine on the LBS+CM, CFS+CM and the CM. Abbreviations: LBS+CM, lumbar body support placed on top of the conventional mattress; CFS+CM, convoluted foam surface placed on top of the conventional mattress; CM, conventional mattress. * = LBS+CM vs. CFS+CM and CM ($p < 0.05$). Data are expressed as means ± SD.

Average EMG activity of the erector spinae muscles

Average EMG activity is represented in tabular form, (table 4.4.) and graphically (figure 4.3.). The EMG activity was significantly lower after resting on the LBS+CM compared to the CFS+CM and CM [LBS+CM (2.68 ± 1.1 mv) vs. CFS+CM (4.46 ± 2.7 mv) and CM (4.19 ± 2.4 mv; $p < 0.05$)]. Although average EMG activity decreased over the 30 minute time period on the LBS, this change was not statistically significant ($p = 1.0$). Furthermore, the interaction between group and time was not significant ($p = 0.46$).

Table 4.4. Changes in average EMG activity of the lumbar erector spinae muscles during 30 minutes in the supine position on the lumbar body support placed on top of the conventional mattress, convoluted foam surface on top of the conventional mattress and conventional mattress alone.

Min	EMG activity (LBS+CM)	EMG activity (CFS+CM)	EMG activity (CM)
10	3.19 ± 1.1	4.64 ± 2.6	3.51 ± 2.0
20	2.74 ± 1.4	4.58 ± 2.8	4.0 ± 1.8
30	2.11 ± 0.9	4.16 ± 2.6	5.06 ± 3.5
Average	2.68 ± 1.1*	4.46 ± 2.7	4.19 ± 2.4

Abbreviations: Min, minute; EMG, electromyographic activity; LBS+CM, lumbar body support + conventional mattress; CFS, convoluted foam surface; CM, conventional flat mattress. * = LBS+CM vs. CFS+CM and CM ($p < 0.05$). Data expressed as values ± SD.

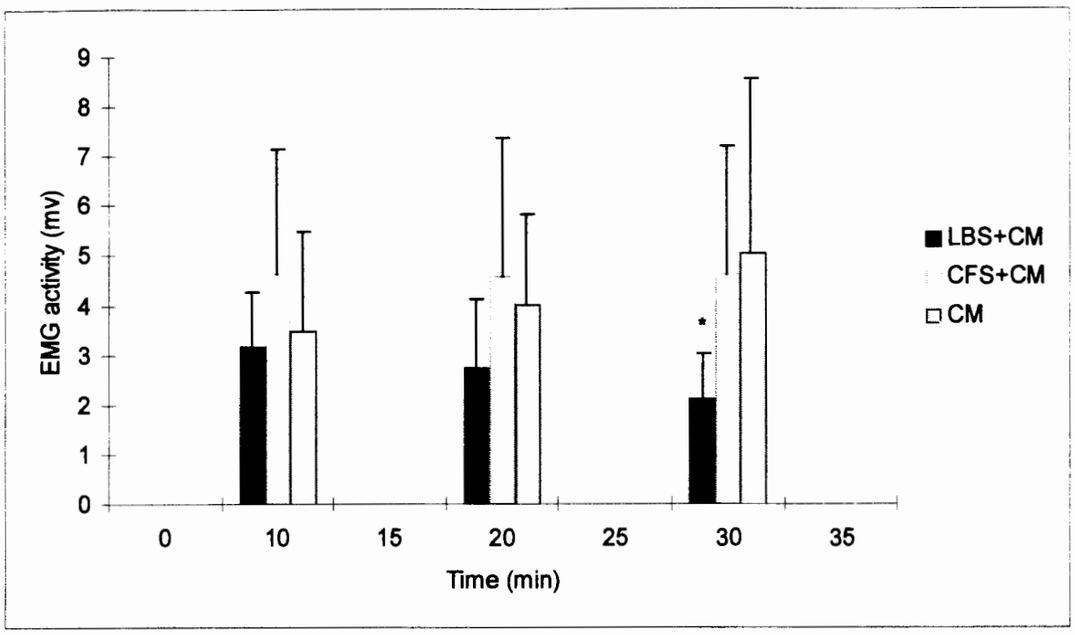

Figure 4.3. Changes in EMG activity of the lumbar erector spinae muscles during 30 minutes in the supine position. Abbreviations: LBS+CM, lumbar body support placed on top of the conventional mattress; CFS+CM, convoluted foam surface placed on top of the conventional mattress; CM, conventional mattress. * = LBS+CM vs. CFS+CM and CM ($p < 0.05$). Data expressed as values ± SD.

Discussion

The most significant finding of this study was that in the short term (30 minutes), patients with lower back pain reported that lying on the LBS+CM was more comfortable than lying on either the CFS+CM or the CM. Ratings of discomfort increased similarly with time when patients lay on either the CFS + CM or the CM. In contrast ratings of comfort improved after 30 minutes on the LBS + CM.

These subjective responses were mirrored by changes in EMG activity of the erector spinae muscles. Average EMG activity was significantly higher following acute exposure to the CFS+CM and CM compared with the LBS+CM. This finding suggests that the myoelectric activity of the erector spinae muscles is increased in patients with acute-upon-chronic lower back pain when lying on either a flat low density 60 mm convoluted foam surface on top of a conventional flat mattress (CFS+CM), or a traditional flat innerspring mattress (CM). This activity decreases when patients lie on a quadruple density foam, contoured lumbar body support, placed on top of the traditional innerspring mattress (LBS+CM). Increase in tonic activity might be responsible for the greater discomfort levels experienced by patients when lying on the CM or CFS+CM.

The above findings are in keeping with the reflex spasm model as described by Geisser et al., (1995). This model relates a specific physiological response to organic pathology. The model suggests an increase in muscle activity due to postural faults, ligamentous strain or tissue inflammation (Collins et al., 1982). One would therefore expect a general increase in muscular activity during rest and during movement in patients with lower back pain as part of the pain-spasm-pain cycle (Traue et al., 1992). In keeping with the above, significantly higher resting state EMG recordings were documented in LBP patients vs. the group without pain (Grabel, 1973). According to his findings, Grabel suggests EMG

feedback-induced muscle relaxation training should be used as an effective treatment modality for low back pain patients.

However, reports in the literature are inconsistent, although some studies have observed higher resting levels of EMG in the lumbar region (Hoyt et al., 1981), in standing (Flor et al., 1989; Flor et al., 1985; Soderberg et al., 1983; Jayasinghe et al., 1978) and in sitting (Kessler et al; in submission). Others like Kravitz et al., 1981 and Miller 1985 found no difference in resting EMG levels in patients with lower back pain. These discrepancies highlight the technical difficulties associated with EMG measurement.

Studies have shown that the use of a lumbar support during sitting reduces EMG activity of the posterior paraspinal muscles (Andersson et al., 1975) and decreases back and leg pain (Williams et al., 1991). This is in accordance with McKenzie (1981), who advocates that the maintenance of a lumbar lordosis decreases the pressure on the pain sensitive structures of the neural foramen due to anterior displacement of the nucleus pulposis. McKenzie (1981) recommends supine lying with the hips in an anatomically neutral position, the knees in extension and a lumbar roll under the lower back.

Resting cardiovascular responses mirrored these different responses in EMG activity and the reported ratings of discomfort in this study after subjects lay on the different surfaces.

Although average heart rate measured over a 30 minute period was lower after lying on the LBS+CM, when compared to the CFS+CM, this difference was not statistically significant. Average heart rate was, however significantly higher, after lying on the CM when compared to the LBS+CM. This suggests that the increased EMG activity and heart rate response after lying on the CM was

associated with either decreased parasympathetic or increased sympathetic activity.

This is in keeping with the psychosocial stress model as described by Traue et al., (1992), which argues that increased muscle activity is related to stressful events and will be found in a symptom specific response pattern of the suffering patient. In support of this model we would expect activation patterns during periods of emotional stress. The assumed causal relationship is that the patient has a physiologic response pattern to stress that is maximal in the paraspinal muscles. This persistent hyperactivity of these muscles leads to chronic low back pain.

In discussing the findings of this thesis it is necessary to describe certain of the shortcomings of the study, which may help future researchers when designing protocols for similar trials. It remains a challenge to medical practitioners and therapists alike to make a precise diagnosis of the exact origin of LBP. The patients who participated in the study have a range of different conditions. This should be controlled to some extent in future studies which should perhaps include a more homogenous sample, for example those patients diagnosed with disc prolapse. In addition future studies are required to determine EMG response of the lumbar muscles after resting on a 90 mm CFS.

The results of this study are important in that they supplement the existing literature on the use of a lumbar body support in supine postures. The findings of this study mirror those of Derman et al., (1995), confirming the value of this body support for patients with lower back pain who have difficulty sleeping at night. This may have important clinical implications for other patients suffering from chronic pain, including metastatic cancer. Furthermore, the true value of the lumbar body support may be under estimated in this study, as patients rested only for a 30 minute period and people sleep for about eight hours a night.

Therefore the long-term effects of sleeping on this body support might be even more pronounced.

In addition, the results of this study suggest that the use of a 60 mm CFS ("egg box mattress") in the management of patients with lower back pain, may not be the optimal form of treatment in terms of improving level of comfort, or in reducing paraspinal muscular spasm as neither rating of discomfort, heart rate or EMG activity decreased after lying on this convoluted foam surface over a 30 minute period. This may be explained by the inherent "softness" of the surface which essentially resembles the characteristics of the underlying mattress, which is flat, low in density and lacking in contour. This will be explored further in the following chapter.

These results are sufficiently positive to warrant further clinical trials with the use of the LBS in the management of lower back pain.

CHAPTER FIVE

PHYSIOLOGICAL EVALUATION OF A POLYSTYRENE MOULD, LUMBAR BODY SUPPORT AND CONVENTIONAL FLAT MATTRESS IN PATIENTS WITH ACUTE-UPON-CHRONIC LOWER BACK PAIN

PHYSIOLOGICAL EVALUATION OF A POLYSTYRENE MOULD, LUMBAR BODY SUPPORT AND CONVENTIONAL FLAT MATTRESS IN PATIENTS WITH ACUTE-UPON-CHRONIC LOWER BACK PAIN

Introduction

The findings from the study described in the previous chapter suggest that a 60 mm convoluted foam surface, with no lumbar support, may not be the optimal sleep surface for patients with lower back pain. Further, in the short term (30 minutes) we have shown that EMG signals, heart rate and rating of discomfort in patients suffering from lower back pain are reduced by using a locally designed lumbar body support when compared to a traditional flat mattress.

