

Combined 6th Conference of European Orthopaedic Research Society and 10th Conference of Nordic Orthopaedic Research Society

Bergen, June 15–16, 1996

Editor: Antti Alho

ORTON Orthopaedic Hospital
Invalid Foundation
FIN-00280 Helsinki
Finland

Joint replacement

1. Rough or polished cemented femoral stems?

N Verdonshot, E Tanck, R Huiskes

Biomech Section, Inst of Orthop, Univ of Nijmegen,
Nijmegen, The Netherlands

Failure of femoral cemented THA reconstructions is initiated by debonding of the stem–cement interface. The effects of debonding can be minimized by increased stem–cement friction. Hence, it can be hypothesized that debonded stems should have a rough surface to minimize cement damage.

Materials and methods: Tapered stems with varying surface finishes were implanted in cement mantles and cyclically loaded. After the tests, cement damage was assessed using scanning electron microscopy (SEM). These laboratory experiments were simulated with an axisymmetric finite element (FE) model (Figure 1). Different friction coefficients, representing different stem roughness values, were implemented at the stem–cement interface. To study the local effects of prosthetic surface roughness on the cement stresses, a local FE model was used, representing a detailed area of the interface (Figure 1).

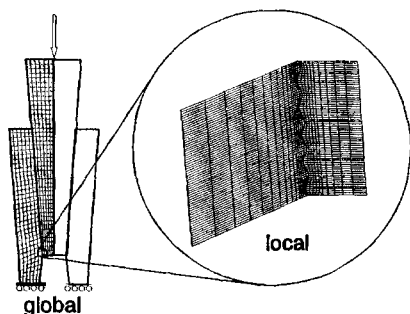


Figure 1.1. The FE model.

Results: SEM analysis of the taper–cement structures showed that the cement damage increased with increasing surface roughness (Figure 2). These results conflicted with those predicted in the global FE analysis. This model predicted decreasing peak stresses, suggesting decreasing cement damage, with increasing surface roughness (Figure 2). The local FE model, however, did predict the results of the laboratory experiments; the local cement peak stresses increased with increasing surface roughness. The model also predicted that after a particular surface roughness, the local cement stresses would decrease again (Figure 2). The roughness value at which this occurred was higher than those of the stems tested.

Conclusion: The study showed that to minimize cement damage and improve the long-term endurance of cemented femoral stems, debonded stems should be either polished or have a very rough surface.

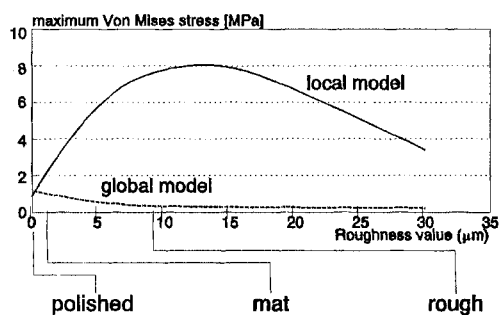


Figure 1.2. C indicates cement, S the prosthetic stem, and I the interface.

2. Load transfer of two press-fit acetabular components in total hip arthroplasty compared to the natural human hip joint

K-H Widmer, B Zurfluh, B Göpfert, EW Morscher

Lab for Orthop Biomech, Univ of Basle and
Orthop Dept, Felix Platter-Hospital, Basle, Switzerland

The implantation of an endoprosthesis alters the mechanical loading conditions of the bone in a significant manner. For noncemented acetabular sockets a hemispheric form appears to be optimal preserving the subchondral plate and enabling close contact. It can be hypothesized that for long-term clinical success the preservation of physiological bone stresses is another prerequisite. Therefore contact areas and stresses before and after implantation of an uncemented socket were investigated.

Materials and methods: In 8 cadaveric hips the pressure was recorded using the Prescale pressure sensitive foil in the natural hip and after implantation of an uncemented hemispheric PCA cup and Press Fit cup under press fit conditions. A single leg stance with body loads up to 1400 N was simulated, thus producing hip joint forces up to 4.5 times the body weight. Digital image analysing methods were used to calculate contact areas.

Results: Contact area in the natural joint was 34% of the articulating surface at 1400 N. Both cups produced higher stresses and contact areas, the Press Fit cup performing better. The pressure distribution pattern showed local maxima at the anterior, superior and posterior part of the acetabulum.

3. Does bone act as a constraint against subsidence around polished tapered THA stems?

N Verdonshot, R Huiskes

Biomech Section, Inst of Orthop, Univ of Nijmegen,
Nijmegen, The Netherlands

Debonding of the stem-cement interface may lead to stress elevations in the cement mantle. However, cement stresses do not increase after debonding when the bone is of high quality and serves as a constraint against prosthetic subsidence and subsequent cement stress elevation. This suggestion was tested in this study.

Materials and methods: A computed tomography (CT) based 3-dimensional finite element (FE) model of straight tapered, collarless prosthesis implanted in a femoral bone was created. The elastic moduli of the bone elements were determined using the CT-data and the relation reported by Carter and Hayes (1977). Bone stiffness was determined using the CT-data and varied between normal, low and high. In the latter two cases the elastic moduli of bone were 10 times lower and higher, respectively, as compared with normal. Stem-cement interface conditions were assumed to be either fully bonded or unbonded ($\mu=0.25$). The effects of the bone stiffness on the cement stress levels were determined

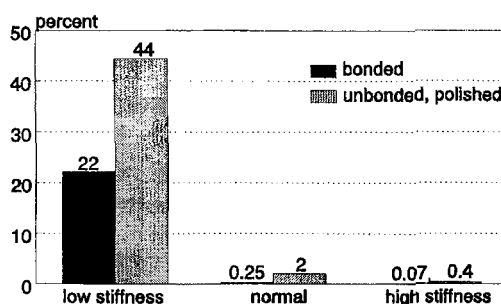


Figure 3.1. The effects of bone stiffness and stem-cement interface on the long-term failure probability of the cement mantle.

by calculating the long-term failure probability of the cement mantle. This failure probability was defined as the percentage of cement volume loaded at a stress level higher than the average strength of bone cement after 10 million loading cycles.

Results: The bone properties and stem-cement interface conditions had a considerable effect on the failure probabilities of the cement mantles (Figure). In every case considered in this study, the bonded stem produced a lower failure probability than the unbonded one. A lower bone stiffness led to an increase of the long-term failure probability of the cement mantle, for both stem-cement interface conditions.

Conclusion: An increased bone stiffness reduces the failure probability of the cement mantle, regardless of the interface condition. The constraining capacity of the bone does not prevent stress elevations after stem-cement debonding, even when the surrounding bone is of high stiffness.

4. Total knee arthroplasty can cause strain-adaptive bone resorption in the distal femur

GH van Lenthe, MC de Waal Malefijt, R Huiskes

Biomech Section, Inst of Orthopaedics, Univ of Nijmegen,
Nijmegen, The Netherlands

Total knee arthroplasties promote periprosthetic bone resorption. In this study the hypothesis was tested that this bone loss can be explained by stress shielding, and that prosthetic bonding characteristics affect bone mass maintenance.

Materials and methods: A finite element model was constructed of an average femur with an implanted knee prosthesis (Figure 1). The long-term prediction of bone density was based on a strain-adaptive bone remodeling theory. The amount of bone remodeling was determined by calculating the gradual changes in BMD from simulated DEXA-scans.

Results: The simulations predicted enormous bone loss (Figure 2), especially in the anterior distal region. In the unbonded analysis the process of bone resorption was slower and resulted in higher BMD.

Conclusion: Comparison of the results with clinical data revealed that similar resorption patterns are found. It is con-

cluded that long-term bone loss under the femoral knee component can be explained by stress shielding. Our results suggest that it can be limited by component design and fixation characteristics.

Acknowledgement: This work was sponsored by the Dutch Platform Alternatives for Animal Experiments.

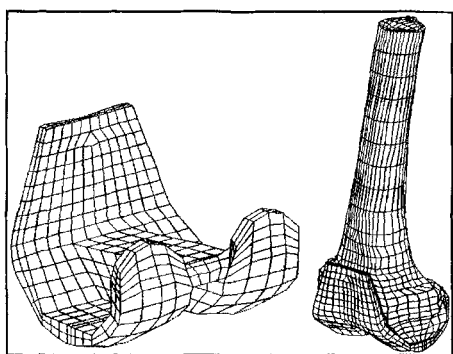


Figure 4.1. Finite element model of prosthesis and operated femur.

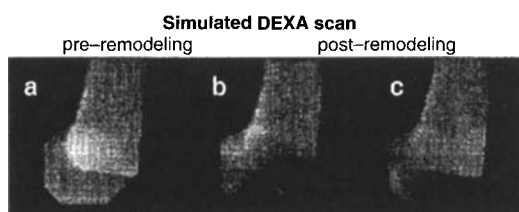


Figure 4.2. Simulated lateral DEXA scans. Prosthesis and cement were removed from the FE model before the DEXA-simulation was carried out. a. Directly postoperative. b. Long-term, bonded. c. Long-term, unbonded.

5. Transepicondylar axis as rotational guide in TKA

DP Pioletti^{1,2}, F-M Meyer¹, P-E Leyvraz¹, P Lemaire¹

¹Hôpital Orthop de la Suisse Romande, Lausanne, ²Biomed Engineering Lab, EPF-Lausanne, Switzerland

When the posterior condyle reference is missing, some authors have described the transepicondylar axis as being a valuable alternative landmark for rotational femoral alignment. The goal of this study was to determine the relationship between these two reference axes.

Materials and methods: Medial and lateral epicondyles of 20 Caucasian human cadaver knees (mean age 70 ± 7 years) were manually marked with two 0.8 mm tantalum pellets. Specimens were examined by CT-scan and then reconstructed in 3D. From these reconstructions, the position of the 2 pellets were located defining a "clinical" transepicondylar axis. Then a second transepicondylar axis was de-

fined, named "anatomical" hereafter. The posterior condylar line was also extracted. We defined 2 angles in the horizontal plane: α_{clin} between the "clinical" transepicondylar axis and α_{anat} between the "anatomical" transepicondylar axis and the posterior condylar line.

Results: For 90% of the specimens, the angles α_{clin} and α_{anat} corresponded to an external rotation of the transepicondylar axis in regards to the posterior condyles line.

Table. Comparison between clinical and anatomical transepicondylar axis, degrees (1 SD)

	α_{clin}	α_{anat}
Men (10 knees)	6.6 (1.5)	7.0 (1.2)
Women (10 knees)	6.4 (2.5)	4.7 (3.5)
Total (20 knees)	6.5 (2.0)	5.8 (2.8)

Conclusion: The present study indicates that the transepicondylar axis is not a relevant reference for rotational positioning of the femoral prosthetic component. The clinical determination of this axis was difficult, corroborated by the large variation of the α value with the two methods used here. Nevertheless, when the posterior condylar line is no more accessible, this transepicondylar axis may be used clinically since it rather induces an external rotation of the femoral component improving the patellar stability.

6. Tibial component positioning in total knee arthroplasty

P Lemaire¹, DP Pioletti^{1,2}, FM Meyer¹, P-F Leyvraz¹, J-F Benvenuti^{1,2}

¹Hôpital Orthop de la Suisse Romande, Lausanne, ²Biomed Engineering Lab, EPF-Lausanne, Switzerland

The best positioning of the tibial implant is a compromise between the optimal cortical support and sufficient alignment of the extensor apparatus. The goal of this anatomical and radiological study was to investigate whether the use of an asymmetrical prosthetic tibial plateau may improve the performance of the construct.

Material and methods: 20 Caucasian human cadaver knees (mean age 70 ± 7 years) are examined by CT-scan. A symmetrical tibial prosthesis (Insall-Burstein II, Zimmer) and an asymmetrical one (Natural-Knee, Intermedics Orthopedics) of an fitting size are "computer-implanted" on the CT-slice passing 8 mm below the articular surface. For every prosthesis, a first implantation is made: the implant tray is placed in order to cover most of the tibial cortical periphery without overlapping. A second implantation is then performed: the same implant is placed with its antero-posterior axis aligned on the middle of the anterior tibial tuberosity (ATT). The angular difference δ between the two implantations is then calculated. The mean angles for symmetrical (δ_{sym}) and asymmetrical (δ_{asym}) trays are then compared.

*Results:***Table.** Angular difference between implementation with optimal coverage and implementation with optimal alignment on the extensor apparatus, degrees

	δ sym	δ asym
20 knees	9.8 (4.1)	19.1 (3.1)

Conclusion: The present study shows that it is impossible to achieve simultaneously an optimal coverage of the tibial epiphysis and a correct alignment of the extensor apparatus notwithstanding the implant geometry. The use of an asymmetrical implant increases the difficulty to achieve a satisfactory compromise. Therefore, it has no justification.

7. Calcium phosphate particles are found at the surface of polyethylene inserts implanted in humans

P Frayssinet¹, D Hardy², JC Cartillier³, JP Vidalain⁴,

¹Bioland, 132 Rte d'Espagne, F-31100 Toulouse, France,

²Hôpital St Pierre. Bruxelles, Belgique, ³Clinique Trarieux, Lyon, ⁴Clinique du Lac, Annecy, France

Calcium phosphate particles were found at the surface of polyethylene inserts implanted with hydroxyapatite- (HA-) coated devices. They were suspected of causing a third body wear leading to polyethylene (UHMWPE) debris release. We examined with SEM and EPMA a series of 11 UHMWPE inserts being implanted with or without HA- coated devices determining the chemical composition of particles found at the implant surface.

Materials and methods: Special precautions were taken by the surgeon to avoid the surface contamination. Proteins adsorbed at the surface were oxidised in a 1.5% NaCl solution for 24 hours. Then, depending on the cup depth, the surface was either directly observed or examined after fragmentation of the cup once its surface was protected.

Results: Most of the samples showed some metal particles at their surface. Alumina particles were found at the surface of one cup. All the implants but one had calcium phosphate particles at their surface, some of them being encrusted in the polymer and their surface flattened.

Conclusions: The presence of calcium phosphate particles at the surface of UHMWPE inserts implanted with non-coated devices suggests that the polyethylene surface provides a good seed material for heterogeneous crystallisation of calcium phosphate, specially in the zone where the polyethylene surface presents molecular periodicity or in the cracks and crevices.

8. Radiopaque bone cement additives cause osteolysis

A Sabokbar, Y Fujikawa, J Brett, NA Athanasou, and DW Murray

Nuffield Dept of Orthop Surg, Nuffield Orthop Centre, Univ of Oxford, Headington, Oxford, OX3 7LD, UK

Barium sulphate (BaSO_4) and zirconium dioxide (ZrO_2) are added to bone cement as radiopaque agents. There is some evidence that these additives enhance the foreign body macrophages reaction and inflammatory response. In previous studies we have demonstrated that when bone cement (PMMA) particles are added to macrophages, under the appropriate conditions these macrophages differentiate into osteoclastic cells and resorb bone. The aim of this study is to determine whether the addition of radiopaque agents to PMMA affects the amount of bone resorption.

Materials and methods: 3 types of bone cement particles ($<50\mu\text{m}$) were prepared: a) PMMA alone, b) PMMA plus ZrO_2 and (c) PMMA plus BaSO_4 . Monocytes were isolated from whole blood and incubated with particles on bone slices previously seeded with osteoblast-like cells. The co-cultures were maintained in the presence of $1,25(\text{OH})_2\text{D}_3$. Bone resorption was assessed by counting the number of bone resorption pits on the surface of bone slices ($n=4$), for each treatment in each experiment ($n=5$).

Results: In the absence of osteoblasts and/or $1,25(\text{OH})_2\text{D}_3$ there were no signs of bone resorption. In the presence of these, monocyte cultures containing all types of PMMA particles, were capable of differentiating into bone resorbing cells. It was found that the number of pits formed in cultures containing PMMA + BaSO_4 and PMMA + ZrO_2 particles, was significantly more ($p<0.0001$) than the number of pits formed with PMMA alone. There was also a significant difference between cultures containing BaSO_4 and ZrO_2 ($p<0.05$).

Conclusion: Both BaSO_4 and ZrO_2 stimulate bone resorption and may therefore contribute to loosening of cemented implants. In addition our results suggest that barium-containing bone cements are more potent in such stimulation than zirconium-containing ones.

9. Transport of wear particles through fibrous tissue interfaces around knee prostheses

X Yuan¹, L Ryd¹, and R Huiskes²

¹Dept of Orthop, Univ Hospital in Lund, S-22185 Lund, Sweden, ²Biomech Section, Inst of Orthop, Univ of Nijmegen, Nijmegen, The Netherlands

Wear particles are often found throughout the interface of retrieved endoprostheses and they have been identified as the initiators of loosening. The flow of joint fluid may be the mechanism by which they gain access to the interface. The objective of this study was to elucidate whether cyclic load

of a tibial component in the knee could induce flow in the interface of a pattern and magnitude which would explain the wear particle distribution.

Methods: The interface was modelled as a biphasic material with solid and fluid constituents and the DIANA biphasic finite element code was used to calculate the flow. A 2-D finite element model representing a knee joint with a cemented unicondylar Marmor tibial prosthesis was developed. The fluid was allowed to flow from the extreme periphery and from the top, adjacent to the tibial eminence. The load was applied cyclically at 0.5 Hz frequency (5 cycles) and acted on the central 7 % of the upper surface of the prosthesis.

Results: It was found that dynamic loading caused flow of the interstitial fluid within the interfacial layer. The peripheral region had a more pronounced flow of interstitial fluid, whereas in the central region it was only minute. Changing the soft tissue properties profoundly influenced the interstitial fluid flow. Increasing the soft tissue stiffness decreased fluid velocity, but did not change the pattern of fluid flow.

Discussion: This study indicates that the flow in the interface caused by cyclic compression is small and confined to the periphery of the prosthesis-bone interface. This flow would thus explain how wear particle may intrude in the order of 3-5 mm into the interface. This flow was most pronounced in fibrous connective tissue. Hence a composition of the interface of fibrocartilage instead of fibrous tissue would have considerable bearing on the results and would decrease the flow. These findings could not explain how wear particles can be spread out evenly throughout the interface. They are, however, in accordance with morphological studies of retrieved tibial components from well-functioning knee arthroplasties, showing wear particles penetrating the periphery.

10. The initial stability of femoral prostheses in human, bovine and sheep impacted bone graft

MJW Hubble¹, J-H Kuiper², ID Learmonth¹

¹Univ of Bristol, ²Robert Jones & Agnes Hunt Orthop Hospital, Oswestry, UK

A series of in vitro experiments have been performed to assess the initial mechanical stability of impaction bone grafted femoral components in three different bone graft types.

