"POSITIVE OR NEGATIVE X-AXIS ROTATION OF THE INNOMINATE AS A CAUSE OF A FUNCTIONAL LEG LENGTH INEQUALITY"

BY

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"I Anthony Victor Peers declare that this work is my own work, both in conception and execution."

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ABSTRACT

The objective of this research was to determine whether there was any reasonable biomechanical evidence to support the chiropractic theory that a positive (anterior) or negative (posterior) x-axis rotation of the innominate bone, could result in a significant functional leg length inequality. This theory was advocated by Winterstein J.F. 1991, Gatterman M.I. 1990 and Herbst R.W. (undated).

The object was achieved by clamping six fresh cadaveric pelves in a specially designed instrument which measured the positive (anterior) and negative (posterior) x-axis rotation of the innominate via the sacroiliac joint and the symphysis pubis, the forces involved, and the associated y-axis translation, z-axis translation and x-axis rotation of the roof of the acetabulum. The extra-capsular iliac tubercle was used as the axis of rotation due to easy palpation and identification of this point. Some authors placed the axis at this point or at a point very close to this area, (Bakland O. et al. 1984; Weisle H. 1955; Bernard T.N. et al. 1991; Bellamy N. et al. 1983).

The results were tabulated, and thereafter a Pearson's moment correlation coefficient was done to show the linearity of the results.
Graphs were then drawn to depict this linearity graphically.
Finally a mean of the differences for each set of results of each cadaver was done to show how the results of each cadaver compared.

The results showed that a positive (anterior) and a negative (posterior) x-axis rotation of the innominate caused a functional lengthening and shortening of the lower limb respectively. These findings concur with those of Winterstein J.F. 1991, Gatterman M.I. 1990 and Herbst R.W. (undated)
The maximum amount of lower limb lengthening varied between 11.75 millimetres and 6.17 millimetres among different cadavers, when 9 degrees of anterior innominate rotation was induced.
The maximum amount of lower limb shortening varied between 10.58 millimetres and 6.16 millimetres among different cadavers when 9 degrees of posterior innominate rotation was induced. This 9 degrees of rotation was via both sacroiliac joints, thus effectively allowing 4,5 degrees of rotation per sacroiliac joint.

This amount of induced rotation was chosen as it coincided with what most authors believed to be the maximum amount of rotation via the sacroiliac joints (Sturreson B. et al. 1989; Egund N. et al. 1978 and Gatterman M.I. 1990).
The maximum force needed to induce this rotation in either direction was no more that 130 Nm (approximately 13 mkp).

It was noted that the older cadavers required greater force to achieve the same rotation as the younger cadavers, this suggesting decreased mobility of the sacroiliac joints.
This is in agreement with the findings of Gatterman M.I. 1990; White A.A. 1990; Sashin D. 1930 and Bernard T.N. 1991.
However, on average, the amount of leg length inequality induced in the older specimens was greater than those in the younger specimens, thus suggesting greater mobility of the sacroiliac joints. These findings seem to contradict each other and may be a topic for further investigation.

It seems possible that a sacroiliac rotational subluxation could cause a leg length inequality, thus substantiating the Chiropractic theory. It is however unlikely that this leg length inequality will be greater than 11.75 millimetres which many authors such as Winterstein J.F. 1991; Hult L. 1954; Gross R.H. 1983; believe to be clinically insignificant.
Other authors such as Giles L.G.F. 1976 and Travell J.G. et al. 1983 believe this amount of leg length inequality to be significant, however this may be an avenue for further research.

UITREKSEL

Hierdie studie beoog om vas te stel of daar enige bio-meganiese getuienis is om die volgende Chiropraktiese teorie, soos voorgestel deur Winterstein J.F. 1991 en Gatterman M.I. 1990, te ondersteun: "dat 'n positiewe (anterior) of negatiewe (posterior) x-as rotasie van die innominaat bene kan lei tot 'n funksionele verskil in been lengte.

Ses vars kadawer bekkenne was ondersoek met hulp van 'n spesiaal onwerpte instrument in 'n poging om die volgende afmetings te bepaal: die magte betrokke by beweging; verwante x-as en y-as verplasing; en die x-as rotasie van die asetabulum dak. As gevolg van maklike palpasie en identifikasie van die ekstra-kapsulere iliak tuberkel, was hierdie punt gebruik as die as van rotasie. Sekere skrywers gebruik dieselfde punt, of 'n punt baie na aan hierdie area, as hulle as van rotasie. (Bakland O. et al. 1984, Weisle H. 1955, Bernard T.N. et al. 1991, Bellamy N. et al 1993).

Hierdie uitslae was getabuleer waarna 'n Pearsons Moment korrelasie koefficient gedoen was om die leariteit van die uitslae te bewys.Grafiese beelde was voorgestel om hieride lenieriteit te illustreer. In 'n poging om die verskillende uitslae van elke kadawer te vergelyk, was 'n gemiddeld van die verskille uit gewerk.

Die resultate het getoon dat 'n positiewe (anterior) en 'n negatiewe x-as rotasie van die innominaat lei tot 'n funksionale verlenging en verkorting van die laer bekenne. Hierdie bevindings is gelykstaande aan die van Winterstein J.F. 1991, Gatterman M.I. 1990 en Herbst R.W. (ongedateerde).

Die maksimale verlenging van die laer bekken wissel tussen 11,75 mm en 6,17 mm in die verskillende kadewers, wanneer daar 'n 9 grade anterior innominate rotasie gebruik was. Die maksimale verkorting van die laer bekken wissel tussen 10,58 mm en 6,16 mm in die verskillende kadawers wanneer daar 'n 9 grade posterior innominaat rotasie gebruik was. Hierdie 9 grade rotasie was deur beide die sakroiliak gewrigte, met 'n effektiewe 4,5 grade rotasie deur die sakroiliak gewrig. Hierdie hoeveelheid rotasie was gekies omdat die meeste skrywers glo dat dit die maksimum hoeveelheid van rotasie is deur die sakroiliak gewrigte (Sturresson B. et al. 1989, Egund N. et al. 1978 en Gatterman M.I. 1990). Die maksimum magte wat benodig was om hierdie rotasie in enige direksie te veroorsaak was nie meer as 130 Nm (+/- 130 mkp) nie.

In die geval van ouer kadawers was daar bevind dat sterker magte benodig was om dieselfde rotasie te bereik as in jonger kadawers, wat bewys dat ouer kadawers minder mobiliteit in die sakroiliak gewrigte het. Dit is in ooreenstemming met die bevindinge van Gatterman M.I. 1990, White A.A. et al. 1990, Sashin D. 1930 en Bernard T.N. et al. 1991. Oor die algemeen is die verskil in been lengtes meer sigbaar in ouer kadawers as in jonger kadawers, wat 'n grooter mobiliteit in die sakroiliak gewrigte van ouer kadawers voorstel. Hierdie bevinding stem nie ooreen met vorige bevindinge nie, hierdie mag 'n verdere studie in die toekoms benodig. Dit is moontlik dat sakroiliak rotasie- subluksasie kan lei tot 'n verskil in been lengte wat lei tot 'n bevestiging van die Chiropraktiese teorie, soos uiteengesit in die eerste paragraaf. Dit is onwaarskeinlik dat die verskil in been lengte meer as 11,75 mm sal wees, wat baie skrywers soos Winterstein J.F. 1991, Hult L. 1954, Gross R.H. 1983, as klinies onbelangrik beskou. Ander skrywers soon Giles L.F.G. 1976 en Travell J.G. et al. 1983, glo dat so 'n verskil nie belangrik is nie. Hierdie bevindinge kan dien as die grondslag vir verdere studies.

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CHAPTER 1

THE PROBLEM AND ITS SETTING.

1.1. STATEMENT OF THE PROBLEM

The aim of this investigation was to assess to what extent forced +ve (clockwise) and -ve (anti- clockwise) x-axis rotational movement applied to the sacroiliac joint and symphysis pubis via the innominate, causes an alteration in the height of the roof of the acetabulum in order to describe the extent of functional lengthening or shortening of the lower limb.

1.2. **SUBPROBLEMS**

1.2.1. Subproblem 1

Subproblem one was to apply +ve and -ve x-axis rotation to the sacroiliac joint and symphysis pubis via the innominate to establish the amount of +ve and -ve y-axis translation of the roof of the acetabulum in order to assess the amount of vertical translation that will occur at the roof of the acetabulum.

1.2.2. Subproblem 2

Subproblem two was to apply +ve and -ve x-axis rotation to the sacroiliac joint and symphysis pubis via the innominate to establish the amount of +ve and -ve z-axis translation of the roof of the acetabulum in order to assess the amount of horizontal translation that will occur at the roof of the acetabulum.

1.2.3. Subproblem 3

Subproblem three was to apply +ve and -ve x-axis rotation to the sacroiliac joint and the symphysis pubis via the innominate to establish the amount of +ve and -ve x-axis rotation of the roof of the acetabulum in order to assess the amount of rotation that will occur at the roof of the acetabulum.

1.2.4 Subproblem 4

Subproblem four was to integrate the amount of vertical and horizontal translation and rotation occurring at the roof of the acetabulum with +ve and -ve x-axis rotation of the innominate via the sacroiliac joint and the symphysis pubis in order to describe the extent of functional lengthening or shortening of the lower limb.

1.3. HYPOTHESES

1.3.1 Hypothesis 1

It was hypothesised that the maximum forced +ve and -ve x-axis rotation of innominate via the sacroiliac joint and symphysis pubis will cause a +ve and -ve y-axis translation of the roof of the acetabulum.

1.3.2 Hypothesis 2

It was hypothesised that the maximum forced +ve and -ve x-axis rotation of innominate via the sacroiliac joint and symphysis pubis will cause a +ve and -ve z-axis translation of the roof of the acetabulum.

1.3.3 Hypothesis 3

It was hypothesised that the maximum forced +ve and -ve x-axis rotation of innominate via the sacroiliac joint and symphysis pubis will cause a +ve and -ve x-axis rotation of the roof of the acetabulum.

1.3.4 Hypothesis 4

It was hypothesised that when the maximum forced +ve and -ve x-axis rotation of the innominate is applied via the sacroiliac joint and the symphysis pubis, the integration of the vertical, horizontal and rotational movements of the roof of the acetabulum will cause a functional lengthening or shortening of the lower limb.

1.4 DELIMITATIONS

1. This scientific study was limited to dissected models of the pelvis, leaving only the ligaments and articular capsules intact.

2. The dissected pelvis were disease free in terms of known patient history and radiographic analysis.

3. This study was limited only to the movement in a normal pelvis with normal joints and thus not anatomically different joints.

4. Only male and female pelves of ages less than 45 years old were used because of ankylosing spondylitis, degenerative disease and fibrosis which sets in after 45 years of age. However delimitation two ruled this out.

5. Race or sex were not taken into account.

6. No other causes of a functional short leg was researched.

7. This research was subject to permission granted by the relevant health departments.

8. This research was limited by the accessibility of cadaver specimens (i.e. number of specimens).

1.5 ASSUMPTIONS

1. It is assumed that there are no biomechanical differences between different race groups in the sacroiliac joints and symphysis pubis, however this assumption does not apply to gender.

2. It is assumed that the range and type of movement in a joint is determined by osseous and ligamentous structures and that muscles only initiate movement.

3. It is assumed that the consensus of authorities regarding the clinical significance of a functional short leg is that a short leg of one and a half centimetres or more is clinically significant.

4. It is assumed that ligaments in a dissected specimen retain most of their original elasticity.

5. It is assumed that the sacroiliac joints and symphysis pubis have a reciprocal movement when the pelvis is rotated in the +ve and -ve x-axis plane.

1.6. IMPORTANCE OF THE STUDY

1.6.1. Background

The notion that relative changes in limb lengths can occur as a result of alterations in pelvic alignment or mechanics is a very controversial subject as there is a large amount of conflicting literature on the subject. There is however very little correlation between the studies and the claims of their authors. Some believe that the leg length inequality is caused by a subluxation in the sacroiliac joint (Winterstein J.F. 1991, Gatterman M.I. 1990 and Herbst R.W "undated").

However, others believe that the leg length inequality is caused by paraspinal muscle spasm which causes a hiking effect of the one limb (Winterstein J.F 1991). Only the former theory was covered in this study.

1.6.2. The need for a solution

The idea that a subluxation in the sacroiliac joint, and consequently the symphysis pubis, may cause a change in relative leg length, is widely accepted in the chiropractic field. This study will examine the extent to which this can occur. In so doing, it will add to the understanding of factors affecting/relating to the development of a functional leg length inequality.

1.6.3. Description of the solution

The solution is to be achieved by using dissected specimens of the pelvis, which will be placed into a specially designed instrument allowing for the forced induction of +ve and -ve x-axis rotation of the innominate via the sacroiliac joint and the symphysis pubis. The corresponding y-axis and z-axis translation and x-axis rotation of the roof of the acetabulum will be recorded. This will indicate to what extent a +ve or -ve x-axis rotation will induce functional leg length inequality. It may not, however, be of the magnitude clinically observed and thought to be clinically important by chiropractors.

1.6.4. Benefits of the solution

The benefit of the solution is that it will add to the understanding of the functional leg length inequality. It will open new doors for further research to find new facts about functional leg length inequality which chiropractors believe is caused by +ve and -ve x- axis rotational movement of the innominate.

This study will show to what extent a +ve or -ve x-axis rotation will cause functional leg length inequality. It may not, however, be of the magnitude clinically observed by chiropractors.

1.7. DEFINITIONS

a) Functional leg length inequality: This is the relative leg length inequality due to pelvic functional inefficiency, i.e. altered pelvic biomechanics.

b) Anatomical leg length inequality: This is the leg length inequality that results from structural inadequacies of the body.

c) +ve or -ve x-axis rotation: This is either flexion or extension of the pelvis or the individual innominates (The innominate rotates in an arc).

d) +ve or -ve z-axis translation: This is the movement of the innominate (or any bone in the body) in a straight line back and forth (i.e. anterior or posterior direction).

e) +ve or -ve y-axis translation: This is the movement of the innominate (or any bone in the body) in a straight line up or down (i.e. superior or inferior).

f) Pelvis and Innominate: The pelvis is made up of the two innominate bones and the sacrum which articulate via the sacroiliac joints and the symphysis pubis.

g) Acetabulum: This is the socket (depression) in the innominate bone where the head of the femur articulates. It is formed by the union of the ischium, ilium and ramus parts of the innominate bone.

h) Subluxation: This is the chiropractic term used to describe the mechanical disrelationship of two bones in the body.

i) Maximum: For the purpose of this study it means the maximum +ve and -ve x- axis rotation of the innominate via the sacroiliac joint and symphysis pubis without anatomical disruption.

CHAPTER 2

REVIEW OF THE RELATED LITERATURE

2. **LITERATURE REVIEW**

The sacroiliac joint is a controversial subject especially regarding the biomechanics thereof, along with contradicting views of different authors. The anatomy of the sacroiliac joint, the biomechanics of the sacroiliac joint, the short leg syndrome, the axis of rotation of the sacroiliac joint, the amount of leg length inequality and the load resistance of the sacroiliac joint are all areas which will be discussed.

2.1 The Anatomy of the Sacroiliac Joint

The joint is a true synovial joint in that it has synovial fluid, a synovial membrane, cartilage and a joint capsule (White .A.A. et al. 1990 and Alderink .G.J. et al. 1991).

The joint is ear-shaped with elevations on the joint surface, and the joint space is very thin. This gives the joint great stability but at the same time decreases range of motion. The joint is reinforced by the capsule and the ligaments of the sacroiliac joint. The ligaments are:

a) Posterior sacroiliac ligaments

b) The interosseous sacroiliac ligaments

c) The sacro-tuberous ligaments

d) The sacro-spinous ligaments

e) The ilio-lumbar ligaments

The two main ligaments (a) and (b) afford stability to the sacroiliac joint, and these must remain intact in the models that will be dissected for the study (White .A.A. et al. 1990; Alderink G.J. et al. 1991; Gatterman M.I. 1990 and Grieve G.P. 1976).

Nordin M. and Frankel H. in their 1989 text state that the physical properties of collagen (and thus of the ligaments themselves) are closely associated with the number and quality of the cross- links within and between the collagen molecules. Up to the age of maturation (20 years) the number and quality of the cross-links increases leading to increased tensile strength of the ligament. As the aging process continues, the tensile strength and stiffness of the tissue begin to decrease. The collagen content of the ligaments also decreases with aging, leading to a decrease in its mechanical properties ie. strength, stiffness and its ability to withstand deformation.

Bernard T.N. and Cassidy J.D. 1991, state that the sacroiliac joint is surrounded by large and powerful muscles of the body, but that none of these muscles has a direct influence on joint mobility.

Haldeman S. 1992, also advocates that the musculature has no direct influence on joint mobility.

Colachis S.C. et al. 1963, state that the sacroiliac joint has muscles to move it and thus it depends solely on the capsule and ligaments that surround it for support.
Therefore the dissected models in this study will have the musculature removed, as their removal will not affect the issues involved in the study.

The iliac surface of the joint is covered with fibrocartilage and the sacral surface with hyaline cartilage (White A.A. et al. 1990 and Gatterman M.I. 1990). It is thought that this does not have any appreciable biomechanical effect. There is also a very common anatomical variant called the accessory sacroiliac joint .
This joint is located between the medial aspect of the posterior superior iliac spine and a rudimentary transverse tuberosity lateral to the second sacral foramina. Thus on x-ray one must not mistake this for ankylosis of the joint (Ehara S. et al. 1988).

The contours of the joint surface continue to change with age and by the third decade there is an increase in the size and number of elevations which interlock and limit movement (Gatterman M.I. 1990).

After the third decade, the cartilage becomes rough, and degeneration leads to fibrosis of fibrocartilaginous adhesions and occasionally ankylosis of the sacroiliac joints (Gatterman M.I. 1990).
Some authors, such as White A.A. and Punjabi M.M. 1990, say that the joint may become completely ankylosed by 50 years of age.
Sashin D.A. 1930, found that motion in the sacroiliac joint decreases after 30 years of age due to adhesions. On 257 post-mortem cases, he found osteophytes in 80% of males and 50% of females between 40 and 49 years of age. 100% of females between 50 and 59 years of age had osteophytes of which 60% had ankylosis.
According to Bernard T.N. and Cassidy J.D. 1991, movement in the sacroiliac joint decreases in men between 40 and 50 years of age and in females after 50 years of age.

For this reason, only dissected pelves of cadavers under the age of 45 years were used. As well, only those which have negative x-ray findings or fibrosis of the sacroiliac joint, will be used.

2.2 The Short Leg Syndrome

In chiropractic literature, it has been claimed that +ve and -ve x- axis rotation of the innominate via the sacroiliac joint may cause a leg length inequality (Herbst R.W, undated).

Of what magnitude it is unknown, but clinically it has been observed to be as great as 2 centimetres. The reason for this belief is that this leg length inequality is corrected when a subluxation in the sacroiliac joint is manipulated/adjusted.

Winterstein J.F. 1991 claims that a posterior rotation of one innominate about a second sacral axis will cause a cephalad lower extremity (i.e. short leg) due to pelvic distortion, and an anterior rotation of the innominate about the same axis will cause a caudad lower extremity (ie. a long leg).
Gatterman M.I. 1990 also describes this phenomenon in her book.
Gonstead C. as discussed by Herbst R.W. (undated) uses different terminology from other authors, suggesting that a posterior-inferior (PI) ilium will cause a lowering of the femoral head on x-ray but due to the biomechanics of the hip this actually results in a physical shortening of the lower limb, and that an anterior-superior ilium will cause an elevation of the femoral head on x-ray but will actually lead to a physical shortening of the lower limb (Herbst R.W. undated)
The above authors suggest the cause of a functional leg length inequality, but do not give the maximum amount of leg lengthening or shortening that can occur, nor do they give evidence for this phenomenon.

Neither do they correlate this mechanism with those clinically observed leg length inequalities of greater than 2 centimetres that may respond to a sacroiliac adjustment.

This research study will attempt to describe the extent to which there is a corresponding leg length inequality when there is a +ve and a -ve x- axis rotation of one innominate via the sacroiliac joint, and whether or not the maximum +ve and -ve x- axis rotation of one innominate causes a leg length inequality of greater than 2 centimetres, without anatomical disrelationship of the sacroiliac joint ligaments and capsules.

Winterstein J.F. 1991 advocates that a sacroiliac subluxation causes neuromuscular facilitation, which in turn causes muscle spasm, thus pulling up the pelvis on that side. This, he states inevitably causes a leg length inequality. This theory, however, will not be included in the scope of this study. It may however suggest a reason for the clinical observation of a sacroiliac adjustment correcting a leg length inequality of greater than 2 centimetres. This study may however show that the subluxation by itself, cannot induce this degree of leg length inequality. It must be noted that the standard way of evaluating a functional leg length inequality is by placing the patient in a prone position and visually determining the difference in the levels of the medial malleoli (once one has ruled out the possibility of an anatomical short leg).

With this method one cannot determine accurately whether the leg length inequality is caused by muscle spasm tilting the pelvis or if it is caused by a +ve or -ve x- axis rotation subluxation of the innominate. New and more reliable and valid methods need to be developed to clinically assess a functional leg length inequality.

2.3 Biomechanics Of The Sacroiliac Joint:

It is important to assess what the maximum +ve and -ve x- axis rotation of the innominate is, via the sacroiliac joint, and also where the axis of rotation is situated.

Bernard T.N. and Cassidy J.D. 1991, indicate that the predominant motion in the sacroiliac joint appears to be +ve and -ve x- axis rotation with some degree of +ve and -ve z- axis translation.

Walheim G.G. and Olerud S. 1979, using electromagnetic measuring techniques, found 0,1 degrees of +ve and -ve x- axis rotation of the innominate and 0,1 millimetres of +ve and -ve z- axis translation.

Aldrink G.J. et al. 1991, cite Pitkin J.C. and Pheasant J.C. who found 2 types of movement of the innominate using x-ray and inclinometry techniques.

The movement relevant to this study is the +ve and -ve x- axis rotation of the innominate of upto 11 degrees with the transverse axis of rotation through the centre of the symphysis pubis. Egund N. et al. 1974, x-rayed four subjects and found rotation of the innominate to be at most 2 degrees with a translation of upto 2 millimetres.

Sturesson B. et al's. 1989, study using stereodiagnosis showed that the maximum extension and flexion (i.e. +ve and -ve x-axis rotation) in each sacroiliac joint was between 2 and 3 degrees (therefore making total +ve and -ve x- axis rotation of the innominate via both sacroiliac joints between 3,2 and 7,8 degrees). He also stated that there was a translation of between 0,1 and 1,6 millimetres in the joint (the mean being ± 0,7 millimetres).

Miller J.A.A. et al. 1987, measured load displacement behaviour of both single and paired sacroiliac joints in fresh cadavers. With both ilia fixed, they put loads onto the sacrum and achieved upto 1,9 degrees of +ve and -ve x- axis rotation of the sacrum. With one ilium fixed they got 2 to 7,8 times more +ve and -ve x- axis rotation of the sacrum; i.e. not of the innominate. However, these were not the movements of the innominate but were the over all movements at the sacroiliac joint.

Gatterman M.I. 1990, suggests that there is a maximum of 3 to 5 degrees of +ve and -ve x- axis rotation of the ilia via the sacroiliac joint.

She claims that the centre of rotation is centred around the iliac tubercle immediately posterior to the sacroiliac joint. She believes that sacroiliac joint motion is a coupled movement consisting of both rotation and translation. In this study, nine degrees of forced +ve and -ve x-axis rotation of the innominate will be induced in each direction as most authors believe the amount of rotation to be within this range.

Weisl H. 1955, in his radiographic studies, found no difference in range of motion between males and females except during the puerperal state. For this reason sex (gender) will not be taken into account in this study.

Of importance too, is the movement of the symphysis pubis. One would expect that with the +ve and -ve x- axis rotation of the ilia via the sacroiliac joints there must be a consequent movement in the symphysis pubis. Chamberlain W.E. 1930, claims that a vertical movement of the symphysis pubis of greater than 2 millimetres is abnormal.

White A.A. and Panjabi M.M. 1990, cite Steiner and colleagues who suggest that 4 millimetres is abnormal. They also quote Hagen as saying that 5 millimetres is the upper normal movement of the symphysis.

Walheim G.G. et al. 1984, in his vivo and vitro studies (where he placed pins on the sides of the pubis and measured the movement at the symphysis pubis electronically) found the upper normal vertical movement in the symphysis pubis to be 3 millimetres.

He also believed there was +ve and -ve x- axis rotation at the symphysis in the order of upto 3 degrees. Although movements of the symphysis pubis are not measured in this study, it is important to note that there is movement at this area and that this movement will occur with rotational movement at the sacroiliac joints.

2.4 The Axis Of Rotation:

There is controversy regarding the position of the axis of rotation. Colachis S.C. et al. 1963, hypothesised that the sacroiliac motion did not occur about a fixed mechanical axis but rather that there was some combination of angular and parallel movements.

Alderink J.G. et al. 1991, cite Farabeuf, who suggested that the axis of rotation is located approximately at the axial (interosseous) ligaments posterior to the sacral articular facets.

Weisle H. 1955, (via radiographic examinations) claimed that the axis of rotation is 5 to 10 centimetres vertically below the sacral promontory, however this may vary between subjects.

Wilder D.G. et al. 1980, stated that there is no fixed axis of rotation but that it varies between individuals.

Lavignolle B. et al. 1983, by using cadavers, measured sacroiliac displacement by fixing the sacrum and applying linear forces and torques to the right and left iliac bones. The measurements were made using comparators and optical systems. They believe that the axis of rotation is located along the cranio-caudal line near the symphysis pubis, in front of and the same distance from the sacroiliac joints.

Bernard T.N. and Cassidy J.D. 1991, summarised the axes of rotation that have been proposed. These are:

a) The interosseous ligaments.

b) The second sacral segment.

c) A point anterior to the sacral promontory.

d) Bonaires tubercle (located between the caudal and cranial segments of the anterior surfaces).

They also state that various plain radiographic and stereo graphic studies (in vivo and vitro) have been done to find the axis of rotation. These studies differ, but the locations of the axis that these studies propose are:

a) A point on the second sacral body at the level of the posterior superior iliac spine.

b) The intersection of three axes at the level of the symphysis pubis.

Bakland O. and Hansen J.H. 1984, describe the axis of rotation as being behind the joint surface in the vicinity of an extra capsular iliac tubercle).

Winterstein J.F. 1991, advocates the sacroiliac axis of rotation to be at the 2nd sacral segment.
Bellamy.N. et al. 1983, state that most authorities place the axis of rotation at the second sacral segment.

For this study, and the carrying out of the experiment, the extra-capsular iliac tubercle will be the point of the axis of rotation as Bernard T.N. et al. 1991; Barkland O. et al. 1984; Alderink G.J. et al. 1991, and Bellamy N. et al. 1983, all place the axis of rotation of the sacroiliac joint at or very close to this area.

2.5 <u>Amount Of Leg Length Inequality</u>

The amount of functional leg length inequality that clinically occurs and its clinical significance (i.e. what leg length inequality causes adverse symptoms, e.g. low back pain), is controversial.

Winterstein J.F. 1991, suggests that a leg length inequality of less than 3 millimetres is of no clinical significance. He also states that between 50 and 80 percent of the population has a leg length inequality of 3 millimetres or more.

Hult L. 1954, concluded that leg length inequality of upto 3,72 centimetres is not associated with low back pain.

Gross R.H. 1983, studied runners and found that a leg length inequality of less than 2,5 centimetres did not appear to have an adverse effect on function.

Giles L.G.F. et al. 1981, found an eight percent incidence of leg length inequality of 10 millimetres or more in a control group compared to 18,3 percent incidence in a low back pain group.

Travell.J.G. et al. 1983, state that a discrepancy of 0,5 millimetres, if uncorrected, can perpetuate myofascial trigger points.

Giles L.G.F. 1976, agreed that a 5 millimetre leg length inequality is clinically significant.

It is clear that there is no consensus between authors on the amount of leg length inequality that is of clinical significance. This may be due to the fact that it is difficult to quantify the term "clinical significance" as well as the technical differences and problems between studies.

2.6 Load Resistance Of The Sacroiliac Joints

Miller J. 1985, suggests that the sacroiliac joints must resist downward shear loads in the range of 300 to 1750N.

He also says that in the relaxed standing position each sacroiliac joint is subject to 500N of downward shear as well as a flexion moment of about 20Nm.

Rothkotter H.J. et al. 1988, tested the stability of 49 sacroiliac joints using an in vitro loading system.

He found that the ligamentous structures of the joint disrupted at 3368+/-923N under transverse loading, 4933+/-1038N under ventrocranial loading, 5150+/-947N under dorsocranial loading.

As shown above the sacroiliac joint is subjected to a torque force of 20Nm in normal loading. For a rotational subluxation of the sacroiliac joint to occur there must be some form of abnormal force or stress on the joint. This abnormal force may be far greater than 20Nm.

2.7 Summary Of The Review Of The Related Literature

Ligaments and joint capsules give the sacroiliac joint stability.

Muscles do not influence the range of joint motion.

The average age for fibrosis in the sacroiliac joint to occur is over 50 years, therefore, in this study, cadavers under the age of about 45 years will be chosen and x-rays will be taken to rule out ankylosis.

There is a chiropractic claim that +ve and -ve x- axis rotation of one innominate via the sacroiliac joint causes a leg length inequality. The amount of leg length inequality possibly induced by this mechanism is unknown.

There is a possibility that sacroiliac dysfunction causes neuromuscular facilitation and thus a unilateral muscle spasm that could cause the pelvis to tilt and thus cause a leg length inequality (not covered in the scope of this study).

The various degrees of +ve and -ve x- axis rotation of the innominate varies:

-0,1 degrees

-± 11 degrees

-2 degrees

-2 - 3 degrees (one joint)

-3,2 - 7,8 degrees (both joints)

-3 - 5 degrees

The average is of use here, however the maximum (i.e. 11) and the minimum (i.e. 0,1) values are important for the purposes of this study.

With movement in the sacroiliac joint, there is a corresponding movement in the symphysis pubis. The vertical movement varies between 2 to 5 millimetres and the rotation at the symphysis is about 3 degrees.

The axis of rotation is controversial but literature shows it to be one of the following:

a) At the axial (interosseous) ligaments posterior to the sacral articular facets.

b) Within the articular facets between the cranial and caudal segments.

c) 5 - 10 centimetres vertically below the sacral promontory.

d) Along the cranio-caudal line located near the symphysis pubis in front and the same distance from the sacroiliac joints.

e) 2nd sacral segment.

f) A point anterior to the sacral promontory.

g) The intersection of three axes at the level of the symphysis pubis.

h) Behind the joint surface in the vicinity of an extra-capsular iliac tubercle (this is the axis of rotation that will be used).

Regarding the question of what leg length inequality is of clinical significance, authors vary greatly in their opinions: from 3,72 centimetres having no clinical significance to authors saying that 0,5 centimetres is clinically significant.

The sacroiliac joint is subjected to a torque force of 20Nm in normal loading. For a rotational subluxation of the sacroiliac joint to occur there must be some form of abnormal force or stress on the joint. This abnormal force may be far greater than 20Nm.

CHAPTER 3

MATERIALS AND METHODS

3.1. **THE DATA**

The data of this research is of 2 kinds; i.e. primary data and secondary data. The nature of each data will be given below.

3.1.1. Primary Data

This is data that is obtained from carrying out the practical application of the research.

The primary data needed are:

1) The numerical value in degrees of the +ve and -ve x- axis rotation of the innominate (independent variable).

2) The numerical value in millimetres of the +ve and -ve y- axis translation of the roof of the acetabulum (dependent variable).

3) The numerical value in millimetres of the +ve and -ve z- axis translation of the roof of the acetabulum (dependent variable).

4) The numerical value in degrees of the +ve and -ve x- axis rotation of the roof of the acetabulum (dependent variable).

3.1.2. Secondary Data

This data is obtained from the relevant literature. The main secondary data needed is:

1) The consensus of the maximum and the minimum +ve and -ve x-axis rotation of the innominate via the sacroiliac joint and symphysis pubis.

2) The consensus on where the axis of rotation is situated.

3) The consensus of what amount of leg length inequality is of clinical significance.

3.2. **The Criteria Governing The Admissibility Of The Data**

3.2.1 Only data obtained from the study, that was under my direct supervision, was admitted in order to rule out data collection error.

3.2.2 Only data from dissected models of the pelvis that were done by a qualified anatomist was admitted.

3.2.3 Data from the cadavers that were free from pathology and disease and were less than 45 years of age were admitted.

3.2.4 Admissibility of the data also depended on the fulfilment of the delimitations.

3.3 The Research Methodology

3.3.1 Sample

A sample size of 6 cadavers was used. The size of the sample depended on the availability of cadavers, however all was done to obtain as large a sample as possible within the time constraints. The technique of sampling was that of convenience sampling.

This method of sampling was unavoidable due to the limited access to cadavers for the purpose of the study. For this reason, the first 6 unclaimed cadavers from the city mortuary to conform to the delimitations were included in this study. The fresh cadavers were under the age of 45 years, of either sex, any race and free from sacroiliac joint pathology (assessed by radiographs).

3.3.2 The method of data collection

Post-autopsy of a fresh cadaver (see plate 1), a postero-antero radiograph of the sacroiliac joints was taken with the x-ray tube was angled 5 to 15 degrees cephalad (Hibbs view). The radiograph was then assessed for sacroiliac abnormalities (see plate 2).

PLATE 1: THE CADAVER AS PRESENTED POST AUTOPSY

PLATE 2: X-RAY OF THE SACROILIAC JOINTS

If the x-ray was clear, the dissection proceeded. The abductor muscles of the hip were dissected from the innominate taking care not to perforate the skin (see plate 3).

PLATE 3: DISSECTION OF ABDUCTOR MUSCLES AWAY FROM LATERAL SURFACE OF THE INNOMINATE.

Once the hip joint capsules were exposed, they were cut so as to allow the femoral heads to be dislocated, which was done by adducting the leg (see plate 4 and 5).

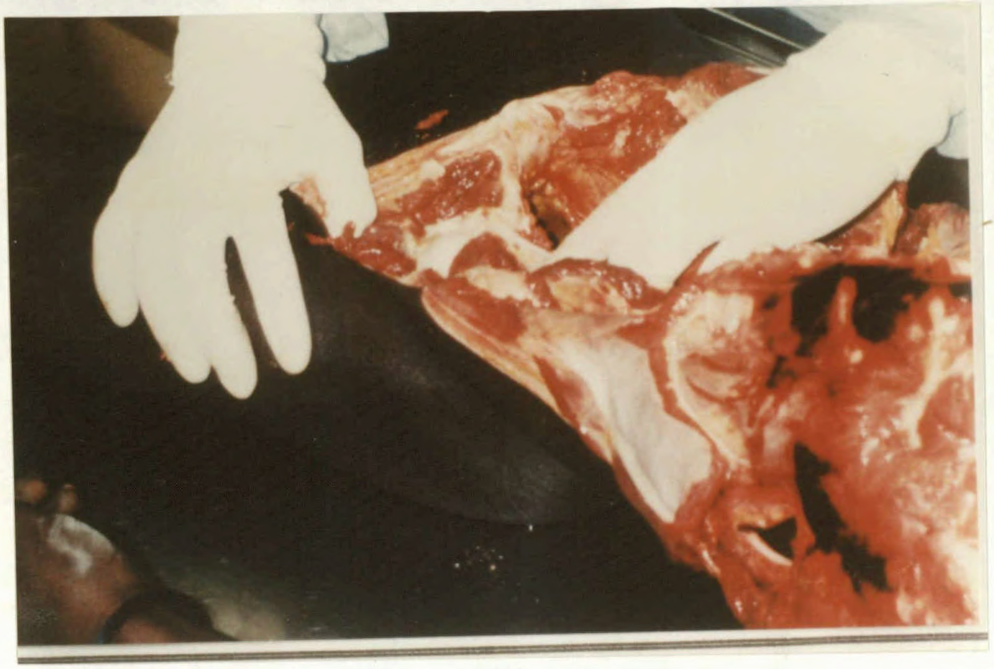

PLATE 4: EXPOSURE OF THE FEMORAL HEAD WITH DISSECTION OF THE HIP JOINT CAPSULE.

PLATE 5: DISLOCATION OF THE FEMORAL HEAD BY ADDUCTING THE LOWER LIMB.

The spine was then cut through the 3rd lumbar disc (see plate 6).

PLATE 6: TRANSECTION OF THE SPINE AT THE 3rd LUMBAR DISC.

The skin was then dissected away from the spinous processes of the spine. The posterior musculature of the spine was then dissected away from the spine down to the extensors of the hip which were also dissected away (see plate 7).

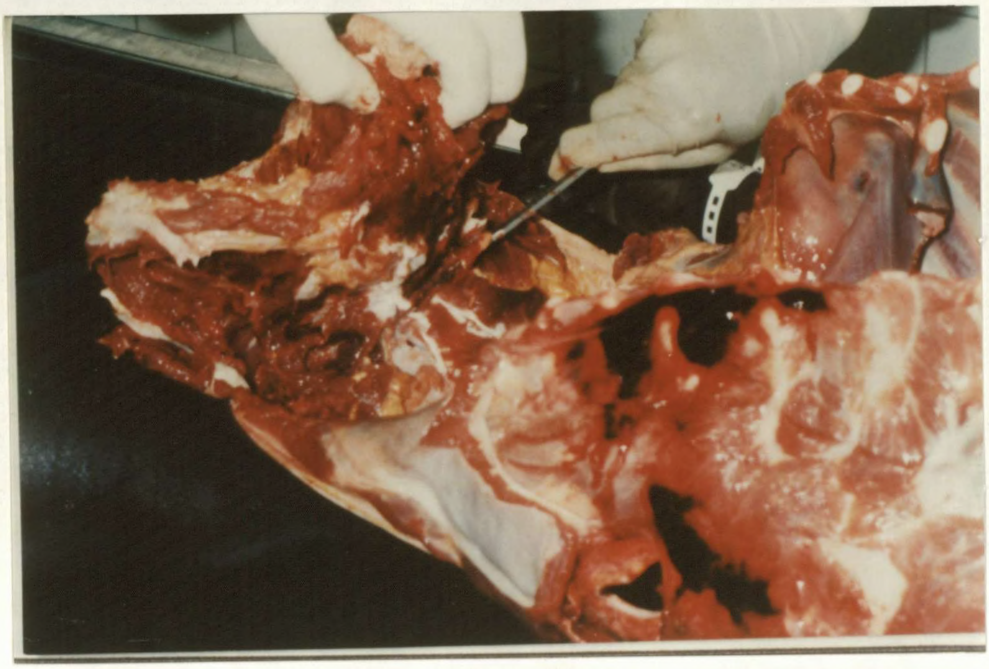

PLATE 7: REMOVAL OF THE POSTERIOR SPINAL MUSCULATURE AND THE EXTENSOR MUSCLES OF THE HIP.

Finally, the flexors and adductors of the hip were dissected away to allow the removal of the pelvis (see plate 8).

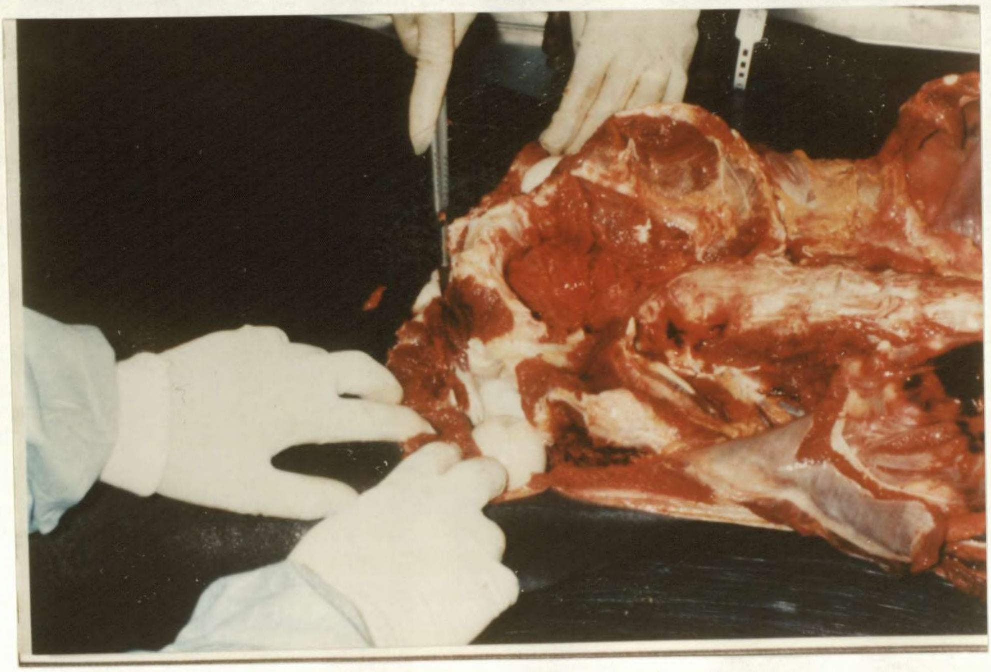

PLATE 8: DISSECTION OF THE FLEXOR AND ADDUCTOR MUSCLES AWAY FROM THE HIP.

Excess muscle tissue was then removed, making sure that the ligaments of the lower lumbar spine, and of the sacroiliac joints as well as the sacro-spinous and sacro-tuberous ligaments were all left intact (see plate 9).

PLATE 9: THE REMOVED PELVIS WITH EXCESS MUSCULATURE REMOVED.

The dissected pelvis was then attached to the following instrument: (see figure 1 and plates 10 and 11).

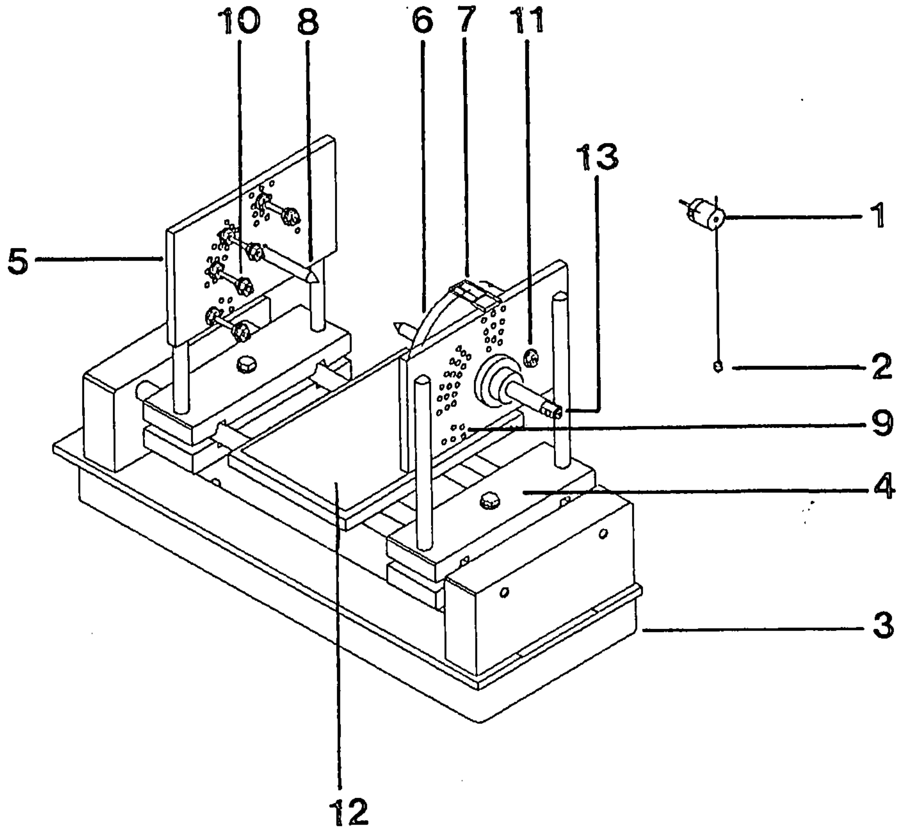

Figure 1:DIAGRAMMATIC REPRESENTATION OF THE INSTRUMENT

1) Rotating drum marked off in degrees
2) Pendulum
3) Metal base
4) Sliding base
5) Vertical holding plate
6) Rotating disc marked off in degrees
7) Marker for taking readings
8) Axis of rotation pins
9) Guide holes for drilling
10) Angled washers, nuts and bolts to clamp the pelvis
11) Locking pin
12) Board with 1mm squared graph paper
13) Fitting for the torque wrench

PLATE 10: ANTERIOR VIEW OF THE INSTRUMENTATION.

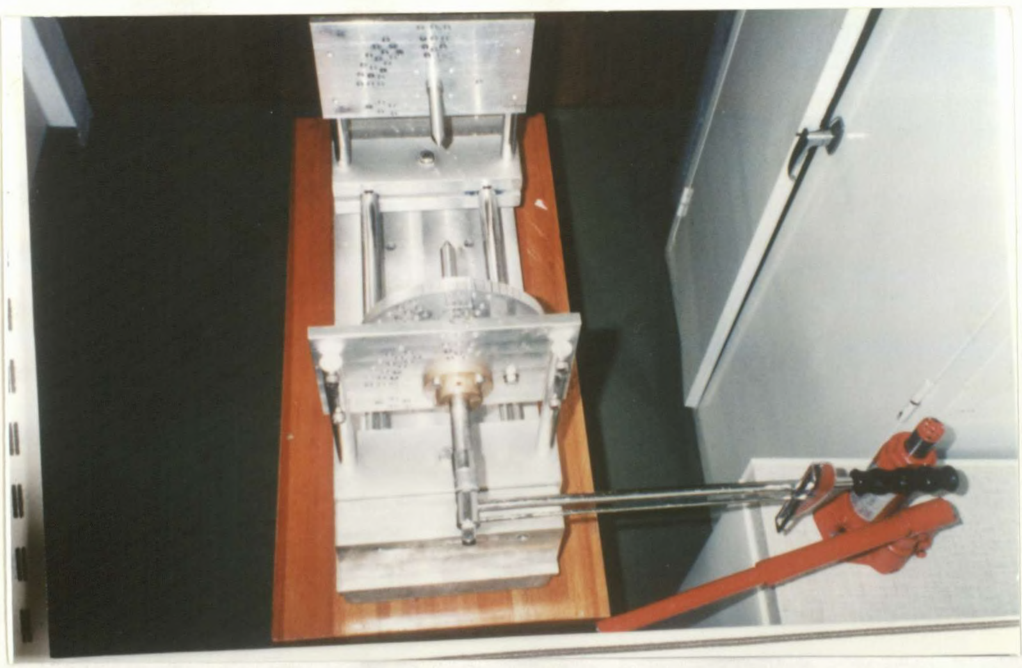

PLATE 11: SUPERIOR VIEW OF THE INSTRUMENTATION.

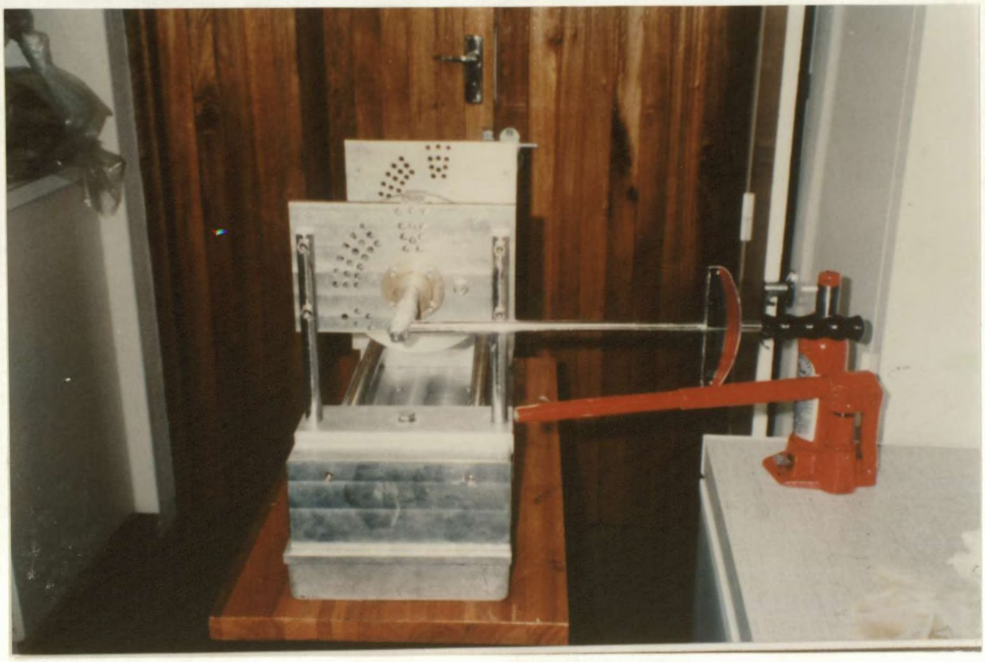

PLATE 12: LATERAL VIEW OF THE INSTRUMENTATION.

A hole was then drilled at the highest point of the acetabulum and a measuring device (ie. rotating drum with a pendulum, (see top right of diagram) was screwed in. The pelvis was then attached to the instrument (see diagram and plates 10, 11 and 12) in the following way:

The two axis of rotation pins of the rig were aligned with the extra-capsular iliac tubercle (ie. the axis of rotation of the sacroiliac joint). With the pelvis supported in this position three holes were drilled into each innominate using the guide holes in the end plates of the rig.The pelvis was then bolted onto the fixed end-plate at one end and to the rotating disc at the other end (see plate 13).

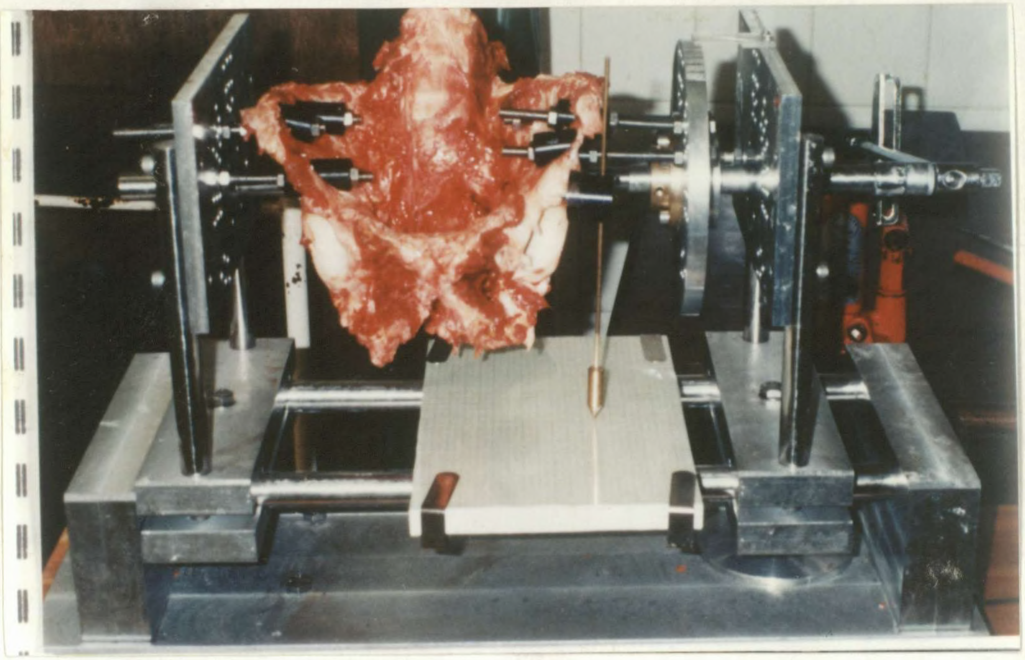

PLATE 13: INSTRUMENT SET UP WITH THE PELVIS AND MEASURING DEVICES.

A board with one millimetre squared graph paper was placed under the pendulum (see plate 14).

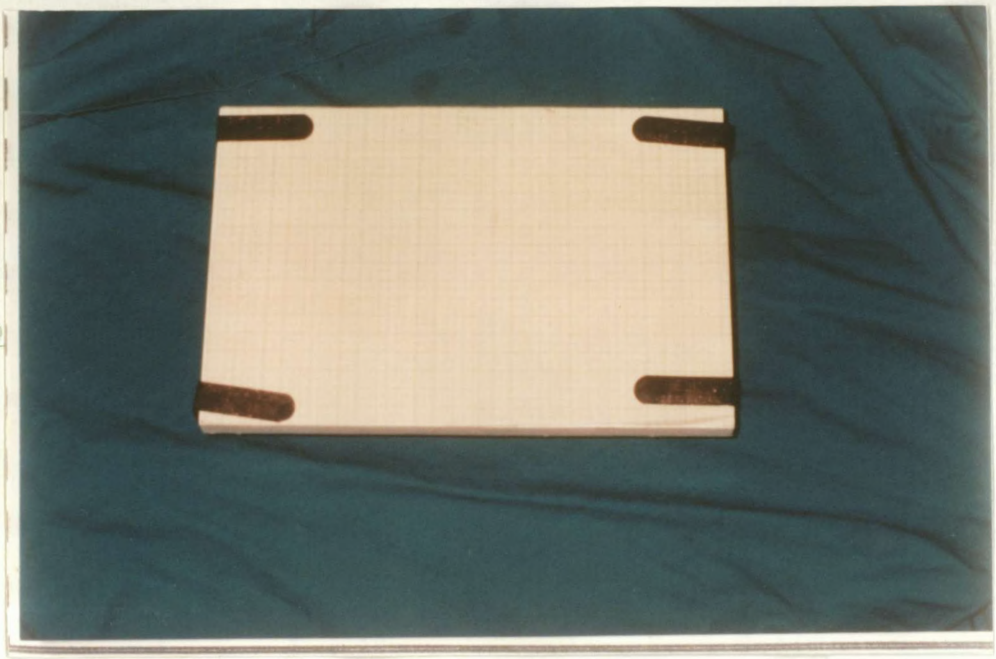

PLATE 14: BOARD WITH 1mm SQUARED GRAPH PAPER.

Where the point of the pendulum was located, a mark was made on the graph paper.The point of the pendulum on the graph paper measured the positive and negative z-axis translation of the acetabulum). The rotating drum was marked off in 5 degree intervals. This was used to measure the positive and negative x-axis rotation of the acetabulum (see plate 15).

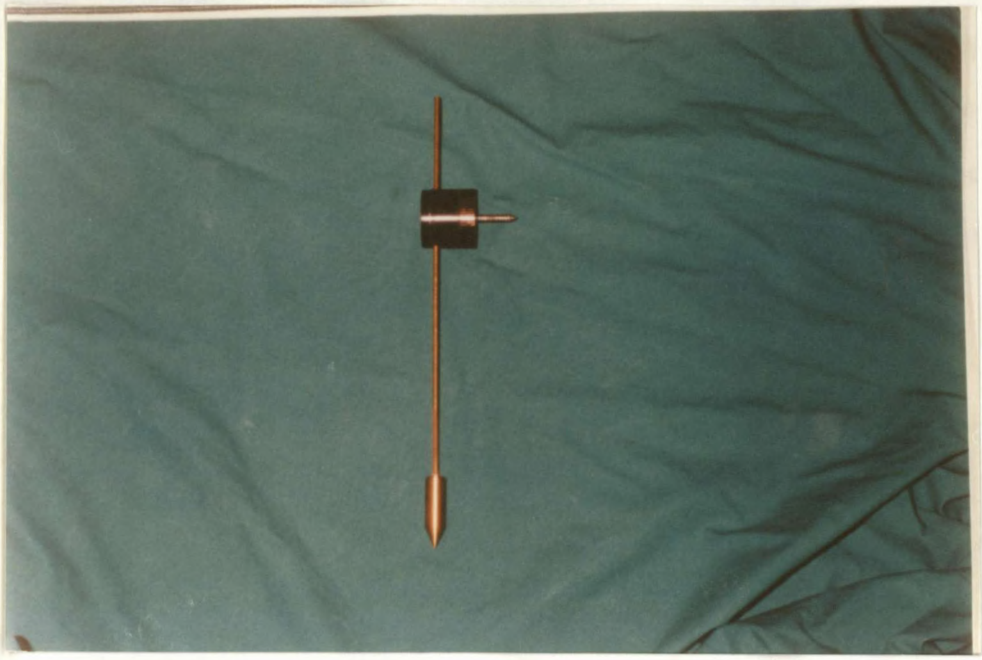

PLATE 15: ROTATING DRUM AND PENDULUM.

The pendulum was then lowered to the graph paper and the height of the upper part of the pendulum (ie. the part attached to the top to the rotating drum) was measured using a digital pair of vernia callipers. This measured the +ve and -ve y-axis translation of the acetabulum (see plate 16).

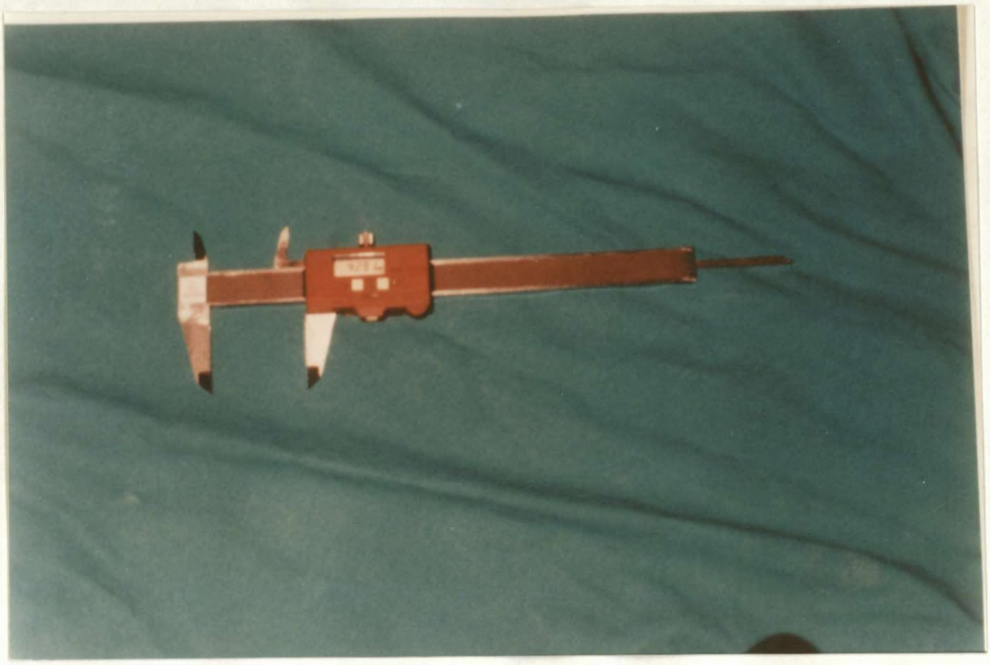

PLATE 16: ELECTRONIC VERNIA CALLIPERS.

All these readings were then recorded and they formed the zero points before +ve and -ve x-axis rotation of the innominate was performed. A torque wrench was then fitted to the rotating disc. This measured the force/torque required to rotate the innominate. The torque wrench was attached to a hydraulic pump which provided sufficient force to rotate the innominate (see plate 17 and 18).

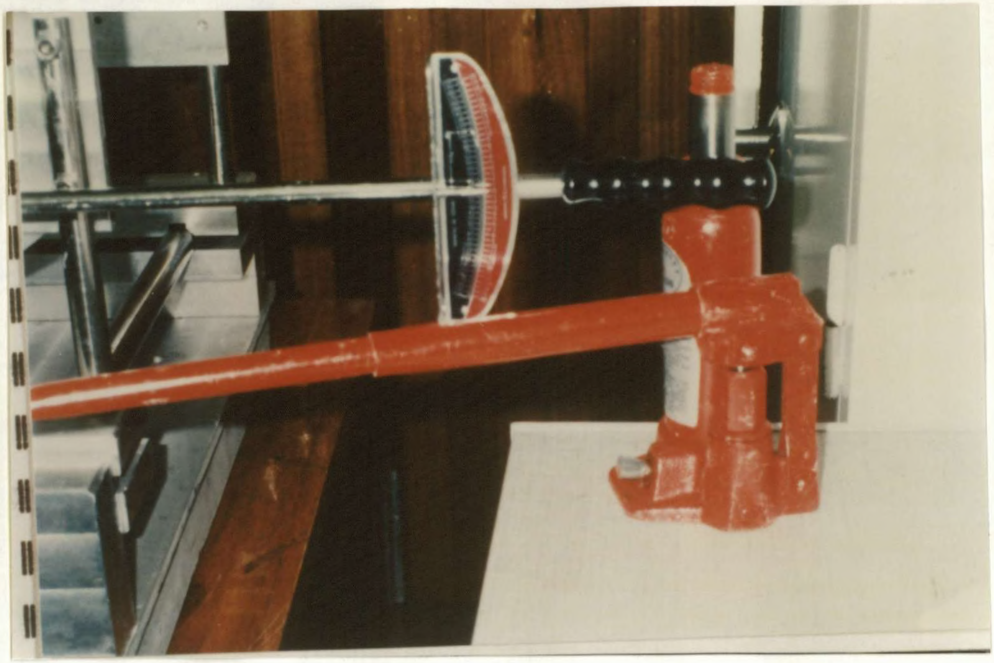

PLATE 17: TORQUE WRENCH AND HYDRAULIC PUMP.

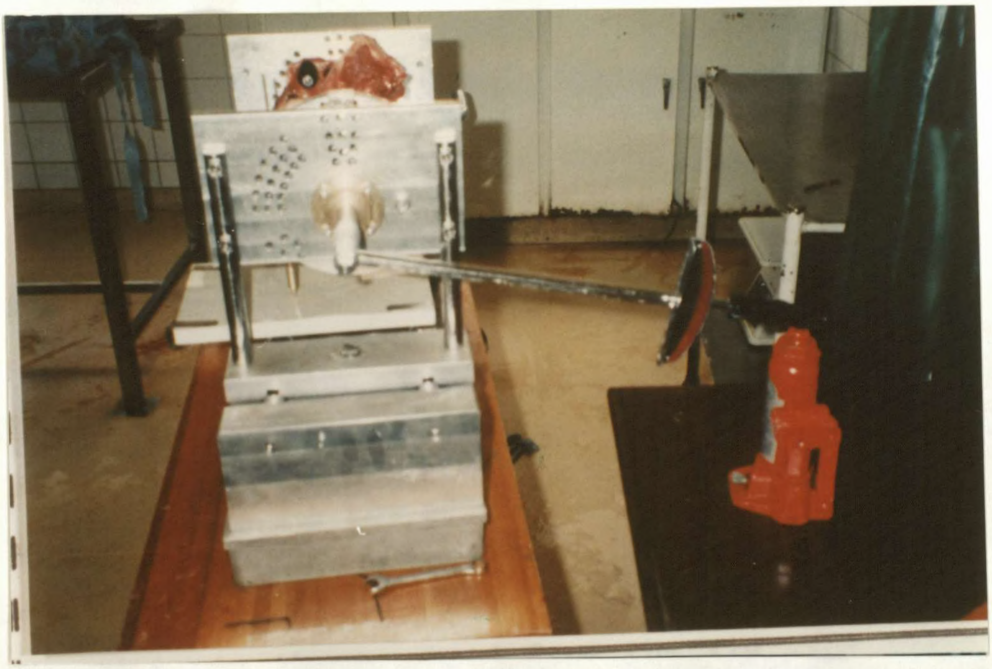

PLATE 18: ROTATION OF THE INNOMINATE, INDUCED BY THE TORQUE WRENCH AND HYDRAULIC PUMP.

The locking pin was pulled out and the innominate was then rotated positively 1 degree. The corresponding force, z-axis and y-axis translation and x-axis rotation of the innominate was then measured and recorded. The innominate was rotated another degree and the process was repeated. The innominate was rotated positively for 9 successive degrees with all the relevant readings being taken, the process was then repeated rotating the innominate negatively for 9 successive degrees and recording the relevant readings (see plate 19).

PLATE 19: DEMONSTRATION OF DATA COLLECTION.

The pelvis was then removed from the rig. It was then returned to the body and secured into its original position with metal strips that held the spine together and screws that held the femoral heads in the acetabulum (see plate 20).

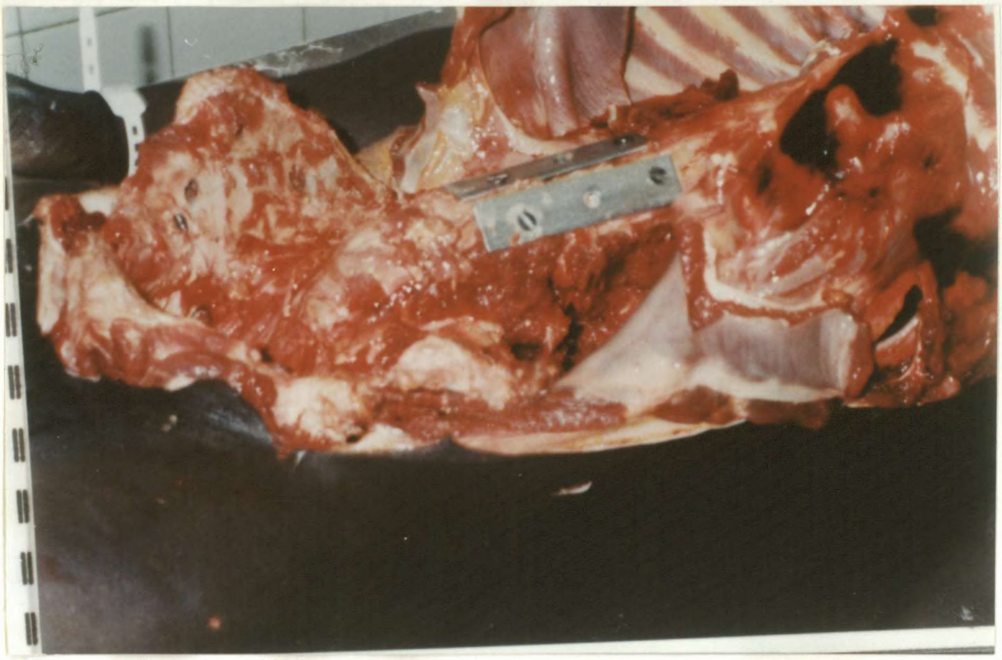

PLATE 20: REPLACEMENT OF THE PELVIS WITH THE USE OF METAL PLATES AND SCREWS.

In order to assess the reliability and validity of the instrumentation, 10 final year chiropractic students were shown and asked to perform the experiment on a block of wood as a substitute for the pelvis. The results were then compared and a standard deviation calculated to assess the accuracy and reliability of the instrumentation.

3.3.3 Staff, Training And Organisation

Permission was granted by Professor Botha of Provincial Pathology laboratory, to conduct the research on unclaimed fresh cadaver specimens at the city mortuary. Dissections were performed by Mr S. Rangiah. The conducting of the experiment was performed by the researcher. Statistical evaluations were performed by Mr K. Reich. Dr F.Burger co-ordinated this research, and the study was supervised by Dr A.G. Till, Dr H.S. Liebenberg and Mr S. Rangiah. The measuring apparatus was designed by the researcher, Dr H.S. Liebenberg and Mr E. Davis. The instrumentation was built by Mr E. Davis and Mr S. Prume.

3.3.4 The Type Of Data Collected

The data were of a continuous type, due to the fact that the corresponding value of the dependent variable (e.g. +ve and -ve y-axis translation, +ve and -ve z- axis translation, and +ve and -ve x- axis rotation of the roof of the acetabulum) could take any value when the independent variable (i.e. +ve and -ve x- axis rotation of the innominate) had a specific set value.

3.3.5 <u>Technique For Processing The Data</u>

The data were tabulated as follows:

Specimen no. 1

+/-x-axis rotation of the innominate (degrees)	+/-y-axis translation of the acetabulum (mm)	+/-z-axis translation of the acetabulum (mm)	+/-x-axis rotation of the acetabulum (degrees)	Force/ torque (Nm.)
X1	Y1	Z1	A12	F1
X2	Y2	Z2	A2	F2
X3	Y3	Z3	A3	F3
X4	Y4	Z4	A4	F4
X5	Y5	Z5	A5	F5
X6	Y6	Z6	A6	F6
X7	Y7	Z7	A7	F7
X8	Y8	Z8	A8	F8
X9	Y9	Z9	A9	F9

NOTE: There are 2 tables for each cadaver specimen (ie. one for +ve x-axis rotation of the innominate and one for - ve x-axis rotation of the innominate).The table was then repeated for the rest of the cadaver specimens (i.e. sample group).

A Pearsons Product Moment Correlation was done for each set of results, to show a relationship between the independent variable (+ve or -ve x-axis rotation of the innominate) and the various dependent variables (e.g. +ve and -ve y- axis translation, +ve and -ve z- axis translation, and +ve and -ve x- axis rotation of the roof of the acetabulum)

Thereafter a graph of each set of results for each cadaver was drawn up, with the dependent variables being either +ve and -ve y-axis , +ve and -ve z- axis translation , +ve and -ve x- axis rotation of the roof of the acetabulum or force/torque, with the independent variable being the +ve and -ve x- axis rotation of the innominate. Finnaly a mean of the differences for both the dependent and independent variables was calculated for each set of cadaver results.

CHAPTER 4

RESULTS

4.1 RELIABILITY OF THE INSTRUMENT

In order to determine the instrumentation reliability, 10 students were shown how to use the instrumentation and were asked to take readings on a mock pelvis (ie.a block of wood).
The tables in appendices A-J display the results of each student.

An analysis of variance was performed between the results of each student. There was no significant difference between the results of the students.

4.2 THE TREATMENT OF THE RESULTS

The sample size consisted of 6 fresh cadavers.

The cadaver's demographics were as follows:

CADAVER NO.	AGE	SEX	RACE
1	30	MALE	BLACK
2	+/- 30	MALE	BLACK
3	27	MALE	BLACK
4	27	MALE	BLACK
5	+/- 24	MALE	BLACK
6	20	MALE	BLACK

The x-rays of the sacroiliac joints showed no abnormalities.

The tables in appendices K-P summarise the results obtained for each cadaver.

The following statistical evaluations were performed on the results (see tables 1 and 2).

NOTE: all these statistical evaluations were performed on all the results of the all the cadavers, aggregated together.

TABLE 1: GENERAL STATISTICS FOR THE RESULTS OF - VE X-AXIS ROTATION OF THE INNOMINATE.

VARIABLE	+VE X-AXIS ROTATION OF THE INNOMINATE. (deg)	-VE Z-AXIS TRANSLATION OF THE ACETABULUM. (mm)	-VE Y-AXIS TRANSLATION OF THE ACETABULUM. (mm)	+VE X-AXIS ROTATION OF THE ACETABULUM (deg)	FORCE/ TORQUE (Nm)
NO. OF READINGS FOR ALL 6 CADAVERS	60	60	60	60	60
MEDIAN	4.4	-3	-4.1	3	64
MODE	3	-4.5	0	4	0
MIN	0	-6.5	-11.75	0	0
MAX	9	O	O	5	130
RANGE	9	6.5	11.75	5	130

TABLE 2: GENERAL STATISTICS FOR THE RESULTS OF + VE X-AXIS ROTATION OF THE INNOMINATE.

VARIABLE	-VE X-AXIS ROTATION OF THE INNOMINATE. (deg)	+VE Z-AXIS TRANSLATION OF THE ACETABULUM. (mm)	+VE Y-AXIS TRANSLATION OF THE ACETABULUM. (mm)	-VE X-AXIS ROTATION OF THE ACETABULUM(deg)	FORCE/TORQUE (Nm)
NO. OF READINGS FOR ALL 6 CADAVERS	60	60	60	60	60
MEDIAN	-4.5	2.75	3.79	-2	51
MODE	-6	3.5	0	-2	0
MIN	-9	0	0	-5	0
MAX	0	6.5	10.58	0	130
RANGE	9	6.5	10.58	5	130

4.3 THE TREATMENT OF THE DATA FOR EACH SUB-PROBLEM

4.3.1 Sub-problem 1:

The correlation coefficient between +ve x-axis rotation of the innominate and the -ve y-axis translation of the acetabulum is r= -0.915255. This suggests a strong linear relationship between the two results. The linear regression (ie. model correlation) is shown below.

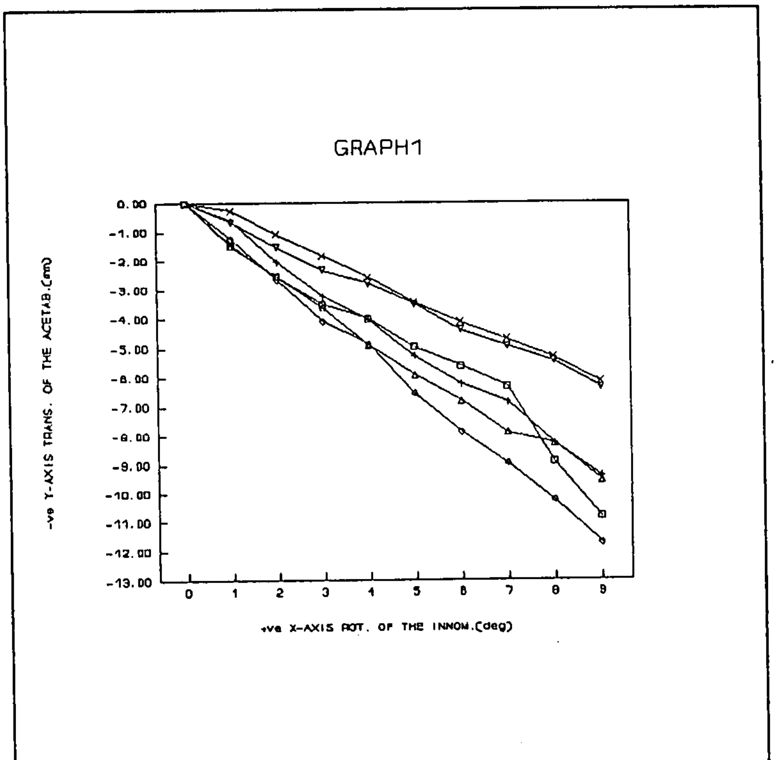

Figure 2: +ve X-AXIS ROTATION OF THE INNOMINATE Vs -ve Y-AXIS TRANSLATION OF THE ACETABULUM.

The correlation coefficient between -ve x-axis rotation of the innominate and the +ve y-axis translation of the acetabulum is r= -0.929943. This suggests a strong linear relationship between the two results. The linear regression (ie. model correlation) is shown below.

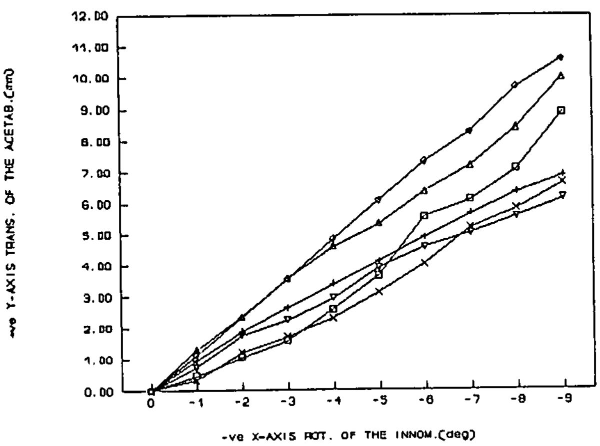

Figure 3: -ve X-AXIS ROTATION OF THE INNOMINATE Vs +ve Y-AXIS TRANSLATION OF THE ACETABULUM.

The mean of the differences of +/- x-axis rotation of the innominate and of +/- y-axis translation of the acetabulum for each cadaver is shown in the tables below (see tables 3 and 4).

TABLE 3: THE MEAN OF THE DIFFERENCES OF +VE X-AXIS ROTATION OF THE INNOMINATE AND -VE Y-AXIS TRANSLATION OF THE ACETABULUM.

CADAVER NO	+VE X-AXIS ROT. OF THE INNOM. (deg)	-VE Y-AXIS TRANS. OF THE ACETAB (mm)
1	1	-1.21
2	1	-1.04
3	1	-1.31
4	1	-1.06
5	1	-0.69
6	1	-0.71

TABLE 4: THE MEAN OF THE DIFFERENCES OF -VE X-AXIS ROTATION OF THE INNOMINATE AND +VE Y-AXIS TRANSLATION OF THE ACETABULUM.

CADAVER NO.	**-VE X-AXIS ROT. OF THE INNOM. (deg)**	**+VE Y-AXIS TRANS. OF THE ACETAB (mm)**
1	-1	0.99
2	-1	0.77
3	-1	1.18
4	-1	1.1
5	-1	0.74
6	-1	0.68

It was hypothesised that the maximum forced +ve and -ve x-axis rotation of innominate via the sacroiliac joint and symphysis pubis will cause a +ve and -ve y-axis translation of the roof of the acetabulum. The results substantiate this hypothesis.

4.3.2 Sub-problem 2:

The correlation coefficient between +ve x-axis rotation of the innominate and the -ve z-axis translation of the acetabulum is r= -0.919138. This suggests a strong linear relationship between the two results. The linear regression (ie. model correlation) is shown below.

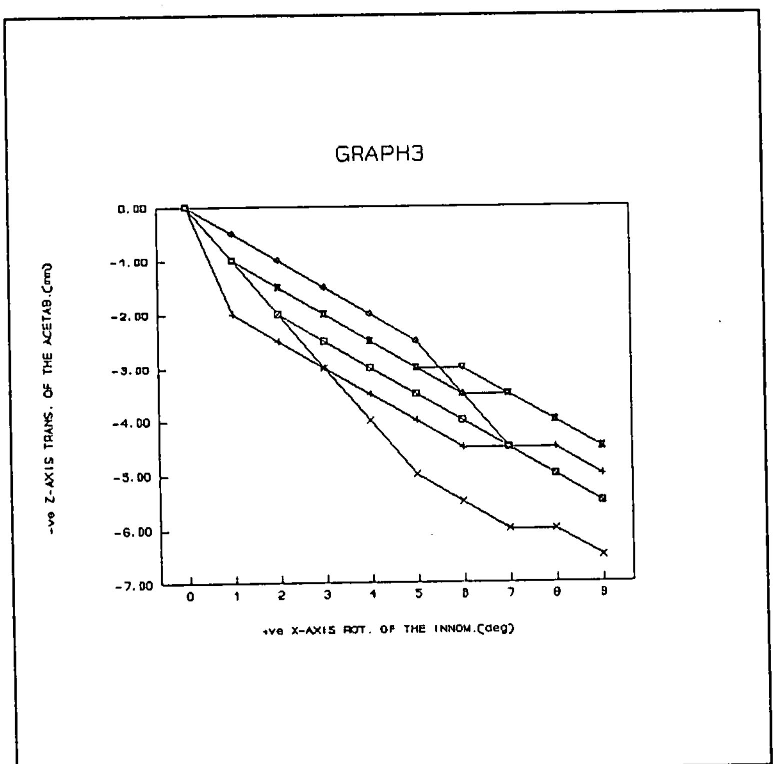

Figure 4:+ve X-AXIS ROTATION OF THE INNOMINATE Vs -ve Z-AXIS TRANSLATION OF THE ACETABULUM.

The correlation coefficient between -ve x-axis rotation of the innominate and the +ve z-axis translation of the acetabulum is r= -0.888989. This suggests a strong linear relationship between the two results. The linear regression (ie. model correlation) is shown below.

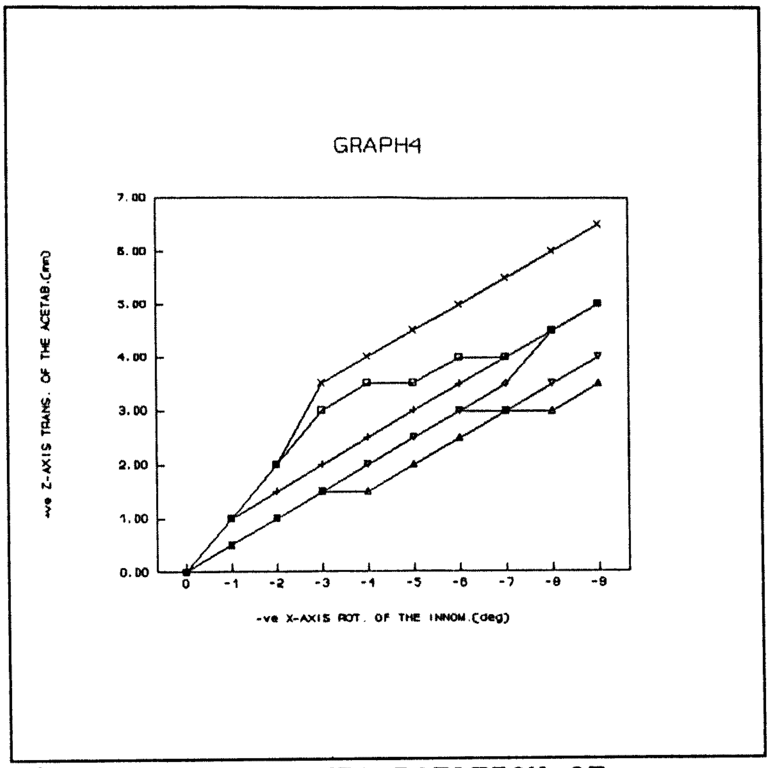

Figure 5:-ve X-AXIS ROTATION OF THE INNOMINATE Vs +ve Z-AXIS TRANSLATION OF THE ACETABULUM.

The mean of the differences of +/- x-axis rotation of the innominate and of +/- z-axis trànslation of the acetabulum for each cadaver is shown in the tables below (see tables 5 and 6).

TABLE 5: THE MEAN OF THE DIFFERENCES OF +VE X-AXIS ROTATION OF THE INNOMINATE AND -VE Z-AXIS TRANSLATION OF THE ACETABULUM.

CADAVER NO.	+VE X-AXIS ROT. OF THE INNOM. (deg)	-VE Z-AXIS TRANS. OF THE ACETAB (mm)
1	1	-0.61
2	1	-0.55
3	1	-0.61
4	1	-0.5
5	1	-0.72
6	1	-0.5

TABLE 6: THE MEAN OF THE DIFFERENCES OF -VE X-AXIS ROTATION OF THE INNOMINATE AND +VE Y-AXIS TRANSLATION OF THE ACETABULUM.

CADAVER NO.	-VE X-AXIS ROT. OF THE INNOM. (deg)	+VE Z-AXIS TRANS. OF THE ACETAB (mm)
1	-1	0.51
2	-1	0.55
3	-1	0.5
4	-1	0.39
5	-1	0.72
6	-1	0.44

It was hypothesised that the maximum forced +ve and -ve x-axis rotation of innominate via the sacroiliac joint and symphysis pubis will cause a +ve and -ve z-axis translation of the roof of the acetabulum. The results substantiate this hypothesis.

4.3.3 <u>Sub-problem 3</u>:

The correlation coefficient between +ve x-axis rotation of the innominate and the +ve x-axis rotation of the acetabulum is r= 0.930469. This suggests a strong linear relationship between the two results. The linear regression (ie. model correlation).is shown below.

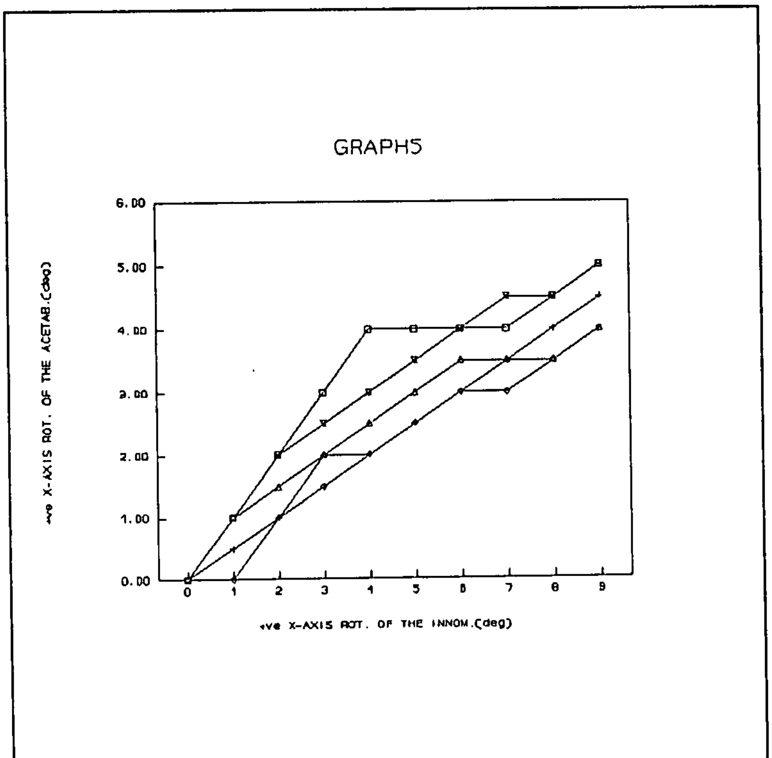

Figure 6: +ve X-AXIS ROTATION OF THE INNOMINATE Vs +ve X-AXIS ROTATION OF THE ACETABULUM.

The correlation coefficient between -ve x-axis rotation of the innominate and the -ve x-axis rotation of the acetabulum is r= 0.844674. This suggests a strong linear relationship between the two results. The linear regression (ie. model correlation) is shown below.

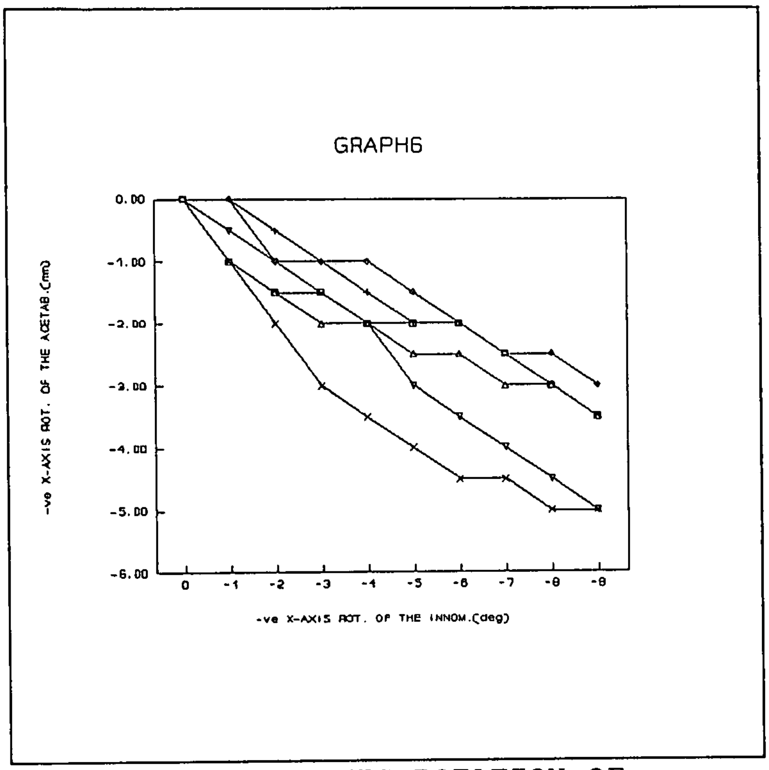

Figure 7: +ve X-AXIS ROTATION OF THE INNOMINATE Vs +ve X-AXIS ROTATION OF THE ACETABULUM.

The mean of the differences of +/- x-axis rotation of the innominate and of +/- x-axis rotation of the acetabulum for each cadaver is shown in the tables below (see tables 7 and 8).

TABLE 7: THE MEAN OF THE DIFFERENCES OF +VE X-AXIS ROTATION OF THE INNOMINATE AND +VE X-AXIS ROTATION OF THE ACETABULUM.

CADAVER NO.	+VE X-AXIS ROT. OF THE INNOM. (deg)	+VE X-AXIS ROT. OF THE ACETAB. (deg)
1	1	0.5
2	1	0.5
3	1	0.44
4	1	0.44
5	1	0.56
6	1	0.56

TABLE 8: THE MEAN OF THE DIFFERENCES OF -VE X-AXIS ROTATION OF THE INNOMINATE AND -VE X-AXIS ROTATION OF THE ACETABULUM.

CADAVER NO.	**-VE X-AXIS ROT. OF THE INNOM. (deg)**	**-VE X-AXIS ROT. OF THE ACETAB. (deg)**
1	-1	-0.39
2	-1	-0.33
3	-1	-0.33
4	-1	-0.39
5	-1	-0.56
6	-1	-0.56

It was hypothesised that the maximum forced +ve and -ve x-axis rotation of innominate via the sacroiliac joint and symphysis pubis will cause a +ve and -ve x-axis rotation of the roof of the acetabulum. The results substantiate this hypothesis.

3.3.4 <u>Sub-problem 4</u>:

There is no actual treatment of the data for this sub-problem, however the data are discussed in chapter five.

3.3.5 <u>Additional Data And Its Treatment</u> :

The correlation coefficient between +ve x-axis rotation of the innominate and the force/torque used is r= 0.900044. This suggests a strong linear relationship between the two results. The linear regression (ie. model correlation) is shown below.

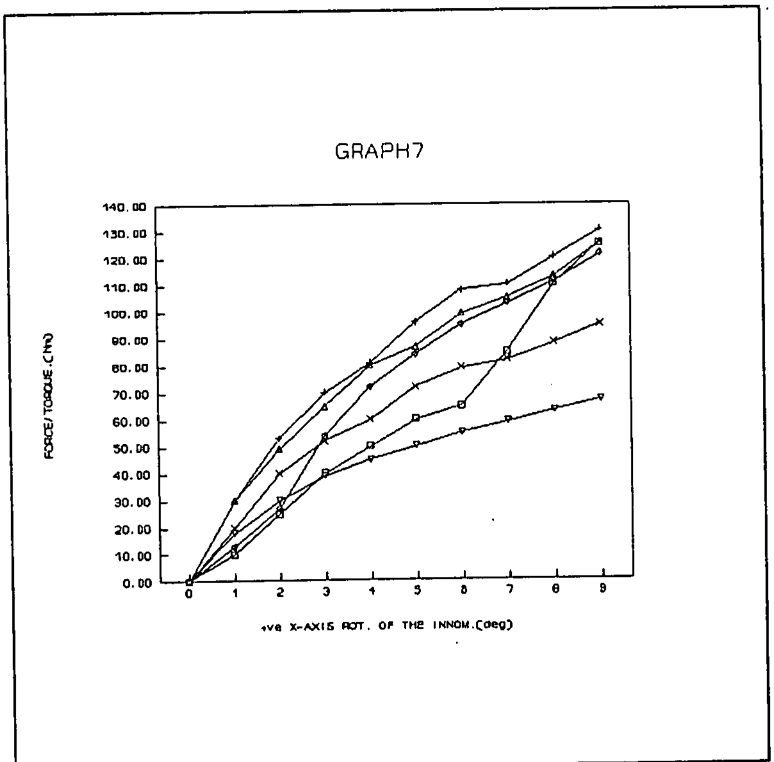

Figure 8: +ve X-AXIS ROTATION OF THE INNOMINATE Vs FORCE/TORQUE.

The correlation coefficient between -ve x-axis rotation of the innominate and the force/torque used is r=- 0.916168. This suggests a strong linear relationship between the two results. The linear regression (ie. model correlation) is shown below.

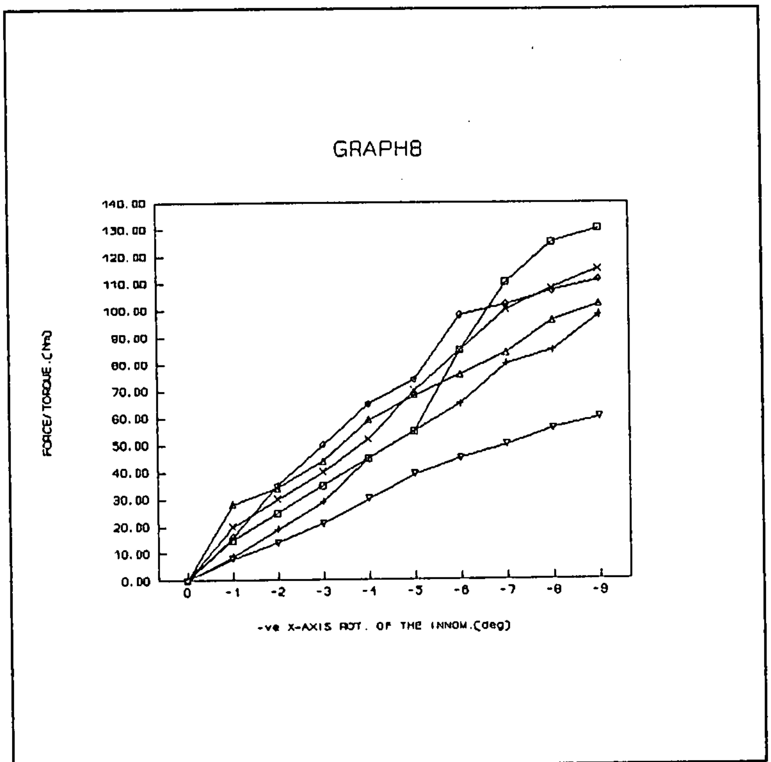

Figure 9: -ve X-AXIS ROTATION OF THE INNOMINATE Vs FORCE/TORQUE.

The mean of the differences of +/- x-axis rotation of the innominate and of force/torque for each cadaver is shown in the tables below (see tables 9 and 10).

TABLE 9: THE MEAN OF THE DIFFERENCES OF +VE X-AXIS ROTATION OF THE INNOMINATE AND FORCE/TORQUE.

CADAVER NO.	**+VE X-AXIS ROT. OF THE INNOM. (deg)**	**FORCE/TORQUE (Nm)**
1	1	13.89
2	1	14.44
3	1	13.44
4	1	13.89
5	1	10.56
6	1	7.44

TABLE 10: THE MEAN OF THE DIFFERENCES OF -VE X-AXIS ROTATION OF THE INNOMINATE AND FORCE/TORQUE.

CADAVER NO.	**-VE X-AXIS ROT. OF THE INNOM. (deg)**	**FORCE/TORQUE (Nm)**
1	-1	14.44
2	-1	10.89
3	-1	12.33
4	-1	11.33
5	-1	12.78
6	-1	6.67

CHAPTER 5

DISCUSSION

In order to asses the reliability of the instrumentation an analysis of variance was done between the results of the ten students (see appendices 1 - 10).

This indicated that there was no significant difference between the results of the students, implying that the instrumentation had good reliability.

This study shows that forced positive (anterior) x-axis rotation of the innominate causes a negative y-axis translation of the roof of the acetabulum. This implies that an anterior rotation of the innominate will cause a lengthening of the lower limb. The converse also occurs as a negative (posterior) x-axis rotation of the innominate causes a positive y-axis translation of the roof of the acetabulum. This implies that a posterior rotation of the innominate will cause a shortening of the lower limb. This correlates with the findings of Winterstein J.F. 1991, Gatterman M.I. 1990 and Herbst R.W. (undated).

The results of this study show that forced positive (anterior) x-axis rotation of the innominate causes a negative z-axis translation of the roof of the acetabulum (i.e. an anterior rotation of the innominate causes the roof of the acetabulum to move posteriorly).
The converse also occurs as a negative (posterior) x-axis rotation of the innominate causes a positive z-axis translation of the roof of the acetabulum (i.e. a posterior rotation of the innominate causes the roof of the acetabulum to move anteriorly).

According to this study a forced positive (anterior) x-axis rotation of the innominate causes a positive x-axis rotation of the roof of the acetabulum (i.e. an anterior rotation of the innominate causes an anterior rotation of the roof of the acetabulum). Conversely a negative (posterior) x-axis rotation of the innominate causes a negative x-axis rotation of the roof of the acetabulum (i.e. a posterior rotation of the innominate causes a posterior rotation of the roof of the acetabulum).

Note that the Pearson moment correlation coefficients and the graphical presentation that were done in this study, indicate that the above findings applied in all the cadaveric specimens.

This study suggests that with all the movements that occur at the sacroiliac joint, an anterior rotation of the innominate via the sacroiliac joint and symphysis pubis will cause the lower limb (taking the roof of the acetabulum as a reference point) to lengthen and move posteriorly.

It will also cause the head of the femur to rotate anteriorly and may increase the rotational stress on the hip joint capsule and ligaments.

Conversely, a posterior rotation of the innominate will cause the lower limb (taking the roof of the acetabulum as a reference point) to shorten and move anteriorly. It will also cause a posterior rotation of the roof of the acetabulum, which may also cause rotational stresses on the hip joint capsule and ligaments.

In this study x-axis rotation of the innominate was forced by the researcher, positively (anteriorly) for nine degrees and then negatively (posteriorly) for nine degrees. It must be noted that this rotation was via both sacroiliac joints thus effectively making the rotation at each joint about 4,5 degrees. This amount of rotation was used as most authors (such as Sturesson B. et al. 1989; Miller J.A.A. et al. 1987; and Gatterman M.I. 1990) found approximately this amount of rotation at the sacroiliac joints.

The results of this study showed that with nine degrees of positive (anterior) x-axis rotation of the innominate, the maximum lengthening of the lower limb (of all cadaveric specimens) was 11.75 millimetres and the minimum lengthening of the lower limb was 6.17 millimetres. With nine degrees of negative (posterior) x-axis rotation of the innominate the maximum shortening of the lower limb (of all cadaveric specimens) was 10.58 millimetres and the minimum shortening was 6.16 millimetres.

Literature does not give consensus on how much leg length inequality is possible via fixations or subluxations of the sacroilac joints.

Clinically it is common to observe a functional leg length inequality of upto 2 centimetres (however there is no consensus amongst authors on this figure). The cause of this leg length inequality, whether it be due to a sacroiliac subluxation or muscle spasm or both, is not always identifiable.

The results of this study suggest that it is possible to obtain upto 11.75 millimetres of lower limb lengthening with an anterior rotational subluxation of the innominate, and possibly upto 10.58 millimetres of lower limb shortening with a posterior rotational subluxation of the innominate via the sacroiliac joint.

In comparing the mean of the differences between x-axis rotation of the innominate, y-axis translation of the roof of the acetabulum and the force/torque used with the age of the cadavers, it can be seen that age has an effect on the amount of lower limb lengthening or shortening with x-axis rotation of the innominate. It appears that the greater the age of the cadaver, the greater is the force required to induce rotation of the innominate. However, the resultant leg length inequality of the lower limb appears to be greater in the older cadavers than in the younger ones.
The literature shows that the older the cadaver or patient, the more adhesions and fibrosis there is within the sacroiliac joint, thus leading to less mobility of the joint (as found by Gatterman M.I. 1990; White A.A. et al. 1990, Sashin D.A. 1930 and Bernard T.N. et al. 1991).

It follows then that more force is needed in the older specimens to obtain the same amount of rotation as in younger specimens, thus suggesting decreased mobility of the sacroiliac joint. The literature, on the other hand, suggests that with increasing age over 20 years there is a decrease in the number of collagen fibres and thus a decrease in the stiffness and tensile strength of the ligaments, allowing more mobility of the joint (Nordin M. and Frankel H. 1989). This study indicates that the older specimens afford greater lengthening or shortening of the lower limb, thus suggesting greater mobility.

These two seemingly conflicting findings are explained using a biomechanical model in chapter six

The maximum force used to apply the nine degrees of rotation in either direction was at most 130 Nm (approximately 13 Mkp) in any of the cadavers. Miller J. 1985 found that the sacroiliac joint is subjected to a torque force of 20Nm in normal loading. For a rotational subluxation of the sacroiliac joint to occur there must be some form of abnormal force or stress on the joint.

This abnormal force may be far greater than 20Nm, this is the reason why such high tortional forces were used in this study.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the results of this studies findings lead to the acceptance of the hypotheses of this study.

The findings of this study concur with the theories of Winterstein J.F. 1991, Gatterman M.I. 1990 and Herbst R.W. (undated), in that a positive (anterior) x-axis rotation of the innominate via the sacroiliac joint and symphysis pubis induces a functional lengthening of the leg, and a negative (posterior) x-axis rotation of the innominate via the sacroiliac joint and symphysis pubis induces a functional shortening of the leg.

The results of this study suggest that the magnitude of this lengthening and shortening of the lower limb is a maximum of 11.75 millimetres and 10.58 millimetres respectively with upto 9 degrees of rotation either way. This is somewhat less than what is at times clinically observed as a functional short leg by many practitioners.

However, in these clinical observations, none of the authors have specified whether the cause of the functional leg length inequality is due to muscle spasm, sacroiliac subluxation or a combination of both.
It is recommended that future studies use larger sample sizes so as to have wider range of results.

The instrumentation in this study showed good reliability, however future instrumentation should show reliability as well as validity. The instrument allowed only x-axis rotation of the innominate via the sacroiliac joint and symphysis pubis, but did not allow any translatory movements of the innominate. Literature indicates that there are slight translatory movements of the innominate via the sacroiliac joints. Future instrumentation should also accommodate any translatory movements of the innominate.

It is recommended that further research in this area is needed, especially with respect to the mobility of the joint.
Authors such as Gatterman M.I. 1990, White A.A. et al. 1990, Sashin D.A. 1930, and Bernard T.N. et al. 1991, believe that the mobility of the sacroiliac joints decreases with an increase in age due to the formation of adhesions, fibrosis and ankylosis of the joints. This study corroborates this due to the fact that older cadaveric specimens needed more force/torque to cause the rotation of the innominate.

However, the older cadaveric specimens had on average more lengthening or shortening of the lower limb, with the same amount of innominate rotation as the younger specimens, thus suggesting more mobility of the sacroiliac joints of the older cadavers.
This corroborates the findings of Nordin M. and Frankel H. 1989 who state that with increasing age over 20 years there is a decrease in the number of collagen fibres and thus a decrease in the tensile strength and stiffness of the ligaments, thus giving a joint more mobility
Biomechanically the above two contradictory views can be explained. As the cadaveric specimens are all relatively young (age ranging from 20-30 years), the fibrous adhesions of the sacroiliac joint may not be well developed or strong. Therefore as the force used to cause an x-axis rotation of the innominate increases, it may overcome the bonds of the adhesions and fibrosis in the sacroiliac joint, thus accounting for the increased forces needed in the older cadavers. Once the fibrous bonds are overcome the ligaments come into play and as the older cadaver's ligaments have decreased tensile strength and stiffness this will lead to more movement in the sacroiliac joint and consequently a greater change in the leg length inequality observed. This is an important concept to be subjected to further research.

This study suggests that an x-axis rotational subluxation of the sacroiliac joint could cause a functional leg length inequality.

This inequality is unlikely to be greater than 11.75 millimetres; which many authors such as Winterstein J.F. 1991; Hult L 1954; Gross R.H. 1983, believe to be clinically insignificant. On the other hand, authors such as Giles L.G.F. 1976 and Travell J.G. et al 1983, believe this amount of leg length inequality to be significant.

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APPENDICES

APPENDIX A: RESULTS OF STUDENT NUMBER 1

X-AXIS ROTATION OF THE INNOMIN-ATE. (DEG.)	Z-AXIS TRANSLA-TION OF THE ACETABU-LUM. (mm)	Y-AXIS TRANSLA-TION OF THE ACETABU-LUM. (mm)	X-AXIS ROTATION OF THE ACETABU-LUM. (Deg.)
1	-1.82	-0.5	1
2	-3.76	-1	2.5
3	-5.5	-1.5	3
4	-7.39	-2	4.5
5	-9.2	-2	5
6	-10.95	-2	6
7	-12.62	-2.5	6.5
8	-14.2	-3	7.5
9	-16.29	-4	8.5
-1	1.76	1	-1
-2	3.81	1.5	-2
-3	5.53	1.5	-3
-4	7.28	2	-4
-5	9.37	2	-5
-6	10.98	2.5	-5.5
-7	12.91	2.5	-6
-8	14.86	2.5	-7
-9	16.83	2.5	-8

APPENDIX B: RESULTS OF STUDENT NUMBER 2

X-AXIS ROTATION OF THE INNOMIN-ATE. (DEG.)	Z-AXIS TRANSLA-TION OF THE ACETABU-LUM. (mm)	Y-AXIS TRANSLA-TION OF THE ACETABU-LUM. (mm)	X-AXIS ROTATION OF THE ACETABU-LUM. (Deg.)
1	-2	-0.5	1
2	-4	-1	2.5
3	-5.58	-1.5	3.5
4	-7.61	-2	4.5
5	-9.3	-2	5.5
6	-11.07	-2.5	6.5
7	-12.09	-3	7.5
8	-14.49	-4	8.5
9	-16.04	-4.5	9.5
-1	1.85	0.5	-1
-2	3.75	1	-2
-3	5.47	1.5	-3
-4	7.35	1.5	-4
-5	9.15	2	-5
-6	10.87	2	-5.5
-7	12.97	2	-6
-8	14.65	2.5	-7
-9	16.52	2.5	-8

APPENDIX C: RESULTS OF STUDENT NUMBER 3

X-AXIS ROTATION OF THE INNOMINATE. (DEG.)	Z-AXIS TRANSLATION OF THE ACETABULUM. (mm)	Y-AXIS TRANSLATION OF THE ACETABULUM. (mm)	X-AXIS ROTATION OF THE ACETABULUM. (Deg.)
1	-1.74	-0.5	1
2	-3.67	-1	2.5
3	-5.29	-1.5	3.5
4	-7.57	-2	4.5
5	-9.16	-2.5	5.5
6	-11.18	-2.5	6.5
7	-12.66	-3	7.5
8	-14.22	-4	8.5
9	-16.07	-4.5	9.5
-1	1.8	0.5	-1
-2	3.86	1	-2
-3	5.57	1.5	-3
-4	7.45	1.5	-4
-5	9.36	2	-5
-6	10.74	2	-5.5
-7	12.85	2.5	-6
-8	14.81	2.5	-7.5
-9	16.56	2.5	-8.5

APPENDIX D: RESULTS OF STUDENT NUMBER 4

X-AXIS ROTATION OF THE INNOMIN-ATE. (DEG.)	Z-AXIS TRANSLA-TION OF THE ACETABU-LUM.(mm)	Y-AXIS TRANSLA-TION OF THE ACETABU-LUM.(mm)	X-AXIS ROTATION OF THE ACETABU-LUM. (Deg.)
1	-1.76	-0.5	1
2	-3.89	-1	2
3	-5.75	-1.5	3.5
4	-7.39	-2	4.5
5	-9.36	-2	5.5
6	-11.11	-2.5	6.5
7	-12.67	-3	7.5
8	-14.16	-4	8.5
9	-16.46	-4.5	10
-1	1.99	0.5	-1
-2	4.07	0.5	-2
-3	5.69	1	-3
-4	7.54	1.5	-4
-5	9.35	1.5	-5
-6	11.1	2	-5.5
-7	13.14	2	-6
-8	14.82	2.5	-7
-9	16.87	2.5	-8

APPENDIX E: RESULTS OF STUDENT NUMBER 5

X-AXIS ROTATION OF THE INNOMIN-ATE. (DEG.)	Z-AXIS TRANSLA-TION OF THE ACETABU-LUM. (mm)	Y-AXIS TRANSLA-TION OF THE ACETABU-LUM. (mm)	X-AXIS ROTATION OF THE ACETABU-LUM. (Deg.)
0	-1.92	-1	1
2	-3.53	-1.5	2
3	-5.6	-2	3.5
4	-7.19	-2.5	4.5
5	-9.15	-3	5.5
6	-11.06	-3	6.5
7	-12.5	-3.5	7
8	-14.2	-4	8
9	-16.11	-0.45	9
-1	1.81	0.5	-1
-2	3.67	1	-2
-3	5.44	1	-3
-4	7.29	1	-4
-5	9.33	1.5	-5
-6	10.89	1.5	-5.5
-7	12.86	2	-6.5
-8	14.69	2	-7.5
-9	16.31	2.5	-8.5

APPENDIX F: RESULTS OF STUDENT NUMBER 6

X-AXIS ROTATION OF THE INNOMINATE. (DEG.)	Z-AXIS TRANSLATION OF THE ACETABULUM. (mm)	Y-AXIS TRANSLATION OF THE ACETABULUM. (mm)	X-AXIS ROTATION OF THE ACETABULUM. (Deg.)
1	-1.97	-0.5	1
2	-3.89	-1	2
3	-5.43	-1.5	3
4	-7.29	-2	4.5
5	-9.16	-2.5	5
6	-11.06	-3	6
7	-12.73	-3.5	7
8	-14.4	-4	8.5
9	-16.22	-4.5	9.5
-1	1.74	0.5	-1
-2	3.36	1	-2
-3	5.16	1	-3
-4	7.22	1	-4
-5	8.97	1.5	-5
-6	11.08	2	-6
-7	12.71	2	-7
-8	14.74	2.5	-8
-9	16.67	3	-9

APPENDIX G: RESULTS OF STUDENT NUMBER 7

X-AXIS ROTATION OF THE INNOMIN-ATE. (DEG.)	Z-AXIS TRANSLA-TION OF THE ACETABU-LUM. (mm)	Y-AXIS TRANSLA-TION OF THE ACETABU-LUM. (mm)	X-AXIS ROTATION OF THE ACETABU-LUM. (Deg.)
1	-1.87	-0.5	1
2	-3.69	-1	2
3	-5.58	-1.5	3
4	-7.37	-2	4
5	-9.33	-2.5	5
6	-10.99	-3	6
7	-12.82	-3.5	7
8	-14.42	-4	8
9	-16.16	-4.5	9
-1	1.75	0.5	-1
-2	3.61	1	-2
-3	5.4	1	-3
-4	7.41	1.5	-4.5
-5	9.22	2	-5
-6	10.91	2	-6
-7	12.73	2	-7
-8	14.6	2.5	-8
-9	16.45	2.5	-9

APPENDIX H: RESULTS OF STUDENT NUMBER 8

X-AXIS ROTATION OF THE INNOMINATE. (DEG.)	Z-AXIS TRANSLATION OF THE ACETABULUM. (mm)	Y-AXIS TRANSLATION OF THE ACETABULUM. (mm)	X-AXIS ROTATION OF THE ACETABULUM. (Deg.)
1	-2	-0.5	1
2	-3.85	-1	2
3	-5.6	-1.5	3
4	-7.48	-2	4
5	-9.5	-2.5	5
6	-11.21	-3	6
7	-12.81	-3.5	7
8	-14.56	-4	8
9	-16.36	-4.5	9
-1	1.65	0.5	-1
-2	3.61	1	-2
-3	5.41	1.5	-3
-4	7.4	2	-4
-5	9.25	2	-5
-6	10.97	2	-5.5
-7	12.78	2.5	-6.5
-8	14.73	2.5	-7.5
-9	16.61	2.5	-8.5

APPENDIX I: RESULTS OF STUDENT NUMBER 9

X-AXIS ROTATION OF THE INNOMIN-ATE. (DEG.)	Z-AXIS TRANSLA-TION OF THE ACETABU-LUM. (mm)	Y-AXIS TRANSLA-TION OF THE ACETABU-LUM. (mm)	X-AXIS ROTATION OF THE ACETABU-LUM. (Deg.)
1	-1.9	-0.5	1
2	-3.9	-1	2
3	-5.4	-1.5	3
4	-7.48	-2	4
5	-9.25	-2.5	5
6	-11.14	-2.5	6
7	-12.81	-3	7
8	-14.58	-3.5	8
9	-16.3	-4	9
-1	1.8	0.5	-1
-2	3.63	1	-2
-3	5.55	1.5	-3
-4	7.26	1.5	-4
-5	9.16	2	-5
-6	11.03	2.5	-5.5
-7	12.79	2.5	-6.5
-8	14.71	3	-7.5
-9	16.33	3	-8.5

APPENDIX J: RESULTS OF STUDENT NUMBER 10

X-AXIS ROTATION OF THE INNOMIN-ATE. (DEG.)	Z-AXIS TRANSLA-TION OF THE ACETABU-LUM. (mm)	Y-AXIS TRANSLA-TION OF THE ACETABU-LUM. (mm)	X-AXIS ROTATION OF THE ACETABU-LUM. (Deg.)
1	-1.98	-0.5	1
2	-3.62	-1	2
3	-5.33	-1	3
4	-7.16	-1.5	4
5	-9.22	-2	5
6	-11.06	-2.5	6
7	-12.72	-3	7
8	-14.4	-3.5	8
9	-16.16	-4	9
-1	1.83	0.5	-1
-2	3.56	1	-2
-3	5.38	1.5	-3
-4	7.23	1.5	-4
-5	9.15	2	-5
-6	11.06	2	-6
-7	12.5	2	-7
-8	14.49	2	-8
-9	16.45	2.5	-9

APPENDIX K : CADAVER NUMBER : 1

X-A-R-I	DF1	Z-A-T-A	DF2	Y-A-T-A	DF3	X-A-R-A	DF4	FORCE/ TORQUE	DF5
0		0		0		0		0	
1	1	-1	-1	-1.49	-1.49	1	1	10	10
2	1	-2	-1	-2.57	-1.08	2	1	25	15
3	1	-2.5	-0.5	-3.52	-0.95	3	1	40	15
4	1	-3	-0.5	-4.01	-0.49	4	1	50	10
5	1	-3.5	-0.5	-4.96	-0.95	4	0	60	10
6	1	-4	-0.5	-5.6	-0.64	4	0	65	5
7	1	-4.5	-0.5	-6.33	-0.73	4	0	85	20
8	1	-5	-0.5	-8.91	-2.58	4.5	0.5	110	25
9	1	-5.5	-0.5	-10.83	-1.92	5	0.5	125	15
0		0		0		0		0	
-1	-1	1	1	0.49	0.49	-1	-1	15	15
-2	-1	2	1	1.06	0.57	-1.5	-0.5	25	10
-3	-1	3	1	1.6	0.54	-1.5	0	35	10
-4	-1	3.5	0.5	2.59	0.99	-2	-0.5	45	10
-5	-1	3.5	0	3.67	1.03	-2	0	55	10
-6	-1	4	0.5	5.55	1.93	-2	0	85	30
-7	-1	4	0	6.11	0.56	-2.5	-0.5	110	25
-8	-1	4.5	0.5	7.11	1	-3	-0.5	125	15
-9	-1	5	0.5	8.9	1.79	-3.5	-0.5	130	5

X-A-R-I ; X-AXIS ROTATION OF THE INNOMINATE (DEGREES)
DF1 ; DIFFERENCE BETWEEN X-A-R-I
Z-A-T-A ; Z-AXIS TRANSLATION OF THE ACETABULUM (mm)
DF2 ; DIFFERENCE BETWEEN Z-A-T-A
Y-A-T-A ; Y-AXIS TRANSLATION OF THE ACETABULUM(mm)
DF3 ; DIFFERENCE BETWEEN Y-A-T-A
X-A-R-A ; X-AXIS ROTATION OF THE ACETABULUM (DEGREES)
DF4 ; DIFFERENCE BETWEEN X-A-R-A
FORCE ; FORCE/TORQUE.(Nm)
DF5 ; DIFFERENCE BETWEEN FORCE/TORQUE

APPENDIX L : CADAVER NUMBER : 2

X-A-R-I	DF1	Z-A-T-A	DF2	Y-A-T-A	DF3	X-A-R-A	DF4	FORCE/TORQUE	DF5
0		0		0		0		0	
1	1	-2	-2	-0.61	-0.61	0.5	0.5	30	30
2	1	-2.5	-0.5	-2.05	-1.44	1	0.5	53	23
3	1	-3	-0.5	-3.25	-1.2	2	1	70	17
4	1	-3.5	-0.5	-4.02	-0.77	2	0	81	11
5	1	-4	-0.5	-5.27	-1.25	2.5	0.5	96	15
6	1	-4.5	-0.5	-6.24	-0.97	3	0.5	108	12
7	1	-4.5	0	-6.84	-0.6	3.5	0.5	110	2
8	1	-4.5	0	-8.27	-1.43	4	0.5	120	10
9	1	-5	-0.5	-9.4	-1.13	4.5	0.5	130	10
0		0		0		0		0	
-1	-1	1	1	0.98	0.98	0	0	9	9
-2	-1	1.5	0.5	1.87	0.89	-0.5	-0.5	19	10
-3	-1	2	0.5	2.64	0.77	-1	-0.5	29	10
-4	-1	2.5	0.5	3.4	0.76	-1.5	-0.5	45	16
-5	-1	3	0.5	4.11	0.71	-2	-0.5	55	10
-6	-1	3.5	0.5	4.91	0.8	-2	0	65	10
-7	-1	4	0.5	5.66	0.75	-2.5	-0.5	80	15
-8	-1	4.5	0.5	6.36	0.7	-2.5	0	85	5
-9	-1	5	0.5	6.9	0.54	-3	-0.5	98	13

X-A- R-I ; X-AXIS ROTATION OF THE INNOMINATE (DEGREES)
DF1 ; DIFFERENCE BETWEEN X-A-R-I
Z-A- T-A ; Z-AXIS TRANSLATION OF THE ACETABULUM (mm)
DF2 ; DIFFERENCE BETWEEN Z-A-T-A
Y-A- T-A ; Y-AXIS TRANSLATION OF THE ACETABULUM(mm)
DF3 ; DIFFERENCE BETWEEN Y-A-T-A
X-A- R-A ; X-AXIS ROTATION OF THE ACETABULUM (DEGREES)
DF4 ; DIFFERENCE BETWEEN X-A-R-A
FORCE ; FORCE/TORQUE. (Nm)
DF5 ; DIFFERENCE BETWEEN FORCE/TORQUE

APPENDIX M : CADAVER NUMBER : 3

X-A-R-I	DF1	Z-A-T-A	DF2	Y-A-T-A	DF3	X-A-R-A	DF4	FORCE/TORQUE	DF5
0		0		0		0		0	
1	1	-0.5	-0.5	-1.24	-1.24	0	0	13	13
2	1	-1	-0.5	-2.67	-1.43	1	1	27	14
3	1	-1.5	-0.5	-4.08	-1.41	1.5	0.5	54	27
4	1	-2	-0.5	-4.85	-0.77	2	0.5	72	18
5	1	-2.5	-0.5	-6.57	-1.72	2.5	0.5	84	12
6	1	-3.5	-1	-7.88	-1.31	3	0.5	95	11
7	1	-4.5	-1	-8.97	-1.09	3	0	103	8
8	1	-5	-0.5	-10.25	-1.28	3.5	0.5	111	8
9	1	-5.5	-0.5	-11.75	-1.5	4	0.5	121	10
0		0		0		0		0	
-1	-1	0.5	0.5	1.13	1.13	0	0	16	16
-2	-1	1	0.5	2.34	1.21	-1	-1	35	19
-3	-1	1.5	0.5	3.56	1.22	-1	0	50	15
-4	-1	2	0.5	4.84	1.28	-1	0	65	15
-5	-1	2.5	0.5	6.09	1.25	-1.5	-0.5	74	9
-6	-1	3	0.5	7.34	1.25	-2	-0.5	98	24
-7	-1	3.5	0.5	8.27	0.93	-2.5	-0.5	102	4
-8	-1	4.5	0.5	9.69	1.42	-2.5	0	107	5
-9	-1	5	0.5	10.58	0.89	-3	-0.5	111	4

X-A- R-I ; X-AXIS ROTATION OF THE INNOMINATE (DEGREES)
DF1 ; DIFFERENCE BETWEEN X-A-R-I
Z-A- T-A ; Z-AXIS TRANSLATION OF THE ACETABULUM (mm)
DF2 ; DIFFERENCE BETWEEN Z-A-T-A
Y-A- T-A ; Y-AXIS TRANSLATION OF THE ACETABULUM(mm)
DF3 ; DIFFERENCE BETWEEN Y-A-T-A
X-A- R-A ; X-AXIS ROTATION OF THE ACETABULUM (DEGREES)
DF4 ; DIFFERENCE BETWEEN X-A-R-A
FORCE ; FORCE/TORQUE.(Nm)
DF5 ; DIFFERENCE BETWEEN FORCE/TORQUE

APPENDIX N : CADAVER NUMBER : 4

X−A−R−I	DF1	Z−A−T−A	DF2	Y−A−T−A	DF3	X−A−R−A	DF4	FORCE/ TORQUE	DF5
0		0		0		0		0	
1	1	−1	−1	−1.48	−1.48	1	1	30	30
2	1	−1.5	−0.5	−2.55	−1.07	1.5	0.5	49	19
3	1	−2	−0.5	−3.63	−1.08	2	0.5	65	16
4	1	−2.5	−0.5	−4.89	−1.26	2.5	0.5	80	15
5	1	−3	−0.5	−5.91	−1.02	3	0.5	87	7
6	1	−3.5	−0.5	−6.81	−0.9	3.5	0.5	99	12
7	1	−3.5	0	−7.89	−1.08	3.5	0	105	6
8	1	−4	−0.5	−8.28	−0.39	3.5	0	113	8
9	1	−4.5	−0.5	−9.56	−1.28	4	0.5	125	12
0		0		0		0		0	
−1	−1	0.5	0.5	1.3	1.3	−1	1	28	28
−2	−1	1	0.5	2.36	1.06	−1.5	−0.5	34	6
−3	−1	1.5	0.5	3.57	1.21	−2	−0.5	44	10
−4	−1	1.5	0	4.59	1.02	−2	0	59	15
−5	−1	2	0.5	5.33	0.74	−2.5	−0.5	68	9
−6	−1	2.5	0.5	6.37	1.04	−2.5	0	76	8
−7	−1	3	0.5	7.2	0.83	−3	−0.5	84	8
−8	−1	3	0	8.41	1.21	−3	0	96	12
−9	−1	3.5	0.5	9.99	1.49	−3.5	−0.5	102	6

X−A− R−I ; X−AXIS ROTATION OF THE INNOMINATE (DEGREES)
DF1 ; DIFFERENCE BETWEEN X−A−R−I
Z−A− T−A ; Z−AXIS TRANSLATION OF THE ACETABULUM (mm)
DF2 ; DIFFERENCE BETWEEN Z−A−T−A
Y−A− T−A ; Y−AXIS TRANSLATION OF THE ACETABULUM(mm)
DF3 ; DIFFERENCE BETWEEN Y−A−T−A
X−A− R−A ; X−AXIS ROTATION OF THE ACETABULUM (DEGREES)
DF4 ; DIFFERENCE BETWEEN X−A−R−A
FORCE ; FORCE/TORQUE.(Nm)
DF5 ; DIFFERENCE BETWEEN FORCE/TORQUE

APPENDIX O : CADAVER NUMBER : 5

X-A-R-I	DF1	Z-A-T-A	DF2	Y-A-T-A	DF3	X-A-R-A	DF4	FORCE/ TORQUE	DF5
0		0		0		0		0	
1	1	-1	-1	-0.27	-0.27	1	1	20	20
2	1	-2	-1	-1.1	-0.83	2	1	40	20
3	1	-3	-1	-1.81	-0.71	2.5	0.5	52	12
4	1	-4	-1	-2.58	-0.77	3	0.5	60	8
5	1	-5	-1	-3.45	-0.87	3.5	0.5	72	12
6	1	-5.5	-0.5	-4.12	-0.67	4	0.5	79	7
7	1	-6	-0.5	-4.7	-0.58	4.5	0.5	82	3
8	1	-6	0	-5.32	-0.62	4.5	0	88	6
9	1	-6.5	-0.5	-6.17	-0.85	5	0.5	95	7
0		0		0		0		0	
-1	-1	1	1	0.33	0.33	-1	-1	20	20
-2	-1	2	1	1.22	0.89	-2	-1	30	10
-3	-1	3.5	1.5	1.71	0.49	-3	-1	40	10
-4	-1	4	0.5	2.31	0.6	-3.5	-0.5	52	12
-5	-1	4.5	0.5	3.13	0.82	-4	-0.5	70	18
-6	-1	5	0.5	4.04	0.91	-4.5	-0.5	85	15
-7	-1	5.5	0.5	5.2	1.16	-4.5	0	100	15
-8	-1	6	0.5	5.83	0.63	-5	-0.5	108	8
-9	-1	6.5	0.5	6.64	0.81	-5	0	115	7

X-A-R-I	;	X-AXIS ROTATION OF THE INNOMINATE (DEGREES)
DF1	;	DIFFERENCE BETWEEN X-A-R-I
Z-A-T-A	;	Z-AXIS TRANSLATION OF THE ACETABULUM (mm)
DF2	;	DIFFERENCE BETWEEN Z-A-T-A
Y-A-T-A	;	Y-AXIS TRANSLATION OF THE ACETABULUM(mm)
DF3	;	DIFFERENCE BETWEEN Y-A-T-A
X-A-R-A	;	X-AXIS ROTATION OF THE ACETABULUM (DEGREES)
DF4	;	DIFFERENCE BETWEEN X-A-R-A
FORCE	;	FORCE/TORQUE.(Nm)
DF5	;	DIFFERENCE BETWEEN FORCE/TORQUE

APPENDIX P : CADAVER NUMBER : 6

X-A-R-I	DF1	Z-A-T-A	DF2	Y-A-T-A	DF3	X-A-R-A	DF4	FORCE/ TORQUE	DF5
0		0		0		0		0	
1	1	−1	−1	−0.67	−0.67	1	1	18	18
2	1	−1.5	−0.5	−1.54	−0.87	2	1	30	12
3	1	−2	−0.5	−2.34	−0.78	2.5	0.5	39	9
4	1	−2.5	−0.5	−2.79	−0.47	3	0.5	45	6
5	1	−3	−0.5	−3.51	−0.72	3.5	0.5	50	5
6	1	−3	0	−4.38	−0.87	4	0.5	55	5
7	1	−3.5	−0.5	−4.93	−0.55	4.5	0.5	59	4
8	1	−4	−0.5	−5.44	−0.51	4.5	0	63	4
9	1	−4.5	−0.5	−6.36	−0.92	5	0.5	67	4
0		0		0		0		0	
−1	−1	0.5	0.5	0.74	0.74	−0.5	−0.5	8	8
−2	−1	1	0.5	1.75	1.01	−1	−0.5	14	6
−3	−1	1.5	0.5	2.24	0.49	−1.5	−0.5	21	7
−4	−1	2	0.5	2.95	0.71	−2	−0.5	30	9
−5	−1	2.5	0.5	3.91	0.96	−3	−1	39	9
−6	−1	3	0.5	4.58	0.67	−3.5	−0.5	45	6
−7	−1	3	0	5.02	0.44	−4	−0.5	50	5
−8	−1	3.5	0.5	5.55	0.53	−4.5	−0.5	56	6
−9	−1	4	0.5	6.16	0.61	−5	−0.5	60	4

X-A-R-I ; X-AXIS ROTATION OF THE INNOMINATE (DEGREES)
DF1 ; DIFFERENCE BETWEEN X-A-R-I
Z-A-T-A ; Z-AXIS TRANSLATION OF THE ACETABULUM (mm)
DF2 ; DIFFERENCE BETWEEN Z-A-T-A
Y-A-T-A ; Y-AXIS TRANSLATION OF THE ACETABULUM(mm)
DF3 ; DIFFERENCE BETWEEN Y-A-T-A
X-A-R-A ; X-AXIS ROTATION OF THE ACETABULUM (DEGREES)
DF4 ; DIFFERENCE BETWEEN X-A-R-A
FORCE ; FORCE/TORQUE.(Nm)
DF5 ; DIFFERENCE BETWEEN FORCE/TORQUE