Biomechanical and Clinical Investigation of Pelvic Ring Injuries

Endre Varga M.D.

Ph.D. Thesis

1999

Albert Szent-Györgyi Medical University
Department of Trauma Surgery
Szeged, Hungary

This dissertation is dedicated to the remembrance for my loved late father...

INDEX

Abbreviations

A/D	Analog/Digital
AMA	American Medical Association
AO	Arbeitsgemeinschaft für Osteosynthesefragen
ATLS	Advanced Trauma Life Support
BME	Technical University of Budapest, Budapest
CAD	Computer Aided Design
FEA	Finite Element Analysis
FEM	Finite Element Model
IS	Iliosacral
ISS	Injury Severity Score
JATE	Attila József University, Szeged
LVDT	Linear Variable Differential Transformer
MTS	Material Testing Machine
OR	Operating Room
PDS	Polydioxanone
PS	Pubic Symphysis
RISRS	Retrograde Intramedullar Superior Ramic Screw
SI	Sacroiliac
SS	Sacrospinous
ST	Sacrotuberous
SZOTE	Albert Szent-Györgyi Medical University, Szeged
TICU	Trauma Intensive Care Unit

I. List of Personal Publications Concerning the Pelvic Project

Reviewed Papers:

I. *Effects of Method of Internal Fixation of Symphyseal Disruptions on Stability of the Pelvic Ring.* E. Varga, T. Hearn, J. Powell, M. Tile INJURY Vol.26, No.2.,pp.75-80, 1995.

II. *Biomechanical Analysis of Hemipelvic Deformation after Cortico-spongious Bone Graft Harvest from the Posterior Iliac Crest.* E. Varga, R. Hu, T.C. Hearn, T. Woodside, J.P. Yang SPINE 21(13). pp.1494-9, 1996.

III. *The Strength of the Iliosacral Lag Screws and Transiliac Bars in the Fixation of Vertically Unstable Pelvic Injuries with Sacral Fractures.* J.T. Gorczyca, E. Varga, T. Woodside, T.C. Hearn, J. Powell, M. Tile INJURY Vol.27, No.8, pp. 561-4, 1996.

IV. *Are there any Proprioceptive Functions of the Pelvic Ligaments? Biomechanical and Histological Studies* E. Varga, B. Dudás, T.C. Hearn and M. Tile (Under revision in JOURNAL OF BIOMECHANICS)

Lectures:

V. Varga E., Nacsai I., Poczik M. (1983) *Hasi parenchymás szervsérülések klinikánk lO éves anyagában.* Fiatal Traumatológusok Fóruma, Budapest, Hungary

VI. Varga E., Kiss Gy., Sándor L. (1983) *A lavage jelentõsége a tompa hasi sérülések diagnosticájában.* Fiatal Traumatológusok Fóruma, Budapest, Hungary.

VII. Vörös E., Ormándi K., Varga E., Fráter L. (1984) *A nativ röntgenvizsgálatok jelentõsége a fedett hasi sérülések diagnosztikájában.* XII. Magyar Radiologus Kongresszus, Debrecen, Hungary

VIII. E. Varga (1994) *Effects of method of internal fixation of symphyseal disruptions on stability of the pelvic ring.* Austrian-Swiss-German Travelling Fellow Meeting, Toronto, Canada

IX. E. Varga, T.C.Hearn, T. Woodside, J. Yang, R. Hu. (1994) *Biomechanical analysis of the remaining strength of the pelvic ring following cortico-spongious bone graft harvesting from the posterior iliac crest.* Austrian-Swiss-German Travelling Fellow Meeting, Toronto, Canada

X. T.C. Hearn, E. Varga, K. Willet, M. Vrahas, M. Tile (1994) *Biomechanical effects of the division of the different ligaments and joints of the pelvic ring to stance related loading.* The Seventh Toronto Pelvic and Acetabular Fracture Management Course, Toronto, Canada

XI. J.T. Gorzyca, E. Varga, T. Hearn, M. Tile (1994) *The strength of the sacroiliac lag screws and transiliac bars in the fixation of vertically unstable pelvic injuries with sacral fractures.* Annual Meeting of the American Orthopaedic Trauma Association (OTA), Los Angeles, USA.

XII. R. Hu, E. Varga, T.C.Hearn, T. Woodside, J. Yang. (1994) *Biomechanical analysis of the remaining strength of the pelvic ring following cortico-spongious bone graft harvesting from the posterior iliac crest.* Annual Meeting of the Canadian Orthopaedic Association (COA), Winnipeg, Canada

XIII. E. Varga, T. Hearn, M. Tile (1994) *Effects of method of internal fixation of symphyseal disruptions on stability of the pelvic ring: A biomechanical study.* Central European Congress on Traumatology, Budapest, Hungary.

XIV. T.C. Hearn, E. Varga, K. Willet, M. Vrahas, M. Tile (1994) *Effects of the division of ligaments on the mechanical response of the pelvic ring to stance related loading.* Central European Congress on Traumatology, Budapest, Hungary.

XV. E. Varga, T. Hearn, J. Powell, M. Tile (1994) *Effects of method of internal fixation of symphyseal disruptions on stability of the pelvic ring.* Surgery the Pelvis and Acetabulum: The Second International Consensus, Pittsburgh, Pennsylvania, USA. [Abstract in Congress Bulletin p.62.]

XVI. J.T. Gorczyca, E. Varga, T. Hearn, M. Tile (1994) The strength of the sacroiliac lag screws and transiliac bars in the fixation of vertically unstable pelvic injuries with sacral fractures. Surgery the Pelvis and Acetabulum: The Second International Consensus, Pittsburgh, Pennsylvania, USA. [Abstract in Congress Bulletin p.63.]

XVII. R. Hu, E. Varga, T. Hearn, T. Woodside ad J. Yang (1995) *Anterior ad Posterior Bone Graft Harvest Site Effects on the Remaining Strength of the Iliac Crest: A Human Cadaveric Biomechanical Assessment.* American Academy of Orthopaedic Surgeons, 62nd Annual Meeting, Orlando, Florida, USA. [Abstract in Congress Bulletin p.57.]

XVIII. Varga E, Hearn T és Tile M (1995) *A symphysis rögzítésének egy lehetséges alternatívája gyermekkorban: a PDS-cord. Biomechanikai összehasonlító vizsgálatok* II. Gyermektraumatológiai Konferencia, Debrecen, Hungary, [Aktuális kérdések a gyermektraumatológiában, p.92-95. Piremon 1995.]

XIX. Varga E. T.C. Hearn, R. Hu, T. Woodside and M. Tile (1995) *A medence teherbírásának biomechanikai analísise a csípõlapát hátsó részébõl vett corticospongiosus csont-graft eltávolítását követõen.* Magyar Ortopéd Társaság Kongresszusa, Szeged, Hungary

XX. Varga E., Török L., J.T. Gorcyzca és M. Tile (1995) *Az iliosacralis csavarozás biomechanikai alapjai és klinikai alkalmazása.* Magyar Traumatológus Társaság Kongresszusa, Békéscsaba, Hungary

XXI. Varga E.(1995) *A new designed 10-mm diameter cannulated cancellous screw for the stabilisation of the posterior pelvic ring injuries.* 6th Congress of the Romanian Society of Orthopaedic and Trauma Association with International Participation, Cluj-Napoca, Romania

XXII. E. Varga (1996) New *Concepts in Sacral Iliac Joint Fixation.* American Orthopedic Association, Belgium Travelling Fellows' Meeting Charlotte (NC), USA

XXIII. E. Varga (1996) *Pelvic Ring Injuries. Biomechanical and Clinical Studies.* Personal Invitation by the Chief of Trauma Care (John T. Gorczyca) of Orthopedic Surgery, University of Kentucky, Lexington, USA

XXIV. E. Varga, L. Török, T.C. Hearn and M. Tile (1996) *Specially Designed Cannulated Screw for the Iliosacral Fixation of the Posterior Pelvic Ring. Biomechanical and Clinical Evaluation.* 2nd Central European Congress of Traumatology, Davos, Switzerland, [Abstract in Swiss Surgery Supplement 2, pp. 43]

XXV. E. Varga, B. Dudás, T. C. Hearn and M. Tile (1996) *Are there Functional Proprioceptive Properties of the Pelvic Ligaments? Biomechanical and Histological Studies* 2nd Central European Congress of Traumatology, Davos, Switzerland [Abstract in Swiss Surgery Supplement 2, pp.42]

XXVI. E. Varga (1996) [referatum] *Biomechanical analysis of the human pelvis with mechanical and mathematical methods to provide adequate postoperative physiotherapy.* Measurements of the Effects of Physiotherapeutic Examinations and Treatments, Szeged, Hungary

XXVII. Varga E., Kuba A., Halmai Cs. és Horváth A. (1996) *Medencegyûrû sérülések ellátási taktikája polytarumatizáltaknál. Biobechanika, klinikum.* Magyar Traumatológus Társaság 1996. évi Vándorgyûlése, Szeged, Hungary

XXVIII. Varga E., Kuba A., Török L. és Hováth A. (1996) *Új lehetõségek a medencesérült betegek diagnosticájában és mûtéti kezelésében. Biomecahnika, számítógépes végeselemes analysis, klinikum.* Harmadik Szent-Györgyi Napok, Szeged, Hungary

XXIX. Varga E. (1996) *Medencegyûrûsérültek ellátásáról. Biomechanika, klinikum.* Magyar Traumatológus Társaság Kelet-magyarországi Csoportjának Tudományos Ülése, Debrecen, Hungary

XXX. Varga E., Horváth A., Balogh Zs., Simonka J.A. (1997) *Operative technique of retrograde intramedullar superior ramus screw for the management of anterior pelvic ring injuries.* 6th International Congress of the Hungarian Society of Traumatology, Budapest, Hungary

XXXI. E. Varga, J.T. Gorczyca, M. Kiss, T.C. Hearn and M. Tile, (1997) *Percutaneous fixation methods for the stabilization of the pelvic girdle injuries using partly newly developed implants.* 2nd European Congress of Trauma and Emergency Surgery, Athens, Greece, [Abstract in the European Journal of Emergency Surgery and Intensive Care, p. 27. Vol. XX. Suppl. to No.3, 1997.]

XXXII. Bencsura K. Varga E. *Mûtétileg kexelt komplex instabilitással járó medencegyûrûsérülések fiziotherapiája.* Magyar Gyógytornászok Társasága I. Kongresszusa, Budapest, Hungary, [Abstract in Congress bulletin p.31]

XXXIII. E. Varga, J.A. Simonka (1997) *Biomechanical and Clinical Aspects of Pelvic Girdle Injuries.* 16. Steirisch-Slovenische Unfall- Und 13. Grenzlandtagung, Szombathely, Hungary

XXXIV. K.Bencsura, E. Varga (1997) *Complex Physiotherapy of Pelvic Injured Patients (video).* 16. Steirisch-Slovenische Unfall Und 13. Grenzlandtagung, Szombathely, Hungary

XXXV. E. Varga, J.T. Gorczyca, P. Hasenfrancz, K. Váradi (1998) *Comparison of strengths of different types of iliosacral screws using finite element models.* 3rd European Trauma Congress, Amsterdam, The Netherlands, [Abstract in Nederlands Tijdschrift voor Traumatologie, Supplement, p.118, 1998]

XXXVI. E. Varga, J.T. Gorczyca, Zs. Balogh, M. Kiss and J.A. Simonka (1998) *Pelvic Fracture Related Hemorrhage. Should they be Immediately, Definitively Fixed?* 3rd European Trauma Congress, Amsterdam, The Netherlands, [Abstract in Nederlands Tijdschrift voor Traumatologie, Supplement, p.35, 1998]

XXXVII. E. Kaczvinszky, E. Kiss, E. Varga and Á. Vetró (poster) *Emotional Reactions following Road Traffic Accident in Children and Adolescents.* 3rd European Trauma Congress, Amsterdam, The Netherlands, [Abstract in the Poster Bulletin of the Congress, No. 66.]

XXXVIII. Varga E. Süveges G. Balogh Zs, Simonka J. A. *Acetabulumtörések kezelési startégiája klinikánkon.* Magyar Traumatológus Társaság 1998.évi vándorgyûlése, Kecskemét, Hungary, [Abstract in Magyar Traumatológia, Ortopédia, Kézsebészet, Plasztikai Sebészet Supplement p. 37-38.1998.]

XXXIX. E. Varga (1998) *Anatomical, Biomechanical and Clinical Considerations for Screw Fixation of the Sacrum.* 17. Steirisch-Slovenische Unfall- und 14. Grenzlandtagung, Bled, Slovenia

XL. E. Varga (1998) *Minimal Invasive Techniques in Pelvic Surgery.* International AO Pelvic Course, Ljubljana, Slovenia

XLI. E. Kaczvinszky, E. Kiss, E. Varga and Á. Vetró (1998) (poster) *Emotional Reactions following Road Traffic Accident in Children and Adolescents.* 14th International Congress of the International Association for Child and Adolescent Psychiatry and Allied Professions, Stockholm, Sweden, [Abstract in the IACAPAP Bulletin, p 412.]

XLII. E. Varga, J.T. Gorczyca, P. Hasenfrancz, K. Váradi (1998) *Comparison of strengths of different types of iliosacral screws using finite element models.* Surgery of the Pelvis and Acetabulum. The 4th International Consensus, Birmingham, Alabama, USA, [Abstract in Congress Book, 1998]

XLIII. E. Varga, J.T. Gorczyca (1998) *Pelvic Fracture Related Hemorrhage. Should they be Immediately, Definitively Fixed?* Surgery of the Pelvis and Acetabulum. The 4th International Consensus, Birmingham, Alabama, USA, [Abstract in Congress Book, 1998]

XLIV. E. Varga, Zs. Balogh, , J.T. Gorczyca (1999) *Pelvic Fracture Related Hemorrhage. Should they be Immediately, Definitively Fixed?* 21st World Congress of Société Internationale de Chirurgie Orthopédique et de Traumatologie (SICOT), Sydney, Australia, [Abstract in Congress Book, 1999. p. 342]

SCIENTIFIC WORKS BASED UNDER MY SUPERVISION IN PELVIC FIELD:

Medencerögzítõcsavarok végeselemes szilárdsági vizsgálata
Thesis of Péter Hasenfrancz graduate engineer. *(1996) [BME]*

A medencegyûrû sérültek komplex fiziotherapiája az utóvizsgálati adatok alapján
Thesis of Timea Czifrák, physiotherapist student. (1997) [SZOTE]

Medencecsont végeselemes biomechanikai elemzése és a sérülés rögzítésének modellezése
Thesis of Péter Hasenfrancz, graduate engineer. (1997) [BME]

Trochanter szeg 3D végeselemes statikus szilárdsági vizsgálata
Thesis of Péter Hasenfrancz, graduate engineer. [1998] [BME]

A dinamikus pedobarographia alkalmazása iliosacralis csavarozással kezelt medencetöröttek utánkövetésében
Thesis of László Itzédy, graduate medical student (1998) [SZOTE]

Ender szeg és trochanter szeg összehasonlító végeselemes szilárdsági vizsgálata különbözõ terhelések hatásásra
Thesis of László Kónya, graduate engineer. (l998) [BME]

PATENT:

10 mm cannulated iliosacral bone screw with washer (implants and instruments) pat. Registered No. 77-6/96.

MEMBERSHIP:

International:
Member of the Association of Sunnybrook Fellows (Canada)
Member of AO almunii
Enrolled member of the European Association of Trauma and Emergency Surgery.
National:
Magyar Traumatológus Társaság (Hungarian Trauma Association)
Magyar Kézsebész Társaság (Hungarian Association of Hand Surgery)
Magyar Traumatológus Társaság Gyermektraumatológiai Szekciója (Section of Child Trauma Surgery of Hungarian Trauma Association)
Magyar Arthroscopos Társaság (Hungarian Association of Arthroscopy)
Dél-Magyarországi Trauma, ortopéd, kéz és Reconstructiv Sebészeti Szekció Vezetóségi Tag (Board member of the South-Hungarian Trauma-, Orthopedic-, Hand- and Reconstruction Surgery)

Co-editors' consultant at the scientific journal;
"***The European Journal of Emergency Surgery and Intensive Care***"
Under the basis of the scientific work

COURSES AND WORKSHOPS IN PELVIC RELATED SURGERY:

1998. SURGERY OF THE PELVIS AND ACETABULUM. THE FOURTH INTERNATIONAL CONSENSUS.
Pelvic fixation and cadaver dissection workshop. [48 AMA Category 1, Credit Hours]
Birmingham, Alabama, USA. {Program director: George Alonso, University of Alabama}

1998. AO Pelvic Course in Slovenia
Pelvic fixation workshop. [Invited lecturer], Ljubljana, Slovenia
{Program director: Martin Tonin, Matej Cimerman, University of Ljubljana)

1995. AO Basis Course
Osteosynthesis Techniques in Trauma Surgery. Halle, Germany
(Program director: Wieland Otto, Martin Luther University)

1994. Surgery of the Pelvis and Acetabulum. the second international consensus.
[invited moderator] Pelvic fixation and cadaver dissection workshop. [46.5 AMA Category 1 Credit Hours]
Pittsburgh, PA., USA (program director: Dana C. Mears)

1994. The seventh Toronto Pelvic and Acetabular Management course. Pelvic fixation and cadaver dissection workshop. Toronto, Canada. (program director: Marvin Tile, University of Toronto)

Awards:
1995. AO/ASIF Fellowship (Swiss grant), for three months, in Carolinas Medical Center, Charlotte, (NC) USA, under the leadership of James *F. Kellam*

1993. AO North America Research Grant for the project entitled:
"*Biomechanics of Symphyseal Fixation and Unstable Open Book Pelvic Ring Injuries*"

1992. Postgraduate grant from The George Soros Foundation, USA for nine months, spent at Sunnybrook Health Science Center under the leadership of *Marvin Tile*, University of Toronto, Toronto, Canada.

II. Introduction

The pelvic girdle is a special region of the human body. It is closely associated with our greatest abilities and disabilities, with our greatest romances and tragedies, our greatest pleasures and pains.

High-speed accidents involving automobiles and two-wheeled vehicles with resultant entrapment and crushing injuries have led to an *ever-increasing incidence of pelvic fracture within the realm of trauma.* Despite the fact that, car manufacturers build a lot of safety features (seatbelts, air-bags, side reinforcements) into the new cars to prevent serious injuries to the human body, certain types of injuries are occurring with increased relative frequency. In the past two decades, traumatic disruption of the pelvic girdle has become a major focus of orthopedic-trauma surgeons' interest, as has the care of polytraumatized patients. These injuries form part of the spectrum of polytrauma and must be considered a potentially lethal injury with mortality rates of 10%-20%. On one hand the provisory stabilization of the unstable pelvic ring in the acute resuscitation of multiply injured patients is now conventional wisdom. On the other hand, the literature on pelvic trauma is mostly concerned with life-threatening problems and pays scant attention to the late musculoskeletal problems.

In order to better understand of the classification of pelvic injuries and rationale of management extensive knowledge of pelvic biomechanics is essential. An accurate analysis of pelvic anatomy is necessary for the understanding of functional investigation. The biomechanical functions must be known for all the particular elements. The reserve capacity of the symphysis and the sacroiliac joints against some typical kinds of forces that commonly occur during motor vehicle accidents must be known, firstly in normal pelves.

Improved data acquisition prior to surgery allows improved surgical procedures. New types of operations and new surgical materials are preferred when we know their functional benefits as well. In this way, we believe it will be advantageous to accurately determine the effects of motor vehicle accidents on the normal pelvis.

II. /1. Anatomical patterns

The three osseous parts of the human pelvis form a continuous structure, because of the symphysis and both iliosacral joints that, owing to their mobility, enable shock absorption of the vertical forces. The pelvis is a ring structure and if the ring is broken in one area and the fragments displaced, then this can lead to a fracture or dislocation in another portion of the ring.

The stability of the pelvic ring depends upon the integrity of the posterior weight-bearing sacroiliac complex, with the major sacroiliac, sacrotuberous and sacrospinous ligaments. The extremely strong posterior sacroiliac ligaments maintain the normal position of the sacrum in the pelvic ring, and the entire complex has the appearance of a suspension bridge. The sacrospinous ligaments join the lateral edge of the sacrum to the ischial spine and resists external rotation of the hemipelvis, whereas the sacrotuberous ligament resists both rotational and shearing forces in the vertical plane. [4,78,79,80.]

II. /2. Understanding the injury

The major forces acting upon a hemipelvis are, external rotation, internal rotation (compression from the lateral side) and vertical shear. In some complex high-energy injuries, the forces may defy detailed description. External rotation is caused by a direct blow on the posterior iliac spines or more commonly by forced external rotation of the legs, which produces an open book type of injury. This is characterized by disruption of the symphysis pubis and, as the force continues by rupture of the anterior sacroiliac and sacrospinous ligaments. The end point is reached when the posterior ilium abuts against the sacrum, but if the force continues the hemipelvis may be sheared off, resulting in gross instability. [57,68.]

II. /3. Historical review

Holdsworth in 1948 reported that 15 of 27 patients with a sacroiliac dislocation were unable to return to their regular work because of continuing disability; but 23 patients with sacral or iliac fractures had more satisfactory results. [35.] In 1958, Pennal studied 359 cases and reported to the Canadian Orthopaedic Association that patients with unstable vertical shear injuries had many late complications including nonunion. [68.] Slätis and Huittinen (1972) [72.] and Monahan and Taylor (1974) [51.] also found a significant percentage of late musculoskeletal problems in patients after unstable pelvic injuries. Tile et al. in 1982 reviewed 248 patients with pelvic ring disruptions. [79.] Tscherne and Pohlemann reported on 1254 patients whose complete files were available for clinical and radiological evaluation of fracture distribution, classification (Tile's classification and anatomical location) and concomitant injuries. A significant increase in the severity of trauma, the severity of the pelvic fracture and the rate of internal stabilization were observed at the Department of Traumatology at the Hannover Medical School during the observation period (between 1972 and 1990). [84.] This experience has now led to standardized procedures for the different fracture locations, with the task of minimizing soft tissue trauma and reducing the implant size. Adapted small fragment implants ("local osteosynthesis") can be applied. [56,58.]

The classification of pelvic fractures (Tile A, B, and C) has been widely accepted in professional circles. Most trauma surgeons agree on the necessity of operative management in most "B" and "C" type cases. However, there are a numerous differences in the choice of surgical methods and implants.

Double plating of the symphysis has been shown to significantly improve sacroiliac stability in combined anterior and posterior fixation of vertically unstable pelves [33.]. Particularly in adolescents, it may be beneficial to preserve the normal joint's shock absorptive functions, in order to avert late complications in other joints [85.]. Stuart et al., Dolati et al. [16,17,75.] recommended the stabilization of the symphysis with tension band wiring (two cancellous bone screws and wire loops), for the preservation of the physiologic elasticity of the pelvic ring. Decker et al. [12.] , Zimmermann et al.[91.], and Ecke et al. [18.] have offered some types of operations with absorbable suture materials. Hoffmann has shown that the stabilization of the pelvic joints with absorbable suture materials has nearly as good results as rigid fixation.

In the future, minimal invasive osteosynthesis, with appropriate mechanical stability for bone healing while providing the conditions for biological tissue healing as well, may provide the key to the biomechanical basis for the management of this complex injury.

II. /4. Scientific Aims:

Working as a practising trauma surgeon, my scientific aim was to better understand the human pelvic biomechanics. The practical, theoretical and technological knowledge gained will help all authentic surgeons in deciding on new approaches and techniques, as well as computer modelling the introduction of new implants and fixation materials, which are also among our responsibilities. [15,23,39,90.]

For these reasons cadaver tests, finite element analysis (FEA) and clinical investigations were performed. The response of pelvic joints, pelvic ligaments and pelvic bones were tested in cadaver pelves. Commonly used different anterior and posterior pelvic fixation methods were also compared in cadavers. Pelvic girdle responses during different loading and accident situations were studied with the help of FEA. Under the basis of the previously mentioned data and clinical experience, new implants were designed for the better stabilisation of the pelvic ring. The new implants were compared with other implants using material testing machine and FEA analysis. Following the biomechanical tests, clinical trials of the new implants followed. As the new implants proved successful for immediate fixation, the polytrauma management could be changed in the pelvic fracture related haemorrhage cases as well.

III. Cadaver Experimental Studies

III. /1. General

III. 1.1. Aims:

Human cadaver study, with the help of MTS (Material Testing Machine) is the basis of biomechanical investigation. To create an accurate 3D human pelvic anatomical model, one crucial part of the project is to know the pelvic biomechanics in details. Understanding the biomechanical properties of the uninjured pelvic joints, as pubic symphysis (PS) and sacroiliac joints (SI) are also fundamental. Determining the material properties of the normal cortical, spongious bones and pelvic ligaments are essential as well. Correct experimental set-up had to be work out for the modelling of the motion of the pelvic ring during cyclical loading of the two normal basis pose as the bilateral and unilateral stance.

III. /2. Material and methods

III. /2.1. Bilateral stance setup

Eight unembalmed pelves, showing no gross evidence of bone and soft tissue pathology, were harvested from cadavers. The mean age was 75.4 years (61-85) and there were six males and two females. After removal of other soft tissues, the ligaments and the joint capsules were left intact. All specimens were stored sealed at -20^0 Celsius. Prior to biomechanical testing, the specimens were thawed 16-20 hours in water at room temperature. Care was taken to keep the test specimens moist prior to and during the experimental testing. The pelves were tested in a position simulating bilateral stance, with the antero-superior iliac spines and the pubic tubercles aligned in a vertical coronal plane. (fig.1.) Each pelvis was mounted in the load train of a servo-hydraulic materials testing machine (MTS Bionix 858) and loaded through a ball freely articulating with a hemispherical adjustable aluminum fixture, anchored at 45^0 onto the proximal surface of the sacrum with 4 axial and 1 sagittal 6.5 mm

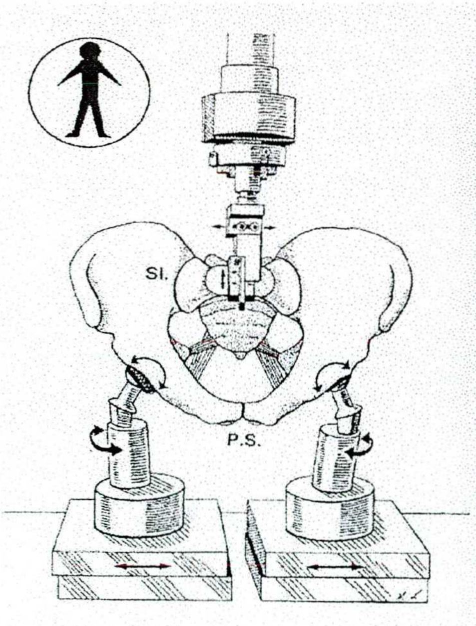


Figure 1.
Bilateral stance setup

cancellous bone screws. Distally, both acetabuli articulated with bipolar cephalic hip prostheses (with appropriate head sizes), completing the double leg stance. The modular stems were potted in Cerrobend (low melting point bismuth alloy) in order to allow rotation of each pot without changing the position of the center of rotation of the hip. The pots were placed in recessed ball bearing slide-plates, which prevented antero-posterior motion while allowing independent, very low friction motion of the hip stems in the coronal plane, to minimize extrinsic stability erroneous addition to the mounted pelvis.

III. /1.2.2. Unilateral stance setup

In the preliminary part of each experimental trial, bone deformation in the intact pelvis was determined. The pelves were tested in a position simulating unilateral (one leg) stance, with the antero-superior iliac spines and the pubic tubercles aligned in a vertical coronal plane. [4.] (fig.2.) They were mounted in the load train of servo-hydraulic materials testing machine (MTS Bionix 858) and loaded through a wheel freely articulating with a grooved aluminium adjustable fixture, allowing free rolling in the medio-lateral direction. The aluminium fixture was implanted onto the proximal surface of the sacrum with four axial and one sagittal cancellous bone screws. The upper and lower surfaces were inclined at 45^0 in the antero-posterior direction, so that the top was approximately horizontal. Distally, the supporting acetabulum was articulated with a bipolar cephalic hip prosthesis (with appropriate head size). The modular stem was potted in low melting point bismuth alloy (Cerrobend) with the head centred so that rotation of the pot would not change the position of the centre of rotation of the hip. This pot was fixed to the base-plate of the MTS. One loop-end of a plastic coated steel cable was fixed with the help of a 3.5-mm reconstruction plate contoured to the inner surface of the iliac wing on the supported side of the pelvis, to simulate abductor forces. The cable was guided through the iliac crest and through a pulley and anchored to the base plate with the help of an

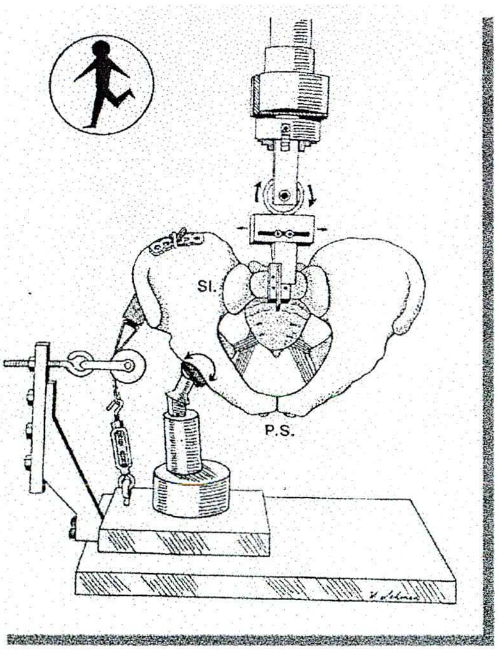


Figure 2.
Unilsteral stance setup

adjustable turnbuckle. This set-up allowed simulation of one leg stance with the supporting hip stabilised by the abductor cable. The application of vertical load downwards through the sacrum resulted in bending loads through the posterior ilium. Cyclic loading was applied in each test at a frequency of 1 Hz until stable hysteresis was observed.

III. /2. Pelvic joints:

III. /2.1. Aims:

To determinate the displacement changes in the PS (pubic symphysis) and in the SI (sacroiliac) joints simultaneously during the bilateral and unilateral stressing of the pelvic ring. The overall axial stiffness of the pelvic ring could be determined from the force and displacement data from the MTS load-cell and actuator, respectively.

III. /2.2. Material and methods:

Motion of the symphysis was measured in two places. One high resolution displacement transducer (LVDT - Linear Variable Differential Transformer RDP/GTX500) measured the displacement of the pubic symphysis in the plane of the anterior surface of the pubic symphysis in a horizontal line 1 cm superior to the superior part of the symphyseal joint (LVDT1). The second LVDT measured the displacement of the pubic symphysis (PS) in the plane of its anterior surface and in a horizontal line 1 cm below the inferior part of the symphyseal joint (LVDT2), (fig.3.)

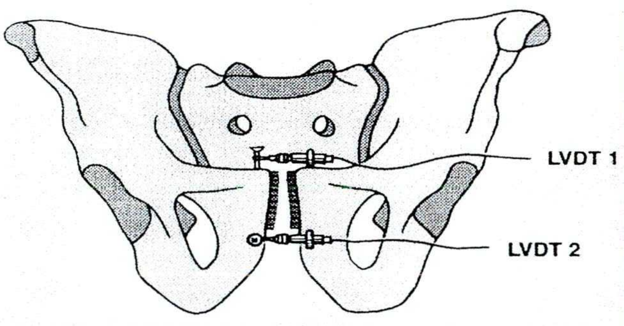


Figure 3.
Location of displacement tranducers
in the anterior pelvic region

Two other LVDT's were located to record the motion of the posterior complex of the pelvic ring. One of them (LVDT3) was placed in a coronal plane and in a horizontal line 1 cm above the level of the superior part of the sacroiliac (SI) joint. Earlier investigations showed that interfragmentary sacroiliac displacements were the largest in magnitude in the medio-lateral axis and also showed the most sensitivity in detecting mechanical differences between fixations [69.] The other transducer (LVDT4) was aligned midway between the sacrotuberous (ST) and sacrospinous (SS) ligaments in the plane of these ligaments, so as to monitor the

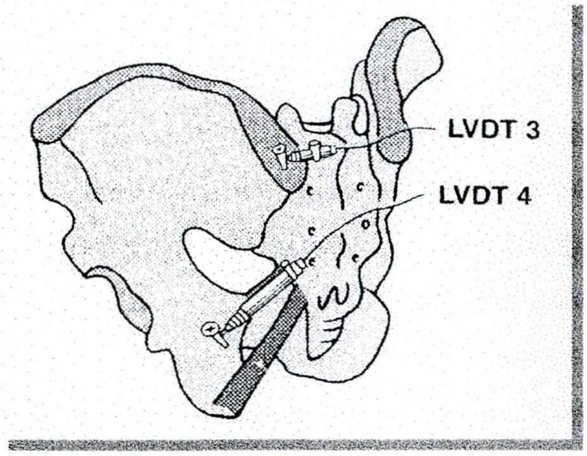


Figure 4.
Location of displacement transducers in the posterior pelvic region

displacement of the sacrum relative to the innominate bone. (fig.4.) All of the LVDT's were fixed with the aid of clamps obtained from various types of external fixateurs. The clamps and the target devices were anchored to the bone with the help of Schanz screws.

Motion of the superior and inferior pubic symphysis and at two levels of the posterior sacroiliac complex, was measured using high-resolution displacement transducers. Each pelvis was tested, recording displacements in response to a cyclic axial load up to a maximum 500 N applied through the proximal sacrum. Digital signal recording was accomplished with a Data Translation 2801-A A/D board interfaced with a Dell 386 SX microcomputer system via Global Lab data acquisition software. Prior to data collection the pelves were preconditioned by cyclically loading by 1 Hz up to a maximum of 250-300 Newtons until stable hysteresis. Failure levels were avoided to allow repeated measures with a sequence of internal fixations. Data collection was carried out during continued cyclic loading, with a sampling rate of 100 Hz for 5 seconds and digitally stored for subsequent analysis.

III. /2.3. Results:

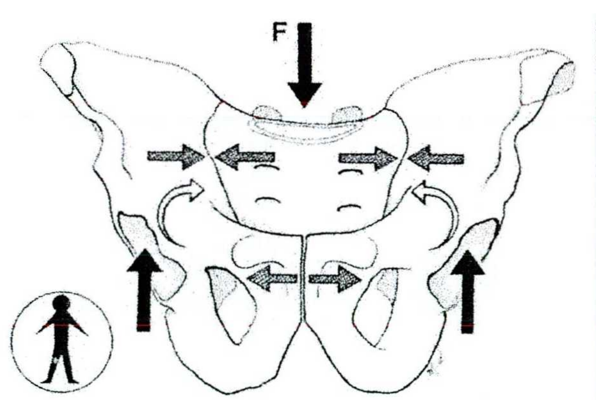


Figure 5.
Motion in the pelvic ring in response to simulated bilateral stance

Compressive displacements were generally observed at the level of the superior PS (LVDT1) and at the superior parts of the SI joints (LVDT3) when the intact pelves were loaded in bilateral stance. (fig.5.) Simultaneously, net tensile displacements were apparent at the inferior part of the PS (LVDT2) and between the sacrum and the innominate bone (LVDT4). The magnitude of the compression and tension oscillated, corresponding to the cyclic loading. Motion in the pelvic ring in response to simulated bilateral stance: the sacroiliac joints are primarily compressed; the pubic symphysis is in net tension; moments are applied to the innominate bones in the directions indicated by the curved arrows.

The displacements of the PS ant the posterior pelvic ring in unilateral stance have also been measured. In unilateral stance the symphysis is compressed and vertically sheared, while supporting sacroiliac joint sustains shear and bending with the superior surface under tension. (fig.6.)

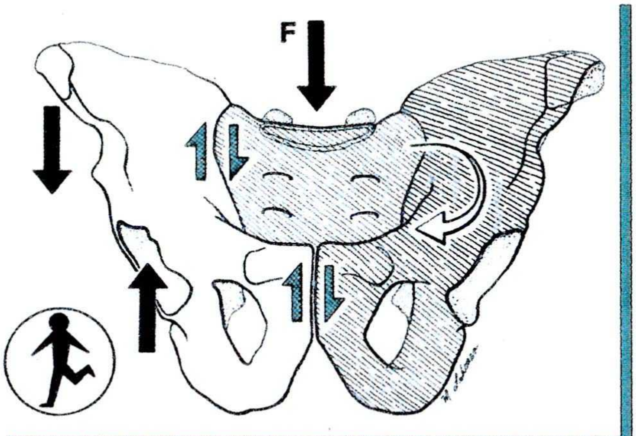


Figure 6.
Motion in the pelvic ring in response to simulated unilateral stance

Care was taken to ensure that the method of restraint did not affect the measure of stability.

The difference in motion of PS joint was measured during erroneously fixed femoral stems as well. The difference in PS displacement between "vise type" setup and physiological bilateral loading allows us to conclude the degrees of freedom of the PS joint in mediolateral direction. (fig.7.)

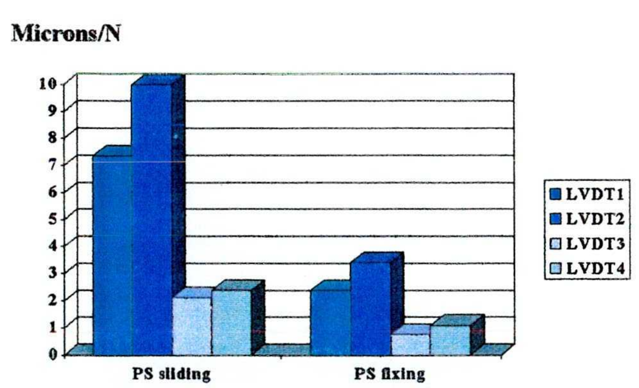


Figure 7.
“Vise type” loading

III. /3. Pelvic ligaments

III. /3.1. Aims:

The basic purpose of this study was to provide more precise guidelines for better understanding detailed patient management with injuries to the posterior pelvic region involving sacrospinous (SS) and sacrotuberous (ST) ligaments. The SS and ST ligaments of the pelvic ring are known as mechanical stabilizers of the pelvic girdle, mainly against rotational forces in the sagittal and horizontal planes. (fig.8.) The aim of this study was to determine whether these ligaments are strictly for mechanical stability or if they have any additional functional properties, i.e. proprioceptive role.

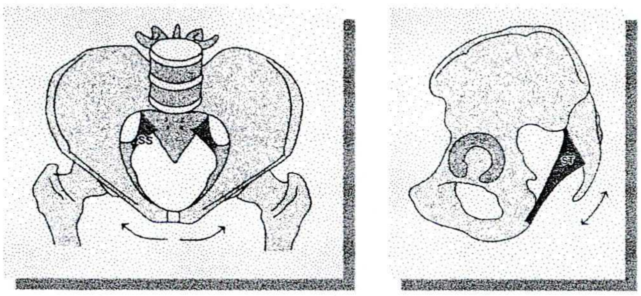


Figure 8.
The mechanical role
of the SS & ST ligaments

III. /3.2. Materials and methods:

III. /3.2.1. Biomechanical tests:

Eight cadaver pelves (mean age 75.4 years [range 61-85] six males and two females) with intact sacrotuberous (ST) and sacrospinous (SS) ligaments were trialed using MTS servo-hydraulic material testing machine as previously described (fig.1.), [85.] The displacement of the pubic symphysis and the sacroiliac joints were measured in four different places with high-resolution transducers during cyclical bilateral loading (fig.3-4). Care was taken to ensure that no extrinsic stability was erroneously given to the mounted pelvis. The displacements of the joints were tested in pelves with both intact and gradually sectioned ligaments. Three groups of tested pelves were created, intact, one ligament (SS or ST) cut and both ligaments cut. The average axial stiffness of the pelvic ring was calculated from the applied force.

III. /3.2.2. Histology:

In order to demonstrate the assumed proprioceptive role of SS/ST ligaments we tried to find the morphological basis for this function through histological examination. In the present study eight young, fresh cadavers (less than 24 hours post mortem) were dissected from both sexes. The SS/ST ligaments were removed from both sides of pelvis with small pieces of bone attachments. Following one-day fixation in 4 % buffered formaldehyde solution, the ligaments were divided into three parts proximal, middle and distal ones. Each of the parts of the ligaments was sliced into longitudinal planes. Both, frozen sections in 30 µm and paraffin sections in 15 µm were obtained and impregnated according to the method of Sevier-Munger neurofibrillum impregnation (modified Bielschowsky silver impregnation) [7.]. To control the course of nerve elements, every 20th (twentieth) slide was stained by cresyl-violet staining as well. After histological preparation, the slides were analyzed under oil immersion with a magnification of 1000 (times).

III. 3.3. Results:

Compared displacements of the pelvic joints did not show any significant differences at the four measuring places. (fig.9.)

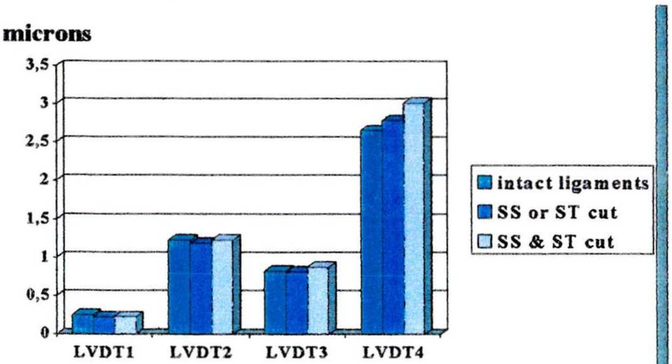


Figure 9.
Comparison of mean pelvic displacement in intact pelvis and one ligament (SS or ST) and both ligaments sectioned pelvis in bilateral stance

The average axial stiffness of the both ligaments sectioned pelvis group was 94.8 % compared to the intact ones. (fig.10.)

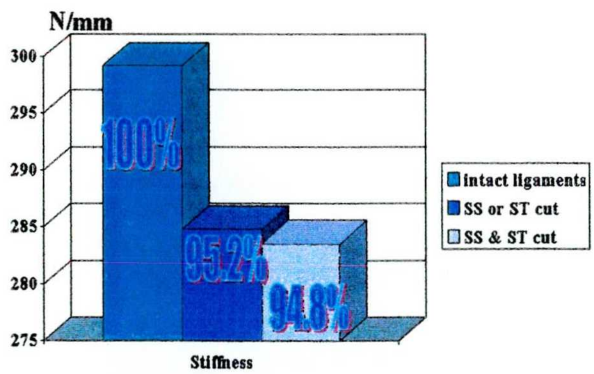


Figure 10.
Comparison of mean pelvic ring stiffness of the intact pelvis and following section of one or two ligaments in bilateral stance

Testing to failure of the sacrotuberous and sacrospinous ligaments was performed and showed only 80 Newton's (on average) mechanical resistance to failure.

Histological examination revealed several nerve fibers running parallel to the collagen bundles. (fig.10)

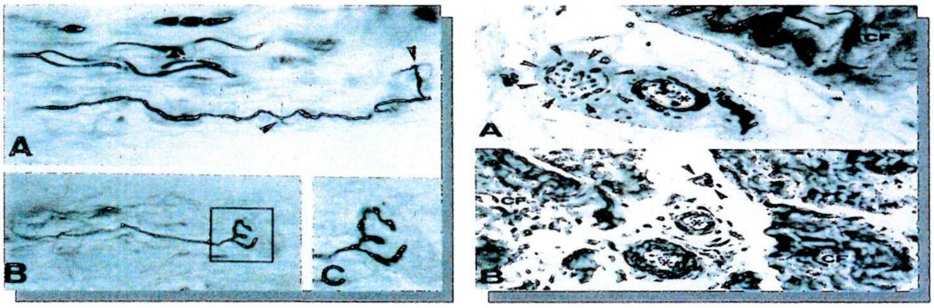


Figure 10.
Arborised nerve elements of the SS ligament [left] (A,B). Cresyl-violet staining demonstrating cross section of nerve elements (arrows) inside the SS ligament (CF: collagen fibers, 1000x magnification[right].

III. /4. Pelvic bones

The original paper entitled, "Biomechanical Analysis of Hemipelvic Deformation After Corticospongious Bone Graft Harvest From the Posterior Iliac Crest" (authors: Endre Varga, MD, Richard Hu, MD, FRSC(C), Trevor C. Hearn PhD, Terry Woodside, BSc, and Jian-Ping Yang, MD has enclosed. [SPINE]

III. 4.1. Aims:

The primary goal of this study is to compare bone strain in the remaining posterior pelvic ring after harvesting of different sizes of cortico-spongious bone, with strain in the intact cadaver pelvis. In addition, we aim to determine, by strength testing in a laboratory model of unilateral stance, the mode of failure of the osteotomized pelvis.

III. 4.2. Materials and Methods:

Unembalmed hemi-pelves (one innominate bone and the sacrum), showing no gross evidence of bone and soft tissue pathology, were harvested from cadavers. After removal of soft tissues, the sacroiliac ligaments were left intact. All specimens were stored sealed at -20^0 Celsius. Prior to biomechanical testing, the specimens were thawed in water 16-20 hours at room temperature and were kept moist before and during the experiments.

The distance from the cross-point of the gluteal crest and the iliac crest to the highest level of the sciatic notch was determined in each specimen. A 2 mm electrical resistance strain gage

(SHOWA Measuring Instrument Co.,Ltd.) was glued to the bone surface of the superior part of the greater sciatic notch, aligned in the plane of the long arch. The lead wires were connected to a strain amplifier (Measurements Group 2100) and the output fed to an A/D converter, (Data Translation 2801-A) controlled with a microcomputer along with the MTS axial force output and actuator displacement.

In the preliminary part of each experimental trial, bone strain in the intact hemi-pelvis was determined. The pelves were tested in a position simulating unilateral (one leg) stance, with the anterior-superior iliac spines and the pubic tubercles aligned in a vertical coronal plane as we described in the general part of cadaver studies. (fig.2.)

The intact pelves were tested prior to the sequential bone harvest. Four or five (depending on the size of the pelvis) rectangles were marked on the outer table of the posterior iliac crest. The shorter sides of the rectangles were 15 mm long and they were aligned as perpendicular as possible to the ridge of the iliac crest. The superior-longer side of the first rectangle was from a point 1.5 cm anterior to the gluteal crest, to a point 1.5-cm posterior to the gluteal crest, as schematically shown. (fig.12.) The bone grafts were removed by using a micro-oscillating saw to make the vertical and horizontal cuts. An osteotome was used to cut the cancellous bone along the plane of the inner surface of the iliac wing. Care was taken to prevent the vertical cuts from extending deeper than the planned fifteen millimeters. In this way, 15x30x15 mm rectangular-sided bone grafts were sequentially removed. The inner cortex of the iliac wing was left intact.

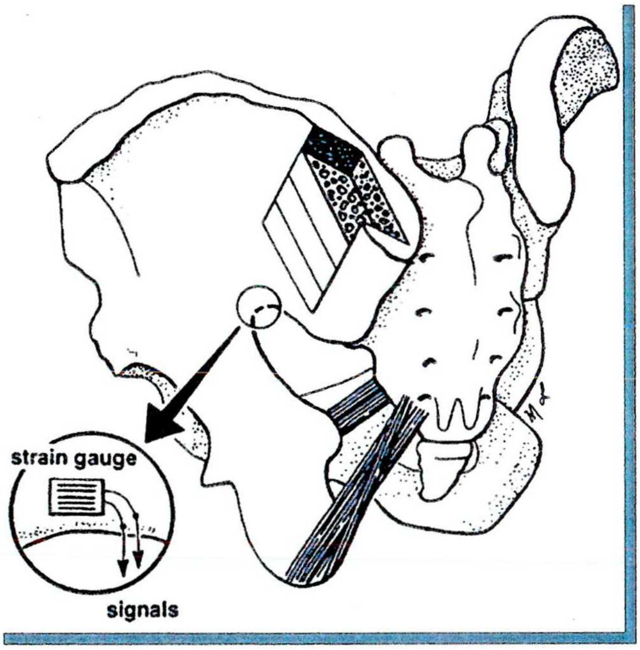


Figure 12.
Four 15x30-mm rectangles marked on the exterior surface of the posterior ilium. The first graft has been removed to a depth of 15 mm. The strain-gauge location is also shown.

Following the last cyclic analysis of the mounted pelvis, increasing loads were applied until failure. The result of fracture pattern, as well as the location of the fracture and the position of the fracture line in relation to the SI joint was noted.

III. /4.3. Results:

After testing to failure, the fracture line usually started from the corner of the removed rectangular graft closest to the sciatic notch. This corner was not only the closest to the sciatic notch, but it was the closest to the sacroiliac joint as well. Under the assumption that for each pelvis, the bone is loaded within its linear elastic range, with a modulus of elasticity that does not change during the tests, the changes in stress are proportional to the changes in strain. Thus the ratio of strain measured in the direction of the gauge element following graft removal, relative to the strain in the intact pelvis, reflects increased bone stress at the location of the strain gauge. Graphs showing bone stress versus amount of graft removed is shown in fig.13.

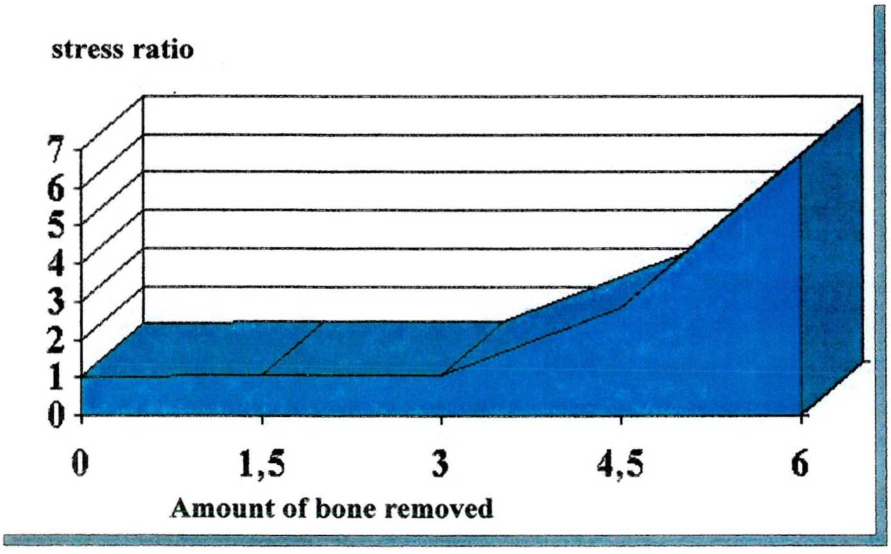


Figure 13.
The effect of total bone graft length removed on mean bone stress relative to intact bone values.

III. /5. Comparison of different fixation methods of the injured pelvis

III. /5.1. ANTERIOR FIXATIONS

Original paper entitled, *Effects of Method of Internal Fixation of Symphyseal Disruptions on Stability of the Pelvic Ring.* (**E. Varga,** T. Hearn, J. Powell, M. Tile, INJURY Vol.26, No.2.,pp.75-80, 1995.) was enclosed.

III. /5.1.1. Aims

The purpose of the study was to quantify the biomechanical effects of three different methods of symphyseal fixation on the mechanics of the symphyseal disruption, and their secondary effects on sacroiliac stability. The fixations tested were (1) double plating (4.5 mm reconstruction plates) (2) wire loops around two 6.5 mm fully threaded cancellous screws and (3) an absorbable suture material (polydioxanone, PDS). Different fixation methods of symphyseal rupture were also compared to the biomechanics of an intact pelvis.

III. /5.1.2. Material and methods

Experimental set-up was assembled as previously described in chapter III. /1.2.1. (Fig. 1.)

Simulation of a C-type pelvic ring injury:

After the intact loading the symphysis pubis was cut and cortical bone of the sacrum was sawn in three places, to a depth of approximately 1-cm. An axial loading in three-point bend was applied until failure. This produced a Denis type-I sacral fracture and a Tile classification Type-C.1.3.1. injury was simulated in all pelves.

Fixation techniques:

All of the sacral fractures of the eight pelves were stabilised by two 7-mm diameter, 32 mm threaded, cannulated cancellous bone screws. All lag screws were inserted into the body of the first and the second sacral vertebral body, to attain maximal interfragmental compression [43.] Each separated symphysis was stabilised in three ways:

(1) The PS was internally fixed with two plates. Preliminary work in this study showed regardless of the posterior fixation, two symphyseal plates resulted in less displacement in the joints than one alone in accordance with the earlier study of Schopfer et al. [69.] One 4-hole 4.5-mm reconstruction plate with fully threaded 6.5-mm diameter cancellous screws was fixed on the superior surface of the PS and a 2-hole 4.5-mm reconstruction plate with appropriate cortical screws was placed anteriorly. The two plates were placed 90^0 to each other [80.]

(2) The PS was internally fixed with wire loops: 1.2 mm stainless steel tension band wire and 6.5 mm fully threaded cancellous screws were used. Preliminary investigation on intact pelves confirmed anatomical studies [29.], indicated that the largest tensile forces in the symphysis region are in the inferior part. The greatest stability could therefore be attained if more loops were applied as inferiorly as possible. Four wire loops were used in this study.

(3) The PS was internally fixed with absorbable suture material: PDS II (Polydioxanone) Synthetic absorbable sutures were prepared from the polyester [polydioxanone], two mm diameter, 60 cm long, with two transosseous guide wires (ETHICON GmbH & Co.KG, Norderstedt). Two fully threaded 6.5-mm cancellous screws were also used for the anchorage of the suture and the absorbable cords were guided through six transosseous holes.

III. /5.1.3. Results:

Displacements of the PS in the intact pelvis and following wire fixation were not significantly different. (fig.14.) There was significantly more symphyseal motion following double plating or PDS suture fixation in comparison with the intact joint (both $F>9.0$, both $p<0.02$). No significant differences in symphyseal displacements were found following double plating or PDS suture fixation. In the region of the superior PS *(LVDT1)* and the inferior PS *(LVDT2)*, the wires were significantly more stable than either plates or the PDS suture (both $F>10$, both $p< 0.02$). Using plates resulted in better stability than the PDS cords in the superior PS region, but in the inferior PS, the motion was less when using PDS cords rather than using plates. However, these differences between the plates and the PDS suture were not statistically significant. In the superior SI region *(LVDT3)*, all methods allowed similar amounts of motion, greater than in the intact pelvis. This difference was statistically significant only following fixation with the PDS suture ($F=8.14$, $P=0.025$). The displacements in the region of the SS\ST ligaments *(LVDT4)* were greater following fixation in comparison with the intact pelvis, but not significantly greater for any method. The motion was significantly less when the symphysis was wired, in comparison with the PDS suture ($F=6.58$, $p=0.037$). There was no significant difference between plates and wires or between plates and the PDS suture.

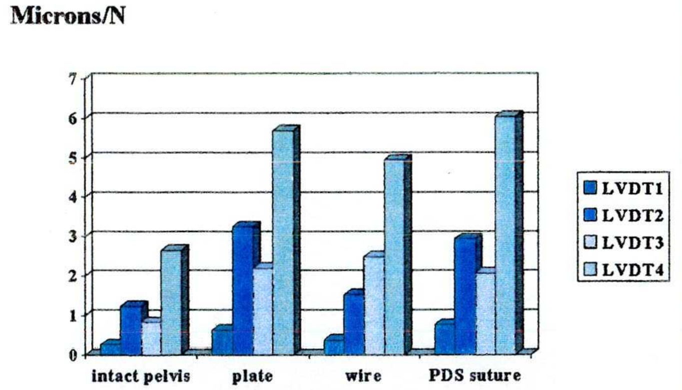


Figure 14.
Comparison of mean pelvic ring displacements in the intact pelvis and following fixation of the disrupted PS with three alternative methods in bilateral stance. n=8

For all of the fixation methods, the reconstructed pelves were lower in overall stiffness than the intact pelvic ring (all $F>8.0$, all $p<0.025$), (fig.15.). (Wiring resulted in significantly greater stiffness than the PDS suture ($F=6.27$, $p=0.04$). There was no significant difference in stiffness between double plating and wiring. There was no significant difference between plating and the PDS suture. *There were no significant differences between plating and the PDS cord fixation method in any of the four measuring places or in the stiffness.*

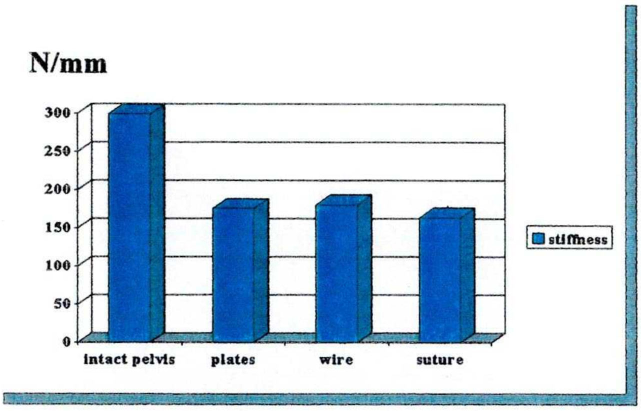


Figure 15.
Comparison of mean pelvic ring stiffness for the intact pelvis, and following fixation of the disrupted PS with three alternative methods in bilateral stance. n=8

III. /5.2. POSTERIOR FIXATIONS

The original paper entitled "*The Strength of the Iliosacral Lag Screws and Transiliac Bars in the Fixation of Vertically Unstable Pelvic Injuries with Sacral Fractures*" (J.T. Gorczyca, **E. Varga**, T. Woodside, T.C. Hearn, J. Powell, M. Tile, INJURY Vol.27, No.8, pp. 561-4, 1996) has enclosed.

III. /5.2.3. Aims:

To compare the relative strengths of iliosacral lag screws and transiliac bars in the fixation of vertically unstable pelvic injuries with sacral fractures. This study was performed to determine whether one of these fixation methods offers a mechanical advantage and to determine whether the biomechanical data obtained could help direct the postoperative course of patients with these injuries.

III. /5.2.2. Material and methods

Eight fresh frozen pelves were mounted in a MTS and vertical sacral fracture was created by vertically loaded the pelvis with the MTS machine until failure. After a vertically unstable pelvic injury had been created, pelves were stabilised anteriorly with a four-hole 3.5-mm reconstruction plate on the superior aspect of the pubis bodies and with a two-hole 3.5-mm reconstruction plate on the anterior aspect of the pubic bodies. Posterior fixation was achieved alternately with either two 6.5 mm iliosacral lag screws inserted from 1.5 cm anterior to the crista glutei into the first sacral vertebral body (fig.16.), or two 6.4 mm transiliac bars with nuts tightened over washers on the posterior ilium. (fig.17.)

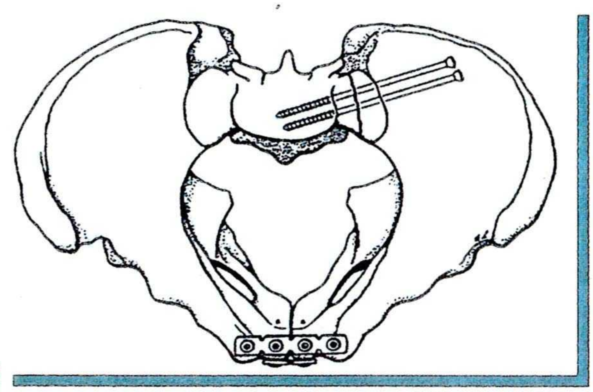


Figure 16.
Fixation with iliosacral lag screws

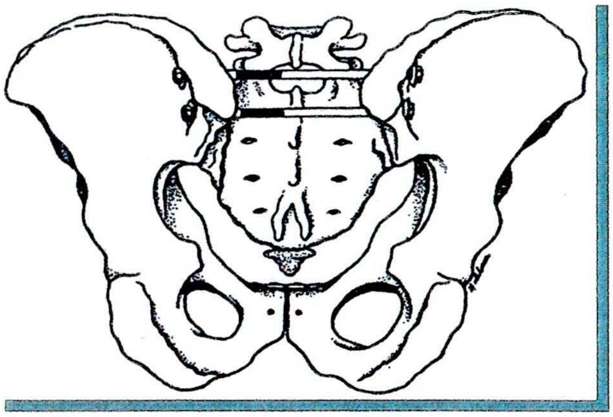


Figure 17.
Fixation with transiliac bars

After stable fixation of the injury the cadaver pelves were vertically loaded by the MTS until failure. The peak force and method of failure were recorded. After initial testing until failure by one fixation method, the posterior hardware was removed, the posterior pelvis was restabilized by the other fixation method the anterior fixation method was revised (if necessary) and testing was repeated.

III. /5.2.3. Results:

The mean strengths of initial lag screw fixation was 819 Newton's, whereas the mean strengths of initial transiliac bar fixation was 1066 Newton's (P=0.3), (fig.18.) The method of fixation failure varied. When lag screws were used to achieve posterior fixation, the vertical load caused the inferior lag screw to pull out as the anterior fixation failed. We were not able to determine whether fixation failure occurred first anteriorly or posteriorly. When the posterior fixation consisted of transiliac bars, the vertical load cased failure by two methods.

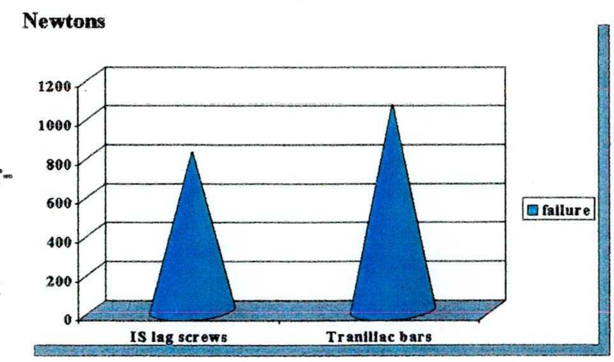


Figure 18.
Fixation strengths of
iliosacral lag screws & transiliac bars

In most cases, the sacrum rotated through the plane of the fracture. In one case, a fracture occurred trough the ilium around the transiliac bar washer.

III. /6. Discussion of cadaver experiments

The results of this study provided biomechanical guidelines for the further understanding of pelvic biomechanics and can assist in the choice of surgical method for restoring pelvic stability. However, biomechanical factors remain only one element in the management of unstable pelvic ring injuries and must be considered within the context of each particular clinical pattern. Our set-up has some specific limitations: only bilateral and unilateral stances were tested. Only one type of posterior ring injury was tested: the Denis type-I sacral fracture and not the pure SI dislocation or iliac fracture. As already reported by previous authors [6.], denuded pelves from elderly cadavers represent probably the worst case scenario, since they are deprived of soft tissue support and some degree of osteopaenia should be expected.

Joints

Within these limitations, the results of the study clearly show that separation of the intact symphysis joint during bilateral stance is not only a simple widening. Under this loading, the widest separation could be observed at the inferior part of the PS, while the superior part was generally compressed, with smaller observed displacements. Net separation of the symphysis was generally observed with distraction of the superior part in some instances. The alignment of the pelvis with respect to the plane of loading appeared to a major determinant of the symphyseal response.

Ligaments

After measuring the mechanical role of the pelvic ligaments, the strength of these ligaments was less than we hypothesized. According to these facts, other putative roles of SS/ST ligaments were theorized. The proprioceptive function of the anterior cruciate ligaments of the human knee joint is well known [26,32,42,50,53.]. Based on this evidence, we predicted that the pelvic ligaments would also have some similar function. Grob and his colleagues [30.], showed nerve elements around the sacroiliac joints which originated from the S1-S4 spinal roots .

Although several nerve fibers running parallel to the collagen bundles were found in SS/ST ligaments, these nerve elements could possibly be motor fibers. Myelinated axons could pierce the SS/ST ligaments to innervate the gluteus maximus, being inserted to the external surface of the ST ligament, and the levator ani originating on the inner surface of the SS ligament. To distinguish the motor and sensory fibers we attempted to find the sensory nerve ending, the putative proprioceptor itself.

The Ruffini and Golgi-organ-like structures are responsible for the detection of touch in ligaments. These structures are composed of ramifying unmyelinated axons ending in leaf-like plates and surrounded by a delicate capsule. As the capsule is lightly or not stained by silver impregnation, the proprioceptive receptors could be identified according to the arborized nerve elements. Analyzing the proximal, middle and distal parts of the SS/ST ligaments, we found more ramifying axons next to the tuberous end of the ST ligament and several Ruffini-like nerve endings next to the spinal end of the sacrospinous ligament. The arborized axons could be free nerve endings because of the absence of the leaf like platelets and having more nerve branches than in the putative proprioceptors.

Based on our biomechanical and histological findings a proprioceptive role of SS/ST ligaments seems plausible. Our results suggest that the role of the sacrospinous and sacro-tuberous ligamentes are not only mechanical, but physiological as well, possibly controlling muscle tone at the link of the human limb and trunk. These results clearly support the need for further and a more detailed investigation to fully reveal the role of the SS/ST ligaments and their proprioceptive function in the pelvis. Furthermore the innervation pattern of these ligaments may provide explanation for various patterns of pseudo-radicular and referred low back pain in patients with pelvic injury.

Bones

The use of autologous bone graft from the posterior iliac crest is a very common procedure in orthopaedic as well as spinal surgery [14.]. Regardless of the technical simplicity of the procedure and despite being only "secondary” to the main operation, it is not without complications. Neurological injuries [31.], vascular injuries [44.], violation of the sacroiliac joint [47,74.] as well as muscle and bowel herniation have been reported. "Stress" fractures of

the pelvis following bone harvest from the posterior iliac crest have also been reported by Conventry *[10.]* and Hu [36,37.]. Although this complication is able to heal with protection from weight bearing until there is total resolution of pain, its prevention is preferable.
The size of the removed bone graft is potentially a major determinant of the occurrence of iliac stress fractures. However, the optimal technique of bone graft harvest from the posterior iliac crest has not been determined. Current techniques are based primarily on practical clinical decision making.

The laboratory model allows constancy of test conditions, enabling the accurate determination of the relative effect of bone graft removal. Hemi-pelves were tested, so that the original ring stiffness was altered appropriately. In the model of single-stance loading we used, we could only approximate the complex dynamic balance of muscle, ligament and bone forces, which occurs in vivo. The results should therefore be expected to differ in absolute values, if comparison with physiological circumstances were possible.

Within these limitations, the biomechanical results clearly showed that bone harvesting from the posterior iliac crest is potentially dangerous, since it is able to reduce the stiffness of the posterior iliac region. In particular, if the length of the removed cortico-spongious bone graft exceeds 3.0 cm, the stiffness of the posterior pelvic ring is decreased substantially. On the basis of our observations of the fracture pattern and of the biomechanical data, bone graft removal beyond 3.0 cm from the posterior iliac wing is not desirable. If a greater cortico-spongious graft is required, it should be removed from a more anterior location, another bone donor site should be selected.

Anterior pelvic fixations

In-patients where the trauma or orthopaedic surgeon has the choice of different options of surgical treatment, attention should be paid to the mechanical aspects and the most advantageous reconstruction of the pelvic ring should be performed. [63,64,75,88.]. Avoidance of complications associated with prolonged bedrest and repeated surgical interventions together with restoration of the normal functions of the joints are important goals of surgical management [68.].

Our data indicate that increasing the stability of the inferior part of the PS results in increased stability of the superior part of the SI joint and reduced motion of the sacrum relative to the innominate bone. A modified form of the usual stainless-steel tension band wire and a completely new method of application of the PDS-cord absorbable suture material were developed as alternative methods, based on the observed symphyseal motion.

The modified wire fixation method could be proposed in elderly patients who show obvious signs of osteoporosis. The PDS-cord could be offered to children, adolescents and in young adults. Several authors claim that preserving the so-called "shock absorption" function of the joints of the pelvic ring is a very important goal. Our results demonstrate that none of the fixation methods applied are as rigid as the intact pelvic ring. The absorption of the PDS could be advantageous, if the repairing soft tissues gradually replace the mechanical function of the absorbable suture material. The other advantage of the PDS-cord is that it does not require removal, in contrast with plates and screws, as recommended Tscherne and Pohlemann [84.].

In summary, complex pelvic ring injuries require attention to stabilisation not only of the SI region, but in the PS joint nowadays as well. "Personalised" osteosynthesis [68.] should be performed, i.e. careful analysis of the fracture and its soft tissue components and thoughtful assessment of the patient's age, health and occupation together with a critical evaluation of the skill of the surgical team and environment are all necessary.[25.]. In this context, the incorporation of biomechanical data can provide further assistance towards the goal of optimal recovery.

The results indicate that in osteoporotic bone as used in this study, symphyseal wiring is best able to oppose the tensile loads in the inferior symphysis that are associated with bilateral stance loading. These biomechanical findings must be interpreted within the broader context of surgical management of these complex injuries [22,28.].

Posterior pelvic fixations

If operative stabilisation of the posterior pelvic injury is performed, a method that provides strong fixation with minimal soft tissue dissection is optimal. Transiliac bars have been effective in stabilising these injuries, but they require a large surgical dissection [13,89.]. The incidence of wound complications with posterior pelvic ring approaches can be as high as 25 per cent [40.]. Iliosacral lag screw fixation requires less posterior dissection than other fixation methods (anterior sacroiliac plate [41.], posterior 4.5mm reconstruction plate [1.], direct posterior small fragment plates [56.] and in some cases can be performed pecutaneously [13,65,66.]. The strength of iliosacral lag screws in resisting vertical load to the vertically unstable pelvis with sacral alar fracture has not been studied previously.

While transiliac bars appear to provide stronger fixation of these injuries, the data from this study do not show the differences in strengths to be statistically significant (p=0.3). We considered repeating the tests with more cadaveric pelves until a statistically significant result was reached. Using sample size calculations, however, we estimated that we would have to test a total of 38 similar pelves to show a statistically significant difference between the strengths of the transiliac bars and the iliosacral lag screws. Our impression was that the high variability of bone quality in cadaveric pelves results in a large standard deviation in strength of fixation. Thus, it is more difficult to prove that a small difference is statistically significant. The test results probably underestimate the fixation strengths that can be achieved in clinical practice. The average age of cadaveric pelves was 75 years (range 61-85). Thus, the bone quality would be weaker than one would expect in a younger injured popultion and these tests result probably underestimate the fixation strength that can be attained in clinical practice. We found no evidence that 6.5-mm iliosacral lag screws have a biomechanical advantage over transiliac bars in terms of strengths. In fact, our findings suggest that transiliac bars may be stronger. Although both fixation methods are strong enough to allow postoperative mobilisation, neither is strong enough to allow full weight bearing in the early postoperative period. Thus we recommend a bed to chair program for at least 6 weeks postoperatively.

IV. Finite Element Analysis

IV. /1. General

IV. /1.1. Aims:

All of the above mentioned biomechanical tests required a huge amount of cadaver pelves, a lot of very expensive equipment and certainly a great deal of time and energy. How can these problems be solved with the FEM? In order to solve these structural analysis problems mechanically, a number of different approximate methods have been devised since the beginning of the twentieth century. The finite element analysis is an interesting and difficult challenge for the orthopedic-trauma surgeons, as well as those involved in biomechanical research [5.]. The last few years there has been an increased number of biomedical scientific works in the context of finite element analysis. [8,11,24,52,54,59,71,79.]. Most of them focused on the future development of artificial hip and knee prosthesis [2,38,45,46,73.]. We aimed to use FEM to study the pelvic ring response to the different loading and accident situations. FEM was also applied to developing a new pelvic iliosacral screw implant and comparing it with commonly use iliosacral screws.

IV. /1.2. Historical review:

One of the earliest solutions replaces the goal of obtaining a continuously varying distributed solution, by that of obtaining values at a finite number of discrete grid or nodal points. The differential equations are replaced by finite difference equations, which together with appropriate boundary conditions expressed in difference form yields a set of simultaneous linear equations for the nodal values [81,82,83.]. An alternative approximate method, the Rayleigh-Ritz method [61.] introduced almost at the same time, seeks to expand the solution of differential equations in a linear series of known functions. The coefficients multiplying these functions are obtained by requiring satisfaction of the equivalent variation of formulation of the problem and are, again, the solution of a set of simultaneous linear equations. These methods have extended the range of problems that may be considered, but have been found to be limited by the extreme difficulty involved in applying them to even more complex shapes. The need to analyze the complicated swept-wing and delta wing structures of high-speed aircraft was the impetus that led to the development the finite element method.

It is common in the traditional analysis of complicated building structures to divide them into pieces and behave on the general states of deformation or loading, but more readily available. The pieces are then reattached, subject to conditions of equilibrium or compatibility. The slope deflection method in statically indeterminate rigid-frame analysis is an example of such an approach. Attempts at rationale analysis of wing-structures initially took the same physically motivated path, but added the improvements of matrix formulations and the use of electronic digital computers. Methods based on Castigliano's theorems were devised for the calculation of flexibility matrices in obtaining deflections form forces and stiffness matrices for the determination of forces from displacement. The formal matrices were used in "force" methods of analysis while the latter were used in "displacement" methods.

An explosion in the development of the finite element methods occurred in the years subsequent to 1960, when it was realized that the method whether based on forces or displacement, could be interpreted as an application of the Rayleigh-Ritz method. It was first suggested for two-dimensional continua R. Courant, who proposed the division of a domain into triangular regions with the desired functions continuous over the entire domain and replaced, by piecewise continuous approximations within the triangles [11.]. The use of flexibility matrices was found too imply the implementation of the principle of minimum complementary energy, while stiffness matrices imply the principle minimum potential energy. The use of this approach permits investigation such topics as the continuity requirements for the piecewise approximation and convergence rates obtained with increasing numbers of elements or with increasing complexity of functional representation. It also allows stiffness or flexibility matrices to be calculate from a conceptually simpler mathematical viewpoint, while indicated the possibility of using variation principles in which both forces and displacements are varied to produced hybrid elements. Despite the possible advantage of hybrid elements for some problems, solutions based upon the principle of minimum potential energy and displacement approximations have become dominant for the simple reason that associated computer software is more universally applicable and requires the least interaction between machine and operator.

In recent years the finite element method has been applied to mechanic problems other then those of structural analysis, i.e., fluid flow and thermal analysis. It has been extended to permit the solution of non-linear as linear problems, those of large deformation geometric nonlinearity and\or material property nonlinearty. It is hard to think of any field in which finite elements are not extensively used to provide answers to problems, which would have been unsolvable only a few years ago [77.].

IV. /2. Pelvic girdle response during loading

IV. /2.1. Aims:

The above mentioned data about pelvic biomechanics helped us instigate the production of a mathematical model for the pelvic ring. We first performed simple pelvis geometry in 2D to study the displacement, stress and strain changes during axial load with the help of the animation program in the COSMOS software. One of our goals was to improve the simulation of the original pelvic *geometry*. This problem was approached in different ways. The COSMOS geometry program generated the simplest geometry of the 2D pelvis. The AutoCAD and ProEngeneer program helped draw the difficult geometry of the 3D pelvis. We also tried to import the medical diagnostic modalities (CT) data. A huge amount of conversion was necessary to configure this CT data into the COSMOS software. The automatic data transport and conversion was solved with the help of mathematician colleagues. However, the amount of the imported data from the CT was so huge that it exceeded our 1.71 COSMOS capacity. (Maximal capacity is 32 000 nodes). The other goal was to use more and more details of *material properties* of the pelvis.

IV. /2.2. Material and methods:

The 2D geometry of the pelvis was designed with the help of COSMOS/M 1.71 version of finite element analysis (FEA) software. (fig.19.) This geometry was produced from key-points (the original pelvis was redrawn from an anatomy atlas) and was connected to each other by curves. Regions were determined from the

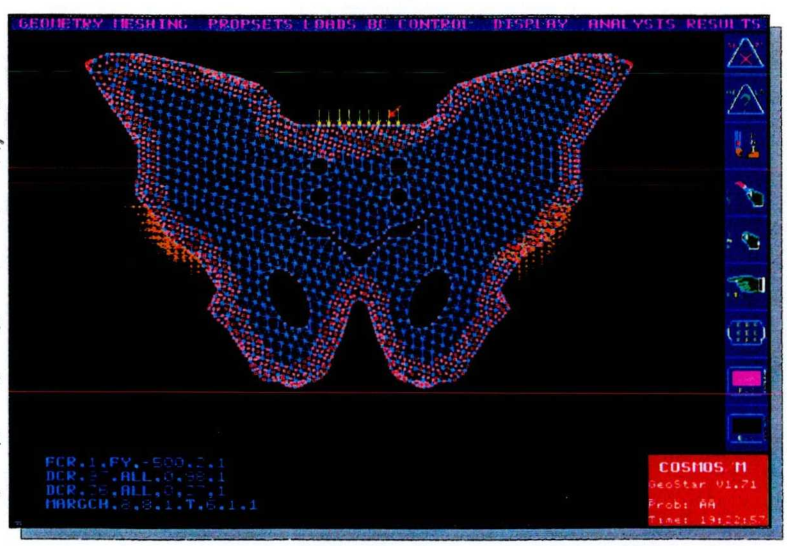


Figure 19.
2D pelvis rendered with COSMOS

curves and automatically meshed with 3 node triangle elements. The 3 node triangle elements were refined to 6 node triangle elements. Differential material properties were chosen from the software's element library to symbolize the cortical bone, spongious bone and pelvic joints. Same axial loading was applied to curves representing the first sacral vertebra exactly as it was in the real material (cadaver) biomechanical tests. The curves, which represent the acetabular region, were grasped in the y-axis, but the freedoms of motion in the x-axis were not fixed. Strain, stress, deformation and displacement data plotted. This data also was observed during animation of cyclic load.

3D pelvic model

To create a 3D pelvic model was an even bigger challenge. The ProEngeneer program performed the 3D geometry and the finite element mesh. The 3D pelvic model was filled up with 6-8 mm sizes TETRA-10 elements (The TETRA-10 element is quadratic, tetrahedron shape element). A plastic copy of an original human bony pelvis determined the size of the parts of the pelvis. (fig.20.) Material properties and real constants were given in the COSMOS FEA program. The applied forces and degree of freedom of displacement of different parts of the pelvis were also given in the COSMOS FEA program. The geometry can you seen in the drawing. (fig.21.) The material properties were; Bones dynamic modulus E=300MPa, Poisson ratio í=0.2, PS dynamic modulus E=50 MPa, SI joint dynamic modulus E=68 MPa, both connective tissue Poisson ratio were í=0.2. These values were provided under the basis of our previous

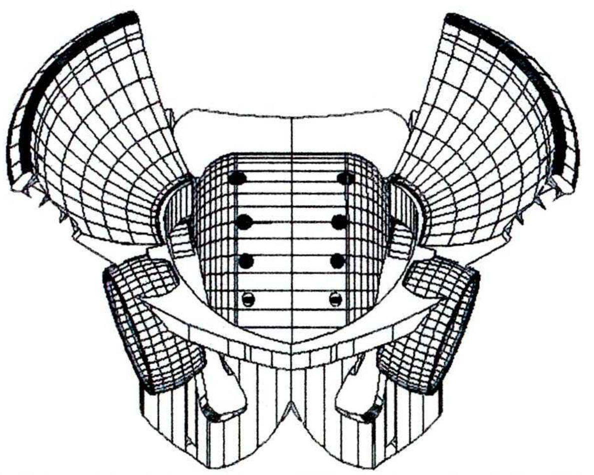


Figure 20.
3D pelvic model

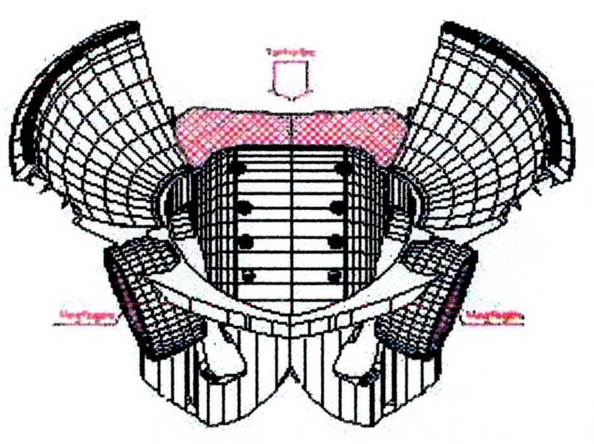


Figure 21.
Applied force to 3D model

cadaver studies and the literature. [5,77.].The angle of inclination was 45°. The applied load was 600 N. Stress, strain, displacement and deformation data were plotted and all of this data were animated.

IV. /2.3. Results:

2D Pelvis

Unilateral and bilateral stances were simulated. Stress, strain, deformation and displacement data were plotted. (fig.22.) The commonly applied physiological loads associated with sitting, standing and walking produce different specific effects in different parts of the pelvic ring. The stress data of this simple model showed that the maximal stress could be seen in the first sacral vertebral body region to run along to the line of the acetabuli. The colored drawing also showed that, in the anterior pelvic region, the maximal stress was in the inferior PS region.

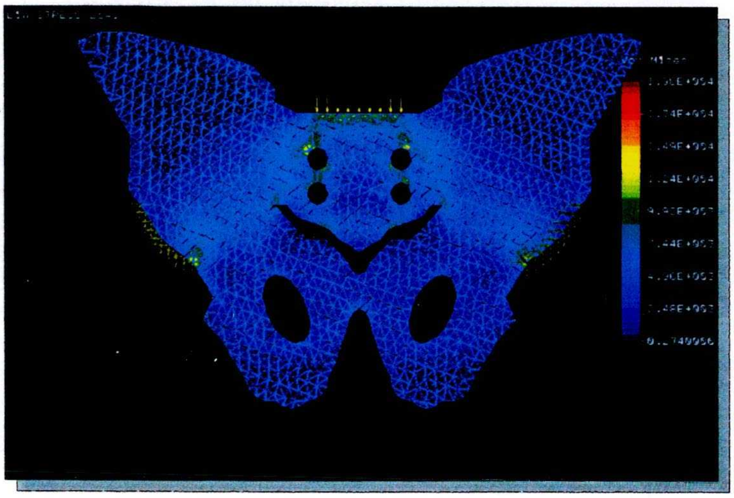


Figure 22.
COSMOS 2D pelvis stress data

3D Pelvis

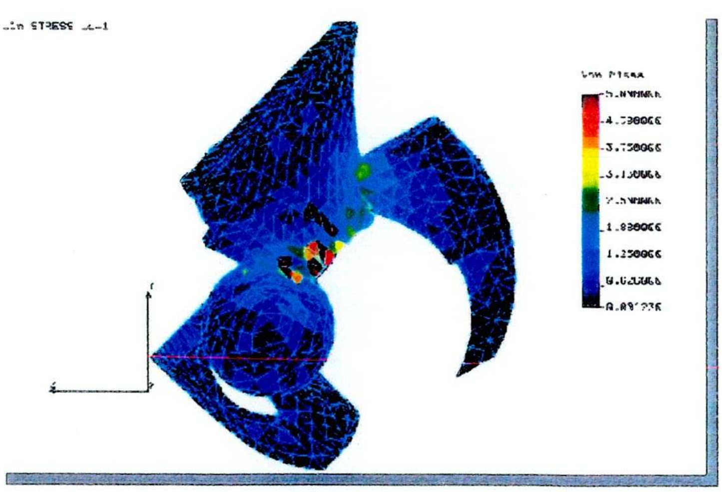


Figure 23.
COSMOS 3D pelvis stress data, lateral view

The stress data result can be seen the following figures (23-24.) Maximal stress could be seen behind and above the acetabuli. The places of maximal stress were at the 228 and 5891 elements. The maximal stress was 18 MPa and this is under of the allowed 50 MPa. Magnification factor is 6.2.

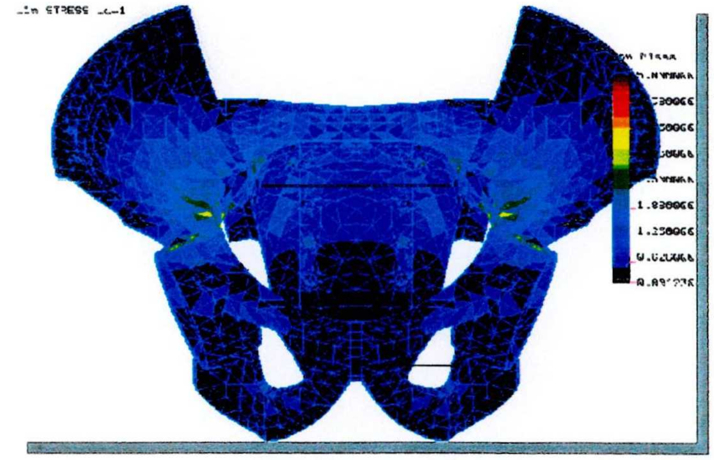


Figure 24.
COSMOS 3D pelvis stress data, AP view

Deformation of the pelvic ring during axial loading in bilateral stance can be seen on fig.25.
The opening of the SI and PS joints and the vertical depression of the sacrum were obvious.

IV. /3. New implant design and its failure analysis with FEA

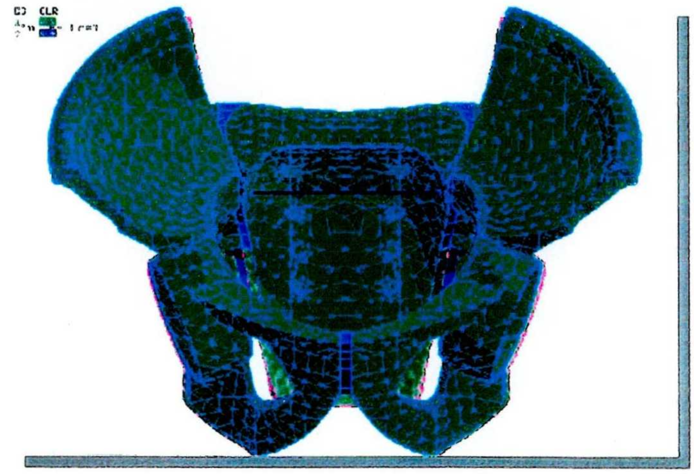


Figure 25.
COSMOS 3D pelvis deformation data, AP view

IV. /3.1. Aims:

Under the basis of above mentioned cadaver studies and FEA analysis, we aimed to design a new posterior iliosacral screw. The goals were to this screw; 1. It has to be cannulated, as percutaneous fixation is desirable. 2. The guide wire have to be strong enough to be able to the provide the provisional reduction of the fracture or SI joint during the surgical procedure of screw insertion. 3. The screw has to be strong enough to hold as big a force as possible. 4. The screw should be able to create as big compression between the fracture sites as possible. The limits of these requirements are the size of the sacral pedicle, as the average sacral dimensions are well known from the literature [3.]. Taking the demands of the above mentioned data into account, a 10 mm 2.8 mm-cannulated iliosacral screw seemed to be optimal for the desired special requirements. [86.] Before industrial producing, FEA analysis were performed to find out whether *these screws will be enough to stabilize the posterior pelvic ring alone or not?*

IV. /3.2. Material and methods

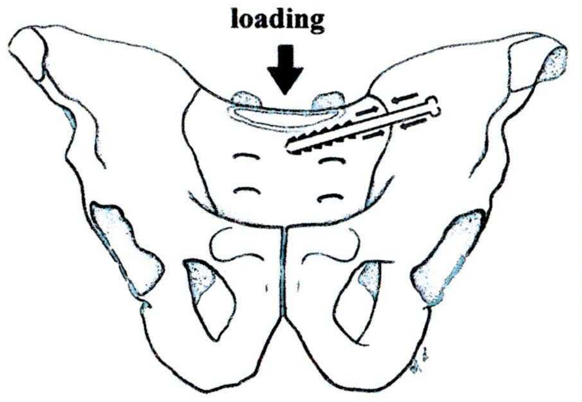


Figure 26.
The scheme of loading

The effects of bending forces on the different screws were compared with the help of Finite Element Analysis. The scheme of the loading can be seen in the figure, where a column had been abstracted from the whole pelvis. (fig.26.)

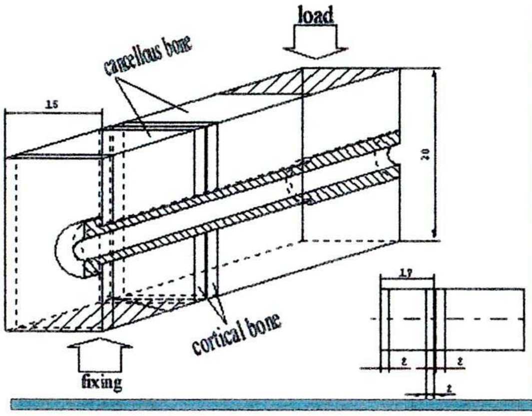


Figure 27.
Simplified geometric model of the screw and pelvic bones

A simplified geometric model is represented on the figure 27. The shorter bone represents the innominate bone, the longer one represents the sacrum. A 500 N axial divided load was applied to the nodes. The screws and the bones were built from SOLID elements and TRUSS3D elements were used for the representation of the connection between the screw-bone and screw-washer region. These elements were continually liquidated during the iterative FEA. Three different material properties were applied to the screws and both to the cortical and cancelleous bone. Material properties were provided under the basis of the literature and our previous biomechanical tests. Material properties of the screws E=210 000 MPa, v= 0.3, cortical bone E= 1100 MPa, v= 0.3 and cancellous bone E= 10 MPa, v= 0.3. Boundary conditions were the same on both screws bending tests. All of the nodes belonging to the inferior surface of innominate bone were grasped (All freedom of motion was stopped). As the half of the screws were prepared for the test, it had to be determinate such a condition at the level of the cut surface as the other half screw would be there. The freedom of the motion in the node x axis, belonging to the cut surface of the screws, were taken out. The work produced by internal forces is the following;

$$W_i = \frac{1}{2} \int_v \varepsilon^T \cdot \sigma \cdot dv$$

where ε **is antimetric strain in nodes** and σ **is state of stress.** Hooke's law can demonstrate the connection between antimetric strain and the state of stress.

$$\sigma = D \cdot \varepsilon$$

σ = State of stress

ε =Deformation of elements in nodes

D =Elastic matrix

Both screws were analyzed under the same conditions, in three different prestressing loading cases. In first case, was not applying any compression between the innominate bone and the sacrum. In the second case 100 N and in the third case a 500 N of prestress was applied. The applied axial load was 500 N. The COSMOS 1.71 software performed all the mathematical analysis. All the important results were plotted.

IV. /3.3. Results:

The following figures (28-31.) will show the differences in stresses among 7.3 mm (A screw) and our designed 10 mm (B screw). The biggest stress could be measured on the upper side of the screw at the level of SI joint. This is 2360 MPa in A screw and when there is no compression (fig. 28.) in the SI joint and 734 MPa in B screw. ***The admissible stress is 828 MPa.*** This means that the risk of metal failure is high in the case of using only one of 7.3-mm

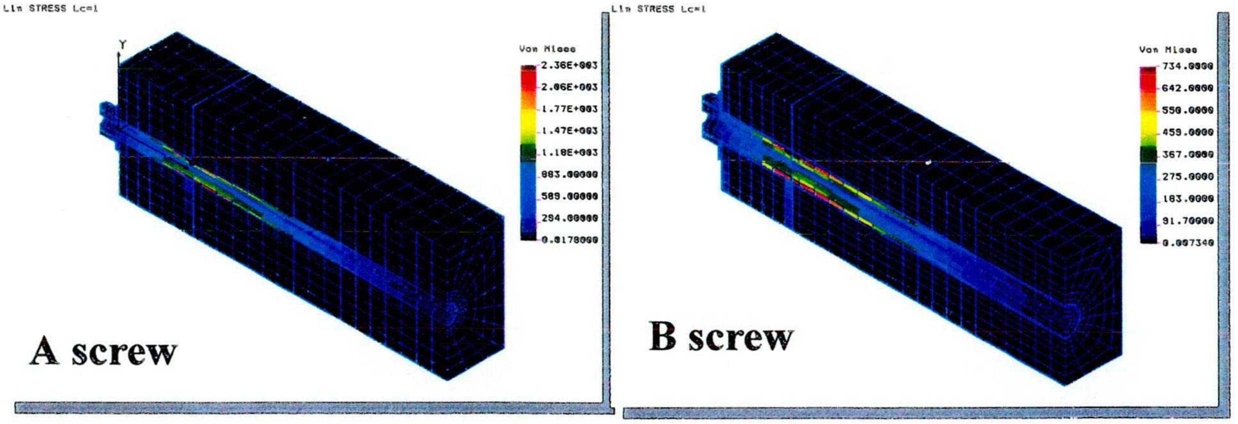


Figure 28.
Stresses in screws, no compression between the SI joint

screw.

The stresses are 2290 MPa in A screw and 715 MPa in B screw at the same level, in the second case where a 100 N prestressing force was applied into the SI joint. (fig.29.)

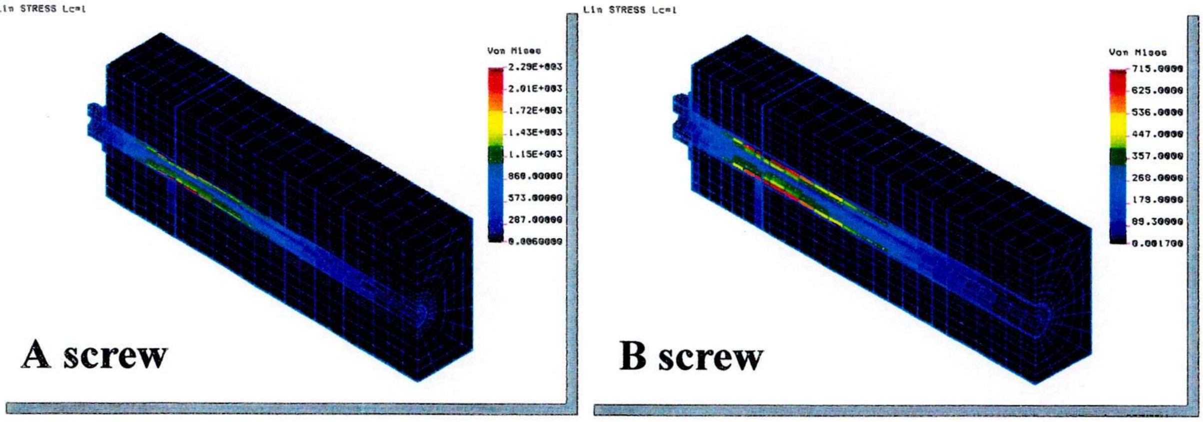


Figure 29.
Stresses in screws, while 100 N prestress was applied.

Applying 500 N prestressing force to the screws, the maximum stresses were observed at the same level, and their values were 2180 MPa in A screw and 725 MPa in B screw. (fig.30.)

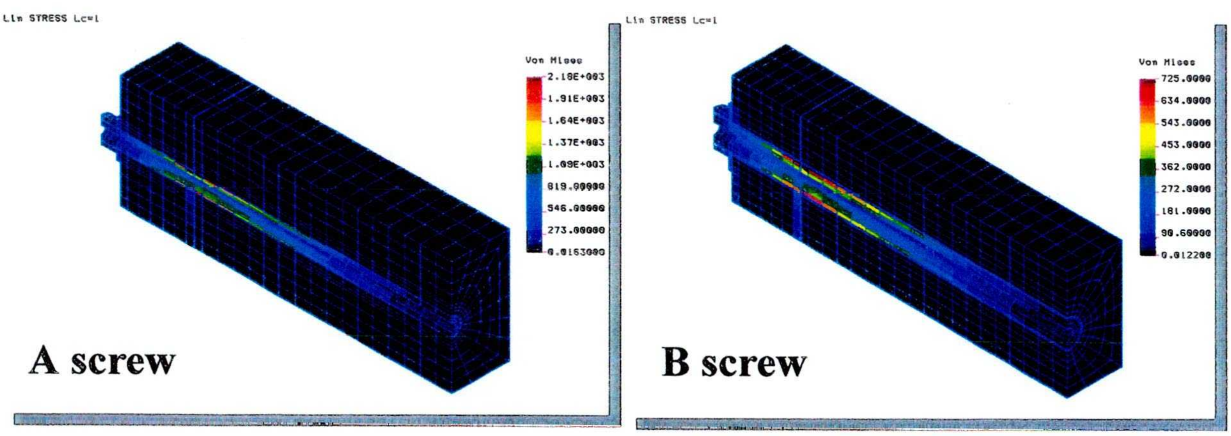


Figure 30.
Stresses in screws, while 500N prestress was applied.

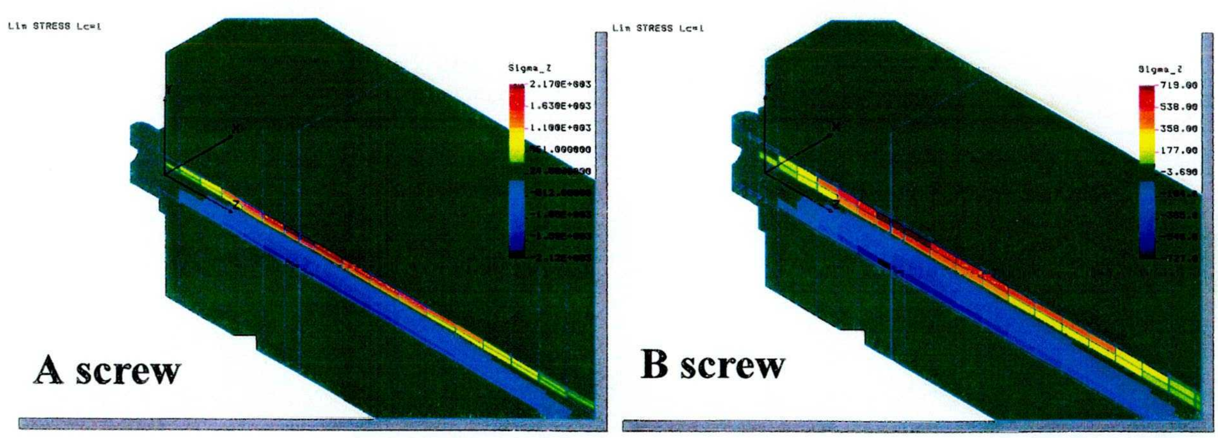


Figure 31.
Stress-distribution in the Z axis of different screws, while 500N prestress was applied.

Stress distribution in the Z-axis in the upper fiber is 2170 MPa in A screw and 719 MPa in B screw. (fig.31.)

Deformation of the 7.3-mm screw and 10 mm screw can be seen in the following drawing. (fig.32.)

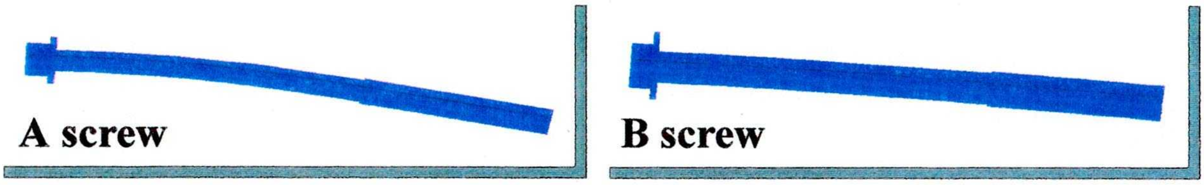


Figure 32.
Deformation of different screws

IV. /4. Computer designed screw failure test

IV. /4.1. Aims:

Under the basis of the above mentioned cadaver studies and FEA examinations a new size iliosacral screw was produced by Sanatmetal Kft. As this screw theoretically and mathematically seemed to be sufficient, a last biomechanical test was performed before the clinical trials. We aimed to measure the extraction strengths of different screws from Styrofoam and Balsa. The screws were compared using a Material Testing Machine at the Biomechanical Laboratory of Orthopedics in the Department of University of Kentucky, Lexington, USA.

IV. 4.2. Material and methods

7.3 mm cannulated and 10-mm cannulated screws of different thread in lengths were inserted in Styrofoam and Balsa. Pullout tests were performed. All tests were repeated 10 times. Digital signal recording and data acquisition from the MTS was performed. Statistical analysis was done. The important data were plotted.

IV. /4.3. Results

There were slight differences in extraction strengths between the two screws from Styrofoam and greater differences from balsa. 10-mm screws were proved more stable in both cases. (fig.33.)

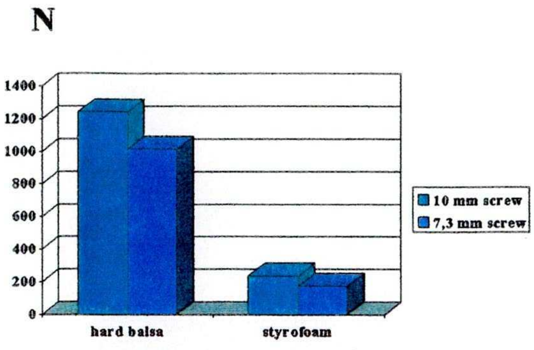


Figure 33.
Comparison of extraction strengths of different

The differences in extraction strengths depended on the lengths of the thread of the same 10-mm thick screws. (fig.34.)

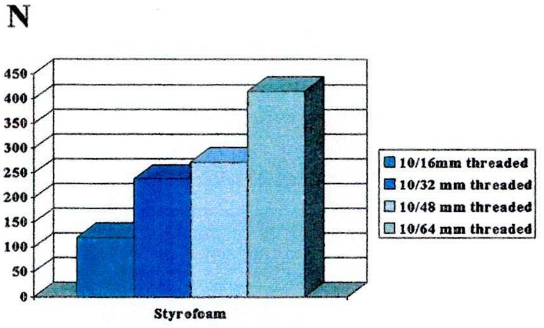


Figure 34.
Comparison of different thread-lengths in 10-mm screws

IV. /5. Discussion of FEA tests

2D MODEL

This type of data could be estimated only relatively, because of the simple model. The animation of this colorful data assisted in meditating on optimal placement of implants in the posterior and anterior pelvic region. These results correlated our observations in the cadaver study. Finite element analysis demonstrates that in both sitting and bilateral stances, the pubic symphysis is subjected to predominantly tensile loads, especially inferiorly, while the sacroiliac joints are subjected to a combine load of compression and bending, with their inferior parts under tension. In the unilateral stance the PS compressed and vertically sheared, while the supporting sacroiliac joint sustained shearing and bending with the superior surface under tension.

3D MODEL

The 3D model is already shows the main geometric features of the pelvis. To increase the geometric details we need exact dimensions. However, common instruments are not precise enough to determine these dimensions. The geometric scope of the pelvis is possible to determine only with 3D instruments. However, constructing a model demands great modelling experience and skills. Non the less, we were able to make the model in another way with the help of faster computers and modern medical radiological image diagnostic modalities. CT scans are suitable to determine the contours of the bone with the help of a custom-tracing program. Connection of these contours in the third direction provides us with a 3D pelvis with proper geometric details. With this model we are also able to place the connective tissues into the right places on the model. Important viewpoint is to determine the material properties as precisely as we can, since a geometrically exact model without the correctly determined material properties decrases the accuracy of the calculations by 30-40 percent.

Screws

Stabilising the posterior pelvic ring among C type pelvic fracture patients is an essential life saving procedure. As these patients are usually polytrauma or multiple injured victims, a rapid, definitive stabilisation procedure is desired. Percutaneous iliosacral screw insertion would be a good choice for this, but the commonly used conventional 6.5 and 7.3-mm screws have some well-known disadvantages. Screw bending, breakage or loosening are known complications of this procedure [65.].

In order to provide enough pelvic stability, two ordinary screws have to be inserted into the first or the first and the second vertebral bodies. However, these facts greatly increase the risk of iliosacral screw insertion procedure. To solve this problem, four years ago we started designing a new iliosacral screw. In order to design a proper screw we had to know the average sacral dimension -which is one of the limiting factors to increasing screw dimensions- the 10-mm cannulated iliosacral screw seemed to be optimal for our desired special requirements.

Summarizing the previous data from the biomechanical extraction tests and finite element analysis, the following statements can be made. The extraction force is bigger if a longer threaded screw is inserted into the sacral vertebral body. 10-mm thick screw extraction requires a bigger force both from both Styrofoam and balsa as 7.3-mm screw does. Maximum stress could be observed in the upper part of the screw at the level of the SI joint. During physiological loading - when applying one 7.3-mm screw to fix the SI joint with or without compression - the stress in the screw will be so large that the risk of the failure of screw is too high. For this reason, two-screw-insertion is desirable. During physiological loading, applying a 10-mm diameter screw to stabilize the SI joint showed that the maximum stress remains under the level of metal failure risk in all prestressing cases. This means one 10-mm screw insertion is sufficient to fix the SI joint. The clinical relevance of this study is that technically on 10-mm iliosacral screw can be inserted into the first sacral vertebral body much more easily than two 7.3-mm screws into the same area. One screw insertion is faster, so this circumstance allows that this method can be performed as an emergency procedure among patients who are in shock condition, related to their pelvic fracture.

V. Clinical Investigations of New Pelvic Implants

V. /1. Percutaneous iliosacral screw fixation of posterior pelvic region

V. /1. 1. Aims

The necessity of internal fixation of the unstable Tile C-type pelvic ring injuries has been accepted worldwide [20,21,34,55,64.]. The methods that stabilized the posterior component of the pelvic ring injury are different. These procedures provide better bony stability and less long-term morbidity than non-operative treatment. Our purpose was to develop a cannulated iliosacral screw with different lengths of thread, that would provide optimal stability for the injured posterior pelvic ring. Furthermore, the insertion of these screws became more safety.

Following the biomechanical tests the new 10-mm screws underwent clinical trials. Our aims were to prove the clinical advantages of these new implants in the pelvic surgery. Our goals also were to work out the optimal surgical strategy and sequence using these implants. The clinical experience led to modify the set to gain finally a handy instrument and implants.

V. /1. 2. Material and Methods

These screws meet the demands of iliosacral fixation, notably the 2.7-mm diameter guide-wires are thick enough to resist the shearing forces during the reduction maneuvers and strong enough to allow physiologic loading in the early postoperative period.

The iliosacral fixation set (fig.35.) consists of a soft tissue protector, guide-wire drill-bit, guide-wire with thread, cannulated 7 mm diameter drill, cannulated depth gauge, cannulated screw tap, cannulated screw-driver with securing screw, self-tapping cannulated screws with different lengths in thread and washer.

Figure 35.
The newly developed iliosacral screw fixation set. (SANATMETAL®). Based on research presented in this thesis.

The procedure can be performed both in supine and in prone position on a radiolucent operating table. Pennal views are necessary to use during the operation.

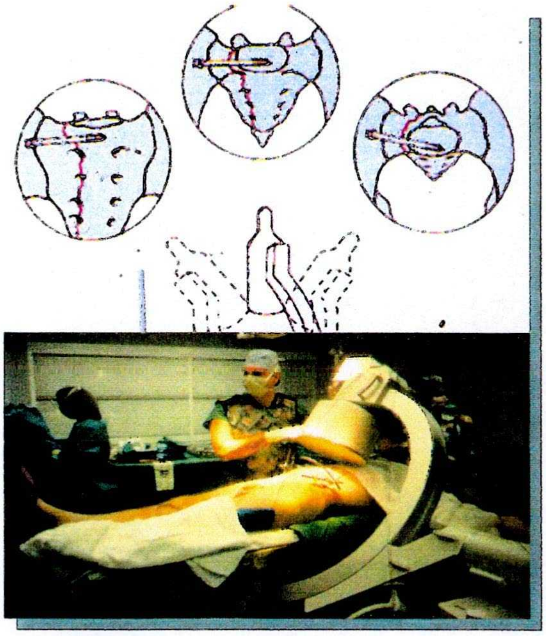


Figure 36.
Iliosacral screw insertion in supine position

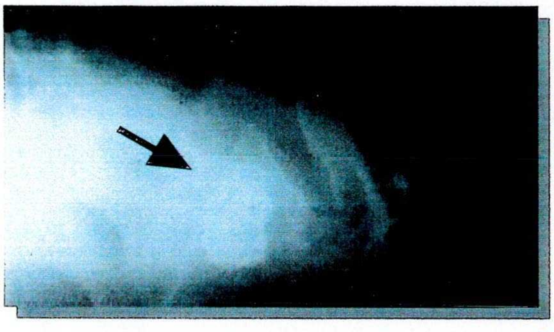


Figure 37.
Lateral view of the screw position (safety zone)

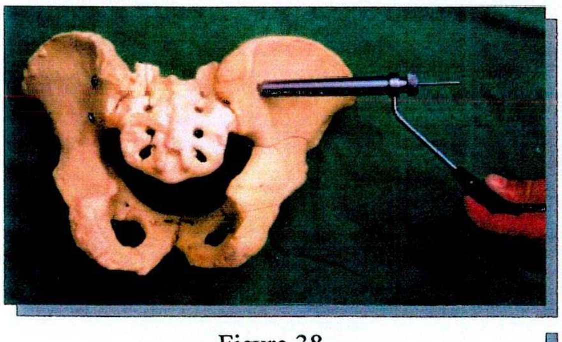


Figure 38.
Working through soft tissue protecteur

(fig.36.) The approximately antero-posterior position of the guide wire up to the sacrum can be recognized on the inlet view when the x-ray beam is approximately 40-degree to cranial positioned. The closely cranio-caudal position to the axis of the sacrum of the guide-wire can be checked on the outlet view when the x-ray beam approximately 40 degree caudal positioned. The entry point of the guide wire is 15-mm distance from the crista glutei. The entry point could be determined in the lateral sacral view where an "L shape" safety area has to be recognized. This area is basically the lateral contour of the lateral sacral mass. (fig.37.) Care must be taken to avoid the damage of the sacral roots and caudal equine. Indirect depth gauging follows the insertion of the guide wire. (fig.38.) Drilling, tapping and the inserting the appropriate screw thread length with washer are the next steps. Drilling procedure has to be done very carefully, using the drill with slow speed and hitting maneuvers. Oscillation drilling is preferable. Drilling have to be stopped 5 mm before the end of K-wire to avoid pulling out of it. As the screws have self-tapping threads you do not need full lengths tapping. However, my experience is that the tapping has to be done through the SI joint. Appropriate length of screw is determined on the basis of the depth gauge data. The lengths of the thread of the screw are based whether lag effect is desirable or not. In cases where lag effect is desirable as long threaded screw insertion is good as possible. If lag effect is not desrable as long thread has to be chosen that it pass through the fracture region. Screw bite can be feel with experience. However, on the X-ray you can see the washer inclination to the surface of the outer table of the ilium. It means that the screw-head will reach its good position sooner. [86.].

The indications and contraindications of this procedure should be clearly outlined. To perform iliosacral screw surgery contraindicates if the fracture lines run through the ilium or through the center of the sacrum. Potential dangers to injury to the L5, S1-2 roots caudal equine, great vessels and rectum. To avoid these complication necessary good understanding of sacral anatomy, adequate fluoroscopy control, accurate preoperative planning and intra-operative detecting of somatosensory evoked potential. Six weeks, 16 weeks and 52 weeks following the surgery force plate tests were performed to know whether how changed the stress distribution among the patient who underwent iliosacral screw fixation.

V. /1.3 Clinical cases & results

Clinical example: (K.K.), (fig.39.) 50-year-old female, who fell from a tree. The Tile C-type pelvic ring injury has not been recognized for 9 months. Continuos low back pain and an ineffective bone healing (hypertrophied nonunion) of the ramii pubis predicted the posterior instability of the pelvic ring. CT-scans confirmed the wider distance in the left sacroiliac

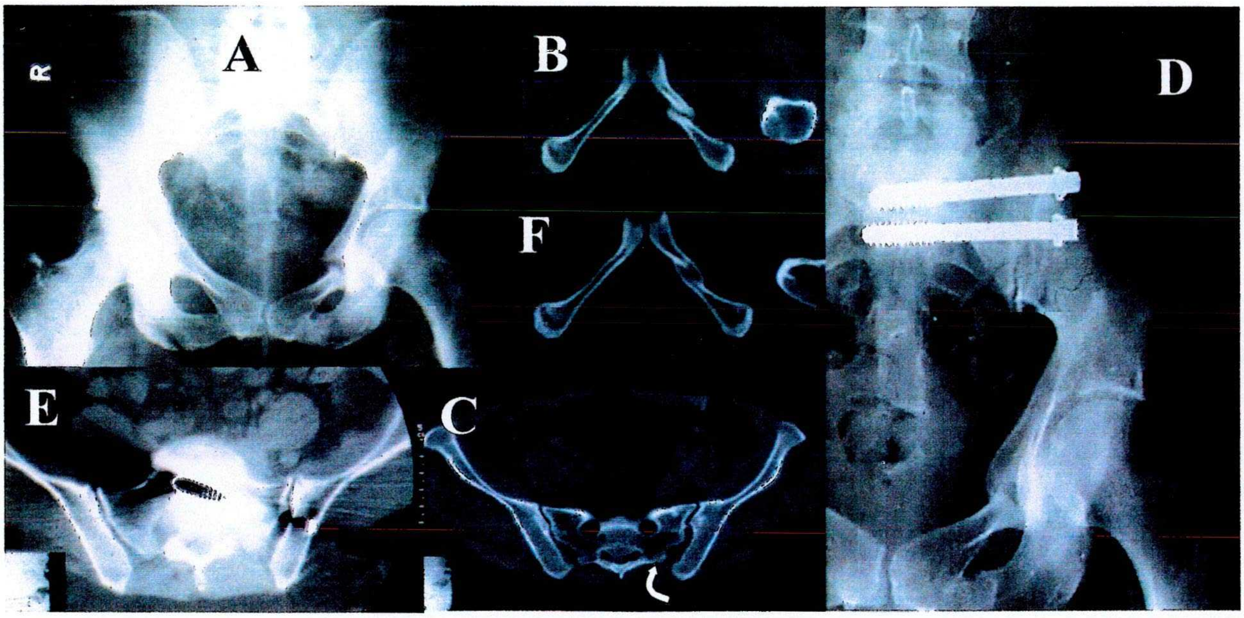


Figure 39.
K.K. Posterior instability, with os pubis non union. Preoperative images: A) AP x-ray, os pubis non union. B) Os pubis non union on the CT scan. C) SI instability [arrow]; Postoperative images: D) AP x-ray 12 weeks following the surgery showed complet union of the anterior pelvic ring. E) CT scan shows the position of IS screw. The screw did not damage the SI joint. F) Complete healing of the nonunion (12wks).

region.
Two new designed iliosacral screws were inserted into the first and the second sacral vertebral body without the stabilization of the anterior pelvic ring. During the early postoperative days the low-back pain of the patient disappeared. Complete bone healing of the ramii could be seen be after 12 weeks post-operatively.

This case is a exceptional clinical example for the ensuring of the fact, that the implants are able to reduce the motion in the anterior pelvic ring up to the level which could be enough to gain the appropriate bone healing.

Nine patients who underwent iliosacral screw fixation and had not any other problems, which could modify the results (i.e. both side injuries, other lower extremity injury etc.), were selected for force plate testing. The results showed that the patient who had iliosacral screw fixation with the new designed implants could walk on the force plate closely the same time and same stress distribution with operated extremities as the intact ones 6 weeks after the surgery. The minimal difference in the force disappeared on the 16 weeks. On the 52 weeks remained the same stress distribution of both extremities.

During the last four years, 64 patients with Tile B3 and C pelvic injury were stabilized with 10-mm diameter cannulated iliosacral screws percutaneously posteriorly. 3 patient of them had both sided injury as the got two screws into the first sacral vertebral body from both sides. 1 patient had late nonunion for this reason she got one screw into the first and on other into the second sacral vertebral body. At the beginning of this project 6 patient were stabilized with conventional 6.5-mm cancellous screws. One patient has got additional our designed sacral bar fixation, as well. One patient was fixed with 4.5 mm Herbert screw. (all 71). The average age was 38.8 years (18-70). Male/female: 40/31.

In the 10-mm implants group no patient had metal breakage, three patients have screw slackening, but only one of them needed revision surgery. One transient S1 nerve injury was observed. No septic complication or wound healing problems was detected. The average OP time of the posterior stabilization was 33 minutes. The average time of using of fluoroscopy was 72 seconds.

V. /2. RETROGRADE INTRAMEDULLAR SUPERIOR RAMIC SCREW (RISRS) FIXATION OF ANTERIOR PELVIC REGION

V. /2.1 Aims

However, the literature and our biomechanical data also showed the less mechanical relevance during loading the anterior pelvic region, clinical complications could be paid attention of this region as well. As we aimed to perform minimal invasive surgery in the posterior pelvic region, we had enthusiasm to perform RISRS fixation following the first clinical trials from Chip Routt [67.].

Our goal was to use this method pecutaneously together with our developed implants.

V. /2.2 Material and methods

The surgeries were performed on radiolucent operating table in supine position. Usually the anterior stabilization were perform prior to the posterior stabilization. Minimal invasive methods were preferred. However, the percutaneous method could not manage limited Pfannenstiel or Stoppa approach was performed. Pennal and Judet views were usually used via surgery. The implants what are we inserted were 3.5-mm cortical (8 screws), 6.5-mm cancellous standard screws (3 screws), and same cannulated screws. Furthermore in some cases (5 screws in 3 patients) Herbert screws were also inserted.

V. /2.3 Clinical cases & results

A 38-year-old Albanian male (HM) (fig.40) injured in a car crash. His ISS score was 41. Beside cerebral contusion, maxillar fracture, diaphragm rupture, left side second degree opened humeral fracture, he also had a C type pelvic fracture as bilateral ramii fractures and SI separation.

Figure 40.
(HM) A) AP view. B) SI joint separation in CT scan. C) AP view post.op.

The percutaneous anterior and posterior stabilization of the pelvic ring can be seen on the pictures.

A 29 year old (RF) polytrauma patient (fig.41.) due to a fall from high, had 50 ISS score. Beside cerebral contusion, subdural haematoma, spleen rupture, open radius and bilateral calcaneal fracture, he had a right-sided intertrochanteric and same-sided C type pelvic fracture, so called floating hip [48.]. The anterior and posterior fixations can be seen on fig. 41. The following pictures show the inlet view in the same case post-op and the obturator view, which demonstrates the fractures in the healing stage.

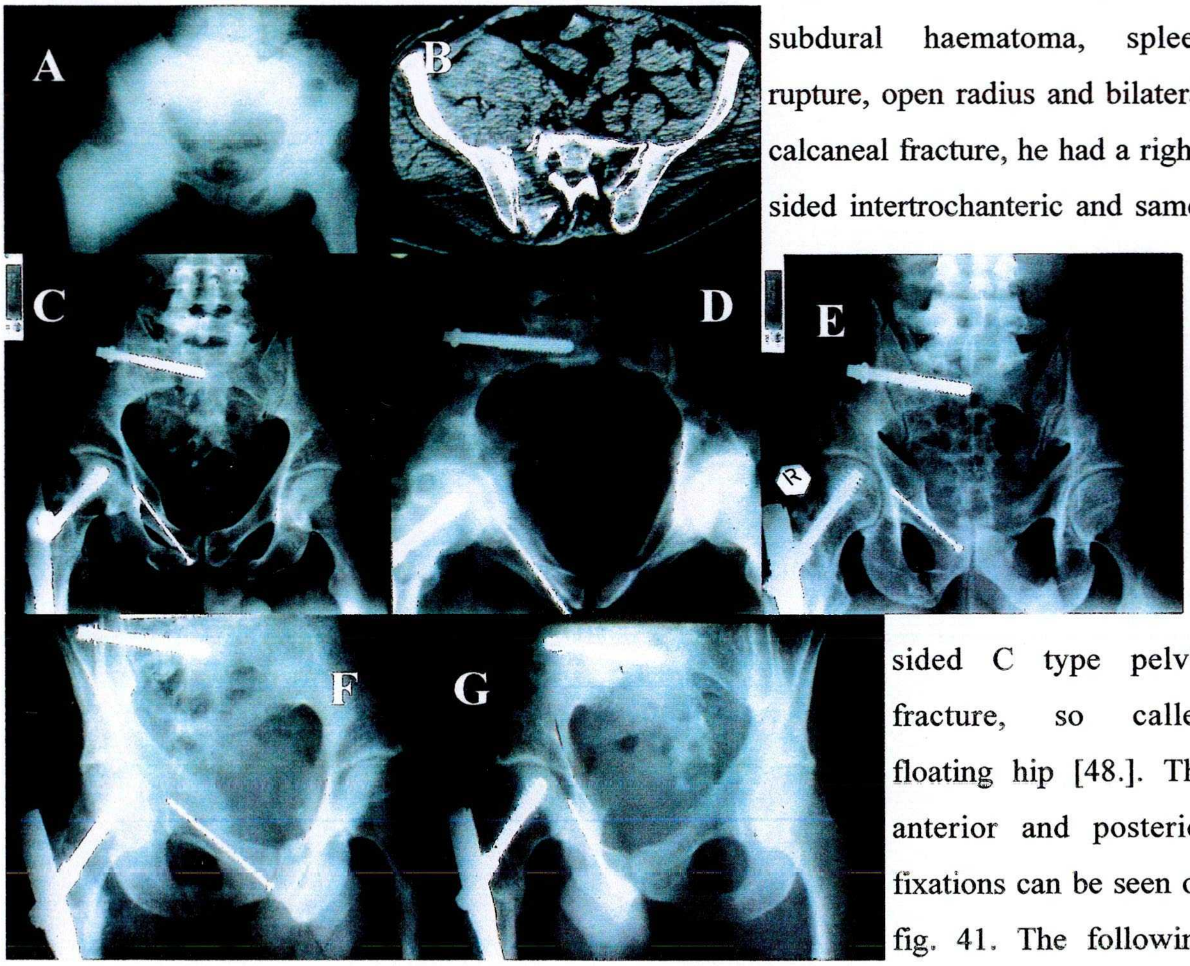


Figure 41.
(RF) A) AP view, B) CT scan shows the sacral frature
C) AP view. Pennal views: D) inlet view. E) outlet view. Judet views: F) obturator view. G) ala view.

During the last four years 10 of pelvic fractured patients having transpubic anterior instability of the pelvic ring were treated with RISRS fixation. The mean age of the patients with RISRS was 35.3 years, (18-48), 7 males and 3 females. The ten patients needed 16 screws insertion.

7 patients were fixed percutaneously the others were fixed via limited Pfannenstiel or Stoppa approach. No metal failures or other vascular or neurological complications were observed. No septic complication was occured.

V. /3. Polytrauma management with minimal invasive technique in pelvic related trauma

V. /3.1 Aims

Under the basis of all the above mentioned experimental and clinical studies and clinical experiences we aimed to train in these methods [27,49,60,62,70,76,87.]. Following a year of practice, we were able to perform the posterior percutaneous stabilisation in less than 20 minutes. Further building on the gained surgical skills and experiences (surgeons and the O.R. personnel's), increased our capacity to perform more and more immediate pelvic fixations were performed.

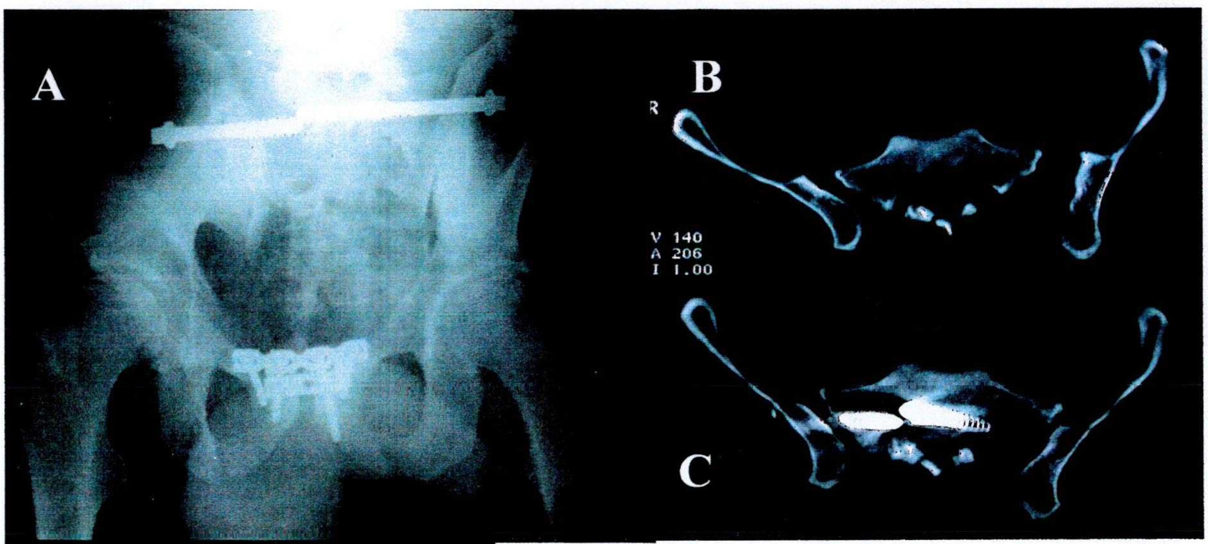
V. /3.2 Material and methods

Emergency pelvic stabilisation was performed in pelvic injured patients who had haemodynamic instability, despite immediate shock management during the diagnostic period. The stabilization procedure was the same as described in the V. /1.2 and V. /2.2. chapters. Usually the anterior fixation was performed first, following the posterior reduction with the help of axial traction and joystick method rotation. The posterior fixation was performed, with the help of our newly designed IS screws, percutneously in all haemodynamically unstable cases.

V. /3.3 Clinical cases & results

A middle-aged male (fig.42.) (PM) suffered a car accident. He had cerebral contusion, left side hptx, rib fractures, spleen rupture, mesenteric rupture, urinary bladder rupture, pelvic fracture C.3. He spent 15 minutes in the emergency unit and in the CT required resuscitation two times. Following laparotomy and spleen removing, bladder and intestine suture, immediate anterior double plating and both sided IS screw insertion was performed. On the fig. 43. you can see the compression of the SI joints following the surgery.

Figure 42.
(PM) A) 3D reconstruction CT AP view. B) inlet. C) 3D cystogram.



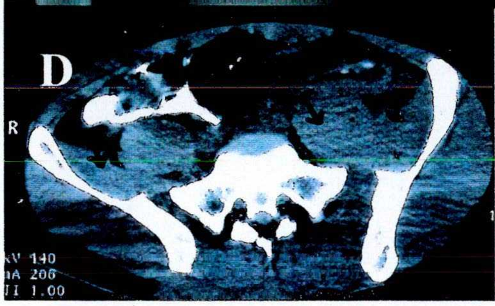


Figure 43.
(PM) A) AP view post.op. B) CT scan show the SI joints separation. C) Compression in the SI joints with minimal malreduction. D) arrows show blood in the SI region before the stabilization.

A 52 year old male (TS), his bodyweight was 155 kg (!) suffered a car accident. On the topogramm you can see the pelvic fracture (fig.44.) and there was no air accumulation in the bowels. This was an optimal condition for immediate fixation. Since the patient had blood in his urine, cystography was also performed. An immediate IS fixation and PS plating was done. Two weeks following the surgery the patient walked in the swimming pool as a part of his physiotherapy. This demonstrated cross and axial traction, should not be chosen as treatment for these seriously injured patients. (fig.45.)

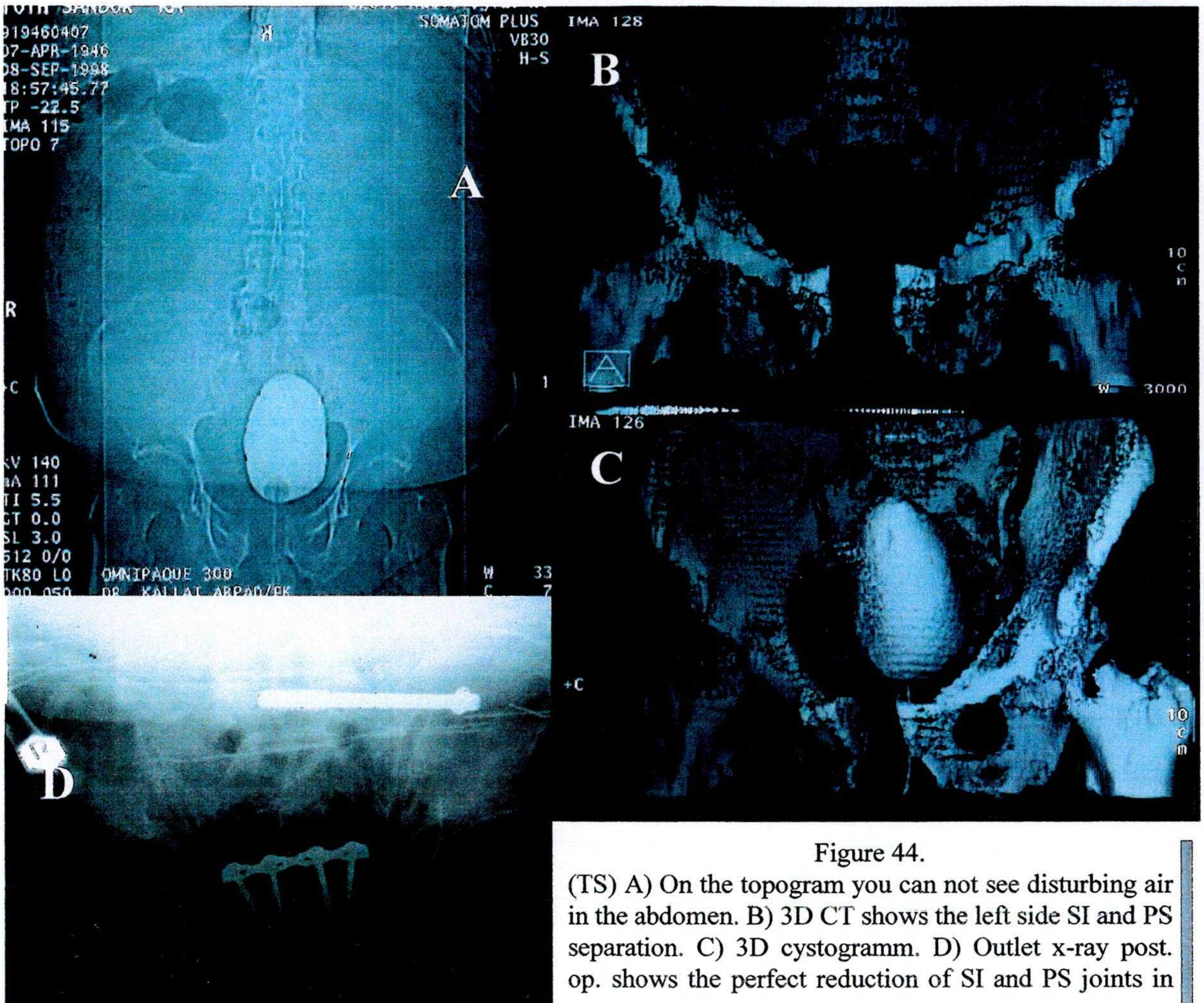


Figure 44.
(TS) A) On the topogram you can not see disturbing air in the abdomen. B) 3D CT shows the left side SI and PS separation. C) 3D cystogramm. D) Outlet x-ray post. op. shows the perfect reduction of SI and PS joints in

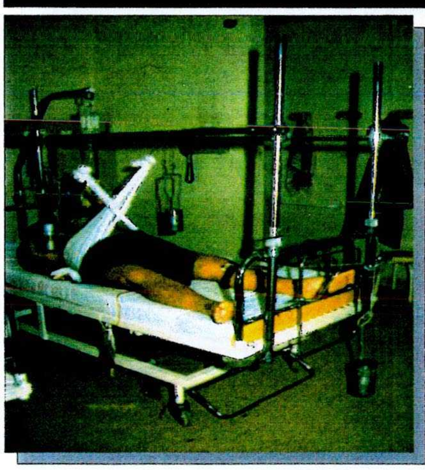


Figure 45.
Cross and axial traction should not be chosen for treatment of seriously injured, haemodynamically unstable, patients.

My last presented case attempted suicide. (fig.46.) She was 47, female (GK) and jumped from the second floor of the University's Dermatology Department. Her ISS score was 35. The 3D pelvic CT and X-ray's following immediate posterior and anterior percutaneous fixations can be seen on fig.46. Short history of this case; Left side haemoptx, left side serial ribs fx-s and a pelvic fracture was found. The patient had serious depression as a side effect of steroid therapy, leukemia, Sezary-Baccareda syndrome (reticulo-histiocytosis maligna) and was under immunosupression. The change of the level of Hbg decreased rapidly during

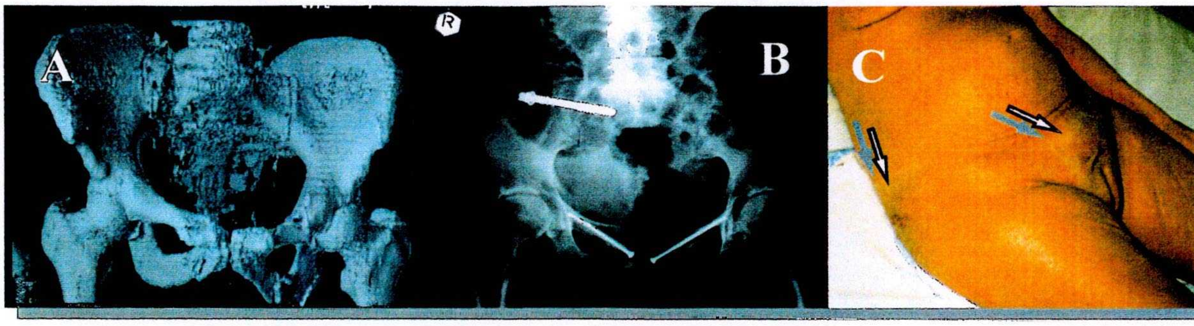


Figure 46.
(GK) A) 3D CT showed anterior and posterior instability of the pelvic ring. B) AP x-ray post. op. C) White arrows show the minimal incisions for these life-saving procedures.

(GK) age 47, female, fall from high, ISS: 35
Dg: left side haempoptx, left side serial rib fx-s, pulmonary contusion, C-type pelvic fx.

the diagnostic period despite blood transfusion. Urgent posterior and anterior stabilization could stabilize the hemoglobin level as well. (fig.47.) Our protocol can be seen on the fig.48.

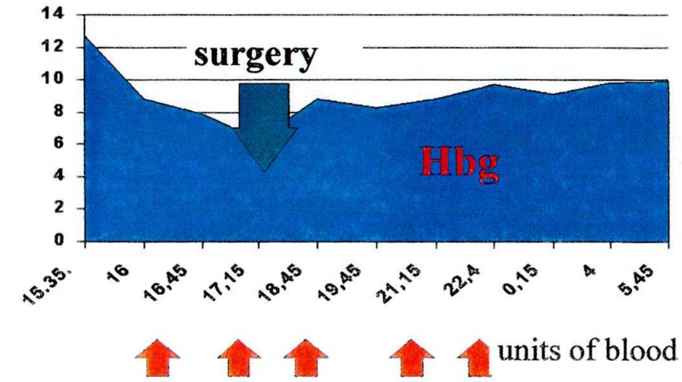


Figure 47.
The change of the Hbg level in the first 14 hours following the injury. Only 2 more units of blood were necessary, following the immediate surgery.

Management of patients with pelvic trauma related haemorrhage:

diagnostic procedures:
Physical examination, compression with vacuum bed
AP, inlet, outlet, x-rays
CT scans

emergency surgery:
Ex.Fix or definitive anterior stabilisation
definitive posterior percutaneous stabilisation

More bleeding:
selectiv embolisation,
packing

Figure 48.
Pelvic related haemorrhage protocoll

V. /4. DISCUSSION OF CLINICAL RELEVANCE

Patients with an unstable pelvic disruption are at much greater general risk than those with a stable pelvis. In Tile's prospective study of 100 patients, 12 of 15 mortalities were in the unstable group. Their blood transfusion requirements were three times greater (15.5 units versus 5,5 units), their ISS score was 37 (versus 29 in those with stable pelvis) and there overall complication rate was three times higher. [9,68,76.]. Patients suffering this complication require massive fluid replacement, as outlined by the American Surgeons' ATLS protocol. Fracture stabilization belongs in the resuscitative phase of management. The expected blood loss in pelvic fracture is over 10 units. However, the 2nd Pelvic Acetabular Course (1994) declared that not only increasing the volume of the pelvic cavity is responsible for bleeding, as it is only 55% in severely injured pelvic separated patient. This still does not fully explain the blood loss. The bleeding from the spongious bone is an additional cause for continuous hemorrhage. Closing the ring with the help of external fixateurs, in B-type fracture is a good way to stop the bleeding. However, in C-type fractures, this method is sometimes unsatisfactory since the external fixateurs are unable to control the motion in the posterior pelvic region. With the development of image control quidance systems, percutaneous fixation of the unstable posterior pelvic ring injury will become safer and will, I believe, become the method of choice for early stabilization. These guidance systems should ensure accurate placement of the percutaneous fixation devices in the acutely multiple injured patient with an unstable pelvic ring. Based on our biomechanical and finite elemet studies, inserting one 10-mm size cannulated iliosacral screw is sufficient to provide proper posterior pelvic stability. (fig.49.)

Figure 49.
Indications for percutaneous fixation in the anterior and posterior region of the pelvic girdle. Green marked - absolute, orange marked - relative.

During the last three years, 64 patients with Tile C pelvic injury were stabilized with 10-mm diameter cannulated iliosacral screws pecutaneously, posteriorly and several different (mostly percutaneous) methods were used for anterior fixation. Eighteen patients in haemodinamically unstable condition were stabilized in the first two hours with iliosacral screw fixation.

VI. Summary

In the past two decades, traumatic disruption of the pelvic ring has become a major focus for trauma surgeons interest (mostly in North America), as has the care of polytraumatized patients. Traumatic pelvic ring disruption is part of spectrum of polytrauma and must be considered a potentially lethal injury, with mortality rates of 10-20%. The stabilization of an unstable pelvic ring in acute resuscitation of multiple injured patients is now conventional wisdom.

As a practising trauma surgeon, my scientific aim was to better understand the human pelvic biomechanics. The practical, theoretical and technological knowledge gained with this research will assist all authentic surgeons in deciding on new approaches and techniques, as well as computer modelling the introduction of new implants and fixation materials.

For these reasons cadaver tests, finite element analysis (FEA) and clinical investigations were performed. The response of pelvic joints, pelvic ligaments and pelvic bones were tested in cadaver pelves. Commonly used different anterior and posterior pelvic fixation methods were also compared in cadavers. These experiments were performed under the supervision of Marvin Tile, in the Orthopaedics Biomechanics Research Laboratory of Sunnybrook Health Science Center, University of Toronto, Canada, during my research fellowship in 1993-94. Pelvic girdle responses during different loading and accident situations were studied with the help of FEA, in Hungary, during the following years. Under the basis of the previously mentioned data and clinical experience new implants were designed that provide better pelvic ring stabilization. The new implants were compared with other implants using material testing machine (Biomechanics Laboratory Lexington, University of Kentucky, USA) and FEA analysis (BME, JATE and SZOTE, Hungary). Following the biomechanical tests, clinical trials of the new implants followed. Parallel to my research I continuously developed my surgical skills. I spent my clinical fellowship (AO-International) at the Carolinas Medical Center, Charlotte, North Carolina, USA, in a first level Trauma Center, under the supervision of James F Kellam.

The newly developed implants proved successful for immediate fixation and polytrauma management could be changed in the pelvic fracture related haemorrhage cases as well.

VII. SCIENTIFIC LITERATURE UPON WHICH THE RESEARCH IS BASED

1) Albert MJ, Miller ME, McNaughton and Hutton WC: Posterior pelvic fixation using a transiliac 4.5-mm reconstruction plate: A clinical and a biomechanical study. *J. Orthop Trauma*, 7:226-232, 1993.

2) Akagi T, Hashizume H, Inoue H, Ogura T and Nagayama N: Computer simulation analysis of fracture dislocation of the proximal interphalangeal joint using the finite element method. *Acta-Med-Okayama* 48(5): 263-70, 1994.

3) Amongero ME, Wilber JH: Upper sacral morphology and its relation to sacroiliac screw fixation. *Surgery of the Pelvis and Acetabulum*: The Second International Consensus, Pittsburgh, 73,1994.

4) Anderson JE: Grant's Atlas of Anatomy. *Williams & Wilkins*, 1980.

5) Beer FB and Johnston ER: Mechanics of Materials. *McGraw-Hill* Inc. 42,1980.

6) Bell A, Smith R Brown T and Nepola J: Comparative study of the Orthofix and Pittsburgh frames for external fixation of unstable pelvic ring fractures. *J. Orthop. Trauma* 2:130, 1988.

7) Bielschowsky M:.Die Silberimpregnation der Axenzylinder. *Zentrelblatt fuer Neurologie* 21: 579-583, 1902.

8) Billet HF, Schmitt WGH and Gay B: Computed tomography in traumatology with special regard to the advances of three-dimensional display. *Arch Orthop Trauma Surg* 111:131-137, 1992.

9) Bosch U and Tscherne H: The pelvic compartment syndrome. *Arch Orthop Trauma Surg* 111:314-17, 1992.

10) Conventry MB and Tapper EM: Pelvic instability. *JBJS* 54.A: 83-101, 1972.

11) Courant R: Variational Methods for the Solution of Problems of Equilibrium and Vibrations, *Bulletin of the Am.Math.Soc.* 49:1-23, 1943.

12) R.Decker, W.Ruf: Traction bracing for symphysis rupture using woven polydioxanone ligaments (PDS) *Z.Orthop* 126:4-18, 1988.

13) DeLong WG and Dalsey RM: Posterior stabilization of the pelvis with sacral bars. *Oper Techn Orthop*, 3:19-25,1993.

14) Dick I.L: Iliac Bone Transplantation. *JBJS* 44:1-13, 1946.

15) Dietrich-M; Kedzior-K; Zagrajek-T: A biomechanical model of the human spinal system. *Proc-Inst-Mech-Eng-H*. 205(1): 19-26, 1991.

16) Dolati B and Spiss R: Elastic stabilisation of the symphysis and the sacroiliac joint. *Surgery of the Pelvis and Acetabulum:* First International Consensus, Pittsburgh, Pennsylvania, 1992.

17) Dolati B: Pathomechanism of open book injuries. Experimental study.*Surgery of the Pelvis and Acetabulum*: First International Consensus, Pittsburgh, Pennsylvania, 1992.

18) Ecke H, Patzak HJ and Hofmann D: Bridging tension band fixation - a method to reconstruct symphysis pubis and sacroiliac joint disruption. *Unfallchirurgie* 17:335-342, 1991.

19) Engelhardt P: Malgaigne's pelvic girdle injury in children. *Ortopäde.* 21:422-426, 1992.

20) Euler E, Betz A, and Schweiberer L: Diagnosis, classification and indication for operative treatment in pelvic fractures. *Orthopäde* 21:354-362, 1992.

21) Euler E, Krueger P, Betz A: Pelvic fractures - do they have to be stabilized? *Unfallchirurg* 95:174-180, 1992.

22) Fabeck L, Descamps PY, Bourgois R and Dhem A: Contribution to the study of pelvic stress during weight-bearing. Role of the pubic branch and trabecular bone. *Rev-Chir-Orthop-Reparatrice-Appar-Mot.* 80(3): 181-7, 1994.

23) Friis EA, Cooke FW, McQueen DA and Henning CE: Effect of bone block removal and patellar prosthesis on stresses in the human patella. *Am-J-Sports-Med.* 22(5): 696-701, 1994.

24) Fyhrie DP and Schaffler MB: The adaptation of bone apparent density to applied load. *J Biomech.* 28(2): 135-46, 1995.

25) Ganz R and Gerber C: Abnormal sequel of skeletal injuries to the growing hip and pelvis. *Ortopäde* 20:346-352, 1991.

26) Girgis GH, Marshall DVM and Al Monajem ARS: The Cruciate Liagaments of the Knee Joints *Clin Orthop Relat R* 106: 216-231, 1975.

27) Goldstein A, Phillips T, Sclafani SJA and al: Early open reduction and internal fixation of the disrupted pelvic ring. *The Journal of Trauma* 26:325-33, 1986.

28) Gordon R and Mears DC: Lateral Compression Injury of the Pelvis. *JBJS* [Am] 73-A:1399-401, 1991.

29) Grace J, Sim FH, Shives TC et al: Wedge resection of the symphysis pubis for the treatment of osteitis pubis. *JBJS* [Am] 71:358-64, 1989.

30) Grob KR, Neuhuber WL and Kissling RO: Die Innervation des Sacroiliacalgelenkes beim Menschen *Z Rheumatol* 54(2): 117-122, 1995.

31) Guha SC and Poole MD: Stress fracture of the iliac bone with subfascial femoral neuropathy: unusual complications at a bone graft donor site: case report. *BJ of Plastic Surgery* 36:305-306, 1983.

32) Haus J, Halata Z and Refior H.J: Propriozeption im vorderen Kreuzband des menschlichen Kniegelenges-morphologische Grundlagen. *Z Orthop* 130: 484-494, 1992.

33) Hearn TC, Willet M, Schoper A, DiAngelo D and Tile M: Mechanical response of the intact, disrupted and internally fixed pelvic ring to stance-related loading. *Surgery of the Pelvis and Acetabulum:* First International Consensus, Pittsburgh, Pennsylvania, 1992.

34) Hofmann D: Ruptures of the pelvic halfjoints. Comparative analysis of different stabilization methods. *Unfallchirurgie* 17247-252, 1991.

35) Holdsworth FW: Dislocation and fracture dislocations of the pelvis. *J Bone Surg* 3OB:461-466, 1948.

36) Hu RW and Bohlmann HH: Fracture at the Iliac Bone Graft Harvest Site Following Fusion of the Spine. *Clin Orthop* 309: 208-13, 1994.

37) Hu RW, Hearn TC and Yang J: Bone Graft Harvest Site as a Determinant of Strength of the Anterior Superior Iliac Spine. *Clin Orthop* 310:252-6, 1995.

38) Ichihashi K, Imura S, Oomori H and Gesso H: Stress analysis on the acetabular side of bipolar hemiarthroplasty by the two-dimensional finite element method incorporating the boundary friction layer *Nippon-Seikeigeka-Gakkai-Zasshi* 68(11): 939-52, 1994.

39) Jia X, Paulsen KD, Buechler DN, Gibbs FA Jr and Meaney PM: Finite element simulation of Sigma 60 heating in the Utah phantom: computed and measured data compared. *Int-J-Hyperthermia* 10(6): 755-74, 1994.

40) Kellam JF and Browner BD: Fractures of the Pelvic Ring. In Skeletal Trauma, Edited by Browner B, Jupiter J, Levine A and Trafton P. Philadelphia, *W.B. Saunders Co.*, 1997.

41) Kellam JF, McMurty R, Paley D, Tile M: The unstable pelvic fracture: Operative treatment. *Orthop.Clin.NorthAm* 18:25-41, 1987.

42) Kennedy JC, Weinberg HW and Wilson AS: The Anatomy and Function of the Anterior Cruciate Ligament. *JBJS Am* 56-A, No. 2: 223-232, 1974.

43) Kraemer W, Hearn T, Powell JN and Tile M. The effect of thread length and location on extraction strengths of iliosacral lag screws. *Injury* 25:5, 1994

44) Kurz LT, Garfin SR and Booth RE: Harvesting Autogenous Bone Iliac Bone Grafts. *Spine* 14:1324-1330, 1989.

45) Lenz J, Schwarz S, Schwickerath H, Sperner F and Schafer A: Bond strength of metal-ceramic systems in three-point flexure bond test. *J-Appl-Biomater* 6(1): 55-64, 1995.

46) Lewis G: A parametric finite element analysis study of the stresses in an endosseous implant. *Biomed-Mater-Eng* 4(7): 495-502, 1994.

47) Lichtbau S: Dislocation of the Sacroiliac Joint. *JBJS* 44A:193-198, 1962.

48) Liebergall M, Lowe J, Whitelaw GP, Wetzler MJ and Segal D: The floating hip. *JBJS* [Br] 74-B:93-100, 1992.

49) McMurtry R, Walton D, Dickinson D, Kellam JF, Tile M: Pelvic Disruption in the Politraumatized Patient: A Management Protocol. *Clin.Orthop* 151:22-30, 1980.

50) Miyatsu M, Atsuta Y, and Watakabe M: The Physiology of mechanoreceptors in the anterior cruciate ligament. *JBJS Br* 75-B, No 4: 653-657, 1993.

51) Monahan PR, Taylor RG: Dislocation and fracture dislocation of the pelvis. *Injury* 6(4):325-333, 1994.

52) Müller R, Hildebrand T and Rüegsegger P: Non-invasive bone biopsy: a new method to analyze and display the three-dimensional structure of trabecular bone. *Phys-Med-Biol.* 39(1): 145-64, 1994.

53) Neurath M F and Stofft E: Collagen ultrastructure in ruptured cruciate ligaments. *Acta Orthop Scand* 63 (5): 507-510, 1992.

54) Oni OO, CapperM and Soutis C: An investigation of the bending stiffness of and the plane stresses generated by a flanged external fixator pin. *J-Orthop-Trauma* 9(1): 83-8, 1995.

55) Pennal GF, Tile M and Waddell JP et al: Pelvic disruption: Assessment and classification. *Clin.Orthop* 151:12-21, 1980.

56) Pohlemann T, Angst M, Schneider E, Gancz E and Tscherne H: Fixation of transforaminal sacrum fractures: A biomechanical study. *J. Orthop Trauma*, 7: 107-117, 1993.

57) Pohlemann T, Gänsslen A, Kiessling B et al: Indications for osteosynthesis in fractures of the pelvis and technique of stabilization. *Unfallchirurg* 95:197-209, 1992.

58) Pohlemann T, Kiessling B, Gänsslen A et al: Standardized osteosynthesis techniques in the pelvis. Analysis of the case files and operative technique. *Orthopäde* 21:373-384, 1992.

59) Prat J, Juan JA, Vera P, Hoyos JV et al: Load transmission through the callus site with external fixation systems: Theoretical and experimental analysis. *J-Biomech.* Apr; 27(4): 469-78, 1994.

60) Rieger H, Penning D, Burg E: Pelvic ring lesion and abdominal trauma. *Unfallchirurg* 94:110-115, 1991.

61) Ritz W: Über eine neue Methode zur Lösung gewisser Variations probleme de matematischer *Physik, j.f.d. reine u. angew. Math.* 135:1-61, 1909.
62) Roder JD, Stubinger B, Gmeinwieser J et al: Results of postoperative treatment of pelvic fractures in polytraumatized patients. *Akt.Traumatol* 18:129-133, 1988.

63) Rommens PM, Vanderschot PM and Broos PL: Conventional radiography and CT examination of pelvic ring fractures. A comperative study of 90 patiens. *Unfallchirurg* 95:387-392, 1992.

64) Rommens PM, Vanderschot PM, DeBoodt P et al: Surgical management of pelvic ring disruptions. Indications, techniques and functional results. *Unfallchirurg* 95:455-462, 1992.

65) Routt MLC: Complications of percutaneous iliosacral screw fixation. *Surgery of the Pelvis and Acetabulum:* The Second International Consensus, Pittsburgh, p59.1994.

66) Routt MLC, Simonian PT, Agnew SG and Mann FA: Radiographic recognition of sacral alar slope for optimal placement of iliosacral screws: A cadaveric and clinical study. *J Orthop Trauma*, 10: 171-177, 1996.

67) Routt MLC, Simonian PT and Grujic L: The retrograde medullary superior pubic ramus screw for the treatment af anterior pelvic ring disruptions: The technique and early results. *Surgery of the Pelvis and Acetabulum:* The Second International Consensus, Pittsburgh, p52.1994.

68) Schatzker J and Tile M: The rationale of operative fracture care. (2nd Ed.) *Springer-Verlag,* 1996.

69) Schoepfer A, Hearn TC, Di Angelo D and Tile M: Biomechanical comparison of fixation methods of vertically unstable pelvic ring disruptions. *59th Meting of the American Academy of Othopaedic Surgeons*, Washington DC, USA, 1992.

70) Seiler H: Timing osteosynthesis in pelvic injuries. Advantages and disadvantages of early operative care. *Unfallchirurg* 95:181-184, 1992.

71) Shirado O: Thoraco-lumbar burst fractures; an experimental study on cadaveric spines and finite element method. *Nippon-Seikeigeka-Gakkai-Zasshi* 67(7): 644-54, 1993.

72) Slätis P, Huittinen VM: Double vertical fractures of the pelvis: a report on 173 patients. Acta Chir Scan 138:799-807, 1972.

73) Steele JR, Basu A and Job A: A three-dimensional representation of an athletic female knee joint using magnetic resonance imaging. *Med-Eng-Phys* 16(5): 363-9, 1994.

74) Stoll P. and Schilli W. Long-term Follow-up of Donor and Recipient Sites after Autologous Bone Grafts for Reconstruction of the facial Skeleton. *J. Oral Surgery* 39:676-677, 1981.

75) Stuart PR, Talbot D and Milne DD: Internal fixation of pubic symphysis diastasis with a tension banding technique. *Journal of Accident Surgery* 21:223-4, 1990.

76) Taeger K: Anaesthesiology problems and point to consider in the care of severe pelvic injuries. *Unfallchirurg* 95:185-8, 1992.

77) Teubner E, Gerstenberger F: Kinematic analysis of the human pelvis. Pathomechanics and grading of dislocations of the pelvic joints, and kinematic and clinical implications for their operative treatment. *Unfallchirurg* 95:50-57, 1992.

78) Tile M: Pelvic ring fractures: Should they be fixed? *JBJS* [Br] 70-B:1-12, 1988.

79)Tile M and McBroom R: Disruptions of the pelvic ring. *Orthop.Transam* 6(3):493, 1982.

80) M.Tile, G.F.Pennal: Pelvic disruption:Principles of management.*Clin.Ortop* 151:56-64, 1980.

81) Timoshenko S and Gere JM: Theory of Elastic Stability. *McGraw-Hill Book Co., Inc. (2nd Ed.)*, 1961.

82) Timoshenko S and Goodier JW: Theory of Elasticity. *McGraw-Hill Book Co.,Inc. (3rd Ed.)* 1969.

83) Timoshenko S and Woinowsky-Krieger S: Theory of Plates and Shells.*McGraw-Hill Book Co., Inc. (2nd Ed.)*, 1959.

84) Tscherne H and Pohlemann T: Modern techniques in fractures of the pelvic ring including acetabular fractures. *Langenbecks Arch f. Chirurgie.* Suppl. Kongressband 491-6, 1991.

85) Varga E, Hearn TC, Powell J and Tile M: Effects of method of internal fixation of symphyseal disruptions on stability of the pelvic ring. *Injury* 26: No2: 75-80, 1995.

86) Varga E: Cannulated Iliosacral Screw. In SANATMETAL® Catalog, 1997.

87) Varney M, Fischer I, Becker H. et al: Intraabdominal injuries in politraumatized patients with pelvic fractures. Difficulty in diagnose and treatment. *Akt. Tarumatol* 20:226-230, 1990.

88) Vécsei V: Results of biomechanical examinations of various external fixation mountings in the pelvic region. *Akt. Traumatol* 18:261-264, 1988.

89) Vrahas M, Hearn TC, Diangelo D, Kellam JF. and Tile M: Ligamentous contributions to pelvic stability. *Orthopedics* 18(3):271-274, 1995.

90) Vukicevic S et al: Holographic analysis of the human pelvis. *Spine* 16(2): 209-214, 1991.

91) Zimmermann T, Patzak HJ, Kelm C et al: Teratment of ruptures of the symphysis and iliosacral joint in pediatric patients. *Eur J Pediatr Surg* 2:348-351, 1992.

VIII. Acknowledgments

Departments:
The *cadaver biomechanical studies* were performed at the Orthopedics Biomechanical Research Laboratory of the Sunnybrook Medical Center, University of Toronto, Canada during my Research Fellowship.

The *histological procedures* were performed at the Anatomy Department of Albert Szent-Györgyi Medical University, Szeged, Hungary.

The *finite element analysis* procedures and *medical image processing* were completed with the assistance of the Institute of Machine Design of Technical University of Budapest, Hungary and the Department of Applied Informatics of József Attila University of Szeged, Hungary.

SANATMETAL Kft., Eger, Hungary, produced the 10-mm, cannulated iliosacral screws.

The *biomechanical testing* of the newly developed 10 mm iliosacral screws were performed in the Biomechanical Lab. of the Orthopedic Department at the University of Kentucky, Lexington, USA.

Most of the *clinical trials* were performed in the Department of Trauma Surgery, Albert Szent-Györgyi Medical University, Szeged, Hungary. Some clinical trials were performed in other Trauma Centers in Hungary in Debrecen, Pécs and Kecskemét.

Persons:
From abroad: prof. Marvin Tile FRCS(C), Richard Hu FRCS(C), Joseph Schatzker FRCS(C), Terry Woodside B.Sc. (eng.)(Canada) Trevor C. Hearn Ph.D. (math.) (Australia) James F. Kellam FRSC(C), John T. Gorczyca M.D. Michael J. Bosse MD, Stephen H Sims MD, Dana C. Mears M.D., Jorge Alonso M.D., Brent L. Norris M.D. (USA), Matej Cimerman M.D. Martin Tonin M.D. (Slovenia)
In Hungary: prof. Dux László, dr. Kuba Attila, dr. Sándor László, prof. Mészáros Tamás, prof. Simonka János Aurél, prof. Biró Vilmos, prof. Nyárádi József, dr. Fröhlich Péter, prof. Bodosi Mihály, prof. Váradi Károly, dr. Kiss Gyula, dr. Süveges Gábor, dr. Nacsai István, dr. Bartha László, dr. Berki Sándor, dr. Tomka János, dr. Török László, dr. Balogh Zsolt, dr. Dudás Bertalan, dr. Janka Csaba, Hazenfrancz Péter, Kónya László, Halmai Csongor, Almássy László, Itzédy László, Ernest Nagy, Christine Powell, dr.Gyimóthy Tibor, prof. Csernay László, dr. Kiss Mariann, dr. Vörös Erika, dr Kardos Lilla, dr. Hortobágyi Anna, dr. Hudák Klára, dr. Kiss Erika, Vassné dr. Csukonyi Katalin, Tóth Magdolna, Thékes Lászlóné, Bencsura Kata, Suti Andrea, Szakáli Ferencné, Dudás Terézia, Gábor Eszter, Ilovai Katalin, Orosz Andrea, Fekete Ilona, Zsák Krisztina, Kaposvári Péterné, Siklósi Andrásné, Korbay Istvánné, dr. Kaptás Tibor, dr. Elek Péter, dr. Papp Tibor, dr. Barzó Pál, dr. Ringler András, Nyerges János, Duka Félix, Tiszaközi Attila, Lidia Földvári dr., Farkas József, Schmuczer Tibor.

Furthermore, I would like to thank all of my unnamed colleagues, ever so much who, supported this research.

Exceptional thanks to my family for their patience, devotion and understanding.

APPENDIX