Materials and methods: Cadaveric sheep femora were cleared of all proximal cancellous bone to simulate the bone stock loss at revision THR. Impaction bone grafting was performed. 3 different milled cancellous bone graft types were used: human femoral heads from the Bone Bank (γ irradiated and stored at -70°C), sheep bone, also prepared by the Bone Bank, and defatted acellular processed bovine bone (Lub-boc). Impacted femora were loaded in a Mechanical Testings System. A 3-D dynamic extensometer, to record both translational and rotational displacement, was attached to the prosthesis and proximal femoral cortex. Loading was ap-

plied stepwise in 200 N increments, with cyclical loading at 0.5 Hz, 6 samples of each graft type were tested. Translational displacement of greater than 2 mm or rotational displacement exceeding 3 degrees was defined as failure.

Results: The largest recorded movements were subsidence and retroversion. At physiological loads (1 000 N in the sheep) prostheses were stable in all three graft types. Bovine bone was the most stable (mean subsidence 26 (SD 22) μm , mean retroversion 1.0 (SD 1.4) min), human bone the next (subsidence 77 (54) μm , retroversion 2.2 (2.9) min) and sheep bone the least (159 (66) μm and 3.2 (4.6) min, respectively). The difference between bovine and sheep bone was statistically significant. Loading was continued to failure. 12 of the 18 prostheses failed by 2400N (4xBW). In all cases this was associated with femoral fracture or cement restrictor migration, and could not be attributed solely to graft type.

Conclusion: We found that femoral prostheses cemented into impacted cancellous bone graft of human, sheep and processed bovine bone were all stable at physiological loads. This has supported the initiation of an in vivo animal study of the use of xenogenic bone as an alternative to allograft for impaction bone grafting in revision THR.

11. Mechanical characteristics of impacted morsellized bone grafts used in revision total hip arthroplasties

E Giesen, H Weinans, N Lamerigts, R Huijskes

Biomech Section, Inst of Orthop, Univ of Nijmegen, Nijmegen, The Netherlands

The use of impacted morsellized bone grafts has become popular in THA revision surgery (1,2). In laboratory loading experiments, it was shown that motions of the revised implant relative to the bone may occur (3,4). The purpose of this study was to establish the mechanical characteristics of the graft material.

Materials and methods: Cancellous bone of the goat sternum was morsellized and impacted in a container (Figure 1). The specimens were loaded by a prescribed displacement in an MTS testing machine, and the resulting forces were measured.

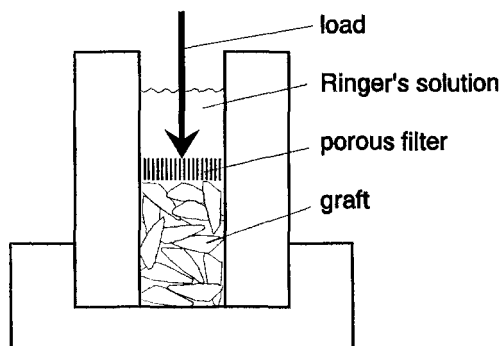


Figure 11.1. Experimental setup

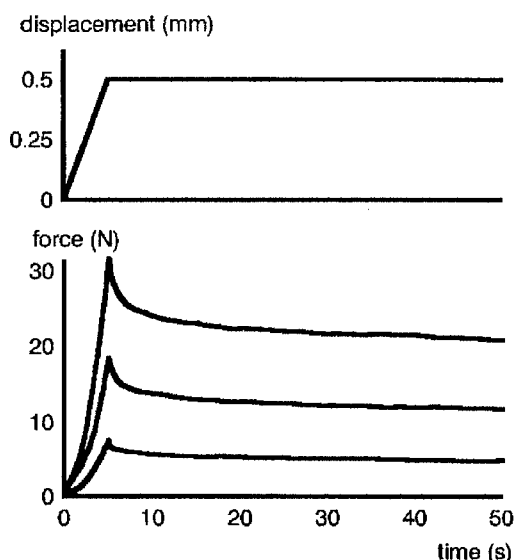


Figure 11.2. Prescribed displacement and force response vs time of three specimens.

Results: The general characteristics of the loading response were quite reproducible. However, the actual values varied greatly from specimen to specimen (Figure 2). The ramp strain produced a nonlinear force–response curve of increasing stiffness. After the maximal displacement was reached, the force exponentially relaxed to an equilibrium value. After release of the displacement, the specimen did not return to its initial dimensions.

Conclusions: The viscoelastic behavior is probably caused by the biphasic nature of bone chips surrounded by marrow, and the permanent deformation by the setting of the bone chips in relation to each other. This is influenced by the geometry of the bone chips and their volume fraction, which depends, in turn, on the degree of impaction. The morsellized graft material is dimensionally unstable directly postoperatively. Stabilization vehicles, such as acrylic cement, or special design features in noncemented fixation should be applied. The impaction procedure should be standardized relative to loads applied.

References: 1) Slooff et al (1984) *Acta Orthop Scand* 55:593. 2) Gie et al (1993) *J Bone Joint Surg* 75B:14. 3) Schreurs et al (1994) *Clinical Materials* 16:105. 4) Schreurs et al (1994) *Acta Orthop Scand* 65:267.

12. Graft composition influences early mechanical stability in impaction grafting

JH Kuiper, JC Merry, K Cheah, JB Richardson

School of Postgrad Med, Keele Univ, Keele, and Unit for Joint Reconstruction, Robert Jones and Agnes Hunt Orthop Hospital, Oswestry, UK

Impaction grafting is a promising method to revise failed

implants. Systematic research into the factors which influence its performance is scarce. The aim of this study is to determine whether graft composition influences early mechanical stability of an impaction-grafted implant.

Materials and methods: Using morsellized human and bovine graft, and hydroxyapatite (HA) particles, 8 groups were made: Standard (St), Coarse (Cr), Fine, Mixed (St and Cr), St $\pm$ HA 1mm, St $\pm$ HA 2 mm, St defatted and Bovine. From each group, 3 samples were impacted inside a metal tube using standardised impulses of 10.3 J/sec, equivalent to average surgical impaction. A taper was then inserted and axially loaded with 27 000 cycles between 10 and 500 N. Particle size distribution in each group was measured from contact radiographs using image analysis. Mineral content was measured using ashing techniques.

Results: On load application, we found an immediate subsidence followed by a continuing creep subsidence at decreasing rate. Creep subsidence was an exponential function of time, so a creep constant could be defined. Within each load cycle, we found pistoning of the taper. Initial subsidence showed large scatter. Only the graft St $\pm$ 2 mm HA showed marked less initial subsidence than the rest (0.27 ± 0.27 mm vs. 1.32 ± 0.50 mm). Creep subsidence was markedly less for the graft St $\pm$ 2 mm HA and the Bovine graft than for the others (0.29 ± 0.17 resp. 0.27 ± 0.12 vs. 0.64 ± 0.13). Taper pistoning did not vary much between the graft compositions (range 44–90 μ m) and no single graft performed significantly better.

Conclusion: Subsidence is facilitated by deformation and/or sliding and rolling of graft particles. Deformation will be prevented by increasing particle strength and stiffness, whereas sliding and rolling will be prevented by increasing particle size. Our results showed performance was only improved when both particle size and strength/stiffness were sufficiently increased. Both factors therefore play an equally important role, suggesting that relatively large particles of good quality bone is the best choice.

13. New bone formation in bone transplants fixed with bone cement

G Waertel¹, E Dingeldein², K Donath³

¹Orthop Klinik, Rheumazentrum, Bad Abbach, ²Coripharm GmbH & Co, ³Abt für Oralpathol, Inst für Pathol, Univ Hamburg, Hamburg, Germany

So far only little is known about the viability of bone grafts in combination with bone cement. Cytotoxic effects of the monomer, heat during polymerisation as well as separation of the bone transplant from the host bone might influence the survival of the bone transplant. In order to evaluate the influence of bone cement on bone transplants an experimental study was performed in mini pigs.

Materials and methods: In Group 1 bone transplants 5.5 mm in diameter and 7 mm in height were press fit inserted (at the bottom) in a bone defect, 9.6 mm in diameter and 10 mm in height, which was placed in the centre of the trochlea

of the femoral condyle. The remaining gap of 2 mm was completely filled with bone cement. In Group 2 the complete bone defect was filled with bone cement and the bone transplant pushed into the bone cement until it reached the base of the defect. In each group 8 animals received allografts in one side and autografts in the other; 4 animals in each group were killed after 5 and 10 weeks. For histological evaluation 2 undecalcified sections were prepared, one for histochemical detection of alkaline and acidic phosphatase, the other stained with toluidine blue for cell morphology.

Results: In group 1 (press fit transplants) active bone remodelling was seen in the autografts after 5 weeks. After 10 weeks no significant differences were found between the transplant and the host bone. Allografts showed new bone formation only in the basal part of the transplant, the press fit contact area, and distinct zones of bone resorption distant from the host bone. In group 2 (loose transplants) no difference was found between autografts and allografts. Only few areas of new bone formation could be located close to the host bone, wide zones of resorption prevailed distant from the host bone.

Conclusions: Bone cement did not inhibit bone ingrowth into autografts or allografts. Resorption seems to be correlated to the contact area between host bone and graft.

14. Cement penetration enhances compressive strength of bone-implant interface

JH Kuiper, P Kölringer, M Northmore-Ball

School of Postgrad Med, Keele Univ, Keele, and Unit for Joint Reconstruction, Robert Jones and Agnes Hunt Orthop Hospital, Oswestry, UK

A thin layer of bone cement on the tibial surface reduces instability and loosening of the tibial component in TKR. This study tests the hypothesis that penetrated cement increases the compressive strength of a bone-implant interface.

Materials and methods: Subchondral plates were removed from 10 bovine tibiae. Proximal ends were cut in 10 mm thick slices perpendicular to the tibial axis using a band saw, leaving a smooth surface. Group 1 had a flat cut surface. Group 2 was cemented and pressurised using a mould to ensure cement penetration. Indentation tests were performed with an 8 mm diameter flat indenter. Stress at failure was recorded. Cement penetration depth in group 2 was determined after testing.

Results: 40 specimens in group 1 and 39 specimens in group 2 were tested. A highly significant difference ($p < 0.001$, t -test) of mean compressive strength was found between the flat cut group (15.2 ± 9.6 MPa) and the cemented group (29.9 ± 13.3 MPa). Cement penetration depth varied between 0.3 and 4.5 mm. Correlation between penetration depth and compressive strength was weak ($r^2 = 0.09$). It was noticed however that little penetration (< 1 mm) did not exclude high strength, yet much penetration (> 3 mm) did exclude low strength.

Conclusion: Compared to a plain flat interface, penetrated

cement significantly enhances the compressive strength of the bone-implant interface. Cutting of bone exposes individual trabeculae which are normally interconnected. These trabeculae will be more prone to bending and buckling. Penetrated cement creates a new "subchondral plate" which restores the connections between the trabeculae and thereby helps to prevent bending and buckling. A cement penetration depth of at least 3 mm may be advisable to ensure high interface strength.

15. Effects of lamination on the strength of bone cement

G Flivik, X Yuan, L Ryd, R Juliusson, L Lidgren

Dept of Orthop, Univ Hospital, Lund, Sweden

To improve cement penetration into the acetabular cancellous bone in hip arthroplasty, it may be feasible to perform sequential cementation of each anchoring hole with a sealing nozzle followed by cementation of the entire acetabulum with a full size pressurizer. This procedure creates laminations in the cement, which may affect the cement strength.

Materials and methods: Palacos® cement bars made at 2, 3 and 4 min, respectively, after the start of cement mixing and with either dry laminations or laminations including blood or saline were tested in tension to the point of fracture. Solid unlaminated bars were used as references.

Results: Dry and saline laminations made up to 4 min after the start of cement mixing did not significantly decrease the strength of the cement. However, if blood was entrapped in the interface, there was a strongly time-dependent decrease in cement strength with a pronounced decrease in strength for laminations made at 4 min, less pronounced at 3 min and none at 2 min.

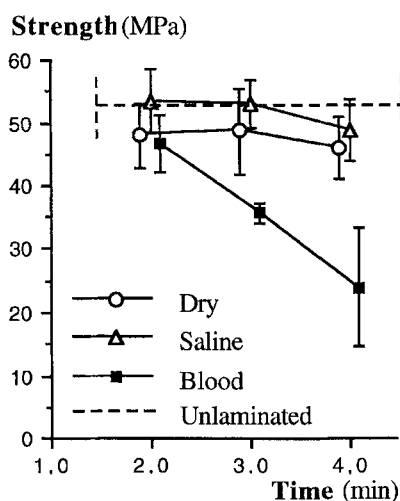


Figure. Relation between interfacial cement strength ($M \pm SD$) and time laps from start of cement mixing up to lamination for 3 different kinds of cement-cement interface.

Conclusion: A sequential cementation procedure is permissible from the point of view of cement strength, provided it is performed within 2–3 min after the start of cement mixing. If the cement area is kept free from blood or cleansed with saline, the time may be prolonged up to 4 min without the risk of weakening the cement strength.

16. Digitized migration measurement of stable hip arthroplasty stems

J Lepistö, A Alho, K Tallroth, M Dickob¹, M Thomas¹, and W Puhl¹

ORTON Orthop Hosp, Invalid Foundation, FIN-00280 Helsinki, ¹Orthop Dept, RKU, D- 89081 Ulm

Digitized migration measurement in hip arthroplasty is a method for early detection of component loosening. We studied the reproducibility of the stem migration measurement system of Dickob et al. (1994).

Materials and methods: The patients were 10 women and 14 men, median age 65 (49–78) years, who had undergone a Biomet uncemented arthroplasty using a stem with proximal porous coating. Clinical and radiographic studies were done 3, 12, 24, 60 and 84 months postoperatively. The radiographs were taken in a standing position using a standardised technique (Turula et al. 1985). None of the stems loosened during the follow-up. Postoperative radiographs were digitized using a CCD scanner, matrix of 2048 x 2048 pixels (PACE MEDICAL, Freiburg, D). Planar measurements of the stem were performed by marking reference points on computer screen. The radiographs 3 and 12 months postoperatively were compared, likewise the radiographs 12 and 24 months postoperatively. 13 radiographs were digitized again 9 months later and measured by the same observer (JL).

Results: The differences in stem axis and lesser trochanter – stem tip distance between two successive radiographs were 0.32° (0.24°) mean (SD) and 0.70 (0.56) mm during the 1st year and 0.26° (0.20°) and 0.67 (0.69) mm during the 2nd year, respectively. The differences between two measurements on the same radiographs were: stem axis 0.35° (0.24°), lesser trochanter to stem tip 3.54 (2.95) mm.

Discussion: We found an unsatisfactory reproducibility in defining the most medial point of the lesser trochanter when the same radiographs were measured repeatedly by the same observer after a long time interval. This problem was distinctly less, when radiographs were measured in 1 session. The present system of migration measurement detects stem subsidence ≥ 2 mm and stem axis changes $\geq 0.8^\circ$ when using of radiographs with standardised technique in standing position.

Conclusion: We found the method expedient and the accuracy corresponded to that of manual measurements.

References: Dickob et al. Transactions of Eur Orthop Res Soc 1994; 4: 18, Turula et al. Skeletal Radiol 1985; 14: 200–4.

17. Migration of porous acetabular cups with ceramic coating

J Kärrholm, J Thanner, H Malchau, P Herberts

Dept of Orthop, Sahlgrenska Hospital, S-413 45 Göteborg, Sweden

This study aimed to compare the fixation of porous coated acetabular cups with and without a coating of HA-TCP.

Patients and methods: 17 patients with primary or secondary arthrosis were operated with a porous coated acetabular cup. The implants had a 75–100 μ m thick layer of hydroxyapatite and tricalcium phosphate. From a database of 75 hips operated on with the same type of prostheses (Group 2), but without HA-TCP coating, 17 were matched according to gender, age, weight, diagnosis and cup size. Radiostereometric examinations in the supine position were done postoperatively and after 3, 6, 12 and 24 months. At 2 years 14 cases (all with HA-TCP) were examined standing on two and on one leg with the hip flexed to 15°–20°.

Results: At the 2-year follow up the absolute mean medial–lateral, proximal–distal and anterior–posterior translations of the cup centre had reached 0.19/0.21, 0.16/0.19, and 0.33/0.50 mm, respectively (Group 1/Group 2, n.s.). Increased rotations about the longitudinal axis were noted when no ceramic coating had been used ($p < 0.05$). In 8 of 14 cases inducible displacements of the cup (0.18–0.73 mm, 0.5°–3.5°) were detected. In the HA-TCP coated group the length of postoperative radiolucent lines decreased or remained unchanged in all cases. In the noncoated group an increase was noted in 8 and 2 cases on the AP ($p = 0.004$) and lateral views, respectively.

Conclusion: The HA-TCP coated implants displayed decreased rotations and improvement of the bone–implant interface after 2 years, suggesting ingrowth into a larger area. Even if this interface might be more resistant to leakage of joint fluid and particulate debris, the presence of inducible displacements after 2 years in some of the cases causes concern.

18. Telemetry of forces from a distal femoral replacement—data for walking and unilateral stance, and implications for fixation

SJG Taylor, PS Walker

Inst of Orthop, Univ College London, Stanmore, Middx, UK

Axial forces and torque were measured in a distal femoral replacement incorporating hydroxyapatite coating and a rotating knee hinge, in vivo. Force measurements at the tip of the IM stem and in the femoral shaft were made at intervals over 9 months, to see the progression of load transfer in the fixation. The ratio of these forces was half of that found in an implant having neither of these features.

Materials and methods: The prosthesis was modified to

enclose strain gauges and circuitry welded within cavities. The surgical procedure was normal. Power was induced and data telemetered using magnetic coupling between an implanted and external coil. The subject (female, age 40) walked unaided during measurements.

Results: The tip and shaft force peaks progressively increased from 0.2 and 1.0 BW respectively at 1.5 months to 0.5 and 2.25 BW at 6 months. The tip to shaft ratio increased from 7% at 1.5 months to 26% at 9 months. These figures are half of those recorded in a proximal femoral replacement not having HA coating (in which the ratio was 54% at 9 months). During stance phase, the axial torque peaked at 7Nm (internal).

Conclusion: The load transfer to the stem tip was significantly reduced, compared to a prosthesis not having HA coating, suggesting that bony bridging at the HA coated shoulder was effective.

This work was supported by Action Research.

19. Extracortical fixation for joint replacement

MJ Coathup, JP Cobb, PS Walker, PS Unwin, GW Blunn
Biomed Engineering, Univ College London, UK

A previous study using survivorship analysis has demonstrated a 55 % chance of a massive distal femoral prosthesis becoming aseptically loose after 10 years in patients under the age of 20 (1). An experimental goat model has been developed to investigate new concepts of fixation using extracortical plated prostheses suitable for massive segmental bone replacements.

Materials and methods: Proximally, either 2, 3 or 6 extracortical plates were anchored to the bone using transcortical bone screws (Figure 1). The plates were coated with hydroxyapatite. Bone remodelling and the interface around the plates were investigated using radiography, back-scattered scanning electron microscopy and histological techniques. Image analysis was used to quantify bone remodelling and FEA to calculate 2nd moments of area.