These findings are supported by the results of previous work which have documented that the use of a lumbar support reduces lower back pain and discomfort whilst sitting (Williams et al., 1991) and lying supine (Derman et al., 1995).

It would be interesting to determine the mechanism whereby the LBS brings about a reduction in muscular activity, heart rate and discomfort in patients with lower back pain. We therefore conducted this clinical trial, in an attempt to determine the mechanism of action of this lumbar support.

It is possible that the lumbar body support is different to the conventional mattress in two ways. Firstly, the LBS has a different density (softer). Secondly, it offers support in the lumbar region (contour). It may be the change in density, the distinctive contour, or a combination of these features that explains the different effects of the different surfaces. In order to study this question further, we compared one medium size LBS and traditional flat innerspring mattress to a polystyrene mould, identical to the shape and size of the LBS. Hence, we retained the shape and size of this support system and increased its density.

Therefore the study aim was to determine the EMG activity of the erector spinae muscles, cardiovascular response and perception of discomfort in patients with acute-upon-chronic lower back pain after lying supine on three surfaces: a medium size lumbar body support on top of the conventional mattress (LBS+CM), conventional mattress (CM), and polystyrene mould (identical to the shape and size of the LBS, but much harder), on top of the conventional mattress (PM+CM).

Patient selection and recruitment

A further ten patients with a history of localised acute-upon-chronic lower back pain of various causes, were referred to the back rehabilitation programme at the Sport Science Institute of South Africa (SSISA) by a medical practitioner, after a physical examination. Patient numbers 1, 2 and 3 participated in the study described in the previous chapter.

Methods

The identical methods and recruitment criteria used in the previous study was implemented in this study. (See chapter three for detailed description of methods used).

Statistical analysis

The statistical analysis was the same as that which was reported in the previous chapter. (See chapter three for details).

Results

Clinical diagnoses and patient characteristics at time of entry into the study are presented in table 5.1. The average patient age (37.8 yrs), height (1.7 m), trochanteric diameter (Td; 92.3 cm) and mass (74.6 kg) is documented. These characteristics with exception of Td are comparable to those of the patients used in the previous trial.

Table 5.1. Characteristics and clinical diagnoses of patients presenting with acute-upon-chronic lower back pain at time of entry into the study.

Patient no.	Gender	Age (yrs)	Height (m)	Td (cm)	Mass (kg)	Clinical diagnosis
1	M	21	1.73	87.3	72	Disc prolapse L_3/L_4;L_4/L_5
2	F	46	1.60	87.0	69	Disc prolapse L_4/L_5
3	M	45	1.80	99.0	80	Mechanical lower back pain
4	M	20	1.81	95.0	80	Disc prolapse L_4/L_5
5	M	27	1.63	87.6	64	Mechanical lower back pain
6	F	25	1.60	94.3	80	Mechanical lower back pain
7	M	27	1.83	98.9	98	Disc prolapse
8	F	47	1.73	88.8	66	Iliolumbar ligament strain
9	F	76	1.55	87.0	60	Osteoporosis
10	M	44	1.80	97.6	85	Laminectomy (L_4/L_5)
Ave		37.8	1.70	92.3	74.6	

Abbreviations: No, number; yrs, years; m, meters; Td; trochanteric diameter; cm, centimetres; kg, kilograms; Ave, average.

Average heart rate response

Average heart rate response after lying supine on each of the three surfaces for a 30 minute period is presented in table 5.2. and in figure 5.1. A two way anova with repeated measures revealed a significant difference between the three groups (group effect) [LBS+CM (60 ± 7 b/min) was significantly different from the PM+CM (66 ± 10 b/min) and CM (68 ± 9 b/min; $p < 0.01$)]. In addition there was a decrease in heart rate over time (time effect) ($p = 0.02$). The Scheffe's post-hoc test could not identify specific time differences, therefore the groups were split and analysed individually over time using a one way anova with repeated measures. This revealed a significant time effect for the LBS+CM ($p = 0.006$), where min 5 was different to minute 30 ($p < 0.05$). Average heart rate decreased from 67 ± 10 b/min to 55 ± 6 b/min on the LBS+CM ($p < 0.05$). There was no significant change in heart rate response over time after lying on the CM (71 ± 12 b/min vs. 69 ± 7 b/min) or the PM+CM (72 ± 8 b/min vs. 63 ± 10 b/min). The interaction between group and time was not significant ($p = 0.78$).

Table 5.2. Changes in average heart rate during 30 minutes in the supine position on the lumbar body support and polystyrene mould placed on top of the conventional mattress and conventional mattress alone.

Min	Ave HR (LBS+CM)	Ave HR (PM+CM)	Ave HR (CM)
5	67 ± 10	72 ± 8	71 ± 12
10	63 ± 7	67 ± 9	67 ± 11
15	61 ± 7	65 ± 8	66 ± 8
20	58 ± 7	66 ± 11	68 ± 10
25	57 ± 7	64 ± 11	69 ± 8
30	55 ± 6**	63 ± 10	69 ± 7
Ave	60 ± 7*	66 ± 10	68 ± 9

Abbreviations: Min, minute; Ave, average; HR, heart rate (b/min); LBS+CM, lumbar body support+conventional mattress; PM+CM, polystyrene mould+conventional mattress; CM, conventional mattress. * = LBS+CM vs. PM+CM and CM ($p < 0.01$). ** = LBS+CM, 5 vs. 30 min ($p < 0.05$). Mean ± SD.

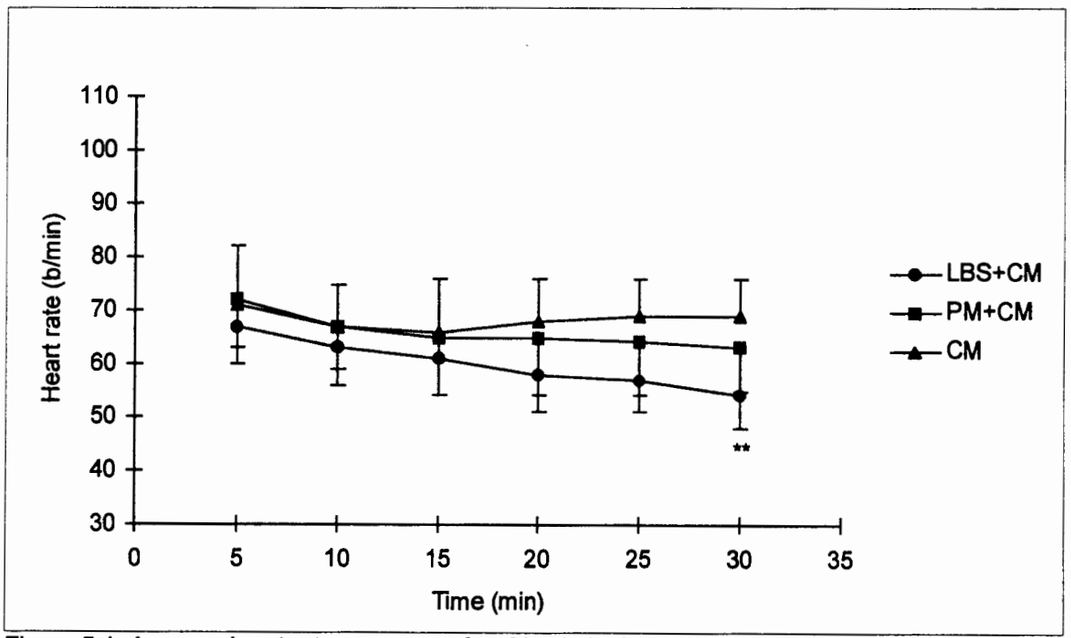

Figure 5.1. Average heart rate response after 30 min in the supine position. Abbreviations: LBS+CM; lumbar body support placed on top of conventional mattress; PM+CM polystyrene mould placed on top of conventional mattress, CM; conventional mattress alone.
** = LBS+CM, 5 vs. 30 min ($p < 0.05$). Mean ± SD.

Average rating of discomfort

Average rating of discomfort (ROD) measured on a 10-point scale reported by patients during the tests is listed in table 5.3. and displayed graphically in figure 5.2. Average ROD over the 30 minute period was significantly lower when patients lay on the LBS+CM (1.8 ± 0.6 units), compared to average ratings of discomfort after lying on the PM+CM (5.7 ± 2.5 units) and CM (4.1 ± 1.8 units; $p < 0.05$).

Table 5.3: Rating of discomfort reported during 30 minutes of lying supine on the lumbar body support and polystyrene mould placed on top of the conventional mattress, and conventional mattress alone.

Min	Ave ROD (LBS+CM)	Ave ROD (PM+CM)	Ave ROD (CM)
5	2.4 ± 0.7	5.6 ± 2.5	3.1 ± 0.9
10	2.1 ± 0.6	5.5 ± 2.5	3.4 ± 1.0
15	2.0 ± 0.7	5.5 ± 2.5	4.1 ± 1.6
20	1.6 ± 0.5	5.9 ± 2.5	4.7 ± 2.4
25	1.5 ± 0.5	5.6 ± 2.3	4.7 ± 2.4
30	1.4 ± 0.5	6.0 ± 2.5	4.8 ± 2.3
Ave	1.8 ± 0.6 *	5.7 ± 2.5	4.1 ± 1.8

Abbreviations: Min, minute; Ave, average; ROD, rating of discomfort; LBS+CM, lumbar body support+conventional mattress; PM+CM, polystyrene mould+conventional mattress; CM, conventional mattress alone. * = LBS+CM significantly different to PM+CM and CM ($p < 0.05$). Means expressed ± SD.

Average EMG activity of the erector spinae muscles.

Changes in average EMG activity of the lumbar erector spinae muscles, measured at 5-minute intervals during supine exposure to the LBS+CM, PM+CM and CM is shown in table 5.4. and figure 5.3. EMG activity was significantly lower when patients rested on the LBS+CM compared to the PM+CM and CM (LBS+CM, 2.5 ± 1.0 mv. vs. PM+CM, 4.3 ± 1.9 mv and CM, 4.6 ± 1.8 mv; $p < 0.01$). Although this activity tended to decrease over time from 10 minutes to 30

minutes, when patients rested on the LBS+CM, this decline was not significant ($p = 0.79$). Furthermore, there was no significant interaction between group and time.

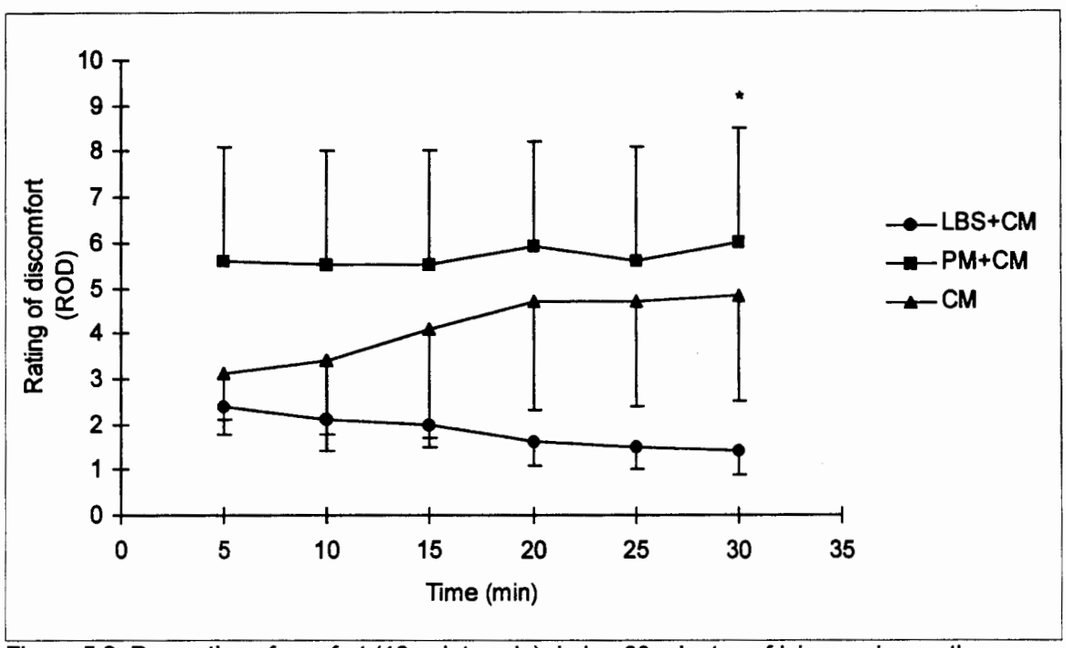

Figure 5.2. Perception of comfort (10 point scale) during 30 minutes of lying supine on the LBS+CM, PM+CM and CM. Abbreviations: LBS+CM; lumbar body support + conventional mattress; PM+CM, polystyrene mould + conventional mattress, CM; conventional mattress. * = LBS+CM vs. PM+CM and CM ($p < 0.05$). Means expressed ± SD.

Table 5.4. Electromyographic activity of the erector spinae muscles during 30 min in the supine position on the lumbar body support and polystyrene mould placed on top of the conventional mattress, and conventional mattress alone.

Minute	Ave EMG (mv) (LBS+CM)	Ave EMG (mv) (PM+CM)	Ave EMG (mv) (CM)
10	3.0 ± 1.4	4.6 ± 2.3	4.2 ± 1.3
20	2.8 ± 0.8	4.2 ± 1.7	4.5 ± 1.7
30	1.8 ± 0.9	4.1 ± 1.7	5.1 ± 2.5
Average	2.5 ± 1.0*	4.3 ± 1.9	4.6 ± 1.8

Abbreviations: Ave, average; EMG, electromyographic activity; mv (microvolts); LBS+CM, lumbar body support+conventional mattress; PM+CM, polystyrene mould+conventional mattress; CM, conventional mattress. * = LBS+CM significantly different to PM+CM and CM ($p < 0.01$). Means expressed ± SD.

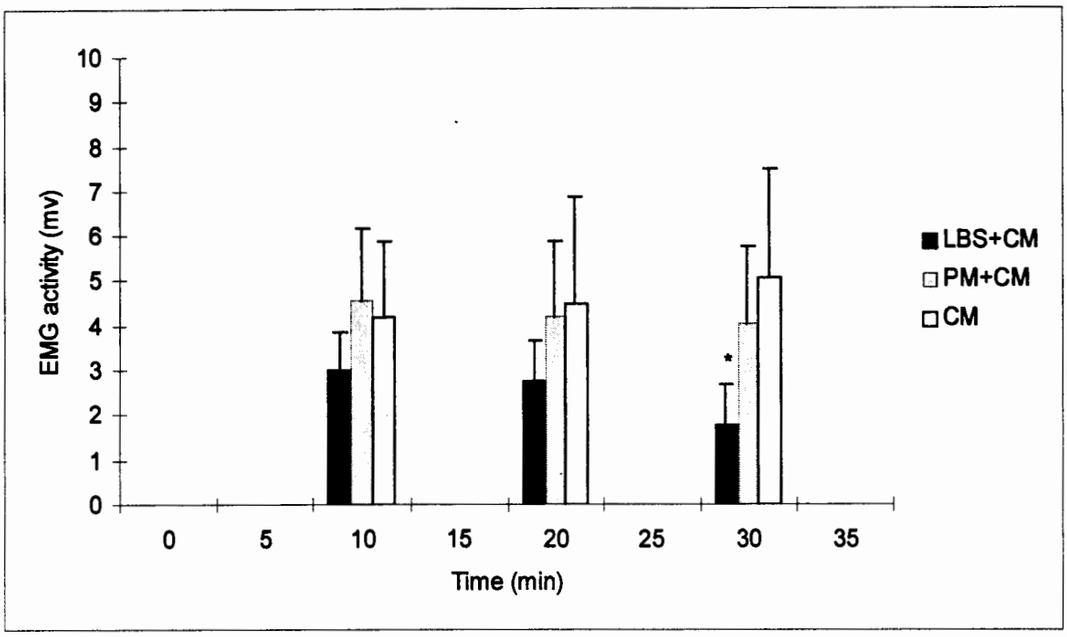

Figure 5.3. Average EMG activity of the erector spinae muscles over a 30 minute period where the LBS+CM is significantly different from the PM+CM and CM; * = $p < 0.01$. Abbreviations: LBS+CM; lumbar body support on top of conventional mattress; PM+CM, polystyrene mould on top of conventional mattress, CM; conventional mattress alone. Means expressed ± SD.

Discussion

The first important finding of this study was that the electromyographic activity in the erector spinae muscles, after lying on the lumbar body support placed on top of the conventional mattress, mirrored the changes documented in the previous chapter and those reported by Derman et al., (1995).

EMG activity was significantly higher after patients lay on the conventional surface (CM), compared to the lumbar support placed on top of the CM. It should be noted that although not statistically significant, there was a marginal decrease in EMG activity at min 30 after patients lay on the polystyrene mould with a tendency for EMG activity to rise when they lay on the CM at the same time period (figure 5.3.).

Despite the many controversies in the literature, muscular spasm is often regarded as a common feature presenting in patients with low back pain, hence a vast proportion of literature advocates the reduction of muscle tension in the paraspinal muscles. This is in keeping with the physical stressor model which advocates that muscle spasm is produced as a result of a pain-spasm-pain cycle, triggered by a physical stressful event which results in an increase in muscle activity (Traue et al., 1992; Geisser et al., 1995).

Additionally, integrated electromyographic (iEMG) technology has been used to compare patients with chronic low back pain to control subjects during a standardised postural endurance test (Biering-Sorensen, 1984). iEMG increases were significantly greater in the group with LBP compared to the controls. In an attempt to explain this phenomenon, Cooper (1993) claims the increased central drive found in patients with lower back pain is secondary to radiographically and histologically proved peripheral abnormalities found within the neuromuscular system. In order to optimise function, these patients may activate different parts or fibre-types of the same muscle, activate more groups of either fibre type, or

activate more of the available fibres. He therefore concludes that paraspinal muscle dysfunction does take place, in part as a result of disuse atrophy and denervation.

One may argue that there are certain assumptions associated with the findings in this study for example, patients were measured for a 30 minute period, yet patients who sleep on the LBS are exposed to it for longer periods (6-8 hours per night). The present results may therefore underestimate the importance of this lumbar support in the adjunctive treatment of lower back pain, as the effects over a longer period may be even more pronounced. Furthermore, measurements were not recorded in the lateral position. Since many patients sleep on their sides as opposed to the supine position, future research should address this intervention with patients in the lateral position.

The level of discomfort was greater after patients lay on the PM+CM and CM when compared to the LBS+CM. Therefore the higher EMG activity recorded after lying over a 30 minute period on the PM+CM and CM relative to the LBS+CM, could be explained by progressively increased discomfort when lying on a PM+CM. This may be further explained by the results of the study by Williams et al., (1991), which indicated that the use of a lumbar support (change of posture from kyphotic to lordotic), has the potential to change perception of pain while in a seated position. Furthermore, a combination of the appropriate density and contour features, such as those found in the LBS, may be a likely explanation for the difference in outcome measures between the various surfaces.

However, many patients with lower back pain find it easier to lie supine with two pillows under the knees and the back flattened out, as not all patients get relief from being in the lordotic position. Causes of back pain are multiple and in some

cases the more flexed position relieves pain, while in others the more extended position does the same.

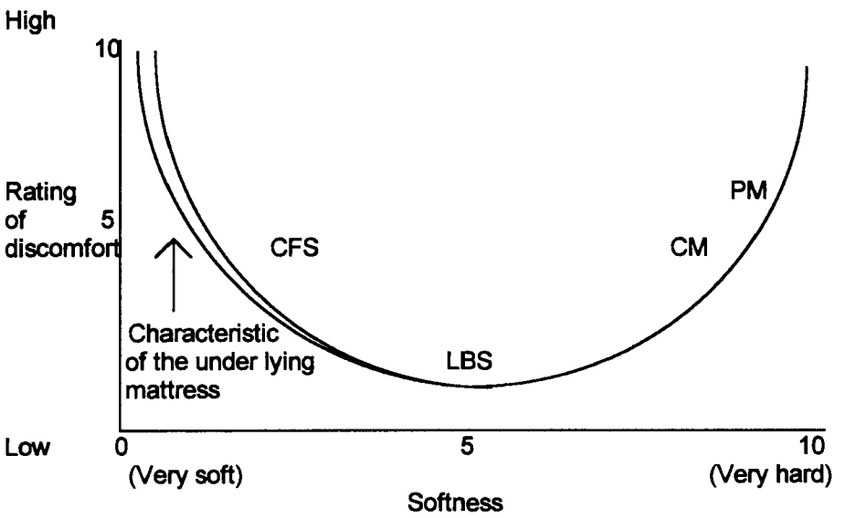

Figure 5.4. Diagram to illustrate rating of discomfort in relation to surface density (softness).

The change in outcome measures in this study could perhaps be explained by the difference in density between the various surfaces. This is represented diagramatically in figure 5.4. In this chapter, resting on a polystyrene mould resulted in the most discomfort. This can be explained by nature of the fact that this is a very hard surface which is high in density. In chapter four, patients were tested on the convoluted foam surface, lumbar body support and conventional mattress. Perception of discomfort was similar for the CM and CFS, but lower after resting on the LBS. This illustrates that the softest surface is not necessarily the most comfortable. Due to its' softness, the convoluted foam surface aquires the characteristics of the underlying traditional flat mattress, therefore the reported comfort levels were not statistically different between these surfaces. The lumbar body support on the other hand is neither too soft nor too hard, hence the low discomfort ratings.

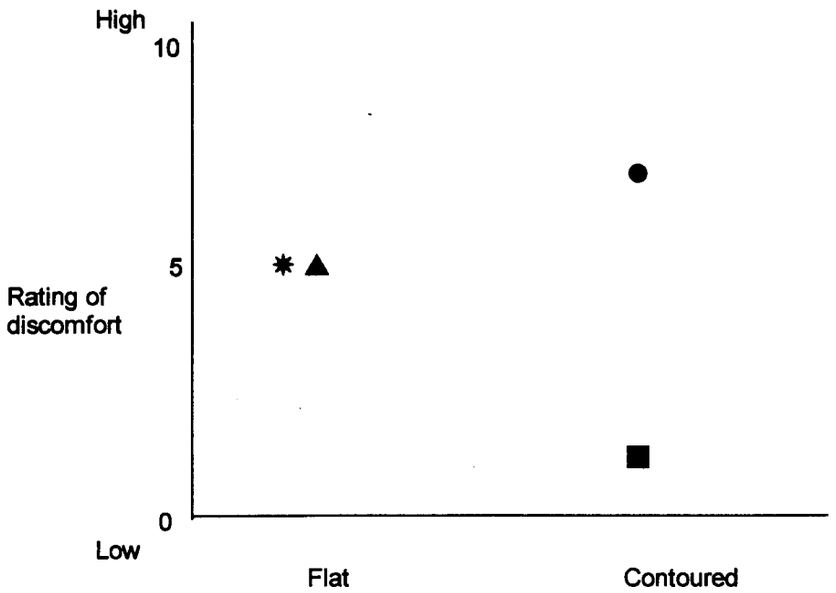

Figure 5.5. Ratings of discomfort after lying on the lumbar body support, the polystyrene mould, the conventional flat mattress and the convoluted foam surface; comparison between flat and contoured surfaces.

Key: ✱ = conventional flat surface ● = polystyrene mould
▲ = convoluted foam surface ■ = lumbar body support

Figure 5.5. represents rating of discomfort after lying on each of the four surfaces (CM, CFS, PM, LBS). It shows that ratings of discomfort were greater after lying on both the flat surfaces (conventional mattress and 60 mm convoluted foam surface) and on one of the contoured surfaces (polystyrene mould). However the reported rating of discomfort was reduced when lying on the other contoured surface (lumbar body support). Therefore it is likely to be a combination of both the contour and density features of the LBS that reduced ratings of discomfort were reported (figure 5.5).

Resting cardiovascular response after lying on the lumbar body support on top of the conventional flat surface was significantly different from both the polystyrene mould placed on top of this flat surface and the flat surface alone. Heart rate had a tendency to decrease after lying on the polystyrene mould on

top of the conventional flat surface, relative to the conventional flat surface alone, however this difference was not significant. This could be explained by Traue et al., (1992) in the psychosocial stress model, whereby it has been proposed that psychophysiological factors underlie the development of lower back pain. Therefore the difference in heart rate response after lying on each of the three surfaces may be explained by increased sympathetic or reduced parasympathetic activity.

The fact that EMG activity and heart rate were similarly elevated for both the PM (contoured, very hard) and CM (flat, soft) could indicate that neither of these surfaces are appropriate for patients suffering from lower back pain as they both resulted in higher heart rates and increased perception of discomfort. As density is increased, so comfort becomes reduced. Similarly, as density is reduced, so too contour or support is lost.

According to these results the ideal surface should incorporate a certain degree of softness, without compromising contour. This will preserve the lumbar lordosis (Williams et al., 1991) and reduce EMG activation of the lumbar paraspinal musculature (Derman et al., 1995).

The findings of this study re emphasise our previous findings that patients with lower back pain have decreased EMG activity and heart rate response, with improved perception of comfort when lying on a LBS placed on top of a traditional surface mattress. This study provides evidence that these responses were significantly elevated when patients lay supine on a PM and CM.

In conclusion, the elevated EMG activity, heart rate and perception of discomfort after lying on the polystyrene mould, suggest that it could be the combination of both the correct density (which was likely too high for the PM) and the correct

surface that is important in reducing muscle spasm in patients with acute-upon chronic-lower back pain.

CHAPTER SIX

EVALUATION OF THE PRESSURE DISTRIBUTION FOR DIFFERENT SLEEP SURFACES IN HEALTHY VOLUNTEERS.

EVALUATION OF THE PRESSURE DISTRIBUTION FOR DIFFERENT SLEEP SURFACES IN HEALTHY VOLUNTEERS.

Introduction

Prevention of pressure sores is an important concern in hospital and community care, especially in persons suffering from chronic pain, those with spinal injury and older patients who are required to spend prolonged periods lying in bed.

It has been documented that pressure build up over bony prominences of sensory deficient skin is one of the most important etiological factors for the development of pressure sores (Vohra et al., 1995). Sustained pressure over an area of tissue can induce capillary collapse, ischaemia and tissue death (Allen 1994). This eventually manifests as a pressure sore. Recent research conducted in this laboratory has shown that there is an increase in EMG activity of the erector spinae muscles in persons lying on the traditional flat mattress (Derman et al., 1995).

Conventionally, patients lying on traditional flat mattresses are turned every two hours to prevent pressure build up in skin areas overlying body parts. However the current shortage of nursing staff has promoted the use of pressure-relieving beds to reduce the risk of pressure sores. A variety of mattress overlays have been developed in an endeavour to achieve an even distribution of pressure across the body. These include foam (Rosenthal et al., 1996; Bliss, 1995; Allen, 1993), gel (Fletcher, 1996), and air (Allen, 1994, Cordell et al., 1995; Lowthian, 1995; Rithalia, 1995) products.

Of the pressure reducing devices, fluidising systems have been the most consistent in diminishing pressure over bony prominences. Additionally the low

air loss beds (powered low pressure systems which conform to and support the body shape) provide safe pressure relief (Wild, 1991; Ryan et al., 1989). Clinical benefits have been found at the occiput and heel in using alternating pressure devices, and a continuous air flow mattress provided benefits at other sites in young healthy volunteers (Allen, 1994).

In chapter four it was established that lying on a locally manufactured lumbar body support (LBS) decreases heart rate and tonic activity of the erector spinae muscles and improves perception of comfort in patients with lower back pain compared to when lying on either a standard flat mattress or a 60 mm convoluted foam surface. These results are supported by the results of Derman et al., (1995) in patients with low back pain and healthy controls.

The findings reported in chapter four imply that either the density or the contour of the LBS is important in reducing tonic activity of the erector spinae muscles and improving comfort in these patients. Further, these findings may have important clinical implications for the treatment of pressures sores and for patients suffering from low back pain, therefore it is necessary to study this possibility further.

The aims of this study are firstly, to determine the pressure at points on the skin surface in people lying supine on a variety of different mattresses of conventional composition (Conventional inner spring, and Hospital mattress), in various foam overlays of different densities (Triple Density Foam, 60 mm CFS, 90 mm CFS) and hard surfaces (polystyrene mould and base). Secondly, to compare the effects on pressure distribution after adding a lumbar body support system (LBS) to certain of these surfaces.

Methods

Ten healthy subjects with no previous history of back pain were recruited for this study. Subjects of average body build were selected (85 and 115 percent of ideal body weight). Ideal body weight is based on insurance industry actuarial tables of height - weight - age data.

Subjects were required to lie in a supine position in random order on eleven different surfaces during which time the values for the maximum and average pressure as well as the size of the area under the pressure were recorded for each surface by means of an Ergocheck pressure measuring device (Braunschweig, Germany).

The Ergocheck evaluates the load distribution by means of a thin air pressure sheet (3'3" x 6'6"), computerised control unit with software and connection cable. The measuring sheet is thin and elastic, thus when placed over each mattress it makes no alteration to the properties of the mattress. There are 684 individual measuring points distributed across the testing surface. Each of these highly sensitive sensors determines the pressure between the body and the surface on which it is lying. The measured values are then processed by the computer and portrayed as pressure distribution between the person and the mattress, which can be printed out in colour for comparisons of different surfaces.

The values for measured maximum pressure, average pressure and the size of the area under pressure were calculated for each bed. Maximum pressure was recorded as the maximum pressure anywhere within the measurement area i.e. in the head and foot area. The average value is representative of the average pressure across the area under load. Area was defined as the total contact area.

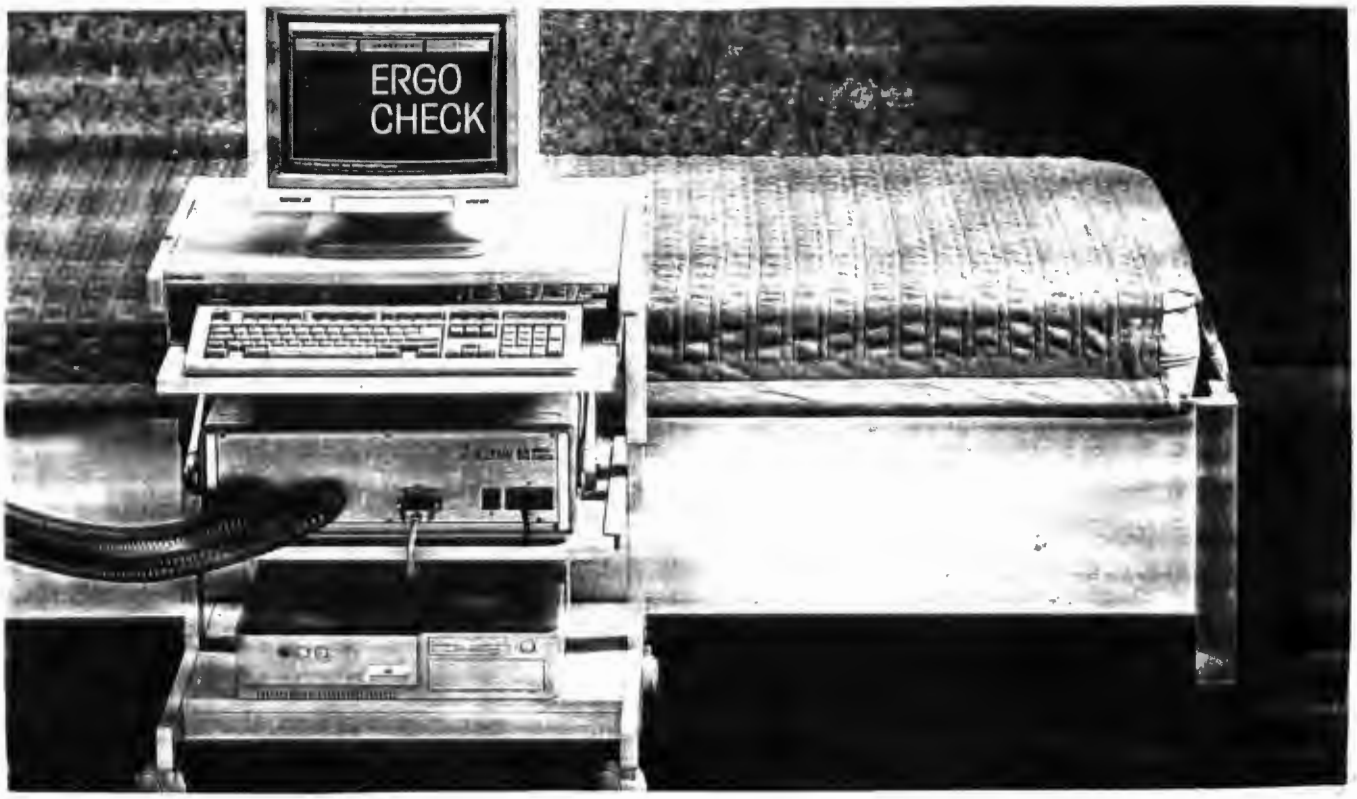

Figure 6.1. The Ergocheck® classic pressure measuring system (ABW, Germany). (684 pressure sensors, 5 x 5 cm; 0-70 mmHg; ± 2.5% full scale; 15^0 C- 35^0 C; software: marketing, industrial and time studies).

The measured values were then portrayed in two dimensional graphs, which show the maximum and average linear pressure loads in the supine position. Likewise, the distribution of area under the load was portrayed linearly.

It is possible that certain errors can occur whilst using the Ergocheck®, therefore the following sources of measurement error cannot be ruled out. The pressure obtained can deviate according to the weight of the person, as the pressure measured consists not only of vertical components, but also horizontal components as a result of the sag produced due to the weight of the subject. A further error comes about due to the electronic noise in the Ergocheck® measurement instrument. These errors can lead to deviations of the result up to a maximum of 2.5% relative to the total bearing capacity of the sheet (Ergocheck measuring system manual, Germany). Each volunteer acted as his/her own control in order to minimise the effect of inter subject error.

The surfaces used in this study have been fully described in chapter 2. Pressure distribution of the body was measured lying on a triple density foam mattress (TD), a standard innerspring hospital mattress (HM), a conventional inner spring mattress (CM) and base of the innerspring mattress (Base). The LBS was then placed on top of each of the four surfaces and the pressures recorded once again. Furthermore, the pressure distribution of the body, after lying on a 60 mm convoluted foam surface (60 mm CFS+CM), a polystyrene shape mould (PM), and a 90 mm convoluted foam surface (90 mm CFS+CM) all placed on the conventional innerspring mattress was recorded for comparison.

Statistical analysis

Data were analysed using a one way analysis of variance (ANOVA) with repeated measures. When values between groups indicated a statistical significance, a Scheffe's post hoc-test was performed to determine specific differences between groups. Statistical procedures were performed including

and excluding data for the base support due to the large difference in pressure between the base and other surfaces. Both sets of statistical analysis are presented in the appendices. All data are presented as mean ± SD. Statistical significance was accepted as $p < 0.05$. The statistical analysis was performed on the Statgraphics software package (Statgraphics, version 6, USA).

Results

The subject characteristics are listed in table 1. Five healthy male and five healthy female subjects (82.3 ± 12.6 kg, height 1.82 ± 0.08 m) participated in the study.

Table 6.1. Subject characteristics

Subject number	Gender	Height (m)	Mass (kg)
1	M	1.96	104.0
2	M	1.89	95.5
3	M	1.90	82.0
4	M	1.76	77.0
5	F	1.78	73.8
6	F	1.67	68.0
7	M	1.90	94.0
8	F	1.75	69.0
9	F	1.83	92.5
10	F	1.78	67.5
Ave		1.82	82.3

Abbreviations: M, male; F, female

Maximum pressures

The maximum pressures are shown in figure 6.2. and table 6.2. The maximum pressure measured after lying on the base only was significantly higher than the other surfaces measured (84.6 ± 23.3 mmHg; $p < 0.01$). This pressure was significantly reduced when the LBS was placed on top of the base (25.5 ± 3.0 mmHg; $p < 0.01$). When data were statistically analysed without the base, there was a significant difference in pressure between the conventional mattress (CM) (38.7 ± 7.2 mmHg) and Hospital mattresses (HM) (38.8 ± 7.0 mmHg) compared to when the LBS was placed on top of the CM (CM + LBS: 23.6 ± 2.2 mmHg), HM (HM + LBS: 25.0 ± 3.1 mmHg) and TD (TD + LBS: 23.3 ± 2.1 mmHg; $p < 0.01$). Furthermore the HM (38.8 ± 7.0 mmHg) and CM (38.7 ± 7.2 mmHg) were significantly different to the PM (30.0 ± 3.1 mmHg), TD (29.4 ± 4.0 mmHg) and 90 mm CFS+CM (29.1 ± 3.6 mmHg; $p < 0.05$).

Although there was a difference in pressure between the TD (29.4 ± 4.0 mmHg) and the TD + LBS (23.3 ± 2.1 mmHg), this was not statistically significant (figure 6.2.). In addition there was no significant difference in pressure between the 90 mm CFS+CM (29.1 ± 3.6 mmHg) and PM (30.0 ± 3.1 mmHg) compared to when the LBS was placed on top of the TD, CM, HM and base. In contrast, the maximum pressure on the 60 mm CFS+CM (32.6 ± 4.0 mmHg), was significantly higher when compared to the TD+LBS (23.3 ± 2.1 mmHg) and CM+LBS (23.6 ± 2.2 mmHg; $p < 0.05$). However no significant reduction in pressure was noted between the 60 mm CFS+CM (32.6 ± 4.0 mmHg), compared to the CM (38.7 ± 7.2 mmHg).

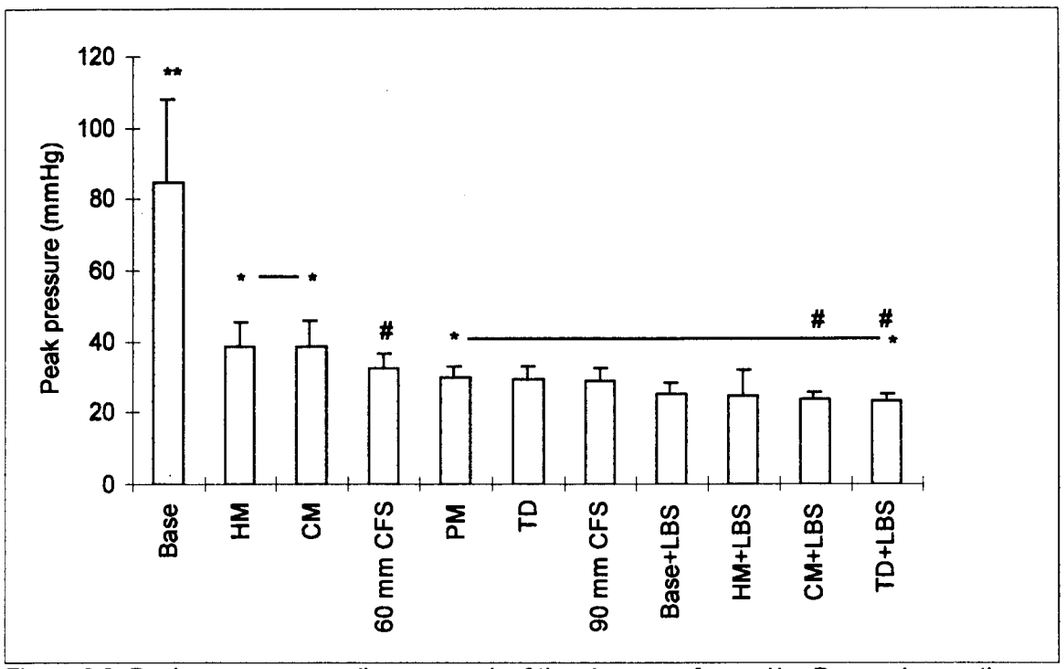

Figure 6.2. Peak pressure recordings on each of the eleven surfaces. ** = Base only vs. other surfaces ($p < 0.01$). * = HM and CM vs. PM, TD, 90mm CFS ($p < 0.05$), base + LBS, HM + LBS, CM + LBS, TD + LBS ($p < 0.01$). # = 60mm CFS vs. CM+LBS and TD+LBS ($p < 0.05$). Abbreviations: HM, hospital mattress; CM, conventional mattress; CFS, convoluted foam surface; PM, polystyrene mould; TD, triple density foam; LBS, lumbar body support.

Average Pressures (average pressure across the area under load)

The average pressures are shown in figure 6.3. and table 6.2. The 60 mm CFS+CM (11.1 ± 0.6 mmHg), CM (11.6 ± 0.6 mmHg) and HM (12.2 ± 0.6 mmHg), were significantly different compared to the 90 mm CFS+CM (9.9 ± 0.6 mmHg) and LBS placed on top of the base (base + LBS: 9.7 ± 0.4 mmHg), HM (HM + LBS: 9.7 ± 0.5 mmHg), CM (CM + LBS: 9.6 ± 0.6 mmHg) and TD (TD + LBS: 9.3 ± 0.5 mmHg; $p < 0.05$).

Furthermore, the average pressure after resting on the HM (12.2 ± 0.6 mmHg) and CM (11.6 ± 0.6 mmHg) was significantly higher than the TD (10.4 ± 0.5 mmHg) and PM (10.3 ± 0.4 mmHg; $p < 0.05$). Likewise, the TD (10.4 ± 0.5 mmHg) was significantly different to the TD + LBS (9.3 ± 0.5 mmHg; $p < 0.05$).

For data analysis including the base, average pressure was significantly higher when subjects lay on the base only (15.3 ± 1.4 mmHg; $p < 0.01$) vs. the other surfaces (figure 6.3. and table 6.2.).

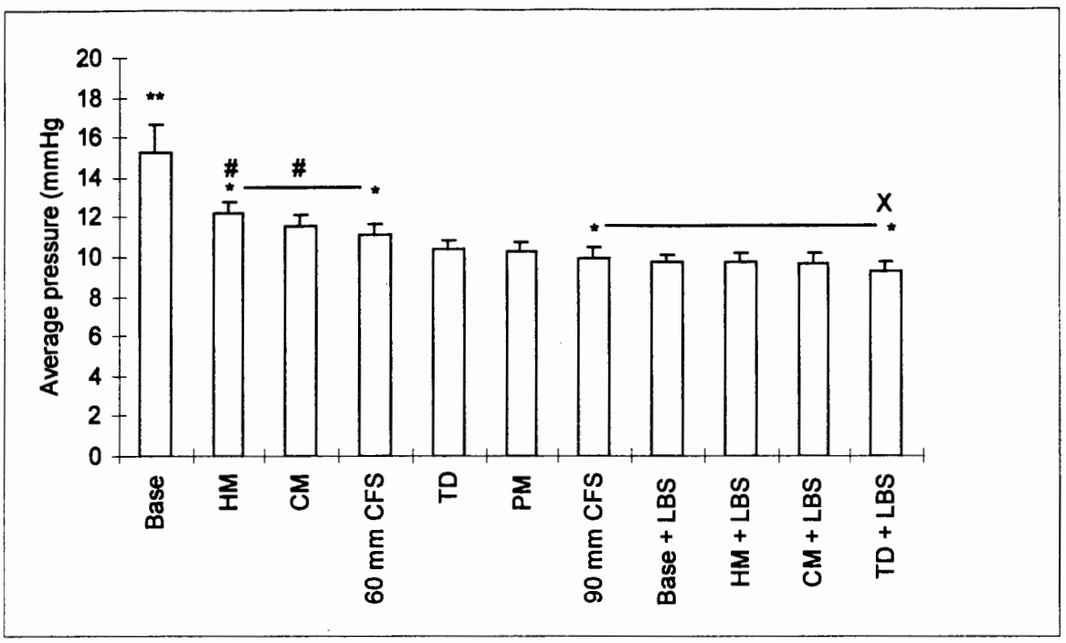

Figure 6.3. The average pressure recorded after lying on each surface. ** = Base only vs. other surfaces ($p < 0.01$). * = HM, CM and 60mm CFS vs. 90mm CFS, base + LBS, HM + LBS, CM + LBS and TD + LBS ($p < 0.05$). # = HM and CM vs. TD and PM ($p < 0.05$). X = TD vs. TD + LBS ($p < 0.05$). Abbreviations: HM, hospital mattress; CM, conventional mattress; CFS, convoluted foam surface; PM, polystyrene mould; TD, triple density foam; LBS, lumbar body support.

Area

When data were analysed excluding the base alone area of pressure distribution was significantly higher when subjects lay on the CM + LBS (61.2 ± 5.8 dm^2), HM + LBS (58.8 ± 6.5 dm^2), TD + LBS (58.3 ± 7.0 dm^2) and base + LBS (57.4 ± 7.1 dm^2) compared to the area of pressure on the HM (44.8 ± 4.4 dm^2; $p < 0.05$). Furthermore, there was a significant difference between the CM + LBS (61.2 ± 5.8 dm^2) and the CM (47.8 ± 5.4 dm^2; $p < 0.05$). Although the TD + LBS (58.3 ± 7.0 dm^2) was higher than the TD (54.6 ± 5.6 dm^2), this difference was not statistically significant. Similarly, recordings for the PM (53.5 ± 5.9 dm^2), 60 mm CFS+CM (51.5 ± 5.3 dm^2) and 90 mm CFS+CM (55.5 ± 5.8 dm^2) were higher than recordings on the HM (44.8 ± 4.4 dm^2) and CM (47.8 ± 5.4 dm^2), but not

significantly so. On analysis of the data to include the base on its own, all other surfaces resulted in a significantly higher area of pressure distribution than the base ($p < 0.05$), with exception of the HM which was not significantly different from the base (HM 44.8 ± 4.4 dm^2 vs. base 35.6 ± 4.5 dm^2) (figure 6.4. and table 6.2.).

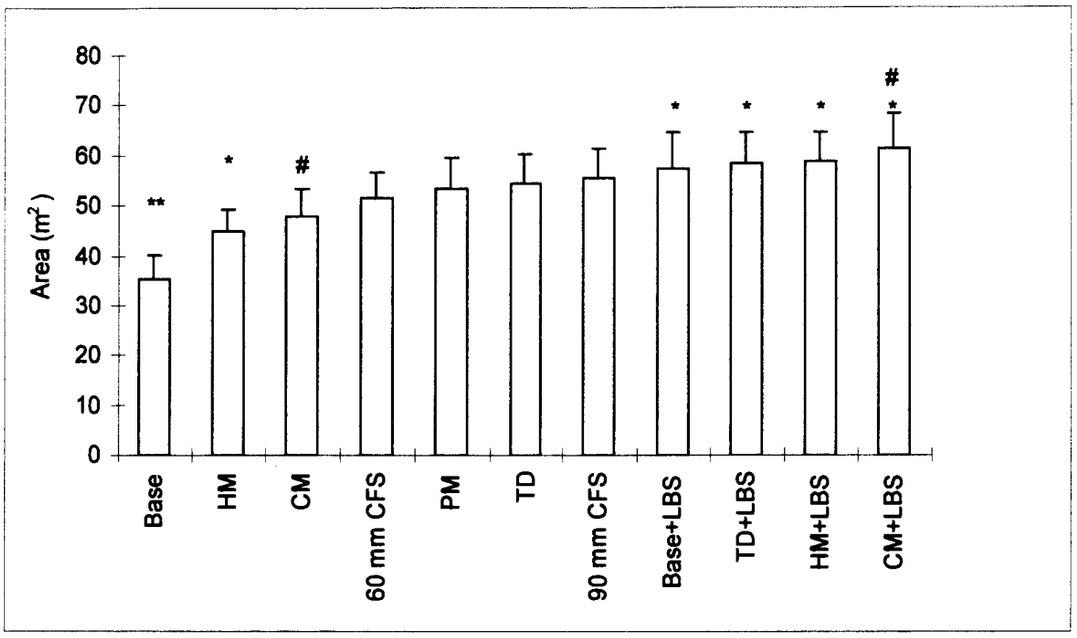

Figure 6.4. Area of pressure distribution after lying supine on each surface. ** = Base only vs. other surfaces except HM ($p < 0.05$). * = HM vs. base + LBS, TD + LBS, HM + LBS and CM + LBS, ($p < 0.05$). # = CM vs. CM+LBS ($p < 0.05$). Abbreviations: HM, hospital mattress; CM, conventional mattress; CFS, convoluted foam surface; PM, polystyrene mould; TD, triple density foam; LBS, lumbar body support.

Table 6.2. Maximum and average pressure distribution and total contact area of the body in healthy volunteers, after resting on eleven different surfaces.

	Pmax (mmHg)	Pave (mmHg)	Surface Area (dm^2)
Base	84.6 ± 23.3**	15.3 ± 1.4**	35.6 ± 4.5**
HM	38.8 ± 7.0*	12.2 ± 0.6 *#	44.8 ± 4.4*
CM	38.7 ± 7.2*	11.6 ± 0.6 *#	47.8 ± 5.4 #
60 mm CFS+CM	32.6 ± 4.0 #	11.1 ± 0.6 *	51.5 ±5.3
PM	30.0 ± 3.1*	10.3 ± 0.4	53.5 ± 5.9
TD	29.4 ± 4.0*	10.4 ± 0.5	54.6 ±.5.6
90 mm CFS+CM	29.1 ± 3.6*	9.9 ± 0.6*	55.5 ± 5.8
Base + LBS	25.5 ± 3.0*	9.7 ± 0.4*	57.4 ± 7.1*
HM + LBS	25.0 ± 3.1*	9.7 ± 0.5*	58.8 ± 6.5*
CM + LBS	23.6 ± 2.2* #	9.6 ± 0.6*	61.2 ± 5.8* #
TD + LBS	23.3 ± 2.1* #	9.3 ± 0.5*X	58.3 ± 7.0*

Abbreviations: Pmax ; maximum occurring pressure, anywhere on the pad (mmHg), Pave; average pressure of the loaded parts of the pad (mmHg), Area; total contact area (dm^2), HM; hospital mattress, CM; conventional innerspring mattress, CFS; convoluted foam surface, PM; polystyrene mould TD; triple density foam, LBS; lumbar body support. Pmax:** = Base only vs. other surfaces ($p < 0.01$). In the analysis excluding the base alone * = HM and CM vs. PM, TD, 90 mm CFS+CM ($p < 0.05$), base + LBS, HM + LBS, CM + LBS, TD + LBS ($p < 0.01$). # = 60 mm CFS+CM vs. CM + LBS and TD + LBS ($p < 0.05$). Pave: ** = Base only vs. other surfaces ($p < 0.01$). In the analysis excluding the base alone * = HM, CM and 60 mm CFS+CM vs. 90 mm CFS+CM, base + LBS, HM + LBS, CM + LBS and TD + LBS ($p < 0.05$). # = HM and CM vs. TD and PM ($p < 0.05$). X = TD vs. TD + LBS ($p < 0.05$). Area : ** = Base only vs. other surfaces except HM ($p < 0.05$). In the analysis excluding the base alone * = HM vs. base + LBS, HM + LBS, CM + LBS and TD + LBS, ($p < 0.05$). # = CM vs. CM+LBS ($p < 0.05$).

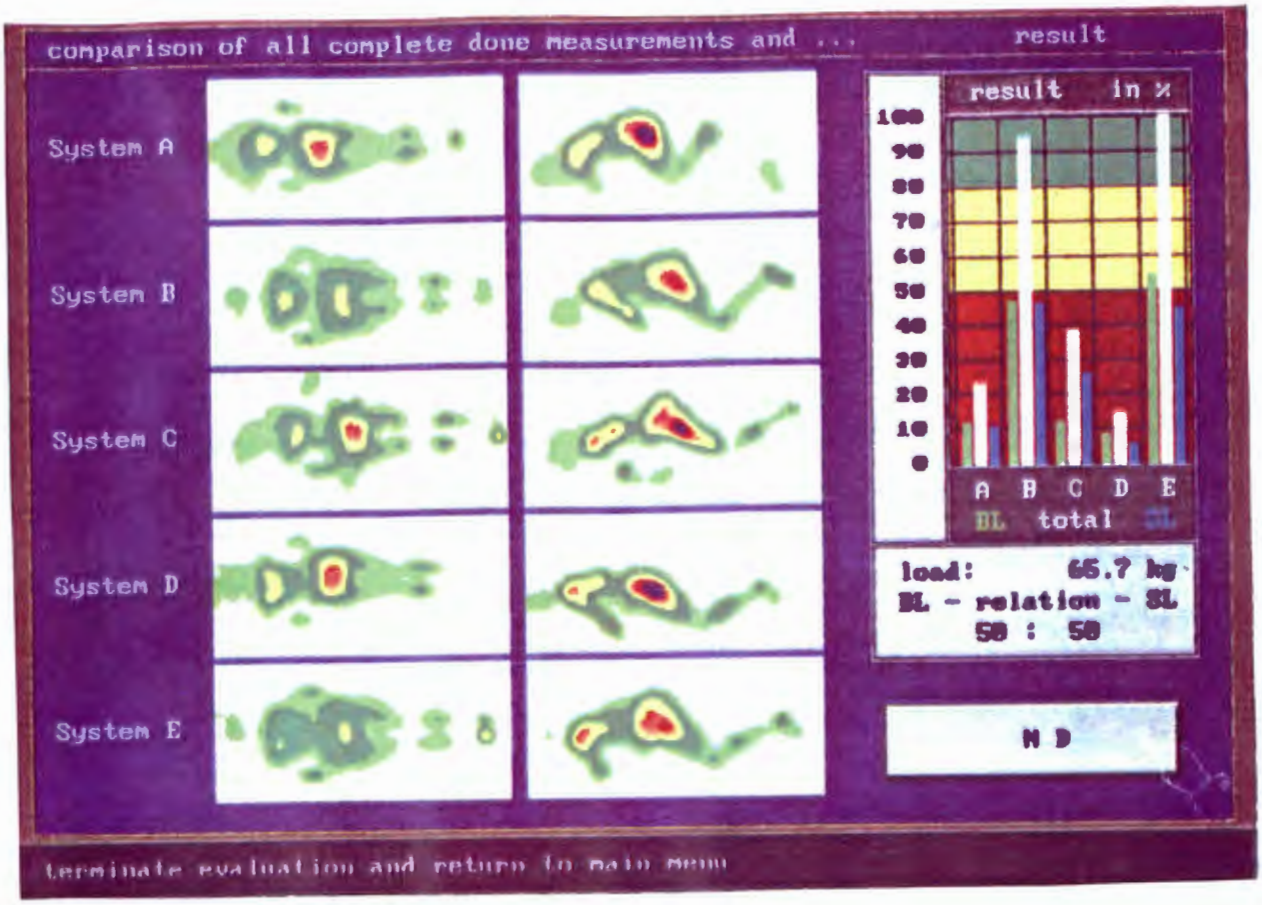

Figure 6.5. Pressure distribution between the body and surface on which the individual is lying. This is a computer generated printout from a single subject. These measured values are represented in the form of a bar graph on the far right. The surface with the best results is evaluated at 100%. The least suited surface classified between 10 - 30% and the remaining ones classified between them.

System A represents the pressure measurement of an innerspring mattress, C a 60 mm CFS placed on top of the innerspring mattress, and D a foam hospital mattress. System B represents the pressure measurement on the LBS on top of a hospital mattress and System E reflects the LBS placed on top of an innerspring mattress. When the LBS is placed on top of the HM (B), the pressures are about 80% lower than the HM alone (D). Similarly, the pressure is about 78% lower when the LBS is placed on top of the innerspring mattress (E) compared to the innerspring mattress alone (A).

Discussion

Pressure sores occur most commonly over the sacrum (43%), greater trochanter (12%), heel (11%), ischial tuberosities (5%), and lateral malleolus (6%) (Peterson 1976; Vohra et al., 1995). Therefore it seems that there is a concentration of forces over specific sites at which pressure sores occur in persons lying on the traditional flat surface, including an innerspring mattress and the hospital bed.

In this study, the LBS placed on top of either of these surfaces, resulted in a significant reduction in peak and average pressure, thus not generating peak pressures at any site of the body. Therefore, the LBS did not cause excessive pressure at single points as do the traditional flat surfaces. Similarly, the 90 mm CFS+CM, TD and PM produced significantly less peak pressure compared to the HM and CM (figure 6.2). Thus there was no significant difference in peak pressure between the polystyrene mould, the foam (TD; 90 mm CFS+CM) surfaces and the LBS placed on top of the flat surfaces. It therefore seems likely that the combination of shape, density and thickness of a surface play a role in reducing maximum pressure.

There was no significant difference in peak pressure between the CM, HM and 60 mm CFS placed on the conventional mattress. In contrast, peak pressure was significantly higher on the 60 mm CFS+CM compared to the LBS placed on top of the CM and TD (figure 6.2). Of particular importance is the significantly lower peak pressure after lying on the 90 mm CFS+CM, compared to the CM and HM. These differences in peak pressure were not similar for the 60 mm CFS+CM. This indicates that the thickness of a flat surface may play a role in reducing pressure between the human body and the sleep surface in healthy volunteers.

Furthermore, the above findings are similar to the average pressure results that tend to mirror peak pressure. However there were some differences. Firstly, the

average pressure on the 60 mm CFS+CM was significantly different to the 90 mm CFS+CM and the LBS placed on top of the flat surfaces. This significant difference in average pressure between the two convoluted foam surfaces indicates that a thicker surface is beneficial in reducing pressure. Secondly, the average pressure for the TD was significantly higher than the TD + LBS (figure 6.3). This indicates that although the TD reduced pressure compared to the CM and HM, an even greater pressure reduction occurred with the LBS on top of this TD surface.

The area of pressure distribution (figure 6.4), resulted in no significant difference between the CM compared to the 90 mm CFS+CM or in comparison to the PM and TD. There was however a significant difference between the CM and the CM + LBS. This illustrates that although the 90 mm CFS+CM, TD and PM reduced peak pressure compared to the CM and HM, the area of pressure distribution remained similar when compared to these two surfaces. In contrast, there was a greater area of pressure distribution for the LBS placed on top of the flat surfaces compared to the HM.

Figure 6.5. represents a computer printout of the result (in percentage) of an individual subject after lying on five of the surfaces measured. This is presented as a bar graph. In this example the LBS placed on top of the HM generates about 80% less pressure than the HM alone and the LBS placed on top of the innerspring mattress results in about 78 % less pressure than the innerspring mattress alone.

The significant reduction in peak pressure recording is further highlighted after placing the LBS on the base. The results show that one could theoretically place a LBS on the floor (as the two are similarly as hard) and get as beneficial effect as when it is placed on an innerspring mattress (figure 6.2.).

When subjects lie on the LBS, the concentration of forces over sites at which pressure sores may develop is spread over a greater area of the body, so although there are high pressures, these are not concentrated at single points. Therefore, this is achieved by the LBS, as increased area of pressure distribution cancels out areas of very high pressure. Pressure is defined as force/area, therefore if the force is spread over a greater area, the average pressure will be less (since pressure = force/area and the force remains the same). It would therefore be desirable to have a surface designed to produce the least possible force for a given area. Pressure is therefore lower when patients rest on the LBS, because this support system fits the contour of the body, thereby distributing pressure over a greater surface area.

The results of this study indicate that both conventional and hospital mattresses provide decreased area of pressure distribution, resulting in areas of high peak pressure. The properties of these mattresses could be improved by placing the LBS on top in order to increase area under pressure and decrease the probability of pressure sores developing. The triple density foam, polystyrene mould and 90 mm CFS placed on top of the conventional mattress produced similar peak pressure results to the LBS. Unfortunately the effects of a 90 mm CFS placed on top of a HM was not tested in this study. Future research is therefore required in order to determine the pressure distribution after placing a 90 mm CFS on top of a hospital mattress, as the effects are likely to be similar.

This could have important clinical implications for persons who are bedridden due to chronic illness, or for those suffering from lower back pain, in particular nocturnal discomfort. According to Closs, (1992) there is a close association between sleep and pain, such that sleep deprivation could lead to further undesirable consequences such as negative mood states and impaired tissue repair. These authors reported that pain was the most commonly reported cause of sleep disruption and that analgesics helped more patients return to sleep than

any other form of intervention. Future research is therefore required and should specifically focus on controlling nocturnal pain.

In conclusion, the most important findings of this study are that: i) A lumbar body support, when placed on a conventional hospital bed, conventional innerspring mattress and bed base, decreases the peak pressure, the average value of the area under load, and increases the total contact area. These results apply to a 30 minute period only. The mechanism responsible for these differences is possibly the contour and density features of the LBS. ii) A 90 mm CFS, when placed on a conventional innerspring mattress reduces the maximum and average pressure without significantly increasing the contact area. These findings are not mirrored by the 60 mm CFS, possibly because the 90 mm CFS is slightly thicker. Therefore similar results were obtained from the LBS and 90 mm CFS via two unique mechanisms.

Since many patients are often required to spend extended periods recumbent, their risk for developing pressure sores would be increased. This study therefore suggests that either the LBS or the 90 mm CFS could prevent the risk of bedsores developing in persons required to lie supine for prolonged periods.

This hypothesis needs to be investigated in future clinical trials with patients who are severely debilitated or paraplegic, as these are often the patients most at risk for development of pressure sores. Furthermore, measurements were taken in a healthy population group, therefore future trials could perhaps be conducted in a lower back pain population group.

CHAPTER SEVEN

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

In summary, we have shown that patients with acute-upon-chronic lower back pain who lie for 30 minutes on either a conventional flat mattress, or a 60 mm convoluted "egg box" shape foam overlay placed on top of the CM, have higher EMG activity, elevated resting heart rate and greater perception of discomfort compared to the lumbar body support.

However, when a lumbar body support is placed on top of the conventional flat surface, resting paraspinal muscular activity and heart rate decreased, while perception of comfort improved. Furthermore, we found elevated EMG activity and heart rate response of patients lying on a polystyrene mould, identical to the shape of the lumbar body support, similar to when they lay on the traditional flat surface. These findings suggest that neither the 60 mm CFS, CM or PM are the optimal sleep surfaces for patients presenting with lower back pain accompanied by paraspinal muscular spasm.

The 60 mm CFS lacks contour and is very low in density, thereby adapting to the characteristics of the underlying "traditional" flat mattress. Although the contour of the PM was identical to that of the LBS, EMG activity, heart rate and level of discomfort was significantly higher when compared to the LBS. These results may have occurred due to the density of the PM which was too great, thereby losing comfort, which increased muscular activity and heart rate.

The final study in this thesis explored the pattern of pressure distribution on the body surface in the supine lying position in healthy subjects. Over a short duration (30 minutes) a LBS placed on a conventional hospital bed, conventional innerspring mattress and bed base reduces the maximum and average pressure and increases the total contact area. Likewise, a 90 mm CFS placed on a conventional innerspring mattress reduces maximum and average pressure

without significantly increasing contact area. A polystyrene mould and triple density foam surface reduce peak pressure but not the average pressure of the area under load. The 60 mm CFS placed on top of a conventional innerspring mattress failed to reduce pressure in the same manner as the LBS and 90 mm CFS. It therefore seems likely that the correct combination of shape, density and thickness of a surface is necessary to reduce pressure on the body surface.

Therefore in conclusion i) it is likely that a combination of the contour and density features of the LBS brought about the reduction in EMG activity and heart rate, resulting in improved comfort after a 30 minute period, in patients with acute-upon-chronic lower back pain. The LBS might prove to be an important adjunctive therapy if longer period studies confirm the trends noted in this study. ii) the LBS might prevent the risk of pressure sores developing in patients forced to lie supine for prolonged periods, because this support system fits the contour of the body, thereby distributing the patients' body weight over a greater surface area. iii) The 90 mm CFS may also prevent the risk of developing pressure sores, possibly as the surface thickness is increased. However this preliminary hypothesis needs to be researched in future clinical trials. Of particular interest would be to examine both pressure distribution and the EMG activity of the lumbar erector spinae muscles using a 90 mm CFS placed on top of a hospital mattress (neither of which were tested in this thesis).

We have shown benefits over a 30 minute period only, therefore the true value of this body support is probably underestimated by these studies, as the effects of this surface over an eight hour sleep period were not studied.

These preliminary results are sufficiently positive to suggest that further clinical trials of the use of the LBS and the 90 mm CFS in the management of LBP and the prevention of pressure sores are warranted. Future research should be conducted to ascertain the effects of the LBS over an extended period.

Furthermore, future clinical trials should be undertaken to determine if patients with bed sores heal quicker when lying on top of either a LBS or a 90 mm CFS, as this may play a large role in the prevention of bedsores.

CHAPTER EIGHT

REFERENCES

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REFERENCES

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CHAPTER NINE

APPENDICES

APPENDICES

Table 9.01. Two way-analysis of variance for average heart rate data after resting on a lumbar body support, convoluted foam surface and conventional mattress. Level of significance = 95%.

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F - ratio	Sig. Level
Main effects					
A: mat	788.01111	2	394.00556	4.127	0.0178
B: time	455.44444	5	91.08889	0.954	0.4477
Interactions AB	318.65556	10	31.865556	0.321	0.9749
Residual	16422.856	172	95.481718		
Total (corrected)	17666.311	179			

Table 9.02. One-way analysis of variance expressing data as area under the curve of heart rate vs. time (lumbar body support, convoluted foam surface and conventional mattress). Level of significance = 95%.

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F - ratio	Sig. Level
Between groups	76180.4	2	38090.208	0.725	0.4934
Within groups	1418078.8	27	52521.435		
Total (corrected)	1494259.2	29			

Table 9.03 Two-way analysis of variance for EMG data after resting on a lumbar body support, convoluted foam surface and conventional mattress. Level of significance = 95%.

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F - ratio	Sig. Level
Main effects					
A: mat	49.759164	2	24.879582	5.114	0.0084
B: time	0.000060	2	0.000030	0.000	1.0000
Interactions AB	17.893098	4	4.4732746	0.920	0.4574
Residual	350.26372	72	4.8647738		
Total (corrected)	417.91604	80			

Table 9.04. Two-way analysis of variance for average heart rate data after resting on a lumbar body support, polystyrene mould and conventional mattress. Level of significance = 99%.

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F - ratio	Sig. Level
Main effects					
A: mat	2165.5399	2	1082.77	13.713	0.0000
B: time	1149.1980	5	229.8396	2.911	0.0152
Interactions AB	500.52056	10	50.052056	0.634	0.7833
Residual	12791.256	162	78.958368		
Total (corrected)	16604.550	179			

Table 9.05 One-way analysis of variance for average heart rate data over time after lying on the lumbar body support. Level of significance = 95%.

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F - ratio	Sig. Level
Between groups	995.8833	5	199.17667	3.662	0.0063
Within groups	2937.100	54	54.39074		
Total (corrected)	3932.9833	59			

Table 9.06 One-way analysis of variance for average heart rate data over time after lying on the polystyrene mould.

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F - ratio	Sig. Level
Between groups	467.9278	5	93.585556	1.032	0.4083
Within groups	4897.0556	54	90.686214		
Total (corrected)	5364.9833	59			

Table 9.07 One-way analysis of variance for average heart rate data over time after lying on the conventional mattress.

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F - ratio	Sig. Level
Between groups	188.5500	5	37.710000	0.411	0.8392
Within groups	4957.1000	54	91.798148		
Total (corrected)	5145.6500	59			

Table 9.08 Two-way analysis of variance for EMG data after resting on the lumbar body support, polystyrene mould and conventional mattress. Level of significance = 99%.

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F - ratio	Sig. Level
Main effects					
A: mat	66.915530	2	33.457765	11.956	0.0000
B: time	1.268323	2	0.634161	0.227	0.7978
Interactions AB	11.496556	4	2.8741390	1.027	0.3993
Residual	201.48433	72	2.7983934		
Total (corrected)	281.16473	80			

Table 9.09 One-way analysis of variance for maximum pressure data analysed without the base alone. Level of significance = 99%.

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F - ratio	Sig. Level
Between groups	2899.4235	9	322.15816	15.939	0.0000
Within groups	1819.1006	90	20.21223		
Total (corrected)	4718.5241	99			

Table 9.10. One-way analysis of variance for maximum pressure data, including the base. Level of significance = 99%.

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F - ratio	Sig. Level
Between groups	30429.131	10	3042.9131	41.693	0.0000
Within groups	7225.317	99	72.9830		
Total (corrected)	37654.448	109			

Table 9.11 One-way analysis of variance for average pressure data analysed without the base. Level of significance = 95%.

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F - ratio	Sig. Level
Between groups	81.604329	9	9.0671477	29.464	0.0000
Within groups	27.696330	90	0.3077370		
Total (corrected)	109.30066	99			

Table 9.12 One-way analysis of variance for average pressure data including the base. Level of significance = 99%

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F - ratio	Sig. Level
Between groups	304.54337	10	30.454337	65.575	0.0000
Within groups	45.97733	99	0.464417		
Total (corrected)	350.5207	109			

Table 9.13 One-way analysis of variance for the area of pressure distribution (excluding data for the base). Level of significance = 95%

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F - ratio	Sig. Level
Between groups	2365.3504	9	262.81671	6.697	0.0000
Within groups	3531.9940	90	39.24438		
Total (corrected)	5897.3444	99			

Table 9.14 One-way analysis of variance for the area of pressure distribution (including data for the base). Level of significance = 95%

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F - ratio	Sig. Level
Between groups	5542.3107	10	554.23107	14.684	0.0000
Within groups	3736.6580	99	37.74402		
Total (corrected)	9278.9687	109			