THE ASSOCIATION BETWEEN
PELVIC SKELETAL ASYMMETRY
AND
SITTING PRESSURE DISTRIBUTION

by

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Dedication

To my parents (May and Solaiman Al-Eisa)
To my husband my baby (Saud and Mae Al-Shanafey)
Thank you for your love and support.
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Abstract

Lateral pelvic tilt (in the frontal plane) and the subsequent musculoskeletal adaptations have been suggested in many reports to cause unequal sitting pressure distribution at the buttock-chair interface. However, those reports have failed to provide objective evidence to support that hypothesis. The purpose of this study was to examine the relationship between lateral pelvic tilt (leg length discrepancy) and sitting pressure distribution in a sample of healthy female volunteers.

An anthropometric frame was used for the pelvic skeletal asymmetry (PSA) measurement, and a force sensing array pressure mat was used for the sitting pressure distribution (SPD) measurement. The reliability study showed that measurements of PSA and SPD were reliable with intra-class correlation coefficients (ICCs) of 0.93 and 0.85 respectively. Using the reliability results, it was determined to use the mean of three measurements for both PSA and SPD. Fifty-two females were initially screened, from which forty-five were eligible for the principal study. Subjects were assigned to two groups based on their PSA measurement; thirty-six subjects in the symmetrical group, and nine in the leg length discrepancy (LLD) group. Sitting testing was performed in a constrained sitting posture in which subjects were asked to sit upright and look straight ahead at a mirror and a plump line placed against it.

Results of correlational statistics showed that there was no association between the measurements of PSA and SPD ($r = 0.18$). Unpaired two tailed t-tests indicated that there were no statistically significant differences between the groups in the demographic factors as well as the pressure measurement ($p<0.05$). Despite the lack of significant difference between the groups, the LLD group had a much larger variance than the symmetrical group. This result suggested that there was a greater variability among subjects in the LLD group, an observation worth further investigation with possibly larger sample size.

The current study is unique in the sense that it is the only study up to date that examined the effect of structural LLD on sitting pressure distribution in asymptomatic population using objective sound measurement procedures.
**List of abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>PSA</td>
<td>pelvic skeletal asymmetry</td>
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<td>LLD</td>
<td>leg length discrepancy</td>
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<td>SPD</td>
<td>sitting pressure distribution</td>
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<td>SD</td>
<td>sitting discomfort</td>
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<td>LPT</td>
<td>lateral pelvic tilt</td>
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<td>IRA</td>
<td>iliac rotation asymmetry</td>
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<tr>
<td>ASIS</td>
<td>anterior superior iliac spine</td>
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<td>PSIS</td>
<td>posterior superior iliac spine</td>
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<td>AR</td>
<td>asymmetry ratio</td>
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<td>AI</td>
<td>asymmetry index</td>
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<td>MPPD</td>
<td>mean peak pressure difference</td>
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<tr>
<td>AP-ID</td>
<td>antero-posterior ischial distance</td>
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<td>I-ID</td>
<td>inter-ischial distance</td>
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<tr>
<td>ICC</td>
<td>intra-class correlation coefficient</td>
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<tr>
<td>SD</td>
<td>standard deviation</td>
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Chapter 1

Introduction

General Overview of Topic

One of the most vital problems for persons in sedentary occupations relates to sitting comfort and quality of seating. In industrialized countries, there is a considerable shift to sedentary work, and sitting takes up an increasing amount of time, both at work and at home. This prolonged time spent in sitting has resulted in many problems, with the most common being low back pain (Grieco, 1986; Kelsey & White, 1980). Since sitting comfort and functional utility of seats not only depends on the chair design, but also on the posture, physical structure, and biomechanics of the human body (Fleischer, Rademacher & Windberg, 1987), there is a need to examine individual human differences when conducting studies on seating.

A common condition in the general population is pelvic skeletal asymmetry (PSA), which is frequently thought to affect posture and lead to the development of musculoskeletal problems, mainly low back pain (Giles & Taylor, 1981). The possible association of pelvic asymmetry with many clinical syndromes has made the measurement of this asymmetry an important part of musculoskeletal examination (Cummings, Scholz & Barnes, 1993; Subotnick, 1981). The most common type of pelvic asymmetry is the frontal plane asymmetry, which is usually referred to as lateral pelvic tilt or leg length discrepancy (LLD). It has been reported that the incidence of LLD in the normal adult population may be as high as 60 to 70% (Woerman & Binder-Macleod, 1984).
It has been suggested that pelvic skeletal asymmetry leads to scoliosis and therefore changes the distribution of forces acting within the body (Egan & Al-Eisa, 1999). Subsequently, with skeletal maturity, PSA could alter a person’s posture (Mahar, Kirby & MacLeod, 1985). The unnatural postures caused by pelvic asymmetry have been examined in standing, but not in sitting. In fact, it has only been empirically hypothesized that PSA could lead to uneven sitting pressure distribution at the buttock-chair interface—particularly pressure concentration over one ischium more than the other (Peterson & Adkins, 1982).

Sitting pressure distribution has been found to be highly influenced by the physical structure and biomechanics of the human body (Bar, 1991). In particular, uneven sitting pressure distribution on ischial tuberosities has been associated with pelvic obliquity in paraplegic patients (Drummond et al., 1982). There is, however, no strong evidence in the literature which proves that an association between those two issues exists in a normal asymptomatic population.

The relevance of sitting pressure measurement arises from the fact that sitting pressure distribution is correlated with subjective feelings of comfort (Corlett, 1989; Dinsdale, 1974). Therefore, measurement of sitting pressure has been widely used as an objective measure of sitting discomfort, as well as a tool to assess suitability of cushions. In addition, pressure measurement at the buttock-chair interface has been used in the prediction and management of pressure sores in wheel-chair-mobile patients (Reddy, Palmieri & Cochran, 1984). With respect to the aspect of pressure sores prevention and
of comfort promotion, the measurement of seating pressure distribution has become increasingly important.

Pelvic skeletal asymmetry, sitting discomfort, and sitting pressure distribution concern many physiotherapists working in the field of orthopaedics, ergonomics, and mostly clinicians working with wheelchair-mobile patients. The pelvic orientation and its relationship to the lumbar spine play a major role in dictating one's seated posture (Kroemer, 1994). However, the effect of a structural pelvic asymmetry on sitting discomfort, as could be reflected by sitting pressure distribution, has never been stressed.

**Rationale / Purpose**

Studies on seating are of particular importance since sitting discomfort can affect job satisfaction and productivity, while comfortable seating design can enhance both productivity and safety of the seated person (Naqvi, Stobbe & Jaraiedi, 1994). In the variety of reports investigating sitting comfort, many influential factors were found, one of which is the sitting pressure distribution. Variations in the weight distribution of the buttocks in different sitting postures were found to be correlated with the subjective feeling of sitting comfort (Corlett, 1989).

Seat functioning is not only influenced by the chair design, the task to be done, and the sitting period, but is also influenced by the individual human differences (Corlett, 1989). Hence, research is needed to study various human factors that might explain variations in sitting pressure distribution and give sitting discomfort a broader identity. Previous
studies which attempted to evaluate the relationship between body factors and seat parameters classified the body factors into part size, weight, shape and hardness of tissues (Yamazaki, 1992), without considering the diversity of other parameters such as pelvic skeletal asymmetry. On the other hand, other authors suggested that in order to understand postural adaptation in the workplace, the limitations and possibilities of human anatomy (i.e., spine and pelvis) have to be investigated (Bridger, Eisenhart-Rothe & Henneberg, 1989; Paluch, 1996). Reports on the effect of lateral pelvic asymmetry on seated posture in asymptomatic population are lacking.

Both pelvic asymmetry and sitting discomfort, have been considered separately as predisposing factors of low back pain. In 1979, it has been reported that, of approximately 18.9 million people who suffered some kind of musculoskeletal pain, 8 million had a disorder of the back and spine (Kelsey, White, Pastides & Bisbee, 1979). Kleeman and Prunier (1982) indicated that more than half of seated workers report musculoskeletal discomfort. Although the exact etiology of low back pain remains relatively unclear, it is common experience that people with low back pain suffer more symptoms when seated. Furthermore, prolonged sitting is thought to be one of the risk factors associated with low back pain (Frymoyer, Pope & Costanza, 1980).

Since there is strong evidence in the literature that the magnitude and distribution of pressure over the sitting area correlate with the subjective feeling of discomfort, the purpose of this research was to examine the relationship between the most common type of pelvic asymmetry (i.e., LLD) and seating pressures. The results of the study should
add greatly to the understanding of these relationships and be of potential importance in the study of predisposing factors of low back pain. Furthermore, understanding how normal symmetrical people differ from those with pelvic asymmetry in their seating habits will, in turn, help in seating design which is traditionally based on assumptions of symmetry. Studying pelvic asymmetry as one of the human factors that could affect sitting comfort will provide a better understanding of the association between those parameters and provide a stronger evidence-base for therapeutic intervention and seating design.

The main objectives of the study are as follows:

1. To establish a reliable protocol to calculate ischial pressure at the buttock-chair interface.
2. To assign subjects to anthropometric groups; i.e., symmetrical and asymmetrical, based on the pelvic skeletal asymmetry measurement.
3. To compare the patterns of seated pressure between groups.
4. To examine the association between the pelvic asymmetry and uneven sitting pressure distribution.
5. To examine the association between the pelvic asymmetry, and the right and left location of the peak pressure at the chair buttock interface.
**Definitions of Terms**

- **Pelvic Skeletal Asymmetry:**

  There are two commonly reported types of pelvic skeletal asymmetry in the literature; lateral pelvic tilt (LPT) and iliac rotation asymmetry (IRA). Lateral pelvic tilt "is manifested as a rotation of the whole pelvic girdle in the coronal plane about a sagittal axis" (Egan, Cole & Twomey, 1995) and is generally associated with an ipsilateral scoliosis on the side of the short leg (Ingelmark & Lindstrom, 1963). In a LPT, both the anterior and posterior iliac spines are lower on one side than the other, and it is usually caused by LLD (Figure 1.1).

  The other type of asymmetry which could be difficult to detect or misinterpreted in some instances, occurs when one innominate bone is rotated anteriorly or posteriorly relative to the other innominate in the sagittal plane (Cummings & Crowell, 1988). Iliac rotation asymmetry (Figure 1.1) is present when the anterior superior iliac spine (ASIS) is lower and the posterior superior iliac spine (PSIS) is higher in one side in relation to the other side of the pelvis (McCaw & Bates, 1991).

- **Leg Length Discrepancy:**

  Various authors classified leg length discrepancies (LLDs) into two groups: true (anatomical), and functional (McCaw & Bates, 1991; Woerman & Binder-Macleod, 1984). Subotnick (1981) classified a third type of LLD; combination of anatomical and functional discrepancies. True LLD occurs when an actual bony asymmetry exists somewhere between the head of femur and the mortise of the ankle, causing a tilt of the
pelvis and a secondary compensation of the spinal column and could result in scoliosis (Subotnick, 1981; Woerman & Binder-Macleod, 1984). In a functional LLD, there is no actual shortening in the limb but an appearance of short leg that is caused by the subject assuming an altered stance due to muscle spasm, pain, or abnormal hip positioning (Egan, 1994; McCaw & Bates, 1991; Subotnick, 1981).

- **Pelvic obliquity:**
  This is a term usually used to describe the failure of the pelvis to lie in a perfectly horizontal position in the frontal plane (Winter & Waldemar, 1986). Another broader definition of pelvic obliquity is any fixed malalignment existing between the spinal and pelvic structures in the frontal, sagittal, or horizontal planes (Dubousset, 1991). Accordingly, the two types of PSA as defined previously, are forms of pelvic obliquity.

- **Pelvic tilt in the sagittal plane:**
  This is commonly defined as the angle between the horizontal plane and a line passing through the midpoint of the PSISs and the midpoint of the ASISs (Levine & Whittle, 1996). In an anterior pelvic tilt, both the ASISs are positioned inferiorly and both the PSISs are positioned superiorly; while in a posterior pelvic tilt, both the ASIS are positioned superiorly and both the PSISs are positioned inferiorly (Alviso, Dong & Lentell, 1988).
Figure 1.1

Anterior and posterior diagrams of the pelvis showing a symmetrical pelvis, leg length discrepancy, and iliac rotational asymmetry. From: Egan (1994).
**Comfort vs Discomfort:**

The concept of comfort is not well defined and not fully distinguished from discomfort. Several studies have suggested that comfort and discomfort are affected by different variables and therefore should be quantified independently (Helander & Zhang, 1997; Zhang, Helander & Drury, 1996). Yet there is no universally accepted operational definition of comfort, and therefore published definitions only reflect the disciplines of the researchers who formulated them (Jianghong & Long, 1994). While comfort is related to a sense of well-being and aesthetics, discomfort is related to fatigue which is correlated with the sitting time period and the time of the day (Helander & Zhang, 1997). The concept of industrial comfort was derived from a study of the comfort experienced by passengers in vehicles, in which the authors hypothesized that the comfort level experienced would be the result of the summation of sensory stimuli experienced via all sense organs (Manenica & Corlett, 1973).

**Peak pressure:**

The highest pressure exerted at particular anatomical sites such as the ischial tuberosities (Redfern, Jenfid, Gillingham & Lunn, 1973). There are various units used for the measurement of sitting pressure, with the most common being mm of mercury (mmHg) and kilo Pascals (kPa).

**Upright sitting posture:**

According to Zachakow (1988), upright sitting posture is the position in which the center of gravity of the trunk is above the ischial tuberosities when the hip, knee and ankle are each at a right angle. For the purpose of this research, upright sitting is specifically
described as sitting with the buttocks positioned at the back of the seat and in contact with the chair back, knees at 90 degrees, feet flat on the floor, eyes fixed horizontally, and forearms resting on the arm rests.
Chapter 2

Review of Literature

The purpose of this review is to investigate the possible association between pelvic skeletal asymmetry (PSA) and sitting pressure distribution (SPD) in the literature. This chapter will also incorporate a review of the types and effects of pelvic asymmetry and the measurement techniques used to assess both PSA and SPD. Finally, a comparison of the pelvis orientation in sitting and standing will be outlined.

Pelvic Obliquity and Sitting Pressure Distribution

Some studies have attempted to correlate pelvic obliquity with uneven pressure distribution during sitting (Drummond, Narchania, Rosenthal, Breed, Lange & Drummond, 1982; Gillespie & Wedge, 1974; Nicol, 1989). Unfortunately, all those studies have lacked objectivity in defining and measuring pelvic obliquity. In addition, the lack of a universally accepted working definition of pelvic obliquity makes the task of reviewing the association between pelvic obliquity and uneven seated pressure in the literature more difficult.

Measurement of seated pressure has been used widely to investigate factors that lead to decubitus ulceration in disabled and paralytic patients (Kilfoyle, Foley & Norton, 1965; Kosiak, Kubicek, Olson, Danz & Kottke, 1958). Through these investigations, pelvic obliquity was found to be a risk factor for the development of decubitus ulcer under one ischium. For example, an increased risk of decubitus ulcers associated with spine fusion of an incompletely corrected scoliosis and pelvic obliquity in paraplegic patients has been
reported (Gillepsie & Wedge, 1974). Kosiak et al. (1958) suggested that decubitus ulcers are directly related to the pressure and the time the skin is exposed to that pressure. Furthermore, Drummond et al. (1982) reported that the amount of pressure measured at the buttock-chair interface is proportional to the weight transferred to each point of contact between the body and the surface on which it rests.

The role of pelvic obliquity with regard to its contribution to trunk imbalance has been stressed. Kilfoyle et al. (1965) defined trunk balance as the relationship of the center of gravity to the ischial tuberosities, and stated that balance is lost as the center of gravity moves laterally. Trunk imbalance was also considered one of the many causes for decubitus ulceration, and was recognized by either an uneven pressure distribution, a shift in the center of pressure, or a combination of the two (Drummond et al., 1982). Since pelvic obliquity is strongly linked and believed to cause trunk imbalance which in turn leads to uneven pressure patterns, one could conclude that a relationship exists between the obliquity and the uneven pressure distribution.

The work of Drummond et al. (1982; 1985) is unique with regard to this issue in the sense that they were the only researchers that used quantitative approach and reliable pressure sensing instrument to examine this relationship. They measured both the pressure distribution and the seated center of pressure in 15 normal subjects and showed that approximately 18% of the total pressure was equally distributed over each ischial tuberosity, 21% over each thigh, 5% over the sacrum, and the remaining pressures distributed evenly throughout the sitting area (Drummond et al., 1982). They also
suggested that the center of pressure when sitting should be located in the midline and in front of the perineum. The positioning of the subjects in that study, with the feet unsupported, could be criticized as not being a normal sitting posture in which the feet are usually supported by the floor or foot-rest. The authors argued that with the feet supported, part of the weight borne by the thighs would shift anteriorly to the feet and some would be shifted posteriorly to the buttocks in order to maintain balance or equilibrium.

A relevant observation was made by Drummond et al. (1982) that in a paraplegic patient with fixed pelvic obliquity, higher on the right, there was an asymmetrical increase in loading on the left ischial tuberosity. This increase in loading led to the development of a full-thickness decubitus ulcer just on the left side. In 1985, Drummond, Breed and Narechania conducted another study that revealed results consistent with those 1982 findings. They also established that the risk of ulceration increased when 30% or more of the body weight was localized over one ischium due to pelvic obliquity.

Peterson & Adkins (1982) also hypothesized that a patient with scoliosis and pelvic obliquity may have all of his weight bearing on one ischium, tuberosity, and thigh. To correct pelvic obliquity in sitting, they proposed making ischial tuberosity cutouts and constructing a preischial bar using a high density polyurethane foam to equalize sitting pressure. The authors indicated that for patients with scoliosis, the front part of the cutout may have to be angled to accommodate one ischium being more forward than the
other (Peterson & Adkins, 1982). Unlike Drummond et al. (1982) and Drummond et al. (1985), Peterson and Adkins (1982) did not provide any data to support their ideas.

In summary, the role of fixed pelvic obliquity in paraplegic patients has been more widely studied with regard to its contribution to two risk factors for developing decubitus ulcers: trunk imbalance and uneven pressure distribution during sitting. However, none of the above studies reported the degree of the pelvic asymmetry, or even indicated their measurement technique to assess the pelvic obliquity. Furthermore, it is difficult to generalize their findings to normal population that has normal skin sensation.

**Incidence of Pelvic Skeletal Asymmetry**

There are various opinions as to the amount of pelvic asymmetry that would constitute clinical significance, and hence to define a cut-off value between symmetry and asymmetry is problematic. Therefore, there is no general agreement on the incidence of PSA in normal subjects due to the different cut-off values used. In addition, the commonly reported asymmetry is usually LLD, while IRA is often unrecognized (Egan, Cole & Twomey, 1995). The reported incidence of PSA will not only depend on the cut-off values, but also on the accuracy of the measurement. The smaller the cut-off value, the greater will be the incidence; and the coarser the unit of measurement, the greater will be the agreement between observers (Nichols, 1960). The following is an overview of the reported incidence of PSA, mainly LLD, in the literature.

A leg length discrepancy of 5 mm or more has been estimated to exist in approximately half of the adult population (Friberg, 1983; Gross, 1983). Ingelmark and Lindstrom
(1962) investigated the incidence of pelvic asymmetry in a group of 370 subjects by taking x-rays of the lower lumbar region, the pelvis and the upper part of the femur with the subject in an upright position. They identified the starting limit of asymmetry to be as low as 1mm, and concluded that over 87% of the subjects were asymmetrical. The authors argued that the right leg of adults was more frequently shorter than the left considering that most people prefer to support higher load on their left leg, which will induce its growth acceleration. In their study of 370 patients with back disorders, they found that 44% had a short left leg and 55% had a short right leg. These findings support the results of Rush and Steiner (1946) who reported that from a sample of 1000 subjects, 36.4% had a shorter left leg and 40.6% had a short right leg.

Subotnick (1981) conducted a survey of over 4,000 athletes and long distance runners seen in his office over a 6 year period, and concluded that 40% of those patients have some form of limb length discrepancy. A radiographic study by Gross (1983) on 35 self selected runners indicated that 14% of the subjects had LLD of 5 mm or more. However, the results of both studies can not be generalized since their samples were strictly athletes and were not selected at random.

Overall, given that the incidence of asymmetry in a random population will be normally distributed, the divergence in the reported incidences of PSA can be attributed to the different cut-off values or the different measurement methods used. The lack of information regarding the incidence of IRA is mainly due to the fact that it has been less acknowledged and understood than LLD.
Effects of Pelvic Skeletal Asymmetry

There are great speculations in the literature on the functional effects of small amounts of LLD in athletes and nonathletes. Subotnick (1976) stated that a leg length discrepancy of less than \( \frac{1}{2} \) inch (1.27 cm) has no pathological implications, but that greater than \( \frac{1}{2} \) inch has the potential to lead to pain and dysfunction. It is important to note that most of the studies on the effects of pelvic asymmetry usually assume a fixed structural deformity that lead to adaptive soft tissue shortening and lengthening as the person reaches skeletal maturity.

Various studies investigating the effect of LLD on low back pain have yielded conflicting results. Jackson and Wiltse (1974), in an overview of low back pain in young athletes, reported that LLD of less than 2 cm was not associated with low back pain, but did not provide substantial evidence to verify this finding. Also, Gross (1978) found that individuals with LLD less than 2 cm did not consider the discrepancy to be a problem. Other authors also have questioned the effect of LLD on the etiology of low back pain (Fisk & Biagent, 1975; Soukka, Alaranta, Tallroth, & Helivaara, 1991; Yrjonen, Hoikka, & Poussa, 1992).

In most cases, when radiographs were used to measure LLD, a relationship was found between LLD and low back pain (Friberg, 1983; Giles & Taylor, 1981). Conversely, studies that did not show a relationship between LLD and low back pain did not use radiography as a method for measuring LLD (Egan, Cole, & Twomey, 1995; Grundy & Roberts, 1984; Pope, Bevins, Wilder, & Frymoyer, 1985; Rowe, 1969). Some
researchers suggest that low back pain symptoms can be reduced if LLD is treated surgically (Rossvoll, Junk, & Terjesen, 1992), or by conservative treatment with shoe lifts (Gofton, 1982). Due to the lack of clear etiology and specificity of low back pain, in addition to the lack of reliable and valid outcome measures, clear evidence of a causal association between PSA and low back pain has not been demonstrated (Egan & Al-Eisa, 1999).

Controversy exists in the literature regarding the effect of LLD on running. Blustein and D'Amico (1985) attempted to investigate factors that contribute to injuries in runners with LLD. They suggested that the long limb pronates to shorten, and the short limb supinates to lengthen. Based upon his subjective observation, Subotnick (1981, 1985) speculated that the short limb rotates externally causing excessive pronation in people with LLD, which contradicts the observations of Blustein and D'Amico (1985). However, the above three articles were all empirically based with no strong evidence to support their statements. They all proposed that compensation occurs along the kinematic chain of the lower extremity in an attempt to equalize the LLD (Bolz & Davies, 1984).

On the other hand, another study indicated that LLD has no substantial effect on running. Bloedel and Hauger (1995) investigated the maximum calcaneal inversion and eversion angles during running in individuals with LLD between ½ inch (1.27 cm) and ¾ inch (1.9 cm). They found no significant difference between the short and long limb for the maximum calcaneal inversion and eversion range of motion, and thus concluded that
subtalar joint kinematics were not significantly altered with this degree of LLD. This conclusion is based on the fact that calcaneal eversion is an important component of subtalar joint pronation, while calcaneal inversion is an important component of calcaneal supination. There are two major limitations to that study. First, testing took place while running on a treadmill, which is different from overground locomotion, and second, subjects were not all wearing the same type of shoes.

Another study on the effect of LLD on treadmill running was conducted by Boone and Hammons (1996). They indicated that acute LLD can predispose people to a slightly higher metabolic demand at the heart level (as reflected in the increase in heart rate and oxygen consumption; $V_{O_2}$). However, they did not test subjects with true LLD, but rather artificially created a LLD of 31.8 mm by asking participants to wear a shoe lift. Higher muscular effort was required to compensate for this sudden change in leg length, which might have lead to the increased $V_{O_2}$ that varied in accordance with the workload.

On the other hand, a case study of the effect of LLD on oxygen consumption at different work loads indicated a decreased oxygen consumption when a lift was utilized on the short leg (DeLacerda & McCrory, 1981). Another investigation with the same subject (LLD of 1.25 inch) indicated that the use of a lift decreased the angular velocities with a corresponding decrease in muscle force requirement (DeLacerda & Wikoff, 1982).

In summary, controversy exists in the literature regarding the effect of LLD on structure and function. Also, it remains unclear if a causal relationship exists between measured
LLD and the observed low back pain symptoms. However, most of the studies agree that correction of LLD can improve the biomechanical efficiency of ambulation. No studies investigating the effect of pelvic asymmetry; in particular leg length discrepancy, on sitting posture or sitting pressure distribution have been found.

**Measurement of Pelvic Skeletal Asymmetry**

Pelvic asymmetry and leg length discrepancy are routinely assessed in daily clinical practice. The importance of an objective and non-invasive clinical measurement technique to measure pelvic asymmetry is to provide the clinicians with a tool to assess patients, design the appropriate intervention, and evaluate the effect of the intervention: i.e. outcome. Furthermore, valid and reliable assessment of pelvic asymmetry is essential in order to obtain sound clinical judgement.

There is no universally accepted clinical method for measuring PSA. Various techniques reported in the literature include: palpation of the iliac crest heights (Friberg, Nurminen, Korhonen, Soinnen & Manttari, 1988; Fischer, 1997), the use of a tape measure (Boone & Hammons, 1996; Hoyle, Latour & Bohannon, 1991; Nichols, 1960), radiography (Friberg, Koivisto & Wegelius, 1985; Kunkle & Carpenter, 1954), goniometry (Gilliarm, Brunt, MacMillan, Kinard & Montgomery, 1994), and the use of an anthropometric frame and asymmetry ratio (Egan et al., 1995, 1999). The reliability and validity studies of these measurement methods have yielded conflicting results as seen in the following discussion.
• **Iliac crest palpation:**

Potter and Rothstein (1985) reported poor inter-tester agreement of visual assessment for the ASIS and the PSIS in the standing position (agreement less than 50%), although the tests were performed by therapists who had specialized in orthopedic physical therapy and had been trained in sacroiliac joint examination. This conclusion conflicts with the findings of Mann, Glasheen-Wray and Nyberg (1984), who reported that experienced physical therapists had higher intra-rater and inter-rater agreement than student physical therapists. The intra-rater scores for the students ranged from 4 to 6 with a mean of 4.65 agreements, while the intra-rater scores for the experienced physical therapists ranged from 5 to 8 with a mean of 6.6 agreements. This indicated that familiarity with patient assessment can enhance the reliability of this test. In all cases, the palpation and observation method of comparing iliac crest heights in the standing position has shown differing degrees of agreement, whereas reliability testing has not been reported.

• **The tape measure method:**

The most common clinical method of assessing true leg length involves using a tape measure to measure from the ASIS to the medial malleolus (MM), with the subject in supine. The tape measure method could be criticized from two perspectives. In addition to the lack of accuracy involved with the visual inspection and palpation of the bony landmarks, this measurement represents the sum of the leg length inequality and any asymmetry at the pelvic level (Ingelmark & Lindstrom, 1962). Therefore the tape measure method would not detect IRA (Egan et al., 1995).
• Radiography:

Radiography measurement is considered the most accurate method for determining PSA. However, the accuracy of this method could be distorted by differential magnification and parallax error (Ingelmark & Lindstrom, 1962). Because of their cost, the potential harm, and inaccessibility, radiographs are inadvisable for determining PSA and LLD clinically (Alviso et al., 1988; Beattie, Isaacson, Riddle & Rothstein, 1990).

• The pelvic leveling method:

Leg length discrepancy has also been assessed by comparing bilateral landmarks; i.e., medial malleoli, tibial tubercles, patellar poles, popliteal creases, gluteal folds, ASIS, PSIS, and iliac crests (Gross, 1995). Jonson and Gross (1997) used 0.5 cm wooden shims under the suspected shorter leg until the iliac crests were leveled. Their reported inter and intra-rater reliability tested using Intra-class Correlation Coefficients (ICCs) ranged from 0.67-0.97. The validity of this method was tested in another study by comparing the measurement of LLD using rigid lifts with standing radiographs (Gross, Burns, Chapman, Hudson, Curtis, Lehmann, & Renner, 1998). These authors reported that the ICC values reflecting agreement between the radiographic measurement and the measurement using the lifts were 0.64 for one investigator, and 0.76 for the second investigator. However, this method fails to detect asymmetric rotation of the innominates that is often associated with LLD (Cummings, Scholz, & Barnes, 1993).

• Trigonometry:

Several authors used trigonometry to measure pelvic tilt in standing. Initially Sanders
and Stavrakas (1981) developed a non-invasive clinical method based on a trigonometric calculation to determine the angle of pelvic tilt relative to the horizontal plane by measuring the distance from the floor to the ASIS and to the PSIS and the distance between the ASIS and PSIS. The distance from the ASIS to the floor is subtracted from the distance from the PSIS to the floor. This number is then divided by the distance from the ASIS to the PSIS. The standing pelvic tilt angle was defined as the angle formed by a line drawn through the PSIS and the ASIS, and the line of the horizontal plane (Alviso et al., 1988). This angle increases in an anterior pelvic tilt, and decreases in a posterior pelvic tilt (Alviso et al., 1988). Unfortunately, Sanders and Starvakas did not report the reliability of their technique.

Gajdosik, Simpson, Smith and DonTigny (1985) studied the intra-tester reliability of the method proposed by Sanders and Starvakas with slight procedure modification and standardization. They reported higher intratester reliability for the dynamic anterior pelvic tilt angle (r = 0.92), compared to good reliability for the standing static pelvic tilt angle (r = 0.88), and the dynamic posterior pelvic tilt angle (r = 0.86). Furthermore, Alviso et al. (1988) investigated the inter-tester reliability of six testers using the above method and reported high intraclass correlation coefficients; 0.95 for static standing pelvic tilt angle, 0.93 for the dynamic anterior pelvic tilt angle, and 0.93 for the dynamic posterior pelvic tilt angle. Despite the high reliability reported for this method, its complexity and the trigonometric calculations have made it unpopular in daily clinical settings.
Cummings and Crowell (1988) stated that when a leg length difference exists, visual assessment could result in false-positive interpretation of innominate rotation. They suggested that the method proposed by Sanders and Starvakas (1981) produces smaller error than visual assessment when determining innominate rotation.

- **Motion analysis systems:**

Isolated pelvic tilt angles (neutral, anterior, and posterior pelvic tilt) were also measured using a computerized system, the Iowa Anatomical Position System. That system obtained coordinates of external body landmarks from which pelvic tilt measurement were determined with high reliability as reflected by correlation coefficient of 0.99 for the X, Y, and Z axes (Day, Smidt, & Lehmann, 1984). A Vicon three-dimensional kinematic system has also been used to analyze pelvic tilt in the sagittal plane (Kadaba, Ramakrishnan, Wootten, Gainey, Gorton, & Cochran, 1989; Levine & Whittle, 1996; Pearcy, Gill, & Whittle, 1987). Levine & Whittle (1996) found that the reliability of the Vicon system ranged from fair to very good for neutral pelvic tilt during standing (ICC = 0.95), maximal anterior pelvic tilt (ICC = 0.85), and maximal posterior pelvic tilt (ICC = 0.78).

- **Goniometry:**

Burdett, Brown and Fall (1986) used a gravity goniometer to measure pelvic angle during stance. They defined the pelvic tilt as the angle between the horizontal plane and the perpendicular to the sacrum. The high inter-tester reliability of their method ($r = 0.84$, ICC = 0.82) was similar to those reported by Gadjosik et al. (1985). However, the
method suggested by Burdett et al. (1986) used the sacrum as the reference surface, which may result in invalid measurement because it does not take into account differences in the orientation of the innominate bones. Also, any motion between the sacrum and the pelvis would be included.

The pelvic angle has also been measured using an inclinometer that consisted of two calipers placed over both the anterior and posterior iliac spines, and a mounted universal protractor (Walker, Rothstein, Finucane & Lamb, 1987). This method allowed for the measurement to be taken without the need for calculations. Gilliam et al. (1994) reported high intertester and intratester reliability of this method (ICCs = 0.95, 0.96 respectively). A comparison of the goniometric measurements of the pelvic angle with the measurement obtained by two radiologists demonstrated only fair correlation ($r = 0.85, 0.68$) between the two methods (Gilliam et al., 1994). Considering that the radiography is the gold standard for the measurement of asymmetry, the previous finding by Gilliam et al. indicated poor validity of the goniometric measurement of the pelvic angle.

- **The use of an asymmetry ratio:**

Egan et al. (1994) developed an asymmetry ratio (AR) method to measure pelvic asymmetry. The AR is the sum of the absolute values of width to height difference ratio for the ASIS and PSIS, to differentiate between symmetry, LLD and IRA. They used adhesive markers to mark ASIS and PSIS, which were superior to using pen markers since it gave a more accurate point to measure (Egan et al., 1995). High intra-class correlation coefficients (ICC = 0.94 to 1.0) indicated high intra-tester repeatability. An
important advantage of this method of measurement is that it provides normalized data that takes into account individual differences in pelvic width. In addition, the AR method detects IRA if present, rather than misinterpreting it as LLD (Egan, Cole, & Twomey, 1999).

In conclusion, reports on the validity and reliability of the measurement of pelvic asymmetry varied widely. Objective methods that incorporate anterior and posterior measurement of the pelvis, and hence detect rotation or twisting, are the most appropriate (Egan & Al-Eisa, 1999).

**Measurement of Sitting Pressure Distribution**

Sitting has been defined as a position in which the weight of the trunk is transferred to the support area mainly by the ischial tuberosities and their surrounding soft tissues (Andersson et al., 1975). It has also been reported that the perceived level of comfort is related to the way the seating pressure is distributed over the buttock-chair interface (Dinsdale, 1974; Staarink, 1996).

The need to quantify sitting pressure was initially derived by the need for clinicians to evaluate wheelchair cushions; their ultimate goal being to prevent pressure sores in people with reduced skin sensation or who could not change their body position to alleviate pressure such as people with spinal cord injuries (Treaster & Marras, 1987). Clinical methods obtained to evaluate pressure at the buttock-chair interface were then modified and used widely by the automotive industry to evaluate seat discomfort. In
particular, pressure under the ischial tuberosities is the most important when evaluating effectiveness of cushions (Bar, 1991).

Overall, the majority of methods used to quantify sitting pressure involved using sensors, such as pneumatic (Mooney, Einbund, Rogers & Stauffer, 1971), capacitive (Bush, 1969), hydraulic (Barbenel & Sockalingham, 1990), and strain gauge (Fleisher, Rademacher & Windberg, 1987). Other pressure-sensing tools that were reported in the literature include mechanical springs (Lindan, Greenway & Piazza, 1965) and force sensing array (Rosenthal et al., 1996). The following is an overview of the sitting pressure measuring technologies used in the literature, their limitations, and the main evaluation considerations for such technology.

- **Pneumatic sensors:**

Other studies have attempted to measure the pressure at the chair / buttock interface using pneumatic sensors (Allen, Ryan & Murray, 1993; Bader & Hawken, 1986; Eckrich & Patterson, 1991; Garber & Krouskop, 1982; Gyi, Porter, & Robertson, 1998). The principle used in these studies have lead to the development of what is known now as the Tally Pressure Monitor (TPM). Another commercially available system is the Pressure Evaluation Pad (PEP) which is an electromechanical device consisting of a pad that contains a 12 by 12 matrix of pneumatically controlled contact switches (Garber & Krouskop, 1982; Garber & Krouskop, 1984, Seymour & Lacefield, 1985). However, pneumatic sensors are only suitable for static situations. Another down side with these sensors is that to eliminate error, the volume of air in a pneumatic cell should be
sufficient to measure the applied pressure without deforming the interface, which can only be achieved by injecting a variable amount of air into the cell (Bader, 1982; Bader & Hawken, 1986). Another example of air cell transducers is the Scimedics system which has been found to be both accurate and reliable (Palmieri, Haelen & Cochran, 1980), but requires care and skill to obtain accurate measurements.

- **Hydraulic sensors:**
  Barbenel and Sockalingham (1990) suggested the use of thin liquid filled sensors which had the advantage of fitting in limited access areas. Clark and Rowland (1989) also used a hydraulic sensor to measure pressure at the sacrum. However, the accuracy of the hydraulic pressure sensors is very dependent on the volume of fluid contained in the sensor (Allen, Ryan, Lomax & Murray, 1993), and is subject to error due to temperature changes.

- **Electrical transducers:**
  Patterson and Fisher (1986) measured pressure over each ischial tuberosity using small flat (1 mm thick by 5 mm diameter) pressure transducers that were taped over the ischial tuberosities. The need to reposition the sensors between trials makes this method of measurement quite problematic and unpractical. Sprigle, Faisant, and Chung (1990) measured pressure at the ischial tuberosities using a contour gauge that consists of 64 probes arranged in a 16x16 inch area. They indicated that the mean pressure within the rectangular region under the ischial tuberosities affords a good presentation of the pressure under the major sitting weight bearing landmarks.
• **Optical sensors:**

Other systems were based on the optical principle of total internal reflection (Treaster & Marras, 1987), and examples utilized by researchers include the "wheelchair barograph" (Mayo-Smith & Cochran, 1981), and the "pedobarograph" (Minns & Sutton, 1982). Kadaba, Ferguson-Pell, Palmieri, and Cochran (1984) recommended using ultrasonic dimension gauging technique to describe the geometry of soft tissues deformed under load in order to predict internal tissue stresses during sitting.

• **Strain gauge transducers:**

Drummond et al. (1982) developed and tested a microcomputer-based pressure scanner. Composed of 64 strain-gauge-resistive transducers, the scanner was capable of measuring multiple pressures in the sitting area simultaneously. The validity and reliability of the strain gauged mat used in that study were not reported. The strain-gauge method was also utilized by other researchers (Ayoub & Smith, 1988). A major disadvantage with the use of the strain gauge scanner is that it is inflexible causing a “hammock effect” which prevents the body from sinking into the supporting surface, resulting in measurement errors (Gyi, Porter & Robertson, 19980.

• **Force sensing array:**

Fenety (1995) used the VERG (Vision Engineering Research Group) interface pressure mat, which is a computer linked force sensing array, to monitor in-chair movement by tracking subjects’ center of pressure (COP) as they sat on the mat. The COP was defined as the point of application of the resultant ground reaction force (Fenety, MacLeod &
Crouse, 1994). The validity of the VERG mat was established (Fenety, 1995) by comparing the readings of the COP coordinates and velocity obtained by the VERG mat with those obtained by a force platform as the gold standard (velocities on X and Y axes: \( r = 0.99, 0.89 \); COP tracking on X and Y axes: \( r = 0.99, 0.97 \)). Also, reliability was indicated (Fenety et al., 1994) by the between trials correlations that ranged from 0.77 to 0.93, and by the fact that there was no difference between days for the COP total displacement (\( p = 0.25 \)).

The VERG force sensing array was further calibrated and validated by Wilcoxon sign test comparison of water weight measurement, test retest reliability, and Pearson correlations as reported by Rosenthal et al. (1996). They also suggested that hammocking of the pressure sensors was minimal because the array readings were significantly correlated with those obtained with the previously validated Scimedics system which has no hammocking (\( r = 0.85, p<0.01 \)). In their study, pressure was measured for 5 anatomic locations determined by palpation and then related to positions on the pressure array as follows: right and left ischial tuberosities (row 11), right and left trochanters (row 9), and coccyx (row 11-12). There was no significant difference between pressures under the right and left ischial tuberosities or right and left trochanters (\( p>0.2 \)), which indicated that pressure did not differ by side.

**Measurement of Sitting Discomfort**

With the advancement of technology, several objective methods to measure sitting discomfort have evolved (Lee, Ferraiuolo & Temming, 1993). Validity and reliability of these methods, as well as the appropriateness of the criteria which the seating is tested
against, has to be ensured before starting an investigation (Corlett, 1989). In the literature, the choice of methods was dependent on the purposes of the investigations and the availability of laboratory equipment and conditions. It is important here to indicate that chair comfort has many dimensions, including the task, the individual human differences, and possibly the appearance (Branton, 1969), which makes the task of evaluating sitting comfort even more difficult. The following section provides an overview of the major aspects of the measurement of sitting discomfort.

- **Subjective scales (self reported):**

  Before using any of the subjective responses regarding comfort, one should assume that the respondents are aware of their feelings of comfort, and that feelings of comfort can be verbalized (Jianghong and Long, 1994). If positive correlation can be established between subjective and objective measurements of sitting comfort, the task of designing a comfortable seat will be greatly enhanced.

There are two commonly used, valid and reliable, subjective scales for evaluation of chair comfort: the General Comfort Rating (GCR) scale (Shackel, Chidsey & Shipley, 1969) and the Body Part Discomfort (BPD) scale (Corlett & Bishop, 1976). There are also fuzzy set comfort scales which are those with phrases such as ‘quite comfortable’ or ‘somewhat comfortable’ (Jianghong & Long, 1994), but reports on the validity and reliability of the fuzzy set scales are lacking.
The GCR scale is very practical, since it gives a single bottom-line number, but its disadvantage is that it assumes that comfort and discomfort are closely related and could be measured as a single variable. On the other hand, the BPD scale is a better representative of the discomfort (Helander & Zhang, 1997). Corlett and Bishop (1976) reported that there was an apparent discrepancy between the overall and the body part scales, which indicated that discomfort was perceived as the summation of discomfort at various parts of the body, and that one uncomfortable area did not represent general discomfort.

In an attempt to correlate subjective comfort with pressure distribution and electromyography (EMG), Lee et al. (1993) surveyed a sample of 100 participants and asked them to provide a numerical rating, on a scale of 0 to 10, of perceived comfort in the ten regions of the neck; upper, middle, and lower back; thighs; buttocks; calves; chest; shoulders; sides; and of overall seat comfort. They concluded poor correlation between subjective comfort and both the pressure data and EMG, but they did not report any numerical values to support their findings.

- **Sitting time:**

Five minutes was considered long enough for a user to become familiar with a chair and give a judgement (Grandjean, Hunting, Wotzka & Scharer, 1973; Shackel et al., 1969). The length of time and time of day are crucial in observational studies (Corlett, 1989). Both the GCR and the BPD scale showed increased discomfort with time on task (Shackel et al., 1970; Corlett & Bishop, 1976).
Rosenthal et al. (1996) measured sitting pressure every 5 minutes over a period of 30 minutes, thus recording 6 readings. Gilsetorf, Patterson, and Fisher measured normal and shear forces continuously for 30 minutes. However, there is no clear indication in the literature of an appropriate time duration or time of the day to take the measurement.

- **Sitting posture:**

Sitting posture, defined as the position of the body segments in space, was thought to have great impact on the intensity and direction of the reaction forces of the seat on the body (Staarink, 1996). Because of the effect of gravity, static muscular effort, known as postural work, is needed to maintain a desired body posture (Andersson, Ortengren, Nachemson, Elfstrom & Broman, 1975). Bader & Hawken (1986) reported that pressure changes at the chair-buttock interface observed with the subject sitting still were relatively small and apparently random in nature.

With poor sitting posture, friction forces originating in the seat will be transmitted in the form of shear forces into the buttocks; and together with the pressure, these shear forces can impede the blood circulation and therefore cause the discomfort (Staarink, 1996). The general prescription for good sitting posture in ergonomics is a chair design that produces minimum constraints and minimum use of static contraction of postural muscles (Bhatnager, Drury & Schiro, 1985). However, the posture of a seated person depends not only on the chair design, but also on the individual sitting habits and the task to be performed (Andersson, 1975). As mentioned above, postural discomfort could be measured by GCR (Shackel et al., 1970) or by BPD scale (Corlett & Bishop, 1976).
Bhatnager et al. (1985) argued that the posture of a worker should not be related just to postural comfort measures, but to performance measures as well. In their study, twelve subjects, four in each of three postural conditions, were asked to inspect printed circuit boards for 3 hours with two five-minute breaks per hour. A video recorder was used to record subjects' posture continuously, and the respective postural angles (trunk, neck, and head) were then digitized from the videotape. The authors reported that the reliability of the digitization method used in this study was high (all correlation coefficients were above 0.96). Performance was measured using a digital clock to record search time and stopping time. They also used the BPD scale to measure perceived discomfort. The results suggested that poor task performance was associated with increased forward inclination of the trunk, increased perceived discomfort, and increased frequency of postural changes.

In conclusion, the wide range of factors that affect sitting discomfort requires further attention. Therefore, measurement procedures should focus on the variables of interest with an attempt to control for all extraneous factors. Also, any measurement procedure must be both valid and reliable. The most commonly used methods for evaluating chairs and seating include: comparison against anthropometric data and chair design (Branton, 1969), fitting trials (Jones, 1969), subjective scales (Corlett & Bishop, 1976; Shackel et al., 1969), and sitting pressure distribution (Rosenthal et al., 1996).
A Comparison of the Pelvis in Standing and Sitting

It is important to understand the role of the pelvis in sitting and standing. When looking at the pelvis in sitting, one should consider any present imbalances in the length and strength of the muscles that surround the pelvis. Studying the pelvic position in sitting may lead to a better understanding of the sitting posture, which would contribute to better seating design. Pelvic orientation and spinal curvature are two of the major aspects of seated posture.

To understand the variation of the pelvic positions or postures in sitting and standing, it is important to discuss the relationship between the pelvis and the lumbar spine. In the assessment of low back pain, several authors have speculated the effect of pelvic tilt on lumbar lordosis (Denslow & Chace, 1962; Polster, Spieker, Hoefert & Krenz, 1974; Thomas, 1965). Objective measurement proved that altering the pelvic tilt significantly changed the angle of lumbar lordosis. That is, anterior pelvic tilt increased the depth of the lumbar curve, while posterior pelvic tilt decreased the depth of the lumbar curve (Day, Smidt & Lehmann, 1984; Kroemer, 1994; Levine & Whittle, 1996). Therefore, posterior pelvic tilt exercise is commonly prescribed for patients with low back pain (Levine & Whittle, 1996; Stanish, 1979). However, the effect of pelvic rotation on the lumbar spine is greatly affected by the condition of the muscles that span the hip joint (Bridger, Wilkinson & Van Houweninge, 1989).

In standing, the line of gravity usually falls posterior to the hip, therefore, gravitational forces will tend to extend the hip and anteriorly rotate the pelvis (Basmajian, 1978; Woodhull, Maltrud & Mello, 1985). When a person sits, the pelvis rotates posteriorly,
and thus the lumbar lordosis, normally observed in standing, diminishes and sometimes changes into kyphosis (Keegan, 1953). In this posture, the ischial tuberosities and the upper half of the posterior thighs become the major weight bearing areas on the seat (Peterson & Adkins, 1982). Therefore, sacral and pelvic support is usually recommended to reduce excessive posterior rotation of the pelvis and the subsequent lumbar kyphosis (Zacharcow, 1988).

In standing, the ischial tuberosities are covered by the gluteus maximus muscle. As a person sits, the gluteus maximus rises up allowing the ischial tuberosities to be the major weight bearing area and be separated from the seat by skin and fat only (Babbs, 1979; Sember, 1994). This explains the increase in discomfort with prolonged sitting in people with normal skin sensation, and the high risk of developing ischial ulcers in spinal cord injured population. To improve these conditions, pressure under the ischial tuberosities must be measured and actively reduced either by cushion modification or altering the sitting posture.

The effects of anter-posterior pelvic tilt on seated posture have been studied, but those of the lateral pelvic tilt have received far less attention. Most of the work done in this area was based on measurement of the pelvis in the sagittal plane; i.e., anterior and posterior pelvic tilt (Bendix, 1984; Reinecke, Coleman & Pope, 1994).

In summary, when the trunk is erect, anterior rotation of the pelvis increases the lumbar lordosis, while posterior rotation of the pelvis flattens out the lumbar lordosis. However,
lateral asymmetry has not been as extensively studied and reported, therefore its effects are less well understood.

**Summary**

Sitting discomfort is often related to certain anthropometric, postural, mobility, and muscular characteristics. Therefore, with the current interest in seating, it is particularly important to identify human factors (such as leg length discrepancy) that may alter or affect objective measures of sitting discomfort (such as sitting pressure distribution). The main objective of this study was to investigate whether LLD can discriminate the presence or absence of uneven sitting pressure distribution, and hence if it can contribute to the severity of the sitting discomfort complains.

A review of the literature found no studies on the effect of pelvic skeletal asymmetry on sitting pressure distribution in normal asymptomatic population. However, a few studies have reported the role of fixed pelvic obliquity in developing unilateral decubitus ulcers in paraplegic subjects (Drummond et al., 1982; Drummond et al., 1985). Unfortunately, these studies did not present objective measurements to justify their results. There is no hard evidence to date to verify the assumption that pelvic asymmetry may lead to excessive peak pressure under one ischial tuberosity more than the other.

It is known that--with skeletal maturity--LLD leads to scoliosis and adaptive soft tissues shortening and lengthening. Altered forces resulting from altered posture due to LLD could lead to altered seated pressure. In view of the foregoing, it was deemed that an objective examination of the association between PSA and seating pressure would
provide more accurate information and be of value in the trend towards evidence-based care.
Chapter 3

Reliability study

It is always important to establish first the reliability of the measurement techniques before drawing any conclusions from the measurement results. Therefore, in preparation for the principal study, a pilot study was conducted to test the reliability of pelvic asymmetry and seated pressure measurement. The starting point of this chapter is to discuss the protocol examined in the pilot study that is quite similar to that used in the principal study. The second part is to highlight the reliability results and therefore assessment of the suitability of the measurement instrumentation and procedure.

Objectives

The pilot study was undertaken in order to:

1. Examine the intra-rater reliability of the pelvic skeletal asymmetry measurement.
2. Examine the inter-trial reliability of the sitting pressure distribution measurement.
3. Establish a sampling protocol for selecting which of the mat's 225 sensors consistently represented left and right asymmetry in sitting. For the purpose of this project, asymmetry in sitting was defined as an inequity between the left and right ischial tuberosities pressure distributions, particularly inequity between the left and right mean peak pressures.

Hypotheses

The following hypotheses were tested:

1. There will be no difference between trials in the measurement of PSA (i.e. ASIS and
PSIS height difference, ASIS and PSIS width).

2. There will be no difference in the mean peak pressure values between trials. There will be an agreement between trials in the measurement of the mean peak pressure.

3. There will be no difference in the spatial measurement of the peak pressure between trials. There will be an agreement between trials in the spatial measurement of the mean peak pressure.

Sample

A sample of convenience, composed of 12 healthy female volunteers over the age of 30 years was used (mean age 35.3yrs, SD 4.2; mean weight 65.8Kg, SD 10.6; mean height 1.65m, SD 0.05, Table 3.1). Volunteers were recruited through personal requests and by using posters. Ethical approval was granted by the School of Physiotherapy Ethics Committee. The subjects' data: age, weight, height, and body mass index are presented in Table 3.1.
Table 3.1

Subjects Data: age, weight, height, and body mass index.

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**Instrumentation**

The anthropometric frame and the FSA (force sensing array) mat were used to measure pelvic skeletal asymmetry and sitting pressure distribution respectively. Both instruments are described in detail in the following section.

- **Measurement of pelvic skeletal asymmetry:**

An anthropometric frame comprised of three orthogonally placed metric measurement tapes was used to measure the horizontal distance as well as the vertical height difference between both anterior superior iliac spines (ASIS's) and posterior superior iliac spines (PSIS's). Adhesive skin markers (8 mm diameter with the center marked) were applied to locate the subjects' ASIS and PSIS.
The frame consists of a horizontal bar, which were readily adjusted in height on two vertical tubular steel poles (Figure 3.1). The poles were mounted in a perpendicular orientation on a solid wooden base. An adjustable three dimensional measurement system, consisting of a horizontal pointed ruler, a vertical scale, and a spring-loaded metal tape measure was attached to a steel sliding block on the horizontal bar. The tape-measure housing was secured to an identical steel sliding block mounted on the right side of the measurement block, and the free end of the measure was attached to the left block. All adjustable components were secured by locking screws.

First, the pointed ruler was aligned with the right ASIS or PSIS to take the height of that bone landmark. In this position, the horizontal tape measure was set at zero. The pointed ruler was then moved to measure the opposite ASIS or PSIS height. While moving the ruler, the tape measure simultaneously extends to measure the ASIS or PSIS width.
Figure 3.1

The Anthropometric Frame used to measure PSA. Note the pointed ruler, the calibration board, the metal walking frame for support, and the wooden foot frame for standard foot position.
- **Measurement of sitting pressure distribution:**

The VERG (Vision Engineering Research Group) interface pressure mat, which consists of a force sensing array (FSA), interface module, connecting cable, and computer software, was used as a quantitative tool to measure the sitting pressure distribution. The FSA mat is a 15x15 array of 1 by 1 inch (2.5 x 2.5 cm) force sensing resistors designed to map pressure at the buttock-chair interface, at a rate of 1 scan per second. The mat was calibrated by the manufacturer to determine pressures from 0-300 mmHg. Calibrating the mat is essential in order to define for every individual sensor the corresponding pressure in mmHg of detected pressure at each known % for the entire pressure range. The mat sensors are thin (< 2mm), thereby allowing it to be flexible and adaptable to a variety of chair seat contours.

The interface module is the electronic communicator between the mat sensors and the computer. The FSA cable connects the interface module to the computer. The computer’s software and hardware collect and store the information gathered by the sensors. The FSA mat has been validated against the Scimedics system with Pearson correlation $r = 0.85$, and reliability was $R^2 = 0.90$ (Rosenthal et al., 1996).

A standard office chair (Harter Furniture, Guelph, ON, Canada) with minimum seat pan contour (i.e., virtually flat) was used for testing, and was secured to the floor (Figure 3.2). Chair height was adjusted by a pneumatic mechanism. The backrest height was fixed at mid position of the chair’s available range. There was no lumbar support used. The angle of the backrest with the seat was fixed at 90°.
Figure 3.2

The testing chair (flat seat contour, angle between the seat and back rest fixed at 90°)

Procedure

The study was conducted at the Dalhousie University School of Physiotherapy. Upon arrival, potential volunteers were introduced to the purpose and methods of the study and signed an informed consent. Next, anthropometric data were recorded prior to the testing session. The subject then proceeded to the research area.
• Measurement of pelvic skeletal asymmetry:

Subjects dressed suitably in a manner that allowed ready exposure of all four pelvic landmarks. The participant’s two ASIS’s and two PSIS’s were palpated and marked by the researcher using adhesive markers (8 mm in diameter). Markers were put on and taken off several times for each subject, before the actual data collection began, until the researcher felt that accurate alignment with the bony landmarks was obtained. The accuracy of the marker placement was previously tested and high reliability was reported with ICC values that exceeded 0.94 (Egan, 1994).

Subjects were asked to stand with their feet supported in a wooden frame, to ensure symmetrical stance position, and with their hands supported on a standard walker, to minimize unsteadiness and postural sway. First, the ASIS height and width measurements were taken for the right and left sides (Figure 3.3 a). Subjects were then asked to turn around and the foot frame was reversed to ensure an identical foot position to that used for the anterior measurement (Figure 3.3 b). The anthropometric frame was adjusted to take the posterior measurements (PSIS height and width). Three sets of measurement were taken for each subject (Appendix B). Throughout the testing, subjects were asked to look straight ahead to maintain upright posture and minimize postural sway.
Figure 3.3

(a) ASIS height measurement, (b) PSIS height measurement
- **Measurement of sitting pressure distribution:**

After completing the pelvic asymmetry measurement, subjects were asked to sit upright in a standardized position on a testing chair (Figure 3.4 a), on which the pressure mat was centered. The chair height was adjusted for each subject to obtain a 90 degrees flexion angle at the knee joint. For shorter subjects who were unable to attain 90°, 1/2 inch thick wooden blocks were used as a foot-rest to ensure the same 90° angle (Figure 3.4 b). The sitting position tested was upright sitting, in which the hip, knee, and ankle are at 90°. The angle between the seat and the backrest was fixed at 90 degrees as recommended by Gossens and Snijders (1995) to reinforce the upright posture, to standardize the methodology, and to provide comparable pressure measurements between subjects.

Subjects were instructed to sit with their back straight and their buttocks placed against the chair back (Figure 3.4 a). The subjects’ feet were aligned with the chair’s front feet to ensure standardization. Subjects looked straight ahead at a picture that was placed in front of them in order to promote static posture during data collection. The measurements were performed with the subject sitting still, relaxed, barefoot, and with the arms on the arm rests.

Sitting pressure distribution data was recorded by a 486 MHz IBM computer. A reading was taken every 5 seconds over a period of 30 seconds (7 readings). Subjects were then asked to stand, walk around for 1 minute, and then sit again to take the second series of measurement. Three sitting trials were recorded, and the testing order (PSA measurement first, then sitting pressure distribution measurement) was standardized.
Figure 3.4

(a) side view of a subject in an upright sitting posture. (b) 1/2 inch wooden blocks were placed under the subject's feet to obtain 90° angle at the knee joint.
Data Reduction

The data for the ASIS and PSIS height and width were manually calculated and recorded in the form presented in Appendix B, and then entered in StatView 4.1 software program for analysis.

Regarding the pressure data, a customized data management program was developed in house (James Crouse, M.A.Sc.) to calculate the average of the maximum pressure over a 3x3 block of sensors for both the left and right sides of the mat. Maximum pressure was defined as the highest pressure exerted at particular anatomical sites such as the ischial tuberosities (Redfern, Jenfid, Gillingham & Lunn, 1973). The program detected the 3x3 block of 9 sensors with the highest pressure on the right and the 3x3 block of 9 highest pressures on the left side of the mat (Appendix C, D), and calculated the mean for both sides (3x3 mean peak pressure right and 3x3 mean peak pressure left). The choice of the 3x3 block was made based on the fact that it would present pressure under the ischial tuberosities. As mentioned earlier, it has been reported that approximately 18% of the body weight is distributed over each ischial tuberosity in an upright sitting posture (Drummond et al., 1982).

In order to test the reliability of the spatial measurement of the average pressure, two arbitrary points were selected [(4,1) on the left, (12,1) on the right]. The average distance from these points to the center of the 3x3 block of peak pressure (Figure 3.5) was calculated in order to give a single number representing the spatial measurement in the right and another for the left side. The resolution of the spatial measurement was 1 inch.
(2.5 cm) due to the fact that every sensor gave a single reading, and the size of each sensor was 1x1 inch.

Figure 3.5

The 15x15 array output. Note the highlighted right and left 9 peak sensors, and the two reference points for the spatial measurement reliability.

The 3x3 array of peak pressure
Data Analysis

Data were analyzed using StatView 4.1 Software Program, using a Macintosh L4500 computer. Repeated measure analysis of variance (RM-ANOVA) was used to calculate variances and p-values to test for differences between trials. Level of significance was set at $\alpha=.05$. Descriptive statistics (i.e. means and standard deviations) were computed for the subjects' age, weight, height, and body mass index.

Intraclass Correlation Coefficients (ICCs) were calculated to determine the agreement between measurements of pelvic asymmetry (intra-rater reliability). Also, ICCs were calculated to examine the agreement between the three sitting trials in the measurement of the average right and left peak pressure (between trial reliability). And finally, ICCs were calculated to test the reliability of the spatial measurement of the mean peak pressure and to examine the effect of repositioning between trials.

Two types of ICC were calculated: ICC\(_1\) describing the within-trial reliability of the 7 pressure readings, and ICC\(_2\) for the reliability of the mean of trials each composed of 7 measures (Verducci, 1980; Winer, 1971). Also, ICC\(_1\) represent the ICC\(_{(1,k)}\) described by Shrout and Fleiss (1979) in which $k$ is the number of trials. Throughout the study, the ICC acceptance level was set at .75 (Burdoek, Fleiss & Hardesty, 1963).

Results

**Reliability of the PSA measurement:**

The results of the repeated measures ANOVA for the reliability of the PSA measurement
are presented in Table 3.2. The p-values (p>0.05) indicate that the within subject differences were not significant for each of the four variables (ASIS height difference, ASIS width, PSIS height difference, and PSIS width). The between trial ICCs were 0.83 or greater, and the reliability estimates for the mean of all treatments were 0.94 or higher for all parameters. Since all measurements were taken by a single rater, these results clearly indicate high intra-rater reliability of the PSA measurement.

Table 3.2

Reliability of the PSA measurement based on the RM-ANOVA

<table>
<thead>
<tr>
<th>Variable</th>
<th>ICC&lt;sub&gt;1&lt;/sub&gt;</th>
<th>ICC&lt;sub&gt;2&lt;/sub&gt;</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASIS Ht Diff</td>
<td>.83</td>
<td>.93</td>
<td>0.07</td>
<td>.93</td>
</tr>
<tr>
<td>ASIS Width</td>
<td>.98</td>
<td>.99</td>
<td>0.70</td>
<td>.51</td>
</tr>
<tr>
<td>PSIS Ht Diff</td>
<td>.85</td>
<td>.94</td>
<td>1.51</td>
<td>.24</td>
</tr>
<tr>
<td>PSIS Width</td>
<td>.97</td>
<td>.99</td>
<td>1.60</td>
<td>.22</td>
</tr>
</tbody>
</table>

ICC<sub>1</sub> = reliability estimate for a single trial (within-trial)
ICC<sub>2</sub> = reliability estimate for the mean of all trials

- Inter-trial reliability of the mean peak pressure:

Tables 3.3 and 3.4 present the reliability results of the mean peak pressure based on the RM-ANOVA. For the left peak pressure, all ICC values were higher than 0.82 for all the combination of trials tested. However, for the right peak pressure, ICC<sub>1</sub> and ICC<sub>2</sub> were higher than 0.81 and 0.89 respectively, except for trials 1,2 where the ICC dropped to 0.72. The p-values in both tables (p>0.05) indicate that the within subject differences were not significant in all trials. These results suggest that the first and second (1,2) trials are not as reliable as taking a set of three trials (1,2,3) or the last two (2,3).
Table 3.3

Reliability of the mean left peak pressure based on the RM-ANOVA

<table>
<thead>
<tr>
<th>Trials</th>
<th>ICC₁</th>
<th>ICC₂</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,3</td>
<td>.86</td>
<td>.95</td>
<td>0.46</td>
<td>.64</td>
</tr>
<tr>
<td>1,2</td>
<td>.82</td>
<td>.90</td>
<td>0.30</td>
<td>.59</td>
</tr>
<tr>
<td>1,3</td>
<td>.94</td>
<td>.97</td>
<td>0.20</td>
<td>.66</td>
</tr>
<tr>
<td>2,3</td>
<td>.84</td>
<td>.91</td>
<td>0.72</td>
<td>.41</td>
</tr>
</tbody>
</table>

Table 3.4

Reliability of the mean right peak pressure based on the RM-ANOVA

<table>
<thead>
<tr>
<th>Trials</th>
<th>ICC₁</th>
<th>ICC₂</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,3</td>
<td>.78</td>
<td>.92</td>
<td>2.40</td>
<td>.11</td>
</tr>
<tr>
<td>1,2</td>
<td>.72</td>
<td>.83</td>
<td>3.60</td>
<td>.08</td>
</tr>
<tr>
<td>1,3</td>
<td>.82</td>
<td>.90</td>
<td>0.13</td>
<td>.73</td>
</tr>
<tr>
<td>2,3</td>
<td>.81</td>
<td>.89</td>
<td>3.24</td>
<td>.09</td>
</tr>
</tbody>
</table>

- **Reliability of the mean peak pressure difference:**

Table 3.5 shows the reliability estimates of the calculated mean peak difference. These results demonstrate that this parameter is less reliable than the left and right mean peak pressures. The first and second trials together (1,2) demonstrated the least reliability as observed previously. The fact that this parameter had lower reliability was expected since it is derived from two measurements: the left and right peak pressure, and hence, the error associated with both measurements will be magnified in its value. The average peak pressure difference of the three trials was found to be reliable.
Table 3.5

Reliability of the mean peak pressure difference based on the RM-ANOVA

<table>
<thead>
<tr>
<th>Trials</th>
<th>ICC₁</th>
<th>ICC₂</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,3</td>
<td>.66</td>
<td>.85</td>
<td>0.06</td>
<td>.94</td>
</tr>
<tr>
<td>1,2</td>
<td>.55</td>
<td>.71</td>
<td>0.08</td>
<td>.78</td>
</tr>
<tr>
<td>1,3</td>
<td>.84</td>
<td>.91</td>
<td>0.04</td>
<td>.85</td>
</tr>
<tr>
<td>2,3</td>
<td>.64</td>
<td>.78</td>
<td>0.04</td>
<td>.84</td>
</tr>
</tbody>
</table>

- Reliability of the spatial measurement of the peak pressure:

Consistent with the results of the mean peak pressure, the reliability estimates of the spatial measurement indicate lower reliability for the spatial measurement of the right peak pressure than the left (Tables 3.6 and 3.7). Furthermore, the first two trials (1,2) and the first and last (1,3) were less reliable than the set of three (1,2,3) or the last two trials (2,3).

Table 3.6

Reliability of the spatial measurement of the left peak pressure based on the RM-ANOVA

<table>
<thead>
<tr>
<th>Trials</th>
<th>ICC₁</th>
<th>ICC₂</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,3</td>
<td>.84</td>
<td>.94</td>
<td>0.45</td>
<td>.64</td>
</tr>
<tr>
<td>1,2</td>
<td>.86</td>
<td>.92</td>
<td>0.46</td>
<td>.51</td>
</tr>
<tr>
<td>1,3</td>
<td>.71</td>
<td>.83</td>
<td>0.07</td>
<td>.79</td>
</tr>
<tr>
<td>2,3</td>
<td>.92</td>
<td>.96</td>
<td>1.64</td>
<td>.23</td>
</tr>
</tbody>
</table>
Table 3.7

Reliability of the spatial measurement of the right peak pressure based on the RM-ANOVA

<table>
<thead>
<tr>
<th>Trials</th>
<th>ICC₁</th>
<th>ICC₂</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,3</td>
<td>.75</td>
<td>.90</td>
<td>0.56</td>
<td>.58</td>
</tr>
<tr>
<td>1,2</td>
<td>.67</td>
<td>.80</td>
<td>0.21</td>
<td>.65</td>
</tr>
<tr>
<td>1,3</td>
<td>.77</td>
<td>.87</td>
<td>1.07</td>
<td>.32</td>
</tr>
<tr>
<td>2,3</td>
<td>.79</td>
<td>.88</td>
<td>0.38</td>
<td>.55</td>
</tr>
</tbody>
</table>

In summary, the measurement of pelvic asymmetry was found to be highly reliable (intrarater reliability). Based on the inter-trial reliability results of the pressure measurement, the average of the 3x3 block mean peak pressure of three trials will be used in the principal study. The spatial measurement was also found to be reliable making it possible to use it in the principal study.
Chapter 4

Methodology

Research Design
A prospective, cross-sectional, correlational, comparative, descriptive research design was used to investigate the relationship between pelvic skeletal asymmetry and sitting pressure distribution in a sample of healthy female adults. The predictor variable (independent variable) was the quantitative measure of pelvic skeletal asymmetry (asymmetry ratio- AR). The outcome variable (dependent variable) was the sitting pressure distribution over the ischial tuberosities measured as the average pressure difference between the right and left mean peak pressures (mean peak pressure difference-MPPD).

Objectives
The main objectives of the study were:

1. To assign subjects to their appropriate anthropometric group based on their pelvic asymmetry measurement.
2. To compare between the two selected anthropometric groups; symmetrical and leg length discrepancy, in the demographic factors and the pressure measurement.
3. To examine the relationship between the pelvic asymmetry measurement, the seated pressure measurement, and the demographic factors.
4. To examine the relationship between the pelvic asymmetry measurement and the spatial measurement of the seated peak pressure.
Secondary objectives included:

5. To examine the relationship between the peak pressure and its spatial measurement.
6. To examine the effect of BMI and age on peak pressure.

**Hypotheses**

The null hypotheses were:

1. There will be no statistically significant difference between the two anthropometric groups (symmetrical and LLD) with respect to the mean peak pressure difference and demographic factors.
2. There will be no relationship between the AR and the mean peak pressure difference.
3. There will be no relationship between the AR and the spatial measurement of the mean peak pressure (i.e., the antero-posterior presentation of the two ischial tuberosities).
4. There will be no relationship between the peak pressure and its spatial measurement.

**Sample**

- **Sample size:**

The proportion of symmetry to LLD had to be determined in order to estimate the number of subjects required in each group, and hence calculate a sample size. To determine this proportion, data from an earlier study was used (Egan, 1994). From that study (n=128, mean AR=0.067, SD=0.0389, range=0.0029-0.2122), it was found that, at 2 SD's (96%), the ratio of symmetry to LLD was 6:1. Therefore, in this study, at least 36 subjects had to be recruited in the symmetry group and 6 subjects in the LLD group.
A sample of convenience, composed of 52 female volunteers between the age of 30-55 years, was initially screened, of which 45 subjects were eligible for the study. This age range of the subjects was targeted in the recruitment process; i.e., over the age of 30 for skeletal maturity (Siffert, 1987), and below 55 for menopause (Stanford, Hartge, Brinton, Hoover & Brookmeyer, 1987).

• Subjects:

Volunteers were recruited in the Metro area through personal requests. To recruit subjects with extreme asymmetry, the researcher contacted a physiotherapy clinic to refer subjects diagnosed with LLD. All subjects were asymptomatic at the time of testing. As part of the screening process, subjects were excluded if they met any of the following exclusion criteria:

i. Acute orthopedic or neurological disorders related to the spine, pelvis, or lower limbs: or lower limb musculoskeletal problems present at the time of testing.

ii. Congenital anomalies in the back or lower limbs (e.g., diagnosed scoliosis).

iii. Pregnancy, from the end of the first trimester to one year post-partum.

iv. Surgery or injury, including motor vehicle accidents, to the back or lower limbs (e.g., fractures or ligamentous sprains).

v. Presence of IRA as detected through the pelvic asymmetry testing.
**Ethical Issues**

Ethical approval was granted by a Faculty of Graduate Studies Ethics Committee at Dalhousie University. All subjects signed an informed consent (Appendix A). Confidentiality and anonymity were provided for all participants. To maintain confidentiality, each subject and all data related to her were referred to by a code number. Subjects received careful instructions throughout the testing, and were accompanied by the tester at all times. Subjects did not experience any discomfort throughout the testing procedure. There were no apparent risks associated with the testing.

**Instrumentation**

The anthropometric frame and the force sensing array (FSA) interface pressure mat were used to measure pelvic asymmetry and sitting pressure distribution respectively. Both instruments are described in detail in the reliability study (Chapter 3).

**Procedure**

The principal study was conducted at the Dalhousie University School of Physiotherapy. Upon arrival, potential volunteers were introduced to the purpose and methods of the study and were requested to read and sign the informed consent (Appendix A). Anthropometric data (weight and height) were recorded prior to the testing session. Subjects were also asked about their dominant hand and leg. The dominant leg was considered the leg used to kick a ball. Subjects who met the inclusion criteria then proceeded to the research area. The testing order was standardized for all subjects: pelvic skeletal asymmetry measurement first, then measurement of sitting pressure distribution.
• **Measurement of pelvic skeletal asymmetry**

The same procedure used in the reliability study was repeated for the measurement of PSA. The two ASISs and two PSISs height and width for each subject were taken and recorded by the researcher in a form like the one presented in Appendix B.

• **Calculating the asymmetry ratio:**

While recording, the researcher assigned negative and positive values to left and right measurements respectively, for the purpose of distinguishing between leg length discrepancy (LLD) and iliac rotation asymmetry (IRA). Three sets of measurements were taken for each subject and the mean values were used to calculate the asymmetry ratio (AR) as follows:

1- The researcher measured the right and left ASIS height and the distance between them (width) three times. The ASIS height difference was calculated, and the mean height difference for the three measurements was recorded. Then, the ratio of the mean ASIS height difference to the mean width was calculated and called the anterior asymmetry ratio (ARa = ASIS height difference / ASIS width).

2- The same procedure was repeated for the PSIS measurement. The ratio of the mean PSIS height difference to width was called the posterior asymmetry ratio (ARp = PSIS height difference / PSIS width).

3- The asymmetry ratio (AR) was then calculated as the sum of the absolute values of the anterior and posterior ratios (AR = ARa + ARp).

4- Thus, if the AR is +/+, it is a LLD with a short left leg, -/- LLD with a short right leg, +/- IRA with a higher right ASIS, -/+ IRA with a left ASIS higher.
In summary, the equation used to calculate the asymmetry ratio was:

Asymmetry Ratio = mean ASIS height difference / mean ASIS width + mean PSIS height difference / mean PSIS width (Egan, 1994).

To further explain this calculation, an example of a subject with LLD is presented in the following:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21</td>
<td>20</td>
<td>+ 1.0</td>
<td>27.7</td>
<td>1</td>
<td>24.6</td>
<td>24</td>
<td>+ 0.6</td>
<td>9.0</td>
</tr>
<tr>
<td>2</td>
<td>20.9</td>
<td>19.9</td>
<td>+ 1.0</td>
<td>27.1</td>
<td>2</td>
<td>24.7</td>
<td>24</td>
<td>+ 0.7</td>
<td>9.1</td>
</tr>
<tr>
<td>3</td>
<td>21</td>
<td>20</td>
<td>+ 1.0</td>
<td>27.4</td>
<td>3</td>
<td>24.8</td>
<td>24.1</td>
<td>+ 0.7</td>
<td>9.0</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td>+ 1.0</td>
<td>27.23</td>
<td>Mean</td>
<td></td>
<td></td>
<td>+ 0.67</td>
<td>9.03</td>
</tr>
</tbody>
</table>

ARa = 1 / 27.23 = + 0.037  
ARp = 0.67 / 9.03 = + 0.074  
AR = ARa + ARp = +/- 0.111

(+/- means that the anterior and posterior AR were both positive, which indicated that this subject had a longer right leg and a short left leg)

The anterior and posterior ratios define the slope between the ASISs and PSISs respectively (Figure 4.1). This measurement was used to designate subjects to the three anthropometric groups, i.e., symmetrical, LLD and IRA, by comparing their AR with the AI calculated in the pilot study as discussed in the following section.
Figure 4.1

Method used to calculate asymmetry ratio showing an example of a subject with IRA.


![Diagram showing a subject with IRA with measurements labeled: h = height difference, w = width, Slope = h/w.]

- Calculating an asymmetry index (AI):

A cut-off value (Asymmetry Index- AI) was calculated using the results of the pilot study. This was essential in order to use it as a criterion for determining objectively the cut-off between symmetry and asymmetry, and therefore assign subjects in their
appropriate anthropometric group. For the purpose of calculating this index, a 1.0 cm ASIS height difference was considered to be clinically significant (Siffert, 1987). Dividing this 1.0 cm over the average ASIS width of the subjects in the pilot study (25.68 cm) gave an anterior asymmetry ratio value ARa (1 cm / 25.68 cm = 0.039). Because an identical value for the posterior slope will be expected in pure asymmetry (LLD), and the ARa is a normalized value for the anterior measurement, then doubling that value provided the needed AI (Egan, Cole, & Twomey, 1999). The cutoff value (AI) for the present study was 0.078 (0.039 X 2 = 0.078). Subjects admitted to the LLD group were required to have asymmetry ratios greater than this value, with the anterior and posterior measurement (ARa and ARP) being either both negative or both positive.

Assignment to the anthropometric groups:
The calculated AR for each potential subject was used to assign volunteers in three anthropometric groups: symmetrical, LLD, and IRA, and to determine the eligibility of subjects to participate in this study. Subjects were classified symmetrical, when their AR, positive or negative, was less than AI (0.078), and asymmetrical when their AR was greater than the AI. The differentiation between the LLD and IRA was made through the signs of the anterior and posterior asymmetry; i.e., negative or positive. When the anterior and posterior asymmetry ratios (ARa, ARP) of a participant were either both negative (i.e., left ASIS and PSIS are higher), or both positive (i.e., right ASIS and PSIS are higher), and the AR was over 0.078, the participant was assigned to the LLD group. When the ARa and ARP had opposite negative and positive values, the subject was assigned to the IRA group. Nine subjects were assigned to the LLD group, seven to the
IRA, and the remaining 36 were all symmetrical. The subjects with IRA were excluded from the study.

- **Measurement of sitting pressure distribution**

The protocol previously described in the reliability study for the sitting measurement was followed in the principle study with slight modification as described in the following.

Subjects were instructed to sit with their back straight and their buttocks placed against the chair back (Figure 3.4 a). A plumb line placed against a mirror was used to align the midline of the participant’s body and to reduce any asymmetry above the pelvis level (for example, tilting the head to one side or dropping one shoulder). Subjects sat in front of the mirror and plumb line, and used that as a guide to sit symmetrically. Subjects looked straight ahead at the mirror in order to ensure static posture during data collection. The seated measurements were performed with the subject sitting still, relaxed, barefoot, and with the arms on the arm rests. The subjects’ feet were aligned with the chair’s front feet to ensure standardization.

A reading was taken every 5 seconds over a period of 30 seconds (7 readings). Subjects were then asked to stand, walk around for 1 minute, and then sit again to take the second series of measurements. Three sitting trials were recorded.

**Data Reduction**

The pelvic asymmetry measurement of each participant was recorded (Appendix C). The mean height difference, mean width, ARa, ARp, and the final AR were all calculated
manually by the researcher. The AR data was then transferred to a Microsoft Excel spreadsheet with the subjects’ age, height, weight, BMI, hand and leg dominance.

The data management program developed in the reliability study was used to calculate the average of the maximum pressure over a 3x3 block of sensors for both the left and right sides of the mat (Appendix D). The mean peak pressure over a 3x3 block of sensors for both the left and right sides of the mat was recorded. Three trials were recorded for each subject. The mean peak pressure difference of the three trials was calculated. Positive and negative values were assigned to the pressure values in the right and left sides of the mat respectively to indicate the side of higher pressure \( (\text{MPPD} = 3x3 \text{ MPP Rt} - 3x3 \text{ MPP Lt}) \). This was essential to identify if pressure differs by side; i.e., right or left, as well as to identify if the subject was right or left sitter. However, in the regression and correlation analysis, only absolute values were used.

The \( x \) and \( y \) coordinates of the peak pressure were calculated for every frame in all trials. The horizontal distance between the two peak pressure points in the right and left sides of the mat was calculated and called the inter-ischial distance (I-ID). The I-ID was used to represent the anatomical bi-ischial distance measured in sitting. In order to measure the antero-posterior presentation of the pelvis, the front-back distance between the two peak pressure points was calculated and called the antero-posterior ischial distance (AP-ID). When the two ischia are aligned, this antero-posterior ischial distance (AP-ID) should be nearly zero. Positive and negative values were given to the right and left sides of the mat respectively, so that if the AP-ID was positive, it indicates that the right peak pressure is forward, and if the AP-ID was negative, it indicates that the left peak was forward.
Data Analysis

Data was stored in Microsoft Excel 97 and analyzed in Minitab statistical software package version 12. For the purpose of summarizing and describing the data, descriptive statistics (i.e., means, standard deviations, minimum, maximum, and range) were used for the subjects’ age, weight, height, body mass index (BMI), asymmetry ratio (AR), mean peak pressure difference (MPPD), inter-ischial distance (I-ID), and antero-posterior ischial distance (AP-ID). Frequency histograms were used to plot the anthropometric data to visually examine the variability in the sample. A normal probability test was conducted on the AR to test if it was normally distributed.

Unpaired two tailed t-tests were used to test for differences between the two tested groups: symmetrical and LLD, in the following parameters: (i) mean peak pressure difference, (ii) the magnitude of the mean peak pressure both right and left, and (iii) the spatial measurement of the right and left mean peak pressure (I-ID, AP-ID). Statistical significance was assumed if a significance difference was observed at p<0.05.

Stepwise regression was conducted to test if any of the independent variables (AR, I-ID, AP-ID, age, weight, height, BMI, and hand and leg dominance) was significant in predicting the mean peak pressure difference. Significance level for stepwise regression was set at 0.15. Correlations between the independent variables; age, weight, height, BMI, AR, I-ID, and AP-ID, were examined.

Correlational statistics (Pearson Product Moment Correlation Coefficient) was used to
examine the association between the asymmetry ratio (AR) and the mean peak pressure difference. When describing the strength of the association, the criterion set by Domholdt (1993) was used ($r = 0.00-0.25$ little, if any correlation, $0.26-0.49$ low correlation, $0.50-0.68$ moderate correlation, $0.70-0.89$ high correlation, $0.90-1.00$ very high correlation). The $r^2$ values were also calculated to determine how much of the variability in the dependent variable (i.e., the mean peak pressure difference) was explained by each independent variable. Only the absolute values of AR and MPPD were used in the analysis.
Chapter 5

Results

Demographic results
Fifty-two female subjects were initially screened. Of these subjects, seven were excluded from the study after calculating that their AR indicated IRA. The mean, standard deviation, minimum, maximum, and range of the forty-five participants' age, weight, height, and body mass index are presented in Table 5.1. The age range of the subjects was within the set range targeted in the recruitment process (30-55 years). The mean and range of BMI indicated that the sample tended toward obesity, given that the obesity BMI index is considered to be over 25. Figure 5.1 shows the four histograms for the age, weight, height, and BMI of the sample. The weight had a bimodal distribution, and the other three histograms showed normal distributions.

Descriptive statistics (mean, standard deviation, minimum, maximum, and range) for the sample's asymmetry ratio (AR), mean peak pressure difference (MPPD), and the spatial measurement of peak pressure (antero-posterior ischial distance: AP-ID, and inter-ischial distance: I-ID) are presented in Table 5.2. Figure 5.2 shows that the distribution of the asymmetry ratios formed a continuum and the normal probability plot in Figure 5.3 indicates that the asymmetry ratios were normally distributed.
Table 5.1

Descriptive statistics for all the subject's age (yr), weight (Kg), height (m), and body mass index (BMI).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (year)</td>
<td>38.5</td>
<td>7.1</td>
<td>30</td>
<td>54</td>
<td>24</td>
</tr>
<tr>
<td>Weight (Kg)</td>
<td>65.6</td>
<td>9.6</td>
<td>48.5</td>
<td>82</td>
<td>33.5</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.6</td>
<td>0.1</td>
<td>1.4</td>
<td>1.8</td>
<td>0.4</td>
</tr>
<tr>
<td>BMI (Kg/m²)</td>
<td>24.5</td>
<td>3.3</td>
<td>18.9</td>
<td>32.0</td>
<td>13.2</td>
</tr>
</tbody>
</table>

Table 5.2

Descriptive statistics for the pelvic measurements: asymmetry ratio (AR), mean peak pressure difference (MPPD: mmHg), antero-posterior ischial distance (AP-ID: cm), and inter-ischial distance (I-ID: cm).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR</td>
<td>0.056</td>
<td>0.031</td>
<td>0.008</td>
<td>0.152</td>
<td>0.144</td>
</tr>
<tr>
<td>MPPD (mmHg)</td>
<td>6.85</td>
<td>6.32</td>
<td>0.02</td>
<td>26.98</td>
<td>26.96</td>
</tr>
<tr>
<td>AP-ID (cm)</td>
<td>0.7</td>
<td>0.6</td>
<td>0.0</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>I-ID (cm)</td>
<td>11.9</td>
<td>1.7</td>
<td>5.0</td>
<td>15.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>
Figure 5.1

Histograms for the subject's age (yr), weight (Kg), height (m), and BMI.
Figure 5.2

Distribution of asymmetry ratios for all subjects (n = 45).
Figure 5.3

Normal probability plot for the asymmetry ratios.

Normal Probability Plot

Average: 0.0557333
StDev: 0.0307190
N: 45

Anderson-Darling Normality Test
A-Squared: 0.443
P-Value: 0.274
**Assignment to the anthropometric groups**

Nine subjects whose asymmetry ratio exceeded the asymmetry index \((AI = 0.078)\), and whose anterior and posterior measurements \((AR_{a} \text{ and } AR_{p})\) being both negative or both positive, were classified as the LLD group. Four of those subjects had a longer right leg \((LLD \text{ Rt})\) and the remaining five had a longer left leg \((LLD \text{ Lt})\). As illustrated in Table 5.3, the results of the unpaired two-tailed \(t\)-test indicated that there was no significant difference between the symmetrical and LLD group in the demographic data. This result indicated that it was reasonable to make further comparisons between the symmetrical and LLD subjects due to the relative homogeneity of the sample.

The raw data for hand and leg dominance are presented in Table 5.4. As expected, most subjects were right side dominant. All the five subjects with a longer left leg \((LLD \text{ Lt})\) were right side dominant. Also, the other four asymmetrical subjects \((LLD \text{ Rt})\) were right side dominant except for one subject who had a left dominant hand. The symmetrical group \((n=36)\) were mostly right side dominant except for one subject who was left side dominant and another who had a dominant left hand. Given the overwhelming proportion of right side dominance and limb preference, it was felt that no further useful observations could be made on this aspect.
Table 5.3

Descriptive statistics and comparisons of the two groups (demographic data)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Symmetrical group ( n = 36 )</th>
<th>LLD group ( n = 9 )</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Age (years)</td>
<td>39.03</td>
<td>7.55</td>
<td>36.58</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>65.42</td>
<td>9.22</td>
<td>66.10</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.64</td>
<td>0.06</td>
<td>1.63</td>
</tr>
<tr>
<td>BMI (Kg/m^2)</td>
<td>24.41</td>
<td>3.17</td>
<td>24.98</td>
</tr>
</tbody>
</table>

Table 5.4

Data for dominant hand and leg

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Dominant Hand</th>
<th>Dominant Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lt</td>
<td>Rt</td>
</tr>
<tr>
<td>Symmetrical</td>
<td>36</td>
<td>1</td>
<td>35</td>
</tr>
<tr>
<td>LLD Rt</td>
<td>4</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>LLD Lt</td>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>
**Comparison between the two selected anthropometric groups**

The results of the unpaired two-tailed t-test for comparison between the two groups are presented in Table 5.5. There were no statistically significant differences between the groups in the mean peak pressure difference (MPPD), the antero-posterior ischial distance (AP-ID), and the inter-ischial distance (I-ID). This result supported the first null hypothesis.

It is worth noting that although the mean pressures and the mean pressure distances of the two groups were not significantly different, the mean values may reflect a trend whereby the subjects with LLD had higher values in the MPPD, I-ID, and AP-ID. In addition, the variance around the mean of the MPPD of the LLD group was approximately double that of the symmetrical group. This finding was interesting because it tended to suggest that subjects with LLD may have had greater variability among subjects, which could be explained by the smaller number of subjects in the LLD group compared to the symmetrical. The mean and standard deviation for the AP-ID were slightly higher in the LLD subjects. However, differences in the I-ID between the two groups were very small.
Table 5.5

Comparisons of the two groups in the mean peak pressure difference (MPPD), antero-posterior ischial distance (AP-ID), and inter-ischial distance (I-ID)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Symmetrical group</th>
<th>LLD group</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>AR</td>
<td>0.044</td>
<td>0.019</td>
<td>0.102</td>
</tr>
<tr>
<td>MPPD (mmHg)</td>
<td>6.42</td>
<td>4.91</td>
<td>8.60</td>
</tr>
<tr>
<td>AP-ID (cm)</td>
<td>0.7</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>I-ID (cm)</td>
<td>12.4</td>
<td>1.9</td>
<td>12.8</td>
</tr>
</tbody>
</table>

* : significant
**Relationships between the AR, the MPPD, and the demographic factors**

In the stepwise regression, no variable met the 0.15 significance level for entry into the model for predicting the MPPD. This indicated that none of the variables (AR, weight, height, BMI, age, hand and leg dominance, and the spatial measurement) was significant in predicting the dependent variable, i.e. the mean peak pressure difference.

Table 5.6 shows the correlations results of the following variables: age, weight, height, AR, and mean peak pressure difference. No associations were found between variables, except for the expected fair correlation between weight and height ($r = 0.47$). The correlation between the AR and MPPD ($r = 0.18$) gives a $r^2$ value of 0.032, meaning that only 3.2% of the variability in the MPPD can be accounted for by AR.

This supported the second null hypothesis which stated that there will be no relationship between the AR and the MPPD. The poor correlation between AR and MPPD is clearly shown in Figure 5.4.
Table 5.6

Pearson Product Moment Correlation Coefficients between: age, weight, height, asymmetry ratio, and mean peak pressure difference.

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Weight</th>
<th>Height</th>
<th>AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>0.264</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>0.271</td>
<td>0.473</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AR</td>
<td>-0.061</td>
<td>0.122</td>
<td>-0.002</td>
<td></td>
</tr>
<tr>
<td>MPPD</td>
<td>0.260</td>
<td>0.086</td>
<td>0.191</td>
<td>0.180</td>
</tr>
</tbody>
</table>

Figure 5.4

Scatter plot of the asymmetry ratio and the mean peak pressure difference. The vertical line represents the cut-off AI at 0.078.
**Relationship between the AR and the pressure spatial measurement**

The mean inter-ischial distance (I-ID), which represented the bi-ischial distance or the horizontal distance between the right and left peak pressure sites, was 11.9 cm. The important spatial parameter in this study was the antero-posterior ischial distance (AP-ID), which indicated the antero-posterior presentation of the two peak pressures under the ischial tuberosities. This AP-ID ranged from 0-2.5 cm (0-1 inch), indicating that the two peaks were always either aligned or one is anterior to the other by one sensor (1 inch).

Pearson Product moment Correlation Coefficients calculated to detect the association of the AR and MPPD with the antero-posterior measurement (AP-ID) were 0.198 and -0.061 respectively (Figures 5.5 and 5.6). This indicated that only 3.9% ($r^2 = 0.039$) and 0.4% ($r^2 = 0.004$) of the variability in the antero-posterior measurement can be accounted for by the AR and the MPPD respectively.

Therefore, this result supported the third and forth null hypotheses which stated that there will be no relationship between both the AR and the MPPD, and the spatial measurement of the mean peak pressure.
Figure 5.5

Scatter plot of the asymmetry ratio and the antero-posterior ischial distance (inch). The vertical line represents the cut-off AI = 0.078.
Figure 5.5

Scatter plot of the mean peak pressure difference (mmHg) and the antero-posterior ischial distance (inch).
**Relationship between the peak pressure and the pressure spatial measurement**

Table 5.7 shows the values of the mean right and left peak pressures with their X and Y coordinates. The X and Y coordinates are presented in inches since the pressure mat is made of 15x15 sensors, and each sensor is 1x1 inch. The coordinates were calculated based on the location of the 3x3 block middle sensor relative to the (0,0) starting point that is at the left corner of the mat in the front side (refer to Appendix C).

The average right peak pressure was slightly higher than the left, with a smaller standard deviation. The raw data of the mean peak pressure difference (MPPD) showed that 21 subjects had the left mean peak pressure higher than the right, and the remaining 24 had the right mean peak higher than the left. This means that 47% of the sample were left sitters (left higher peak pressure), and 53% were right sitters (right higher peak pressure). However, there was no statistically significant difference between the right and left mean peak pressures (p = 0.6).

Table 5.8 shows the distribution of the right and left sitters in the anthropometric groups. Close inspection of the raw data for the right and left sitters revealed that all the five LLD Lt (subjects with longer left leg) were left sitters, while the LLD Rt (subjects with longer right leg) were equally distributed; i.e., two right sitters and two left sitters. Given the small number of subjects in the LLD Lt group, the above observation must be treated with caution. Symmetrical subjects were also not equally distributed.
Table 5.7

Descriptive statistics for the all the sample’s right and left peak pressure (mmHg) and the spatial location of the peak pressure on the mat (inch), n = 45.

<table>
<thead>
<tr>
<th>Pressure</th>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right peak</td>
<td>Average</td>
<td>60.29</td>
<td>10.56</td>
<td>40.34</td>
<td>87.85</td>
</tr>
<tr>
<td></td>
<td>X coordinate</td>
<td>10.38</td>
<td>0.71</td>
<td>8.91</td>
<td>11.76</td>
</tr>
<tr>
<td></td>
<td>Y coordinate</td>
<td>10.54</td>
<td>0.54</td>
<td>9.00</td>
<td>11.67</td>
</tr>
<tr>
<td>Left peak</td>
<td>Average</td>
<td>59.66</td>
<td>12.48</td>
<td>34.97</td>
<td>87.66</td>
</tr>
<tr>
<td></td>
<td>X coordinate</td>
<td>10.30</td>
<td>0.74</td>
<td>8.43</td>
<td>11.52</td>
</tr>
<tr>
<td></td>
<td>Y coordinate</td>
<td>5.58</td>
<td>0.47</td>
<td>4.95</td>
<td>7.00</td>
</tr>
</tbody>
</table>

Table 5.8

Distribution of the right and left sitters in the anthropometric groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Lt sitters</th>
<th>Rt sitters</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symmetrical</td>
<td>14</td>
<td>22</td>
<td>36</td>
</tr>
<tr>
<td>LLD Lt</td>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>LLD Rt</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>24</td>
<td>45</td>
</tr>
</tbody>
</table>
**Effect of BMI and age on peak pressure**

Right and left mean peak pressures were not correlated with the BMI ($r = 0.04, 0.01$ respectively). Furthermore, right and left mean peak pressures were not correlated with the age ($r = 0.39, 0.30$ respectively).

**Summary**

In summary, the main objective of the study was to examine the association between the AR and the MPPD. The two variables were not correlated as revealed by the regression analysis and the calculated Pearson Product Moment Correlation Coefficient. None of the covariates were statistically significant. There was no statistically significant difference in the MPPD between the two anthropometric groups; symmetrical and LLD. The spatial measurement of the mean peak pressure (mainly the antero-posterior ischial distance) was not correlated with the AR or the MPPD. Although the slight trends observed in the raw data tended to show some differences in performance between the symmetrical and LLD subjects, the results of this study indicated that there was no strong evidence to reject any of the null hypotheses.
Chapter 6

Discussion

With the current interest in seating, it is particularly important to identify human factors, such as leg length discrepancy, that may affect objective measures of sitting comfort, such as sitting pressure distribution. A review of the literature found no studies on the effect of pelvic skeletal asymmetry on sitting discomfort in normal asymptomatic population. The current study was the first to use a quantitative approach to examine the common assumption that pelvic asymmetry may lead to excessive peak pressure under one ischial tuberosity more than the other. The results of this study indicated that there was no statistically significant association between leg length discrepancy and uneven sitting pressure distribution.

Reliability study

The pilot study was aimed at investigating the intra-rater reliability of the PSA measurement as well as the inter-trial reliability of the sitting pressure measurement. Another purpose of the pilot study was to examine the reliability of the spatial measurement of the peak pressure as addressed in the following section.

- **Reliability of the pelvic skeletal asymmetry measurement:**

Before commencing the principle study, it was essential to ensure that the measurement of pelvic skeletal asymmetry to be used was both accurate and reliable. In a previous study, the anthropometric frame was found to be highly accurate for the measurement of PSA (Egan, Cole & Twomey, 1995). Part of the present pilot study was aimed at evaluating the intra-rater reliability of the researcher conducting the study. The high ICC values reported in the reliability study (0.83-0.99) indicated high reliability consistent
with the earlier findings of Egan (1994). In addition, those ICC values compared favorably with those reliability estimates previously reported for the measurement of pelvic tilt (Alviso et al., 1988; Burdett et al., 1986; Gajdosik et al., 1985; Gilliam et al., 1994; Jonson & Gross, 1997; Levine & Whittle, 1996). Furthermore, the use of adhesive skin markers provided a more accurate placement of the bony landmarks than the use of pen markers where the control of skin movement is difficult (Simmonds, 1992). Therefore this method of PSA measurement was suitable for use in the principle study.

Based on the above, and given that there is no universally accepted clinical method for measuring LLD, the researcher decided that the anthropometric frame and the procedure used in this study provided an accurate assessment and normalized measurement of pelvic asymmetry. In addition, it made the differentiation between symmetry, leg length discrepancy, and iliac rotation asymmetry possible.

- Reliability of the sitting pressure distribution measurement:

Since it was difficult to propose a single measurement protocol, an important purpose of the pilot study was to evaluate a methodology for testing asymmetry in seated pressure distribution using reliability statistics, and to determine which sitting pressure parameters would be used. It was also necessary to ensure that the FSA mat was appropriate for measuring the parameters of interest in a reproducible and consistent manner; i.e., test-retest reliability. The results of the pilot study demonstrated that reliability based on the mean peak pressure of three trials (1,2,3) or the last two (2,3) is greater than that based on the first two trials (1,2) or the first and last (1,3). The high ICCs found denote small
within-subject variance compared to between-subject variance. Also, the p-values indicated that no statistically significant differences existed between trials.

The ICC reliability coefficients were defined as the true variance divided by the total (true plus error) variance (Shrout & Fleiss, 1976). The higher the variability between-subjects, the higher the ICC (Stratford, Norman & McIntoch, 1989). The sample in the pilot study was relatively homogenous with respect to the following factors: gender (all females), mean age (35.3yrs, SD 4.2), mean weight (65.8Kg, SD 10.6), and mean height (1.65m, SD 0.05, Table 3.1). Despite the apparent homogeneity of the sample, the ICCs were still high.

Most reliability studies on pressure distribution based their comparison of contact pressure at various sites on the calculated average pressure at each site (Allen, Ryan & Murray, 1993; Boorman, Carr & Kemble, 1981; Cark & Rowland, 1989; Kosiak et al., 1958). In the present study, the mean peak pressure, over an area of 3x3 sensors calculated from 7 readings over a period of 30 seconds, was used as the criterion measure. The choice of taking the mean of 3x3 block of sensors was made because it would give more accurate results than the use of a single peak value since the error associated with a single measurement is often greater than that for the average of several measurements (Kroll, 1967).

The use of the mean rating as the unit of analysis has been shown to be appropriate if the reliability of the mean rating is of interest and as long as generalization will not be made
to individual rating (Shrout & Fleiss, 1979). According to Kroll (1967), reliability theory dictates that “if the error variances are considered to be random and uncorrelated, then the proper procedure is to use the mean of all available trials”, so long as no trend or time effects are present. No trend or bias was evident in the data of each individual subject in this study. It was therefore concluded that the 3x3 block mean peak pressure in both sides of the mat was an appropriate measure for the uneven sitting pressure distribution.

Strangely, the right mean peak pressure was less reliable than the left, which might be due to the fact that the right peak pressure was greater than the left in 11 out of 12 subjects (92%). For the purpose of investigating factors that influence the reliability of the pressure measurement, Allen, Ryan, Lomax & Murray (1993) found that under laboratory conditions, the repeatability of the sensor was not dependent on the loading pressure since readings of high interface pressure were as repeatable as those of low pressure. However, another study indicated that average pressure was less repeatable at sites exerting high interface pressures in a more clinical environment (Allen, Ryan & Murray, 1993), an observation consistent with the findings of the pilot study. They argued that the higher the pressure, the wider the spread of readings, which would reduce the reliability.

- **Reliability of the spatial measurement of the mean peak pressure:**

The lower reliability of the spatial measurement compared to that of the mean peak pressure indicate that repositioning the subject on the mat after each trial produced significant changes despite the fact that considerable care was taken to seat the subject in
the same position each time. Also, the reliability of the last two trials (2,3) being higher than the others could indicate that subjects were accommodating to the chair and to the test.

The protocol examined in the pilot study was similar to that suggested by Bader and Hawken (1986) in which five sets of twelve, 60 second readings were obtained while the subject remained as still as possible. They found that repositioning the subject produced statistically significant changes in all pressure parameters (in 19 out of 20 cases) than while the subject remained quietly seated. Their results could be explained by the fact that static sitting postures involve different balances of muscular and supporting forces. Although these differences are not usually perceived by the researcher or the subject, the small changes in supporting forces would be reflected in the variations in pressure distribution (Bader & Hawken, 1986). The spatial measurement in the pilot study was found to be reliable.

In summary, the pilot study provided strong support for the use of the anthropometric frame and the VERG mat for examining the relationships between pelvic skeletal asymmetry and seated pressure distribution.

**Principal study**

- *Comparison between the two selected anthropometric groups:*

In this study, no significant difference was found between the symmetrical and LLD groups for the mean peak pressure difference (MPPD) in upright sitting posture. Therefore, the data of this study did not strongly support the idea that people with LLD
sit with more asymmetrical sitting pressure distribution than those without LLD. Nor did this study support the opinion of Peterson and Adkins (1982) that pelvic obliquity predisposes uneven pressure patterns at the buttock-chair interface.

Although there was no significant difference between the two groups in the MPPD, close inspection of the raw data suggested possible trends. The standard deviation of the MPPD in the LLD group was double that of the symmetrical. This finding was interesting because it suggested that the LLD group had a higher between subject variability than the symmetrical group. However, this finding is hard to explain, and should be interpreted cautiously due to the small number of subjects in the LLD group as compared to that in the symmetrical group. Furthermore, this great difference in the variance between the groups suggests other possibilities for analysis, such as non-parametric tests.

It is important here to note that in this study subjects were asked to sit in a constrained upright position; i.e., controlled using a plumb line and a mirror, and were not allowed to maintain their usual postures. Paluch (1996) suggests that since restraining subjects in a certain sitting position does not allow postural individualism, subjects should be given the freedom to express their usual sitting postures. However, upright sitting posture was chosen for the purpose of this study because it provided a consistent position for measuring pressure under the ischial tuberosities. It is generally agreed that when a person is sitting upright, the pelvis is slightly tilted forward, weight is then borne on the ischial tuberosities, and pressure points will be close to the back rest. In some instances,
subjects may have poor trunk control or might voluntarily tilt the pelvis posteriorly, then the sacrococcygeal area becomes the weight-bearing surface (Peterson & Adkins, 1982), a pattern often observed and called sacral sitters. No sacral sitters were found in this study, which could be explained by the imposed upright position that might have prevented posterior tilting of the pelvis.

It is also a known fact that sitting is a dynamic posture. Since sitting posture dictates pressure distribution at the buttock-chair interface (Patterson & Fisher, 1986), and since it is difficult or nearly impossible to identify an ideal steady sitting posture, the results of the current study should be interpreted carefully with regard to the imposed test position. This position might have masked the true sitting pressure distribution of the asymmetrical subjects by controlling some of their anomalies, for example by evening out the level of the posterior buttock ridge.

- **Relationships between the AR, the MPPD, and the demographic factors:**

Since a strong association between body dimensions and the adapted posture has been reported (Paluch, 1996), the effect of the anthropometric factors on the asymmetry ratio and the sitting pressure was examined in this study. No correlations were found between the measurement of LLD and weight, height, BMI, or age. This was partially consistent with the findings of Soukka et al. (1991), except for the positive correlation they reported between LLD and height. However, since Soukka et al. (1991) used radiographs for measuring LLD in standing, it was hard to compare their findings with the current results which used the anthropometric frame and the asymmetry ratio. Also, there were no
correlations found between the mean peak pressure difference and the demographic variables: weight, height, BMI, and age. This was expected since the MPPD used in this study was a normalized value for each subject that was independent of the demographic factors.

Since palpating the iliac spines may be affected by the fat layer surrounding the bony landmarks, measurement of pelvic asymmetry is usually difficult in obese subjects (Gajdosik, Simpson, Smith, & DonTigny, 1985). Despite the fact that most participants in this study had BMI's approaching obesity (mean 24.5, SD 3.27), they had palpable iliac spines. This would have added to the accuracy of the measurements obtained by eliminating a potential source of measurement error. However, the relatively homogeneous nature of this sample limits the generalizability of the study results. On the other hand, the range of LLD obtained in this study provided adequate data for studying a possible association between LLD and sitting pressure distribution.

The use of the AR for measuring pelvic asymmetry was superior to other commonly used methods since it not only can differentiate between the different types of pelvic asymmetry, but is also a direct measure that is not subject to parallax error. However, the use of the AR only does not take into account the relative anterior or posterior position of the pelvis in the transverse plane. It would be useful to define the ratios between the anterior and posterior slopes to further determine if the subject has a predominantly LLD or IRA.
This study offers the first objective evidence for the effect of LLD on the upright sitting pressure distribution. The lack of correlation between the AR and the MPPD offered further evidence of the lack of significant differences between the two groups.

- **Relationship between the spatial measurement, the peak pressure and the AR:**
  
  In the present investigation, pressure did not differ from side to side. That is, there was no significant difference between pressures under right and left ischii. This result compared favorably with the results of Rosenthal et al. (1996).

  The inter-ischial distance (I-ID) calculated in this study represents the horizontal distance between the two peak pressure points in the right and left sides of the mat. In an upright sitting posture, this peak pressure is expected to be under the ischial tuberosities (Peterson & Adkins, 1982). In the present study, the average I-ID was found to be 12.5 cm. It has been reported that the ischial tuberosities lie approximately 10 cm (4 in) apart in women and slightly closer in men (Meschan, 1975). Kosiak et al. (1958) indicated that inter-ischial distances between the points of maximal pressure in 11 subjects tested ranged from 11 to 12 cm. Akerblom (1948) reported that the average distance between the mid-points of the supporting surfaces of the ischial tuberosities as approximately 13 cm in women, which was consistent with the reported distance in this study (12.5 cm).

  The antero-posterior ischial distance ranged between 0-2.5 cm (0-1 in) which indicated that the maximum separation between the two ischial bones in the transverse plane was 1 sensor. Peterson & Adkins (1982) speculated that people with pelvic obliquity sat with
one ischium more forward than the other ischium. Unfortunately, the authors provided no data to support their opinion. Moreover, the lack of correlation between the AR and the AP-ID found in this study indicated that the antero-posterior presentation of the pelvis in sitting may not be influenced by any lateral asymmetry present in standing.

Rosenthal et al. (1996) used the VERG mat to measure ischial pressure. In their study, location of the two ischium was determined by palpation and then related to position on the pressure array. Rosenthal et al. (1996) indicated that ischial tuberosities were located between rows 11 and 12 at columns left 5 and right 10, a finding which was also supported by the results of the current study as shown in Table 4.6.

- **Effect of BMI and age on peak pressure:**

  The effect of body mass index on seated pressure distribution was examined in order to understand the variability between subjects’ mean peak pressures. The literature reveals conflicting results in this regard. Body build was thought to affect seated pressure distribution (Garber & Krouskop, 1982). Clark & Rowland (1989) concluded that due to reduced muscle tone, sacral contact pressure was higher among the elderly compared to that pressure measured in the young. On the other hand, Redfern et al. (1973) found no correlation between local pressures and body mass. Allen, Ryan & Murray (1993) also found no relationship between interface pressure and subject mass at any of the sites they tested (occiput, scapula, elbow, sacrum, buttock, and heel). The results of the principal study supported the opinion that body mass does not affect the magnitude of peak pressure as indicated by the lack of correlation between BMI and the right and left mean
peak pressures.

Age was believed to have a substantial effect on the seated pressure, since the capability of the body to repair tissue breakdown, resulting from excessive pressure, varies with age (Sember, 1994). The poor correlation between pressure and age found in this study could be explained by the limited age group of the sample (adults over the age of 30 to 55).

**Limitations**

There are two possible limitations with this study, in addition to two limitations with the use of the pressure mat.

First, the results of this study should be interpreted cautiously. Differences in the pelvic orientation between sitting and standing have to be acknowledged. In sitting, there is a strong tendency to tilt the pelvis posteriorly, which could lead to evening the level of the ischial tuberosities and therefore correcting the lateral pelvic asymmetry. Furthermore, these results could be influenced by other variables that were not observed or incompletely analyzed (such as the center of pressure data).

Second, any failure of subjects to maintain upright static posture may have resulted in errors in the measurement of their mean peak pressure. Although every attempt was made to ensure identical sitting position for all trials, this source of error may have been strong enough to alter the results, and may have existed several times as a result of repositioning.
There were also two potential limitations with the use of the pressure mat. The presence of the mat will "perturb" (i.e. alter) the conditions at the interface to some degree, so that the measured interface pressure may differ from the true interface pressure without the mat in place (Ferguson-Pell, 1980; Reddy, Palmeri & Cochran, 1984). In order to reduce perturbation error, the pressure sensors must be flexible, thin (having a thickness to diameter ratio of no more than 0.1), and should not be influenced by changes in either temperature or moisture (Barbenel & Sockalingham, 1990). In general, the more elastic and yielding an interface is, the less the presence of a sensor is noticed, resulting in a lower perturbation error (Allen et al., 1993). Although the design of the VERG mat met these criteria, some perturbation errors may have occurred.

Finally, the existence of shear forces at the interface should be acknowledged (Allen, Ryan & Murray, 1993), especially as the mat used only measures variations in compressive vertical loading. However, this limitation was reduced by the fact that compression is the predominant form of loading at the buttock-chair interface (Bader, 1990). Furthermore, the use of the constrained sitting posture in the current study reduced the shear forces (Gossen & Snijders, 1995), as opposed to unconstrained posture in which subjects exhibit a lot of shear forces.

**Clinical implications**

Ischial pressure ulcers, due to excessive pressure under the ischium, are known to be one of the serious problems for patients with spinal cord injuries. Objective critical evaluation of sitting pressure and pressure distribution is valuable in such cases.
Accordingly, clinicians working with paraplegic or wheelchair-bound patients should consider using the methodology described in this study to measure peak pressures under the ischial tuberosities. The mean peak pressure has been found to be a very reliable measure that provides a good representation of the pressures within the rectangular region under the ischial tuberosities (Sprigle, Faisant, & Chung, 1990). Locating areas of high pressure, like the use of the 3x3 block, would appear to be useful in predicting the site at risk of developing tissue breakdown and discomfort. The 3x3 block mean peak pressure was found to be reliable for the use of locating high pressure regions and is therefore superior to taking a single reading of each sensor.

Pressure at the chair-buttock interface is dependent on the bony configurations, the depth of the soft tissues, and the support surface (Bar, 1991). Patients with spinal cord injuries often have muscle atrophy with very prominent ischial tuberosities. Therefore, the effect of scoliosis and pelvic obliquity on the sitting pressure may be enhanced and more apparent in such populations. Further research with similar objectivity and sound valid and reliable measurement procedures like those used in the current study is needed with spinal cord injury patients. The use of able-bodied subjects in this study provided a realistic estimate of asymmetry in interface pressure measurement having normal muscle tone and bulk in the buttock region.

Clinical physiotherapists frequently make the assumptions that asymmetries such as PSA cause altered force distribution resulting in abnormal tissue stresses, altered functions, and symptoms such as low back pain. More objective evidence to support or refute these
views is needed. Although the present study did not provide convincing evidence to support an association between PSA and one measurement of sitting discomfort; that is sitting pressure distribution, the weak trends observed do provide support for further study on these possible relationships.

**Recommendation for future research**

To date, most sitting pressure studies have focused on evaluating resting surfaces and designing cushions that reduce peak pressures at the buttock-chair interface. Future research should focus on the factors that cause localized areas of peak pressure. If human body build and skeletal variability prove to be important, the task of chair design may become easier, as will the process of client education about the relevance of sitting behavior and posture. This ultimately may reduce the incidence of sitting discomfort complaints.

The following are recommendations for future research in light of the results of this study:

i. To obtain direct comparisons between symmetrical and asymmetrical subjects, it would be advisable to have equal number of subjects in each group.

ii. Subjects with LLD require more detailed assessment which should include dynamic pressure measurement to determine the extent of the pressure variation with time.

iii. Since this study only focused on the effect of frontal plane asymmetry; i.e., LLD, it would be worthwhile to examine the effect of the sagittal plane asymmetry; i.e.,
IRA, on seated pressure

iv. Self reported assessment of sitting comfort of people with asymmetry versus symmetrical subjects is recommended since pressure alone may not account or explain sitting variability.

v. Field comparison between symmetrical and asymmetrical subjects to understand the effects of workplace tasks on sitting pressure distribution would also be useful.

Summary

In view of the growing interest in seated pressure distribution, human anatomical variations were currently examined in order to understand the commonly observed uneven sitting pressure patterns; i.e., right to left pressure differences. A commonly reported form of asymmetry that may lead to altered posture is pelvic skeletal asymmetry. Although pelvic obliquity has long been recognized to cause high pressure concentration under one ischium, objective quantitative assessment of pelvic obliquity has not been clearly evident. This study was undertaken primarily to determine the affect of the most common type of pelvic asymmetry; that is lateral pelvic tilt due to leg length discrepancy, on seated pressure. The results indicated that there were no statistically significant differences between the symmetrical and asymmetrical groups in the mean peak pressure and the position of the peak pressure. In both the symmetrical and LLD subjects, there were no correlations between the AR, the MPPD, and the spatial measurement of the peak pressure. In conclusion, the evidence tended to favor the position that LLD may not act as a confounding variable that interferes with the overall assessment of SPD.
Appendix A

Informed Consent Form

The Association between Pelvic Skeletal Asymmetry and Sitting Pressure Distribution

Principle investigator: Einas Al-Eisa

Supervised by: Dr. David Egan and Dr. Anne Fenety

Thank you for considering participation in this study. The purpose of the study is to test the relationship between pelvic asymmetry in standing and the distribution of weight over the sitting area. The study will be performed in a research laboratory at the School of Physiotherapy, Dalhousie University. Your participation is completely voluntary and you may withdraw at any time without prejudice.

Procedure

You will be first shown the two measurement tools used in the study: a hip-posture measurement frame to measure pelvic skeletal asymmetry, and a pressure mat to measure the sitting pressure distribution. For the testing session, you have been asked to wear a shirt and pants or shorts with elastic waist band. This will allow the examiner to identify and place small adhesive markers just below your waist line, two markers in front of your hip and two in the back of your hip. To ensure your privacy, screens will be put around the testing area.

Then you will be asked to stand barefoot in a wooden frame, and will be supported using a walking frame. The four appropriate bony points will be located and marked with small adhesive markers. The position of these markers will be taken using the metal measurement frame. The measurement will be repeated three times for each point. You will be given adequate rest periods in between to prevent fatigue.
The second part of the testing session involves the measurement of sitting pressure distribution. You will be asked to sit on a chair, with a back rest, on which a pressure sensor mat has been placed. Two upright test positions will be used, one sitting comfortably looking at a picture in front of you, and the other corrected sitting posture in which a plumb line will be used to ensure that you are sitting symmetrically. Each sitting trial will take 30 seconds. You will then be asked to stand for a minute, walk around, and sit again to repeat the measurement. Three trials will be recorded in both sitting positions. Data will be recorded instantly in a computer and analyzed later. The entire testing session will be approximately 45 minutes.

During the seating testing, a Polaroid photo might be taken of you in order to assess your posture in the later analysis. Your face will be masked in the picture. This photograph will not be used in any display or conference unless an explicit written permission is granted by you.

Your participation in the study is completely voluntary. If you feel uncomfortable at any time during the testing session, you may withdraw. There will be no negative effects for you if you choose to withdraw or end the testing session early. To ensure confidentiality, a code number will be given to you and this code number will be used on all data related to you.

**Benefits**

There may not be a direct benefit to you other than the unique opportunity of participating in scientific research. Since one side of the human body is not usually a mirror image of the other, this study will aim to identify the degree of asymmetry between the right and left sides if present in standing or sitting. Furthermore, the study will examine if the asymmetry present in standing still exists in sitting. The results of the study will hopefully contribute to our understanding about seating and sitting discomfort.

**Risks**

There is no risk of injury involved in this study, except for the possibility of loss
of balance while standing. However, this risk is prevented by giving you a walker to hold on to for support. The slight possibility of fatigue caused by prolonged standing still will be prevented by ensuring adequate rest periods. You will receive careful instructions throughout the testing and you should not experience any discomfort. Any questions or concerns you may have will be answered and explained fully. A tester will be with you at all times to ensure that these slight risks are minimized and that you have adequate rest periods during the test procedures.

Your participation is greatly appreciated. If you have any questions or concerns regarding this study or your participation in it, you may contact the investigators: Einas Al-Eisa (902) 494-1446, or Dr. David Egan (902) 494-1655, or Dr. Anne Fenety (902) 494-2634. A copy of this consent will be given to you.

I have read and understand the above consent, and have had my questions and concerns answered by the investigator. I understand that my participation in this study is completely voluntary and that I have the right to withdraw at any time without prejudice.

Name ________________________________

Subject signature ______________________

Witness ______________________________

Date ________________________________

If you would like a copy of the results explained or sent to you, please print your address and telephone number.

Address ______________________________

____________________________________

Telephone #: _________________________
Appendix B

Pelvic measurement: data collection form

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Asymmetry Ratio (AR) = \( \frac{\text{ASIS Ht. Diff.} + \text{PSIS Ht. Diff.}}{\text{ASIS Width} + \text{PSIS Width}} \)
Appendix C

The 15x15 interface pressure mat output

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### Lt side

The 3x3 block of peak pressure

### Rt side

The 3x3 block of peak pressure
Appendix D

The pressure gradient output of the FSA mat

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Sensors included: 117
Variation coefficient: 11.1%
Standard deviation: 28.7
Average pressure: 31.2
Maximum pressure: 200
Center of pressure: 81.87
References


Bolz, S., & Davies, G.J. (1984). Leg length differences and correlation with total leg strength. JOSPT, 6, 123-129.