Results: None of the extracortical plates showed signs of loosening and in most cases a layer of bone surrounded them. Bone apposition of the external surface of the plate was a combination of periosteal bone production, invasion of bone through slots and bone growth over the ends of the plate (Figure 2,3).

Conclusion: The results show that the concept of extracortical plate fixation by bone apposition is worthy of further investigation. Bone appears to surround plates providing enhanced fixation. The plates appear to become integrated into the load-bearing structure of the cortex.

Reference: 1. J Arthroplasty 1993; 8: 259-68.

Funding: Medical research Council

20. Femoral vascular pattern following cementing or nailing the medullary canal—a microangiographic and fluorescence study

UE Pazzaglia, A Di Nucci, L Andriani

Clin Ortop e Traumatol Univ di Pavia – Varese, Ospedale F Del Ponte, I-21100 Varese, Italy

The bone response after medullary reaming is relevant for fixation of prosthetic stems.

Materials and methods: Both femura of Wistar rats (450 g) were implanted with cemented (right) and cementless rod (left). Routine histology, perfusion of the vascular tree with black indian ink and continuous tetracycline labeling were employed to characterize and quantify the bone response to the surgical procedures. At intervals of 7, 15 and 30 days appositional and remodeling activity was evaluated according to the following criteria: Metaphyseal, endosteal and periosteal apposition was graded 0, when there was no increase of the fluorescent bands width compared to normal control at 7 days or to the previous time interval in the same group, and + in the opposite case. Periosteal remodeling was graded in 3 classes according to the percentage of resorption cavities inside the labeled new matrix. Cortical remodeling was graded in 2 classes according to the number of osteons labeled by tetracycline (Table).

Results: Every change in bone, whether involving appositional or remodeling activity was led by proliferation progression and orientation of vessels. There was no endosteal apposition in cemented femura, because of occupation of the whole medullary space by the acrylic resin, but remodeling of subendosteal cortex occurred after 90 days. In cementless

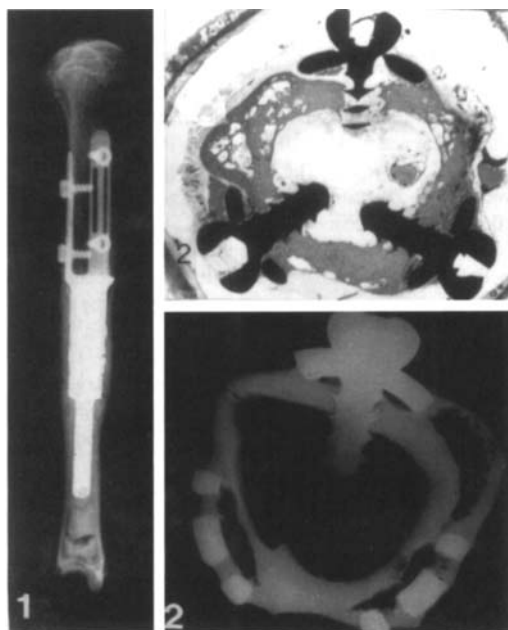


Figure 19.1-3.

stems endosteal apposition of primary woven bone and consequent remodeling formed the basis for bone ingrowth and anchorage of the implant. Periosteal apposition appeared as a general reaction to medullary reaming.

Conclusions: The anatomical factor (pattern of blood supply) has a relevant role to determine the structural organization of the mature lamellar bone around both cemented and cementless implants.

Table. Semiquantitative evaluation of fluorescence in the groups at intervals of 7, 15 and 30 days after continuous labeling with tetracycline (30 mg/Kg/day i.p.)

	Cemented			Cmtless			Reaming			Normal		
	7	15	30	7	15	30	7	15	30	7	15	30
Apposition												
metaphyseal	+	+	+	+	+	+	+	+	+	0	0	0
endosteal	0	0	0	+	+	+	+	+	+	0	0	0
periosteal	+	+	0	+	+	0	+	+	0	0	0	0
Remodeling												
periosteal	0	++	+	0	++	+	0	++	+	0	0	0
cortical	0	0	+	0	0	0	+	0	0	0	0	0

21. Evaluation of gluteal muscle function after endoprosthetic replacement of the proximal femur

A Giurea¹, T Paternostro², G Heinz-Peer³,
M Pretterklieber⁴, G Holzer¹, F Gottsauner-Wolf⁴

¹Dept Orthop, ²Dept Phys Med & Rehab, ³Dept Radiol,

⁴Dept Anat, Univ of Vienna, Vienna, Austria

Replacement of the proximal femur with endoprostheses is associated with loss of muscles and tendon insertions. We evaluated the differences of 2 methods for gluteal muscle reconstruction.

Patients and methods: 14 patients had a replacement of 9 proximal and 5 total femora using the KMFTR endoprosthetic system (I). Patients were divided into 2 groups: Group 1 (n=5): Refixation of a bone block carrying the medial gluteal tendon insertion onto the prosthesis. Group 2 (n=9): Soft tissue repair of the medial gluteal muscle without direct fixation to the prosthesis. Clinical evaluation was done using a modified ISOLS system (2). Isometric muscle strength of hip abduction and foot dorsal flexion was tested bilaterally with Cybex 6000. Gluteal muscle area and density were measured bilaterally on CT scan images.

Results:

Table. Clinical score, excellent and good results (%)

	ROM		Function		Pain		Deformity	
	Strength		Emot. accept.		Stability			
Group 1	60	60	40	80	80	60	100	
Group 2	78	32	56	89	89	43	100	

In group 1 (n=4), the average peak torque of hip abduction was 95% and of foot dorsal flexion 98% in comparison

with the non-operated leg. In group 2 (n=8), the respective values were 53 and 88%. In group 1 (n=4) the cross-sectional area of the medial gluteus muscle was 76% and muscle density 14% compared with the non-operated leg. In group 2 (n=6) the respective values were 52 and 17%.

Conclusion: Refixation of muscle/tendon insertions to endoprostheses resulted in higher isometric muscle strength and better clinical results for stability and strength but in a minor range of motion.

References: 1) Kotz R et al. Orthopedics 1986; 9: 1639. 2) Enneking W. In: Limb salvage in musculoskeletal oncology (ed. Enneking W), Churchill Livingstone 1987; p 626..

Knee

22. The morphology of failed insertion sites after in-vitro mechanical testing—an evaluation of ligament insertions around the rabbit knee

K Messner, J Gao, T Räsänen, J Persliden¹

Dept of Sports Med, ¹Dept of Radiophys, Faculty of Health Sciences, Linköping Univ, S-58185 Linköping, Sweden

The gradual transition from soft tissue to full mineralization at a chondral ligament insertion may enhance the ability of the structure to dissipate force evenly during loading and therefore reduce the risk of failure of this unit. The present study characterizes the failure mode of various chondral ligament insertions around the rabbit knee joint during tensile tests. Materials and methods: The left knees of 20 adult NZW rabbits were used. 10 knees were used for mechanical testing of the patellar, medial collateral and anterior cruciate ligament. The other 10 knees were used for testing of the posterior cruciate ligament and the anterior and posterior attachments of the medial meniscus. Load to failure was applied at low velocity along the anatomical alignment of the structures. The failure sites were evaluated by light microscopy including polarization.

Results: The patella ligament was the strongest and the medial meniscus posterior attachment the weakest structure. 3 typical failures were found macroscopically: avulsion fracture through subchondral bone (most common), avulsion through the insertion site without bone involvement, and a ligament midsubstance rupture. Histologically the failure characteristics were more complex involving several portions of the structure. There were combinations of avulsion fracture and midsubstance rupture or avulsion through the uncalcified fibrocartilaginous zone in the insertion. In rare cases, the ligament failed entirely at the cement line.

Conclusions: The present results confirm that failures only in rare instances concern the insertion site, probably because of its unique tissue characteristics. Failures rather occur in the ligament substance or the bone underneath the

insertion. Within the insertion the uncalcified fibrocartilaginous zone seems to be weaker than other areas in this specialised structure. In addition, the overall inferior structural quality of a ruptured ligament as shown histologically has to be taken into account when parts of the original structure are used for suturing or reconstruction.

23. Quantitative determination of the 3-dimensional changes in the subarticular mineralization of the tibial plateau following correction osteotomy

U Maier, H Anetzberger, KJ Pfeifer, R Putz, and M Müller-Gerbl

Radiol Chir Klinik München, Nussbaumstr 20, D-80336 München, Germany

2-D changes in the density maxima in the subchondral bone of the tibial plateau following correction osteotomy for genu varum have been recently reported. However, no information of the extension of the changes in depth is available. The aim of this investigation has therefore been to develop a method for demonstrating changes involving the extension in depth of the density maxima of the tibial plateau.

Materials and methods: Axial CT scans (1 mm section) were taken of both knees of 7 women (55–71 years) with genu varum, before and 1 year after a correction osteotomy. A C program was developed to evaluate the pre- and post-operative density values in each section followed by a statistical analysis.

Results: Postoperatively, the maximal number of pixels with a density >200 HU displaced to deeper layers, compared with the preoperative situation (average 4 sections). Following the osteotomy, all the treated knees showed a significant decrease ($p < 0.01$) in the HU values in the first 10 mm within 6 months, and a migration of the density maxima to deeper regions of the subchondral bone.

Conclusion: This new method provides us for the first time with a quantitative evaluation of the changes and extension in depth of the subchondral bone.

24. A new functional protocol for knee kinematic investigations

S Zaffagnini, L Nizzi Grifi, S Martelli, M Marcacci

Istit Ortop Rizzoli, Lab Biomecc, Bologna, Italy

The goal of this work was to improve the current accuracy of standard passive tests. Our protocol is based on the use of a passive arm to record position and orientations of the mobile tibia with respect to fixed femur.

Materials and methods: We used the standard Euler method to compute instantaneous rotations and absolute sensor's displacements to measure instantaneous translations. However, we computed a new cartesian frame related to the knee

motion (and anatomy) not needing anatomical landmarks.

Results: The X axis of this "functional reference frame" is perpendicular to the best least square plane fitting the 3D knee PROM. Y is the projection of the helical axis of the first 20 deg of flexion onto the YZ plane, Z is the floating axis (cross product of the two previous versors), the origin is the center of the best least square circle fitting the projection of the knee PROM onto YZ plane. To decompose instantaneous kinematic parameters at all flexion angle a mobile frame attached to the tibia is used, computed rotating the functional reference frame in extension by current angle of flexion (around X). Although knee PROM is not planar least square technique detects the main axis of rotation in a very repeatable way (< 1 mm), and X axis corresponds to the axis of flexion. Y axis corresponds to the secondary rotation near extension and has shown a good correlation with tibial axis in laxities tests. As a consequence Z corresponds to the AP direction and to varus–valgus rotations. This method of acquisition and this numerical elaboration of data coming from passive tests on the knee have shown a good accuracy (1 mm, 1 deg), have been used with a similar repeatability by different operators, give reliable rotations independent on sensor's position within the given accuracy and detect translations during Drawer or Lachmann test with 1.5 mm accuracy and repeatability.

Conclusion: We conclude that this protocol is suitable for improved intraoperative knee kinematics evaluations.

25. Refixation of the anterior meniscal attachment through a bone channel

K Messner, J Gao, X Wei

Dept of Sports Med, Faculty of Health Sciences, Linköping Univ, S-58185 Linköping, Sweden

Insufficient fixation and prolongation of the attachments were discussed as reason for the unsatisfactory results after meniscal replacement procedures. In the present study we characterize the healing tissue after refixation of the medial meniscus anterior attachment into a tibial channel.

Materials and methods: In 35 NZW rabbits the medial meniscal anterior attachment of one knee was transected and immediately refixed through a tibial channel using sutures. The other knee was left untreated. The animals were killed after 1, 3, 6 and 12 weeks. At each time interval 2 animals were used for immunohistochemical demonstration of types I and II collagen and nervous filaments; 3–6 animals each were used for histology; and at 6 and 12 weeks, the refixed attachment was loaded to failure in a material testing machine in 6 animals each.

Results: Granulative healing tissue which formed initially between the attachment and bone matured with time and showed attachment-specific calcified and uncalcified fibrocartilaginous zones already at 6 weeks. These zones were arranged in an oblique manner to the fibre orientation of the refixed tissue. With time the continuity of collagen fibres between the refixed tissue and the newly formed attachment

became more conspicuous. The healing tissue stained mainly for type-I collagen, but at 12 weeks type-II collagen appeared focally. Nerve filaments were found in the healing tissue by 12 weeks. Tensile strength of the refixed meniscal attachment improved with time, but did not gain more than 20% of normal strength. The refixed meniscus failed at the interface between the original tissue and the newly formed attachment.

Conclusion: Despite formation of a new attachment-like structure early after refixation, the mechanical strength of the refixed structure remained low, probably because of insufficient collagenous continuation between the original structure and the new attachment.

26. Sagittal plane knee translation in healthy and ACL deficient subjects during stair walking

A Vergis, J Gillquist

Dept of Sports Med, Linköping Univ, S-58185 Linköping, Sweden

The sagittal translation of the knee during stair walking was compared in anterior cruciate ligament (ACL) deficient and healthy subjects.

Patients and methods: The maximal sagittal plane knee translations were recorded by an electrogoniometer system (CA-4000, OS Inc., Hayward, CA, USA) during 2 types of ascents and descents (straight and side) in 15 healthy subjects (controls) and 14 patients with unilateral ACL deficiency confirmed previously by arthroscopy. The maximal absolute difference between the pathways of tibia during flexion and extension, in the ascent and descent cycles, at corresponding flexion angles, was defined as the maximal translation. The knee flexion angle at which maximal translation occurred as well as the maximum flexion angle during the activities were also recorded.

Results and conclusion: In all groups, during the ascents the tibia moved anteriorly in relation to femur whereas during the descents it moved posteriorly. The maximum translations differed significantly between individuals within a similar range of 1–12 mm (median: 8 mm) in both control and ACL deficient groups. One individual had a maximum translation close to 1 mm and three 1.5–2 mm. The maximal translations occurred at $38^\circ \pm 8^\circ$ of flexion in the involved knees of the ACL deficient group but at $44^\circ \pm 8^\circ$ in the control and non involved knees. In the ACL deficient group the maximal translation was similar in the involved and non involved knees.

27. Comparison of dynamic knee laxity during active and passive motion versus static laxity

A Vergis, M Hindriks¹, Jan Gillquist

Sports Med, Linköping Univ, S-58185 Linköping, Sweden,
¹Maastricht Univ, Maastricht, The Netherlands

Dynamic knee laxity during active and passive motion was compared with static laxity in healthy controls and anterior cruciate ligament (ACL) deficient patients.

Patients and methods: Both knees of 9 healthy controls and 7 patients with arthroscopically confirmed unilateral ACL deficiency were investigated with an electrogoniometer system (CA-4000, OSI, USA) during a-p laxity testing (20° flexion, 135N force), passive flexion-extension, and single step ascents and descents. Static laxity (SL) was determined between the points of significant increase in joint stiffness on the force-displacement curve. Passive laxity was defined as the difference between the tibial position at 45° knee flexion in the anterior and posterior motion limit curves obtained during passive flexion and extension of the knee. Active laxity was determined during ascent and descent of a 15 cm high step. The maximal absolute difference between the pathways of tibia during flexion and extension, in the ascent and descent cycles, at corresponding flexion angles, was defined as the active laxity. All measurements of each subject were calculated as the mean of the three repeated trials. The active and passive laxity were normalized to the static laxity.

Results and discussion: Smaller static laxity in controls than both non-injured and injured knees of the ACL group may reflect different mechanics of the non-injured knee following injury to the contralateral knee. During ascents the amount of active laxity was similar in all groups but the injured knees used a smaller percentage (42%) of the available static laxity compared with non-injured knees (85%) and controls (98%) indicating that the ACL deficient patients of our series were able to keep the active dynamic laxity within normal limits despite revealing abnormal laxity during static tests. The control mechanisms may depend on modification of the knee flexor muscle activity or geometry of the articular surfaces.

28. Simultaneous measurements of sagittal knee laxity with an external device and radiostereometry (RSA)—an in vivo study after reconstruction of the anterior cruciate ligament

LP Jorn, T Fridén, L Ryd, A Lindstrand

Dept of Orthop, Lund Univ Hospital, Lund, Sweden

We examined the total a-p displacement during simultaneous measurements with RSA and the Styker laxity tester^R.

Patients and methods: 4 women and 8 men, age 25 (17–37) years, were studied 3 years after an ACL reconstruction using the bone-patellar-tendon-bone as a free graft. Simultaneous measurements were performed at 90 N and 180 N in both anterior and posterior direction. The total a-p displacement was calculated for each set of loads and method.

Results: Recordings revealed an increasing laxity with in-

creasing load, when the external device was applied: 9.8 ± 1.6 mm at 90 N and 13.8 ± 3.7 mm at 180 N (p 0.0004, Figure). The corresponding recordings with RSA were 5.3 ± 2.7 mm at 90 N and 5.7 ± 2.4 mm at 180 N (n.s.). The difference between the external device and RSA increased with increasing load, and was significant at both 90 N (p 0.0001) and 180 N (p 0.0002).

Conclusion: RSA measurements documented an end-point of joint displacement at 3 years. More than 50% of knee laxity, as measured with the external device at 180 N load, was not an actual femorotibial displacement within the joint, but merely a systemic error from soft tissue deformation.

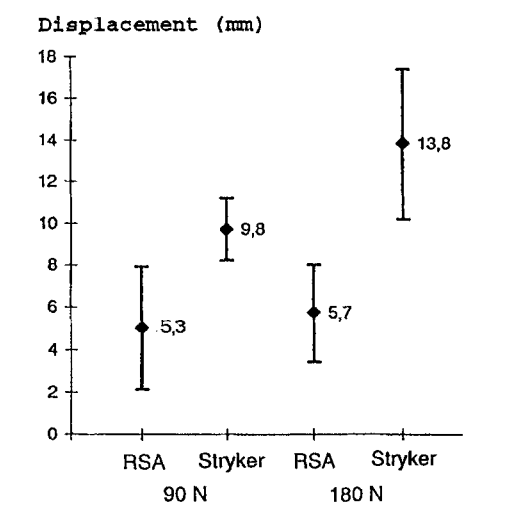


Figure 28.1. Mean total anterior-posterior displacement (mm) at 90 and 180 N loads 3 years after ACL reconstruction. Simultaneous measurements with RSA and Stryker Laxity tester[®].

29. The double-bundle structure of the PCL—an anatomical study for the design of a double-bundle reconstruction of the PCL

MEJ Stevens, TJA Mommersteeg, C van Doorn, AB Wymenga, A van Kampen, JGM Kooloos
Biomech Section, Inst of Orthop, Univ of Nijmegen, Nijmegen, The Netherlands

Posterior cruciate ligament (PCL) injuries are reconstructed in most cases with one single bundle. A double-bundle graft can potentially be better for restoring the function of the PCL. In this study the anatomy of the 2 bundles of the PCL was determined.

Materials and methods: Of 7 formalin fixed human knee specimens the 2 bundles of the PCL (ALB and PMB) were identified and isolated. Bundle lengths and cross-sectional areas were measured. The position of the bundle insertions and relevant anatomical landmarks were digitized electro-

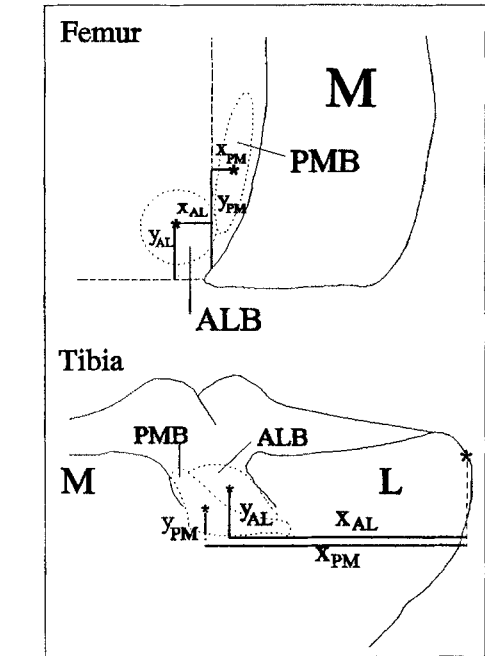


Figure 29.1.

magnetically. Distances between the centres of the insertion sites and the anatomical landmarks (the lateral epicondyle of the tibia (x_{AL} and x_{PM}), the posterior rim of the posterior fossa intercondylaris (y_{AL} and y_{PM}), the lower edge of the femoral notch (y_{AL} and y_{PM}) and the transition of the femoral notch and the lateral side of the femoral condyle (x_{AL} and x_{PM}) were calculated (Figure 1). These distances were scaled to an average human knee joint with a femora interepicondylar distance of 80 mm.

Results: The ALB and PMB had the same lengths (40.1 ± 2.7 mm and 40.0 ± 2.0 mm). The cross-sectional area of the ALB was twice that of the PMB (36.3 ± 7.8 mm² and 19.0 ± 6.4 mm²). The distances of the insertions sites of the ALB and the PMB relative to the bony landmarks are presented in Table 1.

Table 1. Mean distances (SD) in mm

Distances	Femur	Tibia
X _{AL}	2.0 (1.8)	40.2 (1.1)
Y _{AL}	6.1 (1.4)	9.3 (2.1)
X _{PM}	4.5 (2.1)	42.1 (1.9)
Y _{PM}	11.1 (3.0)	5.4 (1.9)

Conclusions: It appeared that the intra-individual variability in the 3-D positions and lengths of the bundles is surprisingly small. Apparently, the bundles can be identified in a rather consistent way. The PMB was much thicker than previously described in literature, which suggest the need for reconstruction of both bundles.

Bone healing

30. Effects of clodronate on bone mineral and fracture healing after a tibial fracture in the rat

JE Madsen^{1,2}, TB Larsen¹, J Falch³, O Kirkeby¹, L Nordsletten¹

¹Inst for Surg Res, Rikshospitalet, ²Orthop Dep, Ullevål Hospital, ³Dep of Int Med, Aker Hosp, Univ of Oslo, Oslo, Norway

Clodronate inhibits bone resorption by impairing the osteoclast activity, and seems to have little negative effects on bone mineralization (Kanis et al. Osteoporosis Int 1993; 3 Suppl2: 23–8). We studied the effects of clodronate treatment on bone mineral and fracture healing in a rat tibial fracture model.

Materials and methods: 35 male Wistar rats, mean weight 349 g, were allocated to 5 groups: Cl/Cl group (n=6) was injected with Clodronate (Bonefos®, Leiras) 10 mg/kg s.c. in 21 days before and 21 days after subjecting each rat's right tibia to a standardized fracture and stabilizing the fracture with an intramedullary nail. Cl/NaCl group (n=7) received clodronate before fracture and saline during the 21 days of fracture healing. The NaCl/Cl group (n=8) was given saline before fracture and clodronate during fracture healing. The NaCl/NaCl– group (n=9) received saline through the whole experimental period, and a fifth group (n=5) served as unfractured controls. 21 days after fracture the calluses were weighed.

Results: The callus weights were equal in the 4 fractured groups, and the biomechanical properties in 3–point bending did not differ between clodronate and untreated groups. BMC and BMD (DEXA) were 30% higher in the 3 groups receiving clodronate compared with the NaCl/NaCl group ($p<0.05$), but there were no difference between the 3 clodronate groups (Table).

Table. Results in different groups, mean (SD)

Group	n	Callus weight (mg)	Bending moment (Nm $\times 10^{-2}$)	BMC (g $\times 10^{-2}$)	BMD (g/cm $^2 \times 10^{-2}$)
Cl/Cl	6	0.18 (0.10)	4.7 (3.8)	0.30* (0.02)	0.17 (0.02)
Cl/NaCl	7	0.17 (0.25)	7.6 (6.1)	0.29* (0.03)	0.17* (0.01)
NaCl/Cl	8	0.26 (0.23)	4.6 (6.0)	0.29* (0.02)	0.17* (0.01)
NaCl/NaCl	9	0.15 (0.16)	4.3 (4.7)	0.23 (0.03)	0.13 (0.01)
Unfractured	5			0.22 (0.02)	0.14 (0.01)

* $P<0.05$ compared to NaCl/NaCl and unfractured groups.

Conclusions: Treatment with clodronate led to 30% higher BMC and BMD in the fractured tibiae, independent of whether clodronate was given before or after fracture, or throughout the whole experimental period. Fracture callus,

however, did not increase. The fracture healing period in this study was too short to detect any long-term clodronate effects.

31. Effect of indomethacin on growth and neovascularization of grafted bone—quantitative in vitro – in vivo analysis

M Leunig, F Yuan, DA Berk, LE Gerweck, RK Jain

Steele Lab, Mass Gen Hosp, Harvard Med School, Boston, MA, USA

The exact mechanisms by which indomethacin alters skeletal tissue generation in vivo are unknown, due in part to methodological limitations. The goal of this work was to quantify the effects of indomethacin in vitro and in vivo.

Materials and methods: By the use of an organ culture assay and dorsal skinfold chambers in T-cell deficient mice, the effect of indomethacin on growth and angiogenesis of neonatal femora was characterized over 16 days. This approach (Lab Invest 1994; 71:300–7) facilitates a non-invasive assessment of both parameters over several weeks by fluorescence microscopy using FITC—dextran and oxytetracycline. Angiogenesis and growth were quantified by means of computerized image analysis of brightfields and epifluorescence images. Each in vitro or in vivo group contained at least 6 samples.

Results: In both assays, femora significantly elongated with time ($p<0.05$). The in vitro growth rate was more rapid than in vivo exhibiting a saturable growth kinetic and dependent on the serum concentration, culture medium and age of mice. Although enhancing the serum content promoted cellular proliferation in organ culture, it dose-dependently suppressed femoral elongation leading at 20% fetal calf serum to identical growth rates as observed to in vivo. Indomethacin supplementation (2 and 10 mg/l) significantly accelerated longitudinal femoral growth in organ culture ($p<0.05$), whereas in vivo indomethacin (2 mg/kg) did not modulate either angiogenesis or elongation of bone.

Conclusion: Our in vitro data suggest an important role of serum in the regulation of bone formation. Albeit indomethacin altered femoral growth in vitro, our study does not support the notion that indomethacin suppresses angiogenesis or growth of bone in vivo. Complexity of physiological events in vivo might have been obscuring a detectable effect.

This work was supported in part by the NCI, SNF and AO/ASIF.

32. New technique for bioassay of osteoinductive substances—radiomorphometric measurement of bone induction in a membrane-guided muscle island flap

V V Viljanen, T–J Gao, TS Lindholm

Med School and Inst of Med Technology, Univ of Tampere, Tampere, Finland

Transformation of mesenchymal-type tissue into cartilage and bone can be induced by bone morphogenetic protein, and by its parent substratum, demineralized bone matrix. We searched for possibilities to test osteoinductive activity of osteoinductive substances in membrane-surrounded muscle island flaps to develop vascularized bones that could be used as autogeneic skeletal grafts.

Materials and methods: In Wistar rats, tubular latissimus dorsi muscle island flaps were created using microsurgical techniques. The flaps were inserted by a cylinder of demineralized bone matrix (DBM), and enclosed in silicone rubber membrane tubes (Figure 1). Rats with DBM implanted in muscle pouches served as controls. Radiomorphometry using an X-ray image scanner and a commercial image processor was developed for quantitative measurement of calcified tissue, the quality of which was confirmed by histology.

Results: A statistically significant linear time-related increase in measured calcified tissue was found in flaps with DBM from 10 days to 5 weeks (Figure 2). At 3 and 5 weeks lamellar and cancellous bone with fully developed marrow was detected microscopically. There was no significant difference in bone quantity in the island flaps after 35 days vs. the muscle pouches DBM, although the difference at 21 days had been still significantly in favor of the flaps.

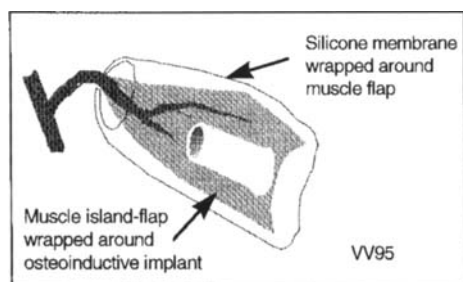


Figure 32.1. Preparation of a vascularized membrane isolated muscle island-flap with osteoinductive implant inside.

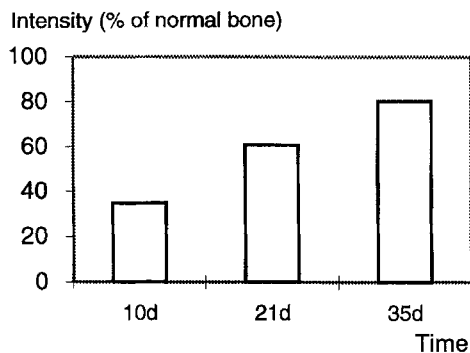


Figure 32.2. Radiomorphometry of calcified tissue induced by DBM in membrane-surrounded rat latissimus dorsi muscle island flaps. Note the increase of calcified tissue with time ($p < 0.001$).

Conclusion: Using allogeneic DBM in rat muscle island flaps surrounded with a silicone membrane it was possible to generate autogenous new bone with good vascular supply and good mobility, allowing of later transfer to another site. The experiment provided a basic method that can be used as a standard bioassay in testing different osteoinductive substances for the production of vascular-pedicled new bone.

33. Moose (*Alces alces*) bone morphogenetic protein: partial purification and characterization—preliminary observations on degradation of bone-inducing activity during storage

VV Viljanen, TJ Gao, A Marttinen, TS Lindholm

Med School and Inst of Med Technology, Univ of Tampere, Tampere, Finland

Materials and methods: Bone morphogenetic protein (BMP) was extracted from fresh bone matrix of the premature moose (*Alces alces*). Bone-inducing activity was investigated by implanting 0.5–20 mg of BMP into thigh muscle pouches of BALB mice. Radiologically detectable formation of new bone required 2.0 mg of partially purified BMP. Immediately after extraction, an analytic TSK4000SW chromatogram with known molecular weight (MW) markers showed three fractions with different MWs. After 15 months of preservation at +1°C lyophilized and desiccated, BMP was fractionated by HPLC gel filtration and bio-assayed. Osteoinductivity was evaluated qualitatively by histology and quantitatively by radiomorphometry, the quantity of calcified tissue per milligram representing the bioactivity of the implanted agent.

Results: Fractions I and III, with high (100–700 kD) and low MW (15–25 kD) respectively, were apparently more effective bone inducers than the second time-tested partially purified BMP complex, the activity of which had significantly ($p < 0.05$) decreased during 15 months of storage compared to initial results after extraction. However, the bone-inducing activity of fractions I and III corresponded closely to the initial activity of the BMP complex. Fraction II, with medium MW (25–55 kD), caused an apparent inflammatory reaction and no bone formation, and was thought to be immunogenic. Fraction III was considered to include the dominant BMP component with MW 18.5 and fraction I an association of BMP with other non-collagenous bone matrix proteins after one-step gel filtration. As to gained quantity of new bone/mg of implanted BMP, the best result was achieved with a 5-mg single dose.

Conclusion: The results suggest that BMP from the premature moose possesses high bone-forming activity. With identification and removal of apparently immunogenic protein fractions the inflammatory reaction and inhibitory effect on bone induction could be eliminated, and still higher bone forming activity was attained. Acid protease enzymes were assumed to be responsible for the observed decline in the inductive activity of semipurified BMP after fifteen months of

storage, as both osteoinductive fractions proved to be acidic in isoelectric focusing.

34. Comparison of the fixation of subcapital femoral neck osteotomies with absorbable self-reinforced poly-L-lactate lag screws and metallic lag screws on sheep

K Jukkala-Partio, O Laitinen, EK Partio, J Vasenius, S Vainionpää, T Pohjonen, P Törmälä, P Rokkanen

Helsinki Univ Central Hosp, Helsinki, Finland

Encouraged by earlier clinical results we wanted to study if it could be possible to use absorbable fixation in fractures and osteotomies exposed to high mechanical stresses.

Materials and methods: Absorbable lag-screws were manufactured of self-reinforced poly-L-lactic acid (SR-PLLA) (Biofix), 3.2 mm in inner diameter. In metallic fixation standard metallic cancellous bone screws in inner diameter 4.5 mm were used. The mean weight was 57 (43–83) kg in the SR-PLLA and 55 (43–69) kg in the metallic group. A transverse subcapital osteotomy was made with an oscillating saw. 7 osteotomies were fixed with 2 SR-PLLA screws and 7 with 2 metallic screws. The femurs were mounted to purpose-built grips and static compression test in a direction parallel to the shaft were carried out, the specimens were loaded to failure at a rate of 10 mm/min. The unoperated right femur of each sheep served as a control.

Results: At 12 weeks all other osteotomies had united, callus formation was similar, 1 insignificant primary displacement was seen in both groups and 1 secondary redisplacement after metallic fixation. The mean load at failure in SR-PLLA group was 5576 (2525–6892) N and in metallic group 4448 (3175–8434) N (n.s.). Before the strength measurements metallic screws were removed while degradation of the SR-PLLA-screws made their removal impossible.

Conclusion: The effect of the remaining screws on the load carrying capacity was difficult to estimate, but the fact, that none of the bones failed at the level of osteotomy but either in the proximal femoral head or in the subtrochanteric part in both groups confirmed that the union of the osteotomy was strong.

35. Intramedullary fixation of distal femoral diaphyseal osteotomies with absorbable self-reinforced poly-L-lactide (SR-PLLA) and metallic intramedullary rods assessed by plain radiographs, quantitative computed tomography and magnetic resonance imaging—an experimental study in rabbits

J Viljanen, J Kinnunen¹, S Bondestam¹, P Rokkanen

Dept of Orthop and Traumatol, ¹Dept of Radiol, Helsinki Univ Central Hosp, FIN-00260 Helsinki, Finland

The aim of this study was to compare the features of the secondary porotic transformation of the cortical bone at two different levels of the distal femoral osteotomy region after intramedullary SR-PLLA and metallic fixation.

Materials and methods: Osteotomies of distal femoral diaphysis were fixed with SR-PLLA intramedullary rods in 19 and with metallic rods in 18 adult rabbits. Plain radiographs, computed tomography (CT), quantitative computed tomography (QCT) and magnetic resonance imaging (MRI) were used to evaluate the bone changes.

Results: There were not any significant differences in cortical bone density compared with the intact in the SR-PLLA fixed femurs at the osteotomy site. When corresponding metallic fixation was used there were statistically significant reductions of cortical bone density at the osteotomy site between metallic fixed femurs and the corresponding contralateral controls.

Conclusion: Our results indicated that constant presence of internal metallic fixation seems to eventually cause osteoporosis to cortical region of the femur. However, this stress protection effect seems to be avoided by using the absorbable SR-PLLA rod indicating better quality of bone after the osteotomies were healed. Furthermore, nonferromagnetic SR-PLLA rod allowed CT, QCT and MRI studies without metallic artifacts giving adequate information of bone healing.

36. Fixation of femoral neck osteotomy with absorbable self-reinforced poly-L-lactide (SR-PLLA) and metallic screws in 21 cadavers

P Rokkanen¹, J Vasenius¹, T Pohjonen², P Törmälä², and A Penttilä³

¹Dept of Orthop and Traumatol, Univ Central Hosp, Helsinki, ²Biomaterials Lab, Inst of Plastics Technology, Tampere Univ of Technology, Tampere, ³Dept of Forensic Med, Univ of Helsinki, Helsinki, Finland

High initial bending and shear strength properties, relatively slow degradation rate and more advanced models of SR-PLLA osteosynthesis implants have encouraged us to study biodegradable osteosynthesis of weight bearing bones. We compared the stability provided by SR-PLLA lag screws and metallic cannulated screws in the fixation of cadaveric femoral neck osteotomies.

Materials and methods: In 21 matched pairs of proximal femora of fresh human cadavers a transverse subcapital osteotomy was stabilized with three parallel SR-PLLA screws or with cannulated metallic screws. Each specimen underwent a cyclic test (1 Hz) with progressive vertical loads. Maximum load carrying capacity and total absorbed load were evaluated.

Results: Metallic fixation showed significantly higher maximum load carrying capacity and total absorbed load. When the load carrying capacity was related with the cadaver's weight, the difference was very significant. The average

maximum load carrying capacity was 3400 (2100–5600) N after metallic fixation and 2600 (1400–4200) N after SR–PLLA fixation. The corresponding values per body weight were 4.6 (3.2–6.9) kN/g and 3.6 (2.0–5.5) kN/g, respectively.

Discussion: The avoidance of implant removal and the side effects caused by corrosion are the advantages that absorbable implants can provide in the treatment of femoral neck fractures. To gain these advantages about 24 % of the initial strength provided by the metallic fixation has to be given up. However, the average maximum load carrying capacity of femoral neck osteosynthesis with SR–PLLA screws was as high as 3.6xBW, which should be high enough even for immediate full weight bearing.

37. Stiffness measurements to assess healing in bone transport using the Orthofix limb reconstruction system

PJ Owen, JRW Hardy, JSM Dwyer, JH Kuiper, and JB Richardson

Robert Jones and Agnes Hunt Orthop and District Hospital NHS Trust, Oswestry, Shropshire, UK

Bone transport is a technique for limb reconstruction that is based on the generation of new bone at a callotasis site and consolidation of a docking site. Little is known about the patterns of healing at these sites.

Patients and methods: Over a 4 year period all patients undergoing tibial bone transport in our two centres were studied. Stiffness assessments of both callotasis and docking sites were made. When the stiffness of a site reached 15 (Nm/degree) the fixator was modified to leave the relevant segment unprotected.

Results: 8 patients underwent tibial bone transport. 2 procedures were unsuccessful resulting in below knee amputation. Stiffness rose in an approximately exponential fashion. The median "healing time" (time in weeks to achieve a stiffness of 15 (Nm/d) of the callotasis segment was 17 weeks and that of the docking site was 26 weeks. There were no re-fractures following fixator removal at either regenerate or docking sites.

Conclusion: Bending stiffness is a clinically useful measure of healing in bone transport. A level of 15 Nm/d allowed safe fixator removal in this series. Patterns of healing were similar to that found in leg lengthening and tibial fractures. The docking site took longer to heal than the callotasis segment.

38. DEXA-scan can be used to determine fracture stiffness of callotasis segments

G Tselentakis, PJ Owen, JB Richardson, JH Kuiper, MJ Haddaway, JSM Dwyer, GA Evans

Robert Jones and Agnes Hunt Orthop Hosp, Oswestry,

Shropshire SY10 7AG, UK

Assessment of fracture healing is essential for the management of patients undergoing callotasis for leg lengthening or bone transport. Fracture stiffness is proved to provide this information but the necessary equipment may not be available. The objective of the present study is to investigate whether a correlation exists between mechanically derived bending stiffness of a healing callotasis segment and the mineral density pattern as obtained from DEXA-scans.

Patients and methods: Patients undergoing leg lengthening or bone transport procedures were studied. Bending stiffness of the newly formed bone was assessed at regular intervals in the sagittal plane commencing 5 weeks after the completion of distraction. Also at regular intervals DEXA-scans were made in the sagittal and transverse plane. 4 variables were developed from the DEXA-scans using different mathematical formulae: minimum DEXA value (longitudinal plane), maximum DEXA value (transverse plane), area and area².

Results: 24 readings of bending stiffness and DEXA-scans were obtained. Stiffness values corresponding to the date of the DEXA-scan were then calculated. Use of the 4 different mathematical formulae was then applied to the DEXA-scan results. A linear correlation was then calculated for each method. The area squared formula gave the highest correlation (R^2 0.77, $p < 0.001$) with the mechanically measured fracture stiffness.

Conclusion: We have found that this area squared formula allows a DEXA-scan to provide a reliable and effective method of determining fracture stiffness. This can be used to indicate when a sufficiently high stiffness has been reached for safe removal of the fixator frame after leg lengthening and bone transport procedures.

Cancellous bone

39. Osteocyte density and morphometric parameters in cancellous bone of 5 mammalian species

MG Mullender, R Huiskes, H Versleyen¹, P Buma¹

Biomech and ¹Histomorphol Sections, Inst for Orthop, Univ of Nijmegen, Nijmegen, The Netherlands

It is suggested that osteocytes are mechano-sensors and are involved in the regulation of bone remodeling. The question investigated here was: do relationships between trabecular morphology and osteocyte density exist?

Materials and methods: Morphometric parameters and osteocyte density were measured in cancellous bone from the femoral heads of 30 adult animals of various species (rat, rabbit, Rhesus monkey, pig and cow).

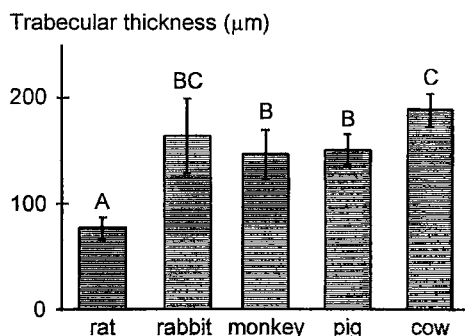
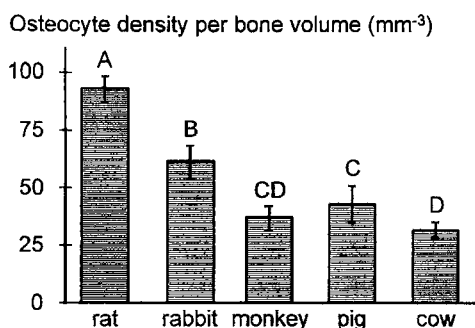


Figure 39.1–2. Different letters represent significant differences between species ($p < 0.01$).

Results: The number of osteocytes per bone volume varied considerably between species: from $93,200 \text{ mm}^{-3}$ in rat to $31,900 \text{ mm}^{-3}$ in bovine cancellous bone (Figure 1). Histo-morphometric parameters varied relatively little between species. Only in rat, bone morphology was different due to the presence of cartilaginous growth plates in the femoral heads of rats. Consequently, trabecular thickness in rats was considerably smaller than in the other species (Figure 2).

Conclusion: Osteocyte density was inversely related to the size of the species and was not directly associated with the macroscopic trabecular architecture. These results agree with results from a computer simulation study (1).

Reference: 1) Mullender MG, Huiskes R (1995) J Orthop Res 13: 503–12.

Conclusion: Using no more than 18 constants obtained from the fit to the relationships of Cowin, all 9 independent entries of the compliance matrices of all 29 specimens can be accurately predicted from MIL and apparent density ($R^2 \leq 0.92$).

References: 1) Van Rietbergen et al. J Biomech 28: 69, 2) Odgaard et al. Bone 15: 335, 3) Cowin. Mech Mat 4: 137.

Acknowledgements: This study was supported by NWO, the Dutch NCF, the Danish Rheumatism Association and the Danish Research Councils.

40. Fabric and density accurately predict the elastic properties of trabecular bone architecture

B van Rietbergen, A Odgaard¹, J Kabel¹, R Huiskes

Biomech Section, Inst of Orthop, Univ of Nijmegen, Nijmegen, The Netherlands, ¹Biomech Lab, Orthop Hosp, Univ of Aarhus, Aarhus, Denmark

Accurate relationships between morphological parameters and mechanical properties of trabecular bone could be extremely useful to determine (changes in) the mechanical integrity of bone in vivo. In the present study it was aimed to find such relationships by using 3-D computer reconstructions of cancellous bone specimens (1).

Materials and methods: 29 cancellous bone specimens were digitized in a serial sectioning procedure (2) and converted to structural FE-models built of 653 533 elements (Figure 1). The same voxel data were used to determine the mean intercept length (MIL) fabric tensor. The results of FE-analyses and MIL measurements were correlated using relationships proposed by Cowin (3) to find 18 constants which were then backsubstituted to predict the mechanical properties from the fabric measurements.

Results: When plotting the predicted compliances, versus those measured from the FE-analyses (Fig. 2), it can be seen that there is an excellent correlation between both, with R^2 values ranging from 0.92 to 0.97.

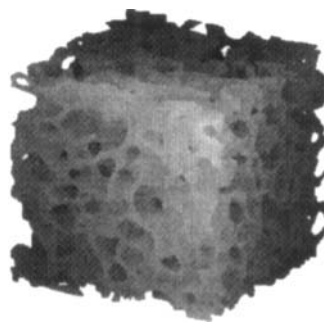


Figure 40.1.

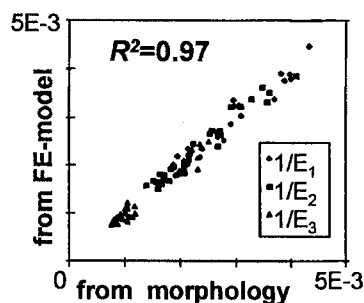


Figure 40.2.

41. Combined effects of oophorectomy and vitamin-D deficiency are necessary to reduce the strength of the femoral neck in rats

T Kaastad^{1,2}, L Nordsletten¹, V Halvorsen², K Obrant³, and O Reikerås⁴

¹Inst for Surg Res and ⁴Center of Orthop, The National Hosp, ²Orthop Dept, Ullevål Hosp, Univ of Oslo, Oslo, Norway, ³Orthop Dept, Malmö Univ Hosp, Malmö, Sweden

Vitamin-D has been found low in postmenopausal patients, and vitamin-D and calcium has reduced the incidence of hip fractures in elderly women. We studied the effect of vitamin-D deprivation and oophorectomy on bone strength neck in rats.

Materials and methods: 40 mature female Wistar rats were randomized into 4 groups, 2 oophorectomized and 2 sham-operated. 1 Ovx and 1 Sham group were fed a vit-D deficient diet (Ovx-D and Sham-D), while the control groups got normal rat chow (Ovx-C and Sham-C). After 12 weeks the rats were killed. The left bones were tested mechanically and the right ones in histomorphometry.

Results: Tibial and femoral weights and lengths did not differ significantly. Tibial area moment of inertia (I) was increased in Ovx groups versus Sham groups ($p < 0.005$), and the femoral I was increased in Ovx-D vs Ovx-C and Sham-D ($p < 0.05$). Tibial ultimate bending moment was increased in Ovx-D vs both Sham-groups (Table). The maximal stress of femoral shaft was decreased in both Vit-D depleted groups vs Ovx-C. The femoral neck was significantly weaker in Ovx-D than in the other groups. In histomorphometry, the trabecular bone volume in the distal tibia was 21% in Ovx-C, 20% in Ovx-D, 37% in Sham-D, and 53% in Sham-C ($p = 0.0005$).

Table. Mechanical parametres in the groups, mean (SD)

Group	Ult bending moment tibia (Nm $\times 10^{-2}$)	Max stress tibia (N/mm 2)	Ult bending mom fem shaft (Nm $\times 10^{-2}$)	Max stress femur (N/mm 2)	Ult bending mom fem neck (Nm $\times 10^{-2}$)
Sham-C	42 ^a (5.7)	279 (27)	67 (20)	156 (42)	68 ^b (8.9)
Sham-D	40 ^a (6.5)	281 (34)	54 (7.7)	138 ^c (32)	60 ^b (6.5) ^b
Ovx-C	45 (9.5)	252 (38)	70 (9.6)	174 (31)	75 ^b (27)
Ovx-D	51 (11)	300 (102)	61 (17)	129 ^c (32)	44 (9.3)

^a $p < 0.05$ compared with Ovx-D, ^b $p < 0.01$ compared with Ovx-D, ^c $p < 0.05$ compared with Ovx-C

Conclusion: Both Ovx and vitamin-D depletion reduced trabecular bone volume, Ovx to the greatest extent. In spite of an increase in tibial bending moment in Ovx-D, the maximal stress remained unchanged, and the femoral maximal stress was reduced in both vitamin-D deficient groups in

spite of equal bending moments. Both indicate a reduction in cortical material quality by vitamin-D depletion. Only vitamin-D depletion and Ovx combined reduced the femoral neck strength.

42. Age related variations in trabecular bone properties in lamb and sheep

A Nafei¹, CC Danielson², F Linde¹, Ivan Hvid¹

¹Biomech Lab and ²Dept of Connective Tissue Biol, Univ of Aarhus, Aarhus, Denmark

Information about trabecular bone in infancy and childhood is missing in the literature. The aim of this study is to illuminate the variations in trabecular bone properties as a function of age, with a special reference to skeletally immature individuals.

Materials and methods: 10 lambs in each of the age groups 3, 6 and 9 months, and 10 sheep in each of the age groups 36 and 80 months were used in this study. Cubes of the subchondral trabecular bone were cut out of the proximal tibia according to a standardized protocol. Nondestructive compression tests in the X, Y and Z directions, and tests to failure in the Z direction of the specimens were performed. Some of the specimens' physical properties were studied. Variables: Modulus of elasticity, strength, ultimate strain, energy absorption to failure, viscoelastic energy, mechanical anisotropy ratio, real & apparent density, and ash & collagen content.

Results:

Table. Statistical summary of the results

Pro-per-ty	Lamb (n=30) Mean SE	Sheep (n=20) Mean SE	P t-test	R correlation with age	P
E	670 53	1241 182	0.02	0.59	0.0001
δ_u	13.3 0.8	22.7 2.9	0.0008	0.63	0.0001
ϵ_u	3.5 0.1	2.9 0.01	0.002	-0.41	0.004
W_u	273 17	274 45	0.001	0.68	0.0001
W_v	1.2 1.4	0.2 0.05	0.0005	-0.54	0.0001
AR	1.9 0.2	1.3 0.2	0.001	-0.21	0.14
pr	2.2 0.01	2.3 0.01	0.0001	0.47	0.0005
pa	.43 0.01	0.62 0.03	0.0001	0.74	0.0001
CC	27.2 0.3	25.6 0.3	0.004	-0.46	0.0001
MC	64.8 0.5	67.0 0.4	0.005	0.45	0.0001

SE= standard error of the mean, r=correlation coefficient with age, E=stiffness (MPa), δ_u =strength (MPa), ϵ_u =ultimate strain (%), W_u =energy absorption to failure (kJ/m 3), W_v =viscoelastic energy (kJ/m 3), AR = anisotropy ratio, pr = real density (g/cc), pa = apparent density (g/cc), CC = collagen content (g per cent), MC=mineral content (g per cent)

Conclusion: Age has a significant influence on all the studied trabecular bone properties. Trabecular bone of skeletally immature individuals is weaker, less stiff and less fragile before failure. It is significantly less dense, and contains significantly more collagen and less minerals.

43. Genu varum leads to different effects on the femorotibial and femoropatellar joint

M Müller-Gerbl, R Putz

Anat Anstalt, Pettenkoferstr 11, D-80336 München, Germany

In previous studies we could show that the subchondral mineralisation of the tibial plateau in patients with angular deformities of the knee exhibit patterns which exactly correlate with theoretical expectations. Aim of the current study was to extent the study to the femoral joint component and the nearby femoropatellar joint.

Patients and methods: The investigation is based on CT datasets (section thickness 1 mm) of the knees of 4 men and 6 women with genu varum (ages 52 to 74 years). Further evaluation was done by means of CT osteoabsorptiometry.

Results: In the medial femoral condyle an increased density and in the lateral condyle a significantly reduced density was found. In the femoropatellar joint the maximum density was found laterally.

Discussion: The medial displacement of the resultant in the presence of genu varum produces an increase of stress in the medial part of the joint, which is reflected in the density patterns of the mediai tibial plateau and in the medial femoral condyle. The reduced lateral stress is equally reflected by a significantly lower mineralisation in the lateral femoral condyle. In contrast to the femorotibial joint, the articular surfaces of femoropatellar joint show the zones of highest density in the lateral compartment. And what is more, the density in the lateral part is even higher than in healthy persons pointing to an overloading of the lateral side.

44. Meniscectomy versus meniscus replacement—a comparative analysis of the subchondral mineralisation patterns by CT OAM

M Müller-Gerbi, H Anetzberger, G Metak, MA Scherer

Anat Anstalt, Pettenkoferstr 11, D-80336 München, Germany

The high incidence of arthrosis following meniscectomy has led to numerous different kinds of replacement techniques, the success of which is judged on morphological and mechanical grounds. We have therefore attempted in an experimental study to contrast changes in the subchondral plate after meniscectomy with those following meniscus replacement.

Materials and methods: The medial meniscus was removed from the left knee in 7 Merino sheep, and in a further 6 animals a primary meniscus replacement was carried out. One year after operation, the subchondral density distribution was measured with CT osteoabsorptiometry.

Results: 1) On the healthy side the density maxima of both knee-joint surfaces were located centrally. 2) On the side subjected to meniscectomy the maximum in the lateral

condyle was located centrally. In the medial condyle, however, the zone of highest density was significantly displaced towards the dorsomedial edge. 3) After meniscus replacement, on the other hand, displacement was only found in a dorsal direction.

Conclusion: While the 2 central density maxima in the control knees point to a more or less even stress distribution, the displacement of the medial density maximum in a posteromedial direction reflects an altered load transmission pattern. The finding that in specimens after meniscus replacement only a dorsal displacement of the mediai maximum occurs, suggests that an improvement in the mechanical situation can be generally achieved.

Cartilage

45. Inductive potential of mandibular chondro-progenitor cells in experimental osteochondral regeneration

N M Girdler

Univ of Newcastle Dental School, Newcastle Upon Tyne, UK

Mature articular hyaline cartilage has virtually no intrinsic capacity for repair following injury (1). In contrast, the articular cartilage of the mandibular condyle can respond to wounding by complete healing and regeneration (2). The objective of this study was to induce regeneration of osteochondral wounds using implants of cultured chondro-progenitor cells harvested from the mandibular condyle in an experimental primate model.

Materials and methods: Proliferative cells from the mandibular condyles of adult marmosets were isolated and cultured. A confluent monolayer of polygonal chondroblasts was obtained after 28 days. The sheet of cells was transferred to an organ culture grid for a further 14 days and then radiolabelled with ^3H -thymidine. Pairs of osteochondral defects were surgically prepared in the femoral condyles of recipient animals. One defect was grafted with cultured mandibular condylar cartilage whilst the second defect acted as ungrafted control or was filled with cultured fibroblasts or hyaline chondroblasts. After periods of 1, 6 and 26 weeks post grafting, sectioned surgical defects were examined using histochemistry, immuno-histochemistry and autoradiography.

Results: By 6 weeks the mandibular condylar cells had integrated with the host tissues. After 26 weeks the articular surface was reconstituted with hyaline-like cartilage containing labelled chondrocytes in a matrix of type II collagen. The subchondral region was filled with fibrocartilage expressing types I and II collagen. The control defects were incompletely repaired with fibrous tissue predominating.

Conclusion: Cultures of proliferative cells harvested from mandibular condylar cartilage appeared to have the potential

to induce hyaline neochondrogenesis when grafted into orthotopic experimental osteochondral wounds.

References: Mankin. J Bone Joint Surg 64A 1982; 460. 2) Robinson. J Oral Maxillofac Surg 1993; 51:1088. 3) Girdler. J Oral Maxillofac Surg 1993; 22:178–84.

46. Maturation-dependent repair of untreated osteochondral defects in the rabbit knee joint

K Messner, X Wei, J Gao

Depat of Sports Med, Faculty of Health Sciences, Linköping Univ, S-58185 Linköping, Sweden

Repair of articular cartilage defects is still an unsolved problem. Also, it is difficult to compare the quality of different repair methods across studies because of the choice of animals in different stages of maturation.

Materials and methods: We studied the repair process in untreated full-thickness cartilage defects in the medial femoral knee condyle of 17 young, 21 adolescent and 19 adult rabbits 3, 6 and 12 weeks after surgery using histology and in-situ indentation tests.

Results: The morphology of all repairs improved from fibrous tissue to hyaline-like cartilage over time ($p < 0.05$), but at 3 and 6 weeks, the repair tissue in young and adolescent rabbits was more cartilage-like than in the adults ($p < 0.05$). Also bonding of the repair tissue to the adjacent cartilage was better in the young and adolescent than in the adult animals ($p < 0.05$). Irrespective of age or observation time, the repair site showed decreased stiffness and larger strain values compared to adjacent or control cartilage ($P < 0.001$).

Conclusions: Younger animals showed a faster filling of the defect and an earlier specialization of the repair tissue than adult animals, but the mechanical quality of the regenerated tissue remained inferior to normal. Accordingly, repair methods can not be compared across studies when animals of different stages of maturation are chosen. Further, the lacking improvement of the compressive properties of the repair tissue despite improvement in tissue morphology underlines the necessity for biomechanical evaluation to sufficiently describe the quality of a repair method.

47. Repair of osteochondral defects using Biocoral and Gateshead grafts in rabbits—effect of early restoration of subchondral bone

YS Qiu, BF Shahgaldi, FW Heatley

Orthop Academic Unit, The Rayne Institute, St. Thomas's Hosp, London SE1 7EH, UK

Premature failure of joint surface reparative tissue may be caused by inadequate subsurface support (1,2).

Materials and methods: Osteochondral defects of 3 mm

diameter and 3 mm deep in femoral condyles of 24 rabbits were grafted with Biocoral rods, Gateshead rods or left empty as ungrafted controls. The left knees were kept intact for normal controls. At 8 and 16 weeks postoperatively, the quality and quantity of repair tissues were examined using radiography, histology, electron microscopy and mechanical testings.

Results: Biocoral grafts were gradually replaced by bone with superior quality and quantity to that of ungrafted defects at 8 weeks. The neocartilage of Biocoral grafted surfaces contained chondrocytes and collagen fibres oriented in similar manners to the normal cartilage, whereas ungrafted defects were fibrocartilagenous. The surface pressures and indentation hardnesses of Biocoral grafted defects were close to the normal controls, but those of ungrafted defects were significantly different from normal controls. The fibrous tissues of intact Gateshead rod grafted surfaces were softer than normal cartilage.

Conclusions: Biocoral grafting enhanced repair of osteochondral defects by an early restoration of a subchondral bone similar to the normal.

References: Shaligaldi et al. J Bone Joint Surg 1991; 73B: 57–64, 2) Messner. Biomed Mat Res 1993; 27:1527–32.

48. Endochondral ossification and the chondrocyte

OOA Oni

The Glenfield Hosp, Groby Road, Leicester, LE3 9QP, UK

The precise role of the chondrocyte in bone formation is not yet agreed. Cartilage may play a scaffolding role only or, alternatively, chondrocytes may transform directly into bone cells.

Materials and methods: Hindlimb sections from 12.5-day old (FDO) and 12.4-week old (FWO) rabbits were stained using respectively haematoxylin eosin (HE), toluidine Blue (TB) and osteocalcin (BGP) immunocytochemistry. And, as a pilot observation, HE and BGP stained fracture callus was examined using a confocal microscope (CM).

Results: In FDO bones, HE and TB reveal mid-section necrosis. Newly formed "bone trabeculae" are covered by BGP-negative and multinucleated giant cells. There is no columnar organisation of chondrocytes. In FWO bones, HE reveals typical growth plate architecture. TB and BGP reveal chondrocytes trapped within bone trabeculae where they have no means of escape. CM reveals nonvacuolated small chondrocytes (SCs) at the periphery of trabeculae interconnected by processes. Vacuolated hypertrophic cells (Hcs) with "footlets" are scattered throughout the trabeculae with their vacuole membrane often deficient in places.

Conclusion: In the early stages of bone development, cartilage remodelling is the predominant feature. After the growth plate has developed, bone forms by direct transformation of chondrocytes into bone cells.

49. Collagen organisation of joint surface reparative tissue: a scanning electron microscopy study of osteochondral defects in rabbits

YS Qiu, BF Shahgaldi, FW Heatley

Orthop Academic Unit, The Rayne Inst, St Thomas's Hosp, London SE1 7EH, UK

Normal articular cartilage has a 3-dimensionally organised collagen fibres essential for the load-bearing function. Whether such organisation can be restored in the joint surface reparative tissue is not known.

Materials and methods: At 8, 16 and 32 weeks, following osteochondral drilling of 3 mm diameter and 3 mm deep defects into femoral condyles of 18 rabbits, the collagen fibre organisation of the surface reparative tissue was studied using scanning electron microscopy (1).

Results: In normal cartilage radially oriented collagen fibres were deployed within sheets that run vertically from bone to the surface, bend at the surface and form horizontal lamellae. At 8 weeks the fine collagen fibres of reparative tissue were loosely and randomly organised. At 16 and 32 weeks radially oriented sheets of collagen fibres resembling those of the normal cartilage was seen at the repair site. Within each sheet the densely organised collagen fibres followed a similar path to that of the sheet.

Conclusion: The 3-D collagen fibre orientation of the normal cartilage was not restored after 32 week's natural healing. Nonetheless, new surface collagen fibres were organised in planes with orientation resembling those of the normal cartilage.

Reference: 1) Jeffery et al. J Bone Joint Surg 1991; 73B: 795-801.

50. The articular cartilage and the peri-articular osteophytes

OOA Oni, I Boyd

The Glenfield Hosp, Groby Road, Leicester LE3 9QP, UK

Osteophytes are bony outgrowths observed at the margins of degenerating joints. A relationship is yet to be established between articular cartilage and osteophyte formation.

Materials and methods: One-half of osteophytes from femoral condyles of 25 osteoarthrotic knees was prepared according to the Tripp and Mackay (TM) technique for identifying mineralisation, bone and osteoid. Comparative histological sections obtained from the other half were stained using respectively, Toluidine blue (TB), haematoxylin-eosin (HE), van Gieson (VG) which preferentially stains collagen and Ralis and Ralis (RR) which highlights different aspects of bone formation.

Results: The osteophytes comprised of a layer of hyaline cartilage overlying trabecular bone. There was hyperplasia of surface cells at the junction with a well vascularised fibrous tissue. In TB sections, the chondrocytes in the middle

zones appeared to be isogenic. Collagen fibres were observed in VG stained sections arranged in longitudinal bundles in between chondrocyte columns. TM and RR staining revealed endochondral ossification at the chondro-osseous junction.

Conclusion: According to these findings, the micro-architecture of the osteophyte is identical to that of the articular cartilage with which it is in continuity. This raises the possibility that osteophytes are derived from this source.

51. Maturation-dependent mechanical properties of normal rabbit knee articular cartilage

T Räsänen, X Wei, K Messner

Dept of Sports Med, Faculty of Health Sciences, Linköping Univ, S-58185 Linköping, Sweden

The rabbit knee joint is widely used for research on articular cartilage. Detailed knowledge of articular cartilage mechanical properties in an intact joint is a prerequisite to analyse the effect of different treatments. This work studies the changes in healthy knee articular cartilage during maturation.

Materials and methods: Both knees of 5 young (2.5 months), 5 adolescent (4.5 months), and 5 adult (>7 months) NZW rabbits were tested in a creep indentation machine. 7 joint surfaces were tested: anterior and posterior regions on medial and lateral femoral condyles, patellar groove and medial and lateral tibial plateaux. The cartilage was loaded with a steep ramp function to 0.1 N load and left to creep for 55 s. An elastic modulus was calculated from the slope of the ramp at a 5 gram load, and another elastic modulus at 15 s after the start.

Results: Ramp and 15-s moduli decreased significantly during early maturation in the lateral femoral condyles and in both tibialplateaux. In the lateral femoral condyles, cartilage thickness decreased during early maturation, whereas in the tibial condyle the thickness increased during late maturation.

Conclusion: Cartilage short-term stiffness (ramp modulus) decreased markedly during maturation. This general cartilage softening may be a natural answer to increasing joint size and contact areas during growth.

52. Growth plate damage in developmental dislocation of the hip—MRI for diagnosis and prognosis

Jacek Kruczynski

Dept of Orthop, Karol Marcinkowski Univ of Med Sciences, Poznan, Poland

Injury to the subcapital growth plate (physis) of the proximal femur may result in leg-length inequality, hip deformity and

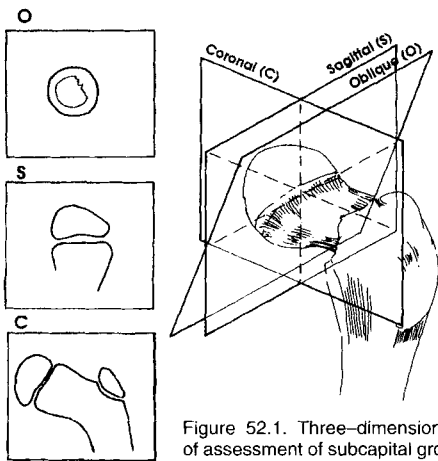


Figure 52.1. Three-dimensional model of assessment of subcapital growth plate shows planes of MR serial images [coronal (C), sagittal (S), and oblique in a plane of the growth plate (O)]

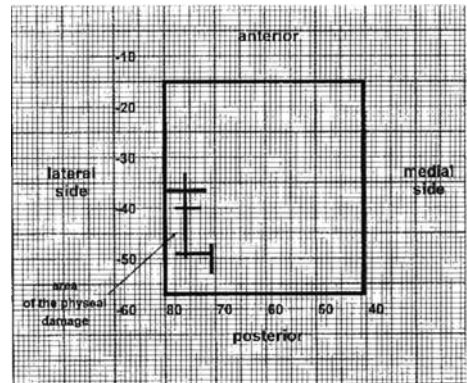


Figure 52.2. Cross sectional drawing of the physeal damage on a graph paper.

disability in early adulthood and later arthrosis. The aims of the study were to find MRI sequences adequate for imaging subcapital growth plate disorders and to develop a method of mapping the damage.

Patients and methods: 24 patients (33 hips) were treated in 1985–91 for developmental dysplasia of the hip and complicated by avascular necrosis. The average age at the evaluation was 10 (4–14) years. Conventional a–p views of the hips were taken. The MRI examinations were performed with 1.0 T unit. The standard pulse sequence used was coronal, Spin-Echo (SE) (TR, TE/ 500, 15), and FLASH 3D FAT SAT (TR, TE, FA/48, 7, 40). MR images were also made in sagittal and oblique planes (Figure 1).

Results: The extent of growth plate damage visible on MR images ranged from focal disturbance of signal intensity (23 hips) to the picture of premature complete closure of the growth plate (4 hips). The appearance of the physeal damage varied with the pulse sequences used. The extent of growth plate damage analysed on each of the coronal and sagittal cuts and plotted on the outline of the physis (or to ease the procedure on a quadrangle containing the outline) allowed for drawing a map of a physis on the graph paper.

Conclusion: Sequences SE T1 and FLASH 3D FAT SAT appeared to be useful and complementary in imaging and mapping the subcapital growth plate damage.

relative with a THR or TKR. 3455 informative replies were received. Patients with a sibling history were contacted by telephone to determine the indication for THR or TKR in them and their sibling(s).

Results: Overall, 13.3 % individuals, along with at least 1 sibling, underwent THR or TKR for idiopathic OA. Published results estimate local prevalence of THR for idiopathic OA in > 65 year-olds between 2–4 %; we estimate local TKR prevalence between 0.7–1.3 %. These figures suggest relative risks, of THR or TKR for OA, to siblings at between 2.5–4.9.

In a subsequent prospective survey of 402 individuals who consecutively underwent THR or TKR for idiopathic OA, the prevalence of THR or TKR for idiopathic OA was determined in their siblings and spouses. Of 1171 siblings, 60 had THR, 15 had TKR and 5 had both, whereas of 376 spouses, 12 had THR and 1 had TKR. Relative to spouses, sibling risks for joint replacement in those > 65 years were: THR 1.9 (0.9–3.7), THR or TKR 2.3 (1.2–4.4) and TKR 4.8 (0.6–36.4). Heritability was estimated at 31 % for THR or TKR and 27 % for THR.

Conclusion: These studies suggest a significant familial tendency to symptomatic OA of the hip and knee and provide estimates of genetic involvement in end-stage "idiopathic" OA of these joints.

53. Genetic factors in end-stage osteoarthritis of the hip and knee

J Chitnavis, K Clipsham, JS Sinsheimer, P Burge, A Carr
Nuffield Orthop Centre, Oxford OX3 7LD, UK

The aim of the study was to analyse familial tendencies to symptomatic osteoarthritis (OA) of the hip and knee.

Materials and methods: All 3996 patients who underwent a total hip (THR) or knee (TKR) replacement in 1989–93 were contacted by post and asked if they had a 1st-degree

54. Promising results of Ilizarov joint distraction in the treatment of ankle osteoarthritis

AA van Valburg, PM van Roermund¹, J van Melkebeek², J Lammens³, AJ Verbout¹, FPJG Lafeyber, JWJ Bijlsma

Depts of Rheumatol and ¹Orthop, Univ Hospital, Utrecht, The Netherlands, ²Dept of Orthop, OL V Middelares Hosp Deurne and ³Univ Hosp, Leuven, Belgium.

Osteoarthritis (OA) is a degenerative joint disease for

which no remedy is available yet. Joint distraction is a relatively new, still experimental approach in the treatment of OA. In the present study we evaluate the clinical results of joint distraction by use of an Ilizarov external fixation frame applied to patients with ankle OA. This treatment aims at a short-term distraction of talus and tibia (Fig.1) preventing articular surfaces to contact in a way that intraarticular intermittent hydrostatic pressure during walking under distraction is ascertained (1).

Patients and methods: Patients with posttraumatic OA of the upper ankle joint were treated with Ilizarov joint distraction for a period of 3 months. Changes in pain, joint motility and radiological joint space narrowing were graded using a tetramorous score: ++ significant improvement, + improvement; = unchanged and – worsened. 11 patients were evaluated retrospectively (mean follow-up period 20±6 months). Consequently, a prospective study has been initiated using a detailed protocol. Of the 25 patients included until now, the results of the first 9 patients with follow-up of >9 months (mean 14.5 months) are presented.

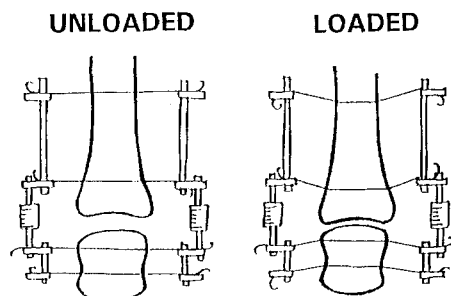
Results: Table 1 shows the results of the retrospective and the prospective study. It appears that in 50% of the patients an improvement for all 3 parameters was obtained.

Table. Results of the retrospective/prospective study in %

	++	+	=	-
Pain improvement	45/78	55/22	0/0	0/0
Increase in motility	19/11	36/33	36/0	9/56
Joint space widening	33/0	17/50	50/50	0/0

Conclusions: The preliminary results of the prospective study confirm the findings of the retrospective study that mainly pain and joint space widening and to a lesser extent joint mobility have improved. We speculate that the joint space widening represents regeneration of the articular cartilage. An ongoing animal study corroborates this idea. We suggest that the combination of mechanical unloading of the articular surfaces in combination with intraarticular intermittent hydrostatic pressure originates the clinical beneficial effects. This is also suggested to explain the positive clinical results of articulated distraction of OA hips (2). Joint distraction may delay the need for an arthrodesis or joint replacement in OA.

References: Van Valburg et al. J Bone Joint Surg 1995; 77B: 720–5. 2) Aldegheri et al. Clin Orthop 1994; 301:94–101.



Miscellaneous

55. The reliability of the clinical assessment of upper limb kinematics

JR Williams, VB Conboy, AJ Carr, EN Biden

Oxford Orthop Engineering Centre, Nuffield Orthop Centre, Headington, Oxford OX3 7LD, UK

The reliability that can be attached to collected data or calculated results is important for the formulation of conclusions. We describe a "frame by frame" method for analysing the uncertainties in the calculation of the joint rotations of the shoulder and elbow joint during kinematic analysis of the upper limb.

Materials and methods: We have used the Vicon 370™ movement analysis system to study the motion of the upper limb during Activities of Daily Living (ADLs). The main source of error in the displacement data for the skin markers is the movement of the skin during motion. The relative rotations between these axes systems are calculated using the Joint Co-ordinate System of Grood and Suntay 1983. We are able to describe the 3 rotations at each of the shoulder and elbow joint. By using the method described by Taylor 1982 for functions with multiple inputs we have calculated, at each time frame (1/50 sec), the total uncertainty in the rotations based on the maximum measured errors. Taylor states that if variables $x, \dots, z$ are measured with individual uncertainties of $\delta x, \dots, \delta z$, and are used to compute the function $F(x, \dots, z)$ then the uncertainty in F is:

$$\delta F = \sqrt{\left(\frac{dq}{dx} \delta x^2 + \dots + \frac{dq}{dz} \delta z^2\right)}$$

The terms $\delta x, \dots, \delta z$ are the measured errors along the Cartesian co-ordinates for the 9 markers (27 variables). The $dq/dx, \dots, dq/dz$ terms are the gradients of the of the joint rotation curves, with respect to the individual inputs, $x, \dots, z$, calculated at each time frame. These are calculated from the function,

$$\frac{dq}{dx} = \frac{f(i+\Delta) - f(i)}{\Delta}$$

where Δ is a very small addition, in this case 1×10^{-6} mm. It gives the maximum band width of the uncertainties in the calculated joint rotations. As the measured errors for the 9 markers vary with the different ADLs, 4 different sets of inputted errors have been used: full flexion, forward reach, perineum and up reach.

Results: The measured errors along the orthogonal Cartesian laboratory co-ordinates for the 9 skin markers varied from 0.8–1.4 mm with a mean value of 4 mm (SD 3 mm). The actual values vary depending on the ADL being studied, hence difference experimental data is used for the calculation of the uncertainties for each ADL. The uncertainties in the calculation of some angles is sufficiently great to mean that they can not be used for comparison between subjects.

Conclusions: We have defined the reliability boundaries for kinematic assessment in the upper limb and show that at low flexion angles the uncertainty is at its greatest,

56. Assessment of normal shoulder and elbow motion during activities of daily living

JR Williams, VB Conboy, AJ Carr, EN Biden

Oxford Orthop Engineering Centre, Nuffield Orthop Centre, Headington, Oxford OX3 7LD, UK

Normal patterns of lower limb joint rotations have been established for gait. We have studied ADLs in order to assess the normal rotations for the upper limb joints. We have produced data against which pathological motion patterns can be compared.

Methods: Vicon 370TM movement analysis system was used for the study. The 3 orthogonal rotations of the shoulder and elbow are calculated from the displacement data of the markers by constructing "embedded axis" systems for each segment and using the Joint Co-ordinate System (Grood & Suntay 1983). We have studied 6 ADLs in normal individuals. Each ADL has been studied in 7 subjects with 5 to 10 repeats of each activity. The rotation data is standardised to the length of the cycle for comparative purposes. This is done by curve fitting using a Fourier series and resetting to 100 % points per cycle. The standardised rotations are statistically analysed with respect to whole cycles. This method looks at each trace as a whole and assesses the max distance that it deviates from the mean trace at any point in its cycle. This is different from the normal method that looks at the data points in isolation. Statistical analysis is performed using the Statistical Bootstrap (Efron 1979), which uses a random sample and replace method to create addition bootstrap samples from the initial sample. In this way we are able to define the boundary for the rotations that includes 95 % of whole traces. As well as examining the rotations at each joint the speed or cadence of the ADLs is calculated from the raw rotation data prior to standardisation.

Results: All the data for the 6 ADLs has been processed and described. The analysis shows that the boundaries to include 95 % of whole traces lie all around 3SD from the mean, rather than the 2SD for the individual data points. The mean cadence for the ADLs is 0.44 cycles/sec (SD 0.08). The variation is distributed more tightly at the extremes of motion than at other parts of the cycle.

Conclusions: This method has allowed us to define the representative angular displacements during each of the ADLs; that which contains 95 % of all traces. From this data we are able to compare recordings from patients suffering from upper limb disorders with our normal data and to study the effects of treatment, medical or surgical.

57. Conduction of tissue pressure across compartmental boundaries of the leg

K Hvaal, S Øvre, V Halvorsen, A Alho

Orthop Dept, Ullevaal Hospi, Univ of Oslo, N-0407 Oslo, Norway

Direct measurement of raised interstitial pressure in acute

compartment syndromes is the objective basis for surgical intervention. In lesions of the lower leg, a catheter for monitoring is often placed in the anterior compartment. It is assumed to reflect the pressure in all 4 compartments. The aim of this study was to test the hypothesis that an expansion in 3 compartments of the lower leg will lead to an elevated pressure in the 4th.

Materials and methods: 28 cadaver specimens divided into 4 groups were infused with Ringer acetate in 3 compartments and the pressure measured in all 4 with an electrooptical catheter and a digital pressure recorder (Camino V420, Cannula Lab, San Diego, CA, USA). Medians and ranges of differences infused – measured (I–M) for each I compartment in 4 groups – M anterior, M lateral, M deep posterior and M superficial posterior – were calculated from the measured values after 20 min infusion.

Results: The median pressure for all compartments was 66 mmHg, the gradients being highest in group 4 (M superficial post) (20 [20–75] mmHg) and lowest in group 2 (M lat) (20 [–5 to 40] mmHg) with groups 1 (M ant) and 3 (M deep post) in the intermediate range.

Conclusion: The pressure in a compartment of the lower leg did not reflect satisfactorily the pressure increase in any other compartment. Increased stiffness of the cadaver specimens may have been a factor here. Our results suggest that the superficial posterior compartment is not suitable for monitoring tissue pressure outside itself. Lateral compartment had the lowest gradients in the present study.

58. Digital CT whole leg scout view measurement for length and axes, a new application with lower radiation dose

T Wels¹, N Ishaque¹, I Augele¹, H Kienapfel², H Sitter³, J Petermann⁴, I Celik⁴

¹Dept of Diagn Radiol, ²Dept of Orthop, ³Inst of Theor Surg, ⁴Dept of Traumatol, Philipps Univ, Marburg, Germany

The objective of this study was to develop a digitised CT scout view technique including a special board for the simulation of the body weight to determine alignment and length parameters in TKA and to compare the results using this new technique with the results of full length a–p radiographs.

Method: 35 patients who were admitted for TKA or osteotomies were submitted to 49 conventional and CT digital radiographs with simulation of BW. For the latter, we made 2 scout views of each 512 mm and combined them with a special software. For the simulation of the gravity we used a board with abutments supports at the shoulder and strain gauges at the foot site. Intraindividual radiations were compared. The evaluation of the scout views was performed both online on the CT screen and on exposed films. The hip–knee–ankle angle (HKA) and the distance of load axes (LAD), the tibial plateau angle and the hip center–femur shaft angle (CCD) were assessed. 5 staff members evaluated the conventional and the online radiographs.

Results: A comparison of the techniques demonstrated for the angle measurements a highly significant difference. With the different applications, the variance of the investigators showed very high correlations ($R\ 0.95\text{--}0.99$). Between the different applications there was a good correlation ($R\ 0.76\text{--}0.87$). The heavier the patient related to height, the more she gets profit by the reduction of the CT radiation dose up to the factor of 12.

Conclusions: CT scout views as a digital application of radiographs are appropriate to replace the conventional radiographs of the whole leg.

59. Somatosensory evoked potentials recorded in patients with the familiar idiopathic scoliosis have the same properties both in parents and their children

P Rogala, J Huber¹, M Glowacki

Dept of Orthop, ¹Dept of Pathophysiol of Locomotor Organs, Karol Marcinkowski Univ of Med Sciences, Poznan, Poland

The initiation and progression of the pathological spinal column curve is multifactorial. Brain stem or equilibrium abnormalities are correlated with idiopathic scoliosis. There may also be a genetic basis for idiopathic scoliosis (1). This study was undertaken to find out the family incidence of idiopathic scoliosis.

Patients and methods: SEPs were recorded in 30 volunteers, 14 mothers and their 16 daughters, aged 5–39 years. All had thoracic scoliosis with curvatures $10^\circ\text{--}65^\circ$, judged from a–p radiograms. During SEPs sessions electrical transcutaneous square wave pulses of 0.2 ms duration and strengths, adjusted to cause small twitches of innervated muscles, were applied to the median and tibial nerves on concave and convex sides. Standard points of the cortical bipolar recording following the bipolar stimulation were used (2). To evaluate the conduction time of impulses along afferent pathways of the deformed spinal cord, additional recordings from levels of terminal lumbar (L), cervical (C) and apical thoracic (T) vertebrae were performed.

Results: The comparison of scalp and spinal C and T recordings obtained in patients with thoracic scoliosis led to the conclusion about longer latencies of potentials induced when nerve branches on the concave side of the curvature were stimulated. These differences were more significant in case of tibial ($P<0.01$) than median ($P<0.05$) nerve branches. The same phenomenon was common to mothers and daughters.

Conclusions: The results of our study support the findings of Machida et al (3). Similarly, the latencies of SEPs recorded at the cortical level were longer with stimulation of the tibial nerve ipsilateral to the concave side. Additionally, we proved electrophysiological family correlations in idiopathic scoliosis. The scalp SEPs had the same properties both in mothers and their daughters. In patients with thoracic idiopathic scoliosis, SEPs recorded at the cortical level and spi-

nal levels above the apical vertebrae, have different latencies on the concave and convex sides following stimulation of tibial nerves. This may suggest the thoracic level as the point of delay of the afferent signals are delayed. Current results support the hypothesis that idiopathic scoliosis results from dysfunction in the central nervous system, probably also at the thalamocortical level and represents a specific impairment of the higher cortical function.

References: Abbot–Byrd. Clin Orthop 1988; 229:114–9. 2) Kopeć and Kopeć. Biocybern Biomed Eng 1990; 10:25–41. 3) Machida et al. J Pediatr Orthop 1994;10:329–35.

60. Press fit implantation of bone and ceramic cylinders in comparison with bone and ceramic chips

P Schnettler¹, E Dingeldein², K Donath³

¹Klinik für Unfallchir, J Liebig Univ, Giessen, ²Coripharm & Co, Dieburg, ³Abt für Oralpathol, Inst für Pathol, Univ Hamburg, Hamburg, Germany

The aim of this experimental study was to compare the reaction of host bone to defect fillings with loose bone or ceramic chips with stable press fit implantation of bone and ceramic cylinders in minipigs.

Materials and methods: In female minipigs bone defects, 8.5 mm wide and 10 mm deep, in the centre of the femoral condylar trochlea were filled with: 1) autograft bone chips, 2) hydroxyapatite ceramic (HA) chips of the same size as the bone chips, 3) cancellous bone cylinders (8.7 mm wide) and 4) HA cylinders (8.7 mm wide). Chips were implanted in 8 animals (f/u 6 and 12 weeks) and press fit cylinders in 4 animals (f/u 6 weeks). For evaluation the femora were x-rayed and undecalcified sections, longitudinal to the implant axis, were stained with toluidine blue.

Results: In the groups of loose bone and HA chips, the host bone showed wide zones of resorption close to the joint at 6 weeks. Deep in the defect, new bone had filled the gaps between the bone or HA chips. At 12 weeks, fibrous tissue had formed in the upper zones of resorption; new bone had grown from the basis to the middle of the defects. In the press fit groups, new bone had grown up to the centre of bone cylinders but only into the outer 2–3 pore layers of the HA cylinders after 6 weeks; no bone resorption was observed.

Conclusion: If complete reconstruction of a bone or cartilage/bone defect is the aim, press fit implantation of an autograft shows the best results followed by HA cylinders. Chips lead to zones of resorption and formation of fibrous tissue in the host bone.

61. 13 Mhz sonography (SG) of the lateral ligaments of the ankle in vitro and in vivo

S Milz, P Milz¹, T Mittlmeier¹, M Steinborn¹, M Reiser¹, and R Putz

Anat Anstalt and ¹Inst für Radiolog Diagnostik, München, Germany

The aim of this study was to assess the diagnostic value of 13 MHz SG for examining the anterior tibiofibular, anterior talofibular and calcaneofibular ligament. These are most frequently injured in an inversion trauma.

Materials and methods: To identify anatomically the echogenic structures interpreted as ligaments, 48 formalin-fixed specimens were marked with a dye injection under direct sonographic control and then dissected. To assess the clinical value 20 patients with an inversion injury were examined by SG and MRI (control).

Results: The anterior talofibular ligament was correctly identified in 89%, the calcaneofibular ligament in 87% and the anterior tibiofibular ligament in 89% of the specimens. In 92% an injured talofibular and in 100% a calcaneofibular ligament was correctly diagnosed by SG. The anterior tibiofibular ligament was correctly diagnosed in 66%.

Conclusion: These results suggest that 13 MHz SG is excellent for examining intact and injured ligaments of the lateral ankle, although improvement is necessary with the anterior tibiofibular ligament.

Posters: Joint replacement

62. Radiostereometric analysis using computer-based image analysis

SE Østgaard¹, L Gottlieb², S Toksvig-Larsen⁴, A Lebech³, A Talbot², B Lund¹

¹Dept of Orthop, ²Dept of Med Engineering, ³Dept of Radiol, National Univ Hosp, Copenhagen, Denmark and

⁴Dept of Orthop, Univ Hosp, Lund, Sweden

2-dimensional position of markers in radiographs for RSA is usually determined using a measuring table. The purpose of this study was to evaluate the reproducibility and accuracy of a new RSA system using digitised radiographs and image processing algorithms to determine the marker positions in the radiographs.

Materials and methods: 4 double RSA examinations of a phantom and 18 RSA examinations from 6 patients included in different RSA studies of knee prostheses were used to test the reproducibility and accuracy of the system. The radiographs were scanned at 600 dpi resolution and 256 levels of grey. The centre of each of the tantalum-markers in the radiographs was calculated by the computer program from the contour of the marker with the use of an edge detecting soft-

ware algorithm after the marker was identified on a PC monitor.

Results: The results of the comparison of the knee prosthesis data with the data from the system in Lund (Unikum, Umeå, Sweden) are given as the results from the new system minus the Lund results. The mean (2 SD) difference (Δ) for translation along the X-axis was 0.010 (0.055) mm, along the Y-axis -0.011 (0.032) mm and for translation along the Z-axis -0.022 (0.059) mm. The mean Δ for rotations around X, Y and Z axes were 0.031° (0.080)°, -0.030° (0.087)° and 0.015° (0.052)°. Maximal Total Point Motion Δ was -0.040 (0.090) mm. A linear regression analysis line after comparing the MTPM results from the two systems was: $y = 0.957x - 0.106$, and the R^2 was 0.96. The Δ in Mean Error from all the analyzed examinations for the comparison was -0.028 (0.017) mm.

Conclusion: The study showed that computer-based image-analysis can be used in RSA-examinations. The advantages of using image processing software in RSA are that the markers positions are determined in an objective manner, and that there is no need for a systematic manual identification of all the markers on the radiograph before the actual measuring. A set-up for the roentgen examinations resulting in adequately sized radiographs must be used, and high quality of the radiographs is important.

63. Distance effect in relative motion analysis

X Yuan, L Ryd, L Blankevoort¹

Dept of Orthop, Univ Hosp, S-22185 Lund, Sweden,

¹Biomech Section, Inst of Orthop, Univ of Nijmegen, Nijmegen, The Netherlands

Kinematic analysis of rigid body motion analysed by RSA is performed using noisy input data and the error propagation is a limiting factor for small motions and for small marker configurations. Woltring (J Biomech 1985; 18: 379-89) investigated the error propagation for single rigid body and presented an error-model valid for isotropic conditions. So far, this model was not fully valid for relative motions between two bodies.

Method: For relative motion, it was derived that the distance (d) between the two marker sets is a factor. The error propagation for the relative motion between two bodies follows the model:

$$\sigma_{\theta_i}^2 = \frac{2\sigma^2}{m_1 \rho_1^2} + \frac{2\sigma^2}{m_2 \rho_2^2} \quad i \neq j \neq k = x, y, z$$

$$\sigma_{r_i}^2 = \frac{2\sigma^2}{m_1} + \frac{2\sigma^2}{m_2} + \frac{2\sigma^2}{m_2 \rho_1^2} (d_j^2 + d_k^2)$$

To validate this model, a computer simulation was performed. The simulation was divided into 2 groups. The 1st

group focused on the distance effects and the 2nd tested the influence of the rigid body size (p) and the number of markers (m).

Result: In the 1st group, the maximum absolute differences were found to be 0.15 % for rotation (O) and 0.06% for translation (T). In 2nd group, 5 different combinations were evaluated and the maximum absolute differences for rotation and translation were 0.58% and 0.04%.

Conclusion: The results indicated that a distance effect exists and it will affect the error of translation in RSA investigations. The influence of the number of markers, the rigid body size and the marker position error for the relative motion were similar to that of a single rigid body model.

64. A new method for 3-dimensional relative motion measurements in the prosthesis-bone interface with micrometer-accuracy

B Zurfluh, K-H Widmer, B Göpfert, EW Morscher

Lab for Orthop Biomech and Orthop Univ Clinic, Felix Platter-Hosp, Basle, Switzerland

A solid fixation of cementless endoprostheses by osseointegration presupposes a high initial stability, ie the relative motion between implant and adjacent bone must be minimized. The development of a novel miniaturized micromechanical sensor for in vitro measurements of 3-D relative motions in the bone-prosthesis interface was the goal of this project. They will be used to compare the initial stability of prostheses with different designs, surface textures and materials under dynamical loading.

Materials and methods: The sensor consists of a silicon chip made for pressure measurements, and a palp fixed rigidly on the membrane of the chip. 4 piezo-resistive zones in the silicon film allow to perceive spatial dislocations of the palp tip relative to the chip. The whole sensor has an outer diameter of 3.5 mm. It is anchored in the bone in direct proximity of the interface while the palp tip stands on the prosthesis.

Results: On-line measurements (50 Hz) with several sensors in parallel operation deliver an accuracy of 2.0 μm and a resolution of 0.5 μm . The actual range measures 200 μm in transversal and 50 μm in axial direction but can be adapted to other requirements. Regarding its small size the sensor causes minimal bone impairment.

65. Corrosion of retrieved stainless steel hip prostheses—morphology and composition of corrosion products

JP Walczak, BF Shahgaldi, FW Heatley

Orthop Academic Unit, The Rayne Inst, St Thomas' Hosp Campus, London SE1 7EH, UK

We report on our unique findings of corrosion of 9 out of 11 retrieved contemporary Stainless Steel Hips (fabricated to AISI-316L and BS 3531 pt 1:1968–1978). We examined the composition and morphology of the corrosion products, which to our knowledge has not been previously reported on any retrieved stainless steel implant.

Materials and methods: 11 prostheses retrieved for aseptic loosening were examined. 7 Müller and 2 Charnley stems were visibly corroded at mean duration of implantation 13.3

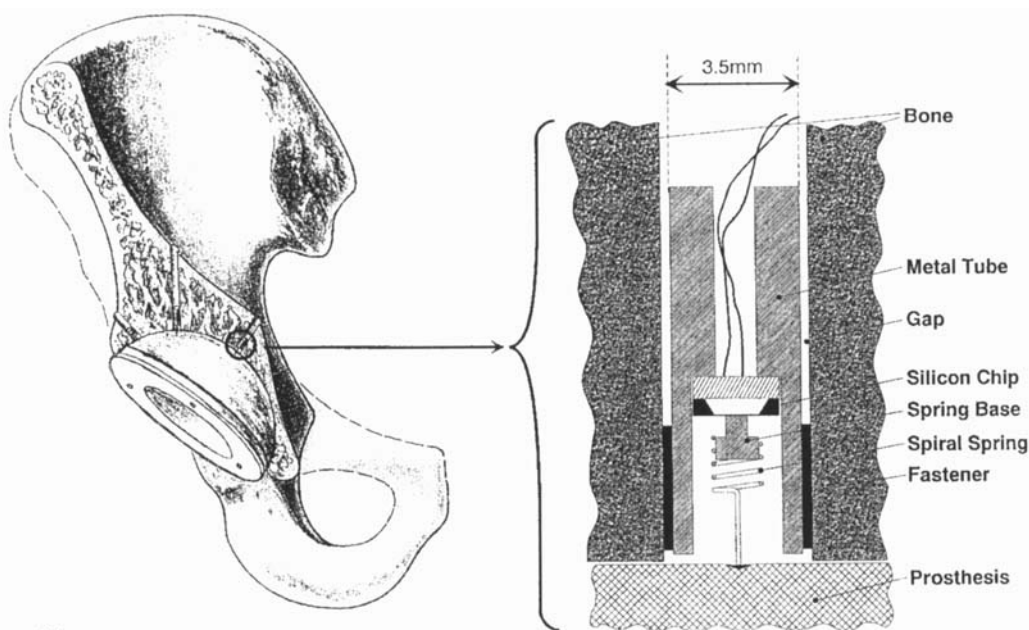


Figure 64.

years. The corrosion products were examined with scanning electron microscopy with energy dispersive X-ray analysis.

Results: Corroded areas (in the form of surface plaques) occurred in the distal grooves of the Müller implants and in the proximal third of the Charnley stems. The plaques had a complex multi-lamellar structure. Deeper layers were Cr-rich and superficial layers Fe-rich. Varying quantities of Ca, P, Cl, S and O₂ were also present.

Conclusion: The location of corrosion varied with implant design. We believe that was due to corrosion fatigue and fretting in the Charnley stems and crevice corrosion with fretting in the Müller stems. The stratification of elements in the plaques may represent chromium depletion, followed by iron complex formation. This composition is very different to the elemental composition of the implant and to our knowledge is uniquely described here.

66. Comparative study of HA- and Ti-coatings fixation of cementless stems and the relative weight of mechanical stability

UE Pazzaglia, R Chiesa, L Andriani, G Zatti

Clinica Ortop e Traumatol Univ di Pavia – Varese, Ospedale F Del Ponte, I-21100 Varese, Italy

Ti-rods plasma-spray-coated with hydroxy apatite (HA) or porous titanium (Ti) of similar roughness were compared in different stability condition.

Materials and methods: 13 Sprague Dawley rats had both femurs implanted; 2 rats had 0.3 mm over-reaming before insertion of the rod to get poor fit of the implant. Integration was assessed with a radial reticulum, classifying each intersection of the bone-implant interface in 2 classes: contact with soft tissue interposition (a) or without (b). Integration % for each femur was calculated as $b/a+b$.

Results: In the group of stable implants, HA-coated rods (n=5) showed a significantly higher integration (90%) than Ti-coated rods (n=5, 53%). The mean intersections (a) $b \pm SD$ were 58 ± 4 and 34 ± 9 , resp ($P < 0.001$, Students t-test). All over-reamed implants were surrounded by connective tissue without points of integration.

Conclusions: The study documented early adhesion of osteoblasts and direct deposition of bone matrix on the HA substrate, while on spongy Ti osteogenesis was observed only in proximity of the surface. Remodeling of the reactive, primary bone formed a capsule surrounding the mechanically stable implants with radial bridges connecting the latter to the endosteal surface. Number, height and thickness of these bridges appeared to be the factors capable to determine the implant stability, rather than the extent of the bony capsule on the perimeter. Over-reaming of the medullary canal produced micromotion sufficient to inhibit the bone ingrowth process in both the HA- and Ti-coated surfaces suggesting that stability is more relevant than the osteo-conductive properties of the surface.

67. Cementless total hip arthroplasty in rheumatoid arthritis and revision surgery—a computer assisted micromotion analysis

M Dominkus, A Wanivenhaus, M Morscher

Univ Clinic of Vienna, Dept of Orthop, Waehringer Guertel 18–20, A-1090 Vienna, Austria

Materials and methods: In a retrospective study a-p radiographs of 82 THAs using the cementless Alloclassic® system according to Zweymüller in 61 patients suffering from rheumatoid arthritis (RA) were investigated at a mean follow-up of 89 (26–117) months by a modified digital micromotion analysis, which allows for correction of x-ray magnification and correction of the tilt of the pelvis at follow-up investigations. The calculated accuracy of this method is 1.3 mm. The results were compared with “normal data of migration” obtained from 40 patients with 45 THA due to osteoarthritis (OA) using the same type of implant. A third group consisted of 50 patients with 58 THA who were revised after loosening of a cementless Endler cup.

Results: Micromotion of the socket occurred within the first 2 years and showed no significant difference between the OA group and the patients with RA. However, after dividing the RA group into 3 subgroups according to the clinical course of disease (oligoarticular, polyarticular and mutilating RA), a significant migration vector in medio-cranial direction of the last group compared with the 2 others could be detected. Patients after cementless revision of the acetabular component showed a significant increase of cranial migration.

Conclusion: The results of cementless THA in RA are comparable with those of OA. Additional primary acetabular bone grafting for acetabular protrusion is recommended in mutilating RA.

68. Clinical factors contributing to polyethylene wear in a hinged knee tumor prosthesis—a retrieval study

C Wurnig, PD Postak, U Helwig, R Windhager, AS Greenwald

Univ of Vienna Orthop Clinic, Vienna, Austria, Orthop Res Lab, Mt Sinai Med Center, Cleveland OH, USA

This study analyses retrieved polyethylene bushings from a 2nd generation knee tumor prosthesis and quantifies clinical factors which contribute to component wear resulting in varus/valgus instability.

Materials and methods: Bushings were retrieved from 18 consecutive revisions of the HMRS design. A specially designed apparatus enabled the application of physiologic moments to the knee assembly. Varus/valgus displacements resulting from retrieved and control bushings were measured.

Results: The measurements revealed significant correlation between component varus/valgus displacement and BW

(p 0.0096), BW $\times$ height (p 0.0085), age (p 0.042), and duration of implantation (p 0.0096). Light and SEM revealed polymer surface damage inclusive of creep, polishing third body abrasion, and edge cracking as well as fusion defects.

Conclusion: This study strongly indicates that both design and patient factors described will strongly effect the wear process of prosthetic devices used in limb salvage procedure.

69. New model and biomechanical concept of the total hiparthroplasty

P Rogala, M Kaczmarek, M Rogala

Dept of Orthop, K Marcinkowski Med Sciences Univ, Physics Faculty, A Mickiewicz Univ, Poznan, Poland

Our design of the needle palisade THA is a mixture of cemented and cementless stem and of conventional and surface replacement arthroplasty. The object of this study is to compare important mechanical characteristics of our model of prosthesis on stress distributions.

Materials and methods: We used 40 layers of soft foam to simulate different chondral and subchondral surfaces of bone. We compared 2 models: a standard cuboid model and a model with double surface of basis compressed to the same lateral surfaces of cuboid model. These cuboid and truncated pyramid models were treated by static and dynamic strains. Measurements of deflections were done by an indicator, amplifier power supply, measuring console and IBM computer.

Results: We found significant differences between static and dynamic strains. Also, great difference existed between 2 cuboid and truncated pyramid models. Absorption of energy was very important in truncated pyramid model, especially for dynamic strains. Stress distributions were symmetric and vertical. One quarter of energy in static model and one half in dynamic model were absorbed. Truncated pyramid model gave a good shock absorber design. We found that augmentation of adhesion surfaces of femoral and acetabular component ought to be 7 times more, than surface at the loading part of prosthesis.

Conclusions: Our design of prosthesis respects a biological environments of joint. It represents cancellous and cortical bearing of load with vertical direction of forces. 7 times augmentation at the surfaces of adhesion convinced with physiological stress distributions in femoral and iliac bone. The advantages of the new palisade-needle model of THR are: biological silence to ingrowth the osteoblasts into the palisade-needle system, good biomechanical conditions for force translation between the implants and bone, good lubrication, no free spaces between needles at the basis surfaces of the pyramids (basis surfaces ought to be triangular, cuboid, hexagonal or octagonal), amelioration energy absorption capacity and stress-riser system of biocompatible material.

70. A novel method for diagnosing and preventing peroperative femoral fractures occurring during uncemented arthroplasty

JP Walczak¹, RJ Collier², G Kalavas²

¹Orthop Acad Unit, The Rayne Inst, St Thomas's Hosp, Lambeth Palace Rd, London, SE1 7EH, ²Electronic Engineering Lab, Univ of Kent at Canterbury, Canterbury, CT2 7NT, UK

We have used spectral analysis of the sound produced during seating of an uncemented hip prosthesis in vitro, in an attempt to diagnose and prevent iatrogenic proximal femoral fractures. The incidence and severity of such fractures are often underappreciated peroperatively and on postoperative radiographs.

Materials and methods: We quantified the change in the sound produced during impaction of a variety of press-fit prostheses into 12 femoral Sawbones[®] and one cadaveric femur. An accelerometer was used to sample the sound and the signal thus produced was quantified using Waveview[®] PC software. Impaction continued until a displaced fracture was sustained.

Results and conclusion: Qualitative analysis of the sound wave produced by impaction was compared with quantitative analysis with Fast Fourier transform. As the prosthesis became tighter in the canal, a complex change in the decay of the sound wave produced was noted. It was possible by qualitative analysis alone to identify changes in the waveform preceding a fracture and therefore to prevent it's occurrence. An undisplaced fracture was similarly readily identified. Such identification could help to minimise the severity of an intra-operative fracture or enable definitive fixation of an unstable fracture at the index operation.

71. CAD-based preoperative planning of total hip replacements

P Lubinus

Lubinus Klinik, Steenbekerweg 25, D-24106 Kiel, Germany

Preoperative planning (PP) of a primary THR by drawing is helpful; it allows to foresee problems in finding the correct pivot point, as to its height and lateralisation, it helps to choose an implant with the right CCD-angle and neck length to establish the correct offset, thus helping to avoid unwanted leg length discrepancies and poor gait. PP of a complex THR is mandatory, because due to abnormalities of the anatomy some of the clinical intraoperative tests i.e. tension of the capsule and soft tissue cannot be used in order to reconstruct a proper biomechanical situation. Measuring the correct size of implants is in all cases essential not to overream weak bone stock in the acetabulum as well as in the femur.

Materials and methods: A geometric analysis of pre- and postoperative ap-radiographs was done on 150 consecutive

patients who have been operated by the author after PP between Sep 1993 and Jan 1996. After selecting the cases with a normal geometry of the side not to be operated, we measured on the postoperative radiographs the height and lateralisation of the pivot point, the leg length and the length of the muscle lever arm and compared these data with those from the PP.

Results: 1) Postoperative leg length discrepancy averaged +3.4mm (SD 6.5mm); 2/3 of the patients left hospital with a leg length discrepancy below 5mm. 2) Reconstruction of pivot point geometry in the x-axis was -0.3mm (5.6mm) and in the y-axis +0.3mm (5.6mm). 3) Reconstruction of the muscle lever arm was -4.3mm (6.5mm). 4) Correct prediction of the implants to be used was possible for 97% of the cemented stems, 92% of the cemented cups and 85% of the uncemented ones. 5) We had 2 cases (1,3%) with ossifications grade II (Arcq), and none of higher grade. 6) We had 1 (0,7%) postoperative dislocation. 7) The intended use of a ceramic head was possible in 97%.

Conclusions: CAD-based preoperative planning is a helpful device to obtain a good accuracy of the postoperative geometric parameters in primary total hip replacements. The improved accuracy seems to coincide with a lowered rate of postoperative complications, an improved early functional result and maybe with a better longterm result.

Posters: Joints

72. Incongruity determines subchondral bone remodeling in the human elbow

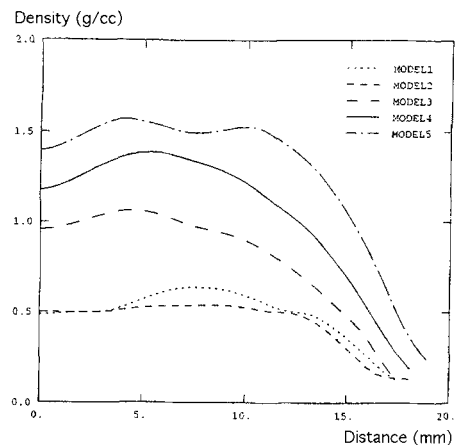
F Eckstein, C Jacobs, M Müller-Gerbl, H Sittek, B Merz, M Reiser, R Putz

Anat Anstalt, LMU München, Pettenkoferstr 11, D-80336 München, Germany, Dept of Orthop, Penn State Univ, Hershey Med Center, PA, USA

Experimental studies indicate that the human elbow joint is physiologically incongruous (1). The objective of this study was to determine this incongruity with MRI, the distribution of subchondral mineralization with CT, and the relationship between incongruity and bone density with computer simulation.

Materials and methods: 4 elbow specimens were imaged with a special MR sequence, and 36 joints with CT. Five 2D finite element models were designed (congruous, wider socket, 5%, 10%, 20% deeper sockets), 5 load-cases selected, and bone remodeling algorithms implemented according to Jacobs et al (2).

Results: With MRI, the humeroulnar joint is shown to have a deeper, and the humeroradial joint a flatter or congruous socket. With CT, bicentric density patterns are demonstrated in the first and bicentric patterns in the latter. The computer models with the flatter and congruous sockets



yield central density maxima, but those with the deeper sockets show higher densities towards both margins (Figure).

Conclusion: Both the geometry and the distribution of subchondral mineralization of the humeroradial and humeroulnar joint are strikingly different. The remodeling simulation suggests that the differences in subchondral mineralization are determined by different types of incongruity. CT and MRI may be combined to assess elbow joint loading in vivo.

References: 1) Eckstein et al. Anat Rec 1995; 243:318. 2) Jacobs et al. J Biomech 1995; 28:449.

73. Direct comparison of contact areas, contact stress and subchondral mineralization in the human hip

R v Eisenhart-Rothe, F Eckstein M Müller-Gerbl, J Landgraf, R Putz

Anat Anstalt LMU München Pettenkoferstr 11, D-80336, München, Germany

Recent findings suggest that in human hip subchondral mineralization patterns change from bicentric to monocentric as a function of age. These changes may indicate an alteration in the joint geometry. The purpose of this study was therefore to compare contact areas, contact stress and subchondral mineralization in the hip.

Materials and methods: 12 specimens without cartilage lesions (2 fresh and 10 fixed, 34 – 86 years) were investigated. The contact areas were determined by polyether casting and the contact stress with Fuji film. The subchondral mineralization was assessed using CT osteoabsorptiometry.

Results: The contact areas were initially located in the periphery of the lunate surface. In some joints the contact started at the acetabular roof (Figure 1a), in others in the anterior and posterior horns (Figure 1b). The contact stress ranged 8–9 MPa at 300% body weight. Maxima of subchondral mineralization were found in the acetabular roof, in the anterior and posterior horns (Figure 1c), or in all three locations (Figure 1d). There was no clear correlation between the distribu-

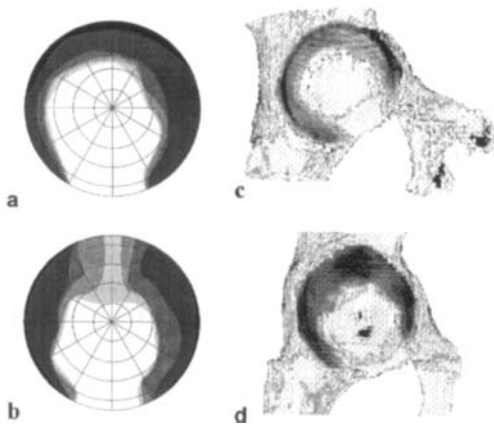


Figure 1. a and b. Contact areas at 25% body weight (dark), 50%, 100%, 200% and 300% (light); c and d. Subchondral mineralization in corresponding specimens.

tion of contact and subchondral density.

Conclusions: Different types of incongruity yield important variations in the distribution of contact and pressure in the hip joint. However, the subchondral mineralization patterns cannot be exclusively explained by the contact stress.

74. Noninvasive determination of topographical cartilage thickness maps with MRI

C Adam, F Eckstein, H Sittke, S Milz, C Becker, E Schulte, M Reiser, R Putz

Anat Anstalt, LMU München, Pettenkoferstr 11, D-80336 München, Radiolog Diagnostik, Klinikum Grosshadern, Marchioninistr 15, D-80377 München, Germany

Quantification of articular cartilage thickness is important for designing computer models of synovial joints and determining cartilage material properties. However, no approved method exists for measuring cartilage thickness in vivo.

Materials and methods: The knees of 6 healthy volunteers and 3 cadavers were imaged using a fat-suppressed FLASH-3D sequence (resolution $2 \times 0.3 \times 0.3 \text{ mm}^3$). In the volunteers the flip angle was systematically varied. In the cadaveric patellae the cartilage thickness was determined from MRI, CT arthrography, A-mode ultrasound and anatomical sections. Topographical maps were obtained by interpolation from regularly distributed measuring points and compared using image analysis.

Results: The highest contrast-to-noise ratios between the cartilage and the periarticular tissues were found at a flip angle of 30° (Figure). The thickness maps obtained with MR yielded the same degree of similarity to those derived from CT, ultrasound and anatomical sections as these methods did with each other (Table). On average, MR appeared to slightly underestimate the cartilage thickness compared with CT and

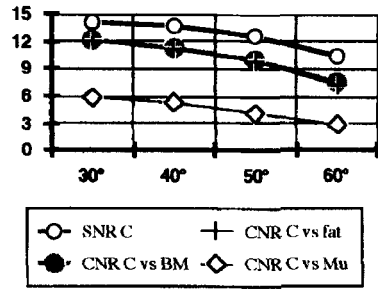


Figure 74.1. Signal- and contrast-to-noise ratios of cartilage (C) at flip angles of 30° and 60° . C = cartilage, BM = bone marrow, and Mu = muscle.

the sections, and to overestimate it compared with ultrasound.

Table. Percentage of image points in identical, higher and lower intervals. US = ultrasound, AS = anat. sections

	identical	higher	lower
MR/CT	47	23	30
MR/US	46	29	25
MR/AS	50	23	27
CT/US	41	31	28
CT/AS	45	25	30
US/AS	47	25	28

Conclusion: Fat-suppressed gradient-echo sequences provide superb contrast and may be employed for accurate non-invasive determination of cartilage thickness throughout joint surfaces.

75. Modelling ACL through discrete surface fibers

S Martelli, A Joukhar, S Zaffagnini, M Marcacci, S Lavalley, G Champeboux

Inst Ortop Rizzoli, Lab Biomecc, Bologna, Italy, INRIA, Equipe SHARP and J Fourier Univ, TIMC, Grenoble, France

ACL has a fundamental role in knee biomechanics and models have been proposed in literature to simulate its behaviour. In most models used for knee kinematics investigations ACL is described as one or more elastic lines. These approximations are useful to reproduce some aspects of ACL function, but give controversial results and are hard to integrate with microscopic and mechanical properties (Fuss 1989). We propose a new model of ACL, based on a more accurate reproduction of anatomical and mechanical features of the ligament.

Materials, methods and results: ACL is described as a collection of 8–10 curvilinear surface fibers, made of 20 knots each. Knots on the same fiber are linked by a vis-

coelastic relation, with elastic constant deduced from Smith (1993) and dumping coefficient determined empirically. In addition weak angular viscosity on fibers gives ACL a certain resistance to flexion, and inter-fiber viscosity gives ACL a 3D cohesion.

The model has been validated on 4 pig specimens, acquiring fibers' shape in flexion with a 6 dof sensor (FARO arm) and simulating ACL deformations and forces during PROM. The model's simulation of fibers' elongations are qualitatively in agreement with literature (Fuss 1989, Mommersteeg 1995), and they show that anterior ACL fibers are active near full flexion, when they stretch and tighten, while they bend without exerting forces on insertions in flexion. On the contrary posterior fibers are progressively recruited in flexion and a medial and lateral fiber between the two sets stay isometric and always inactive during PROM. Fibers' lengths and forces plottings are very well correlated and consistent with mechanical measurements on ACL (Smith 1993). Moreover the model shows acceptable 3D deformations of ACL and allows computation of ACL global stresses.

Conclusion: We think that this ACL model can provide a reliable tool for surgical simulation and testing of biomechanical hypothesis, and we envisage a possible use on humans with anatomical data extracted from CT or MRI.

Posters: Bone healing

76. Quantitative evaluation of osteoconductive bone healing by testing Vickers' microhardness

F König¹, M Kufeld¹, G Fischer², A Wulf³, A Schmid²

¹Dept of Orthop, ²Dept of Traumatol, Univ of Göttingen,

³Inst of Applied Materials Testing, Fraunhofer Soc, Bremen, Germany

The osteoconductivity of hydroxyapatite (HA) implant material is evaluated in the drill hole model on rabbit femoral condyles. To receive quantitative biomechanical data the microhardness of Vickers under load was determined.

Materials and methods: 26 specimens with different HA material were selected: specimens without drill hole, autogenous spongiosa, spongy material (Endobon®, Pyrost®), pure granular material (Altipore®, Frialit®) and mixed with autogenous spongiosa. The measurements were made on subchondral compact bone, normal trabecula (cancellous bone between subchondral compact bone and drill hole), at the mid zone of the drill hole, distal and proximal peripheric drill hole area. An Optidur testing machine produced quadratic impressions by a diamond pyramid applying a load of 50g. The length of the impressions' diagonals delivers, when transformed mathematically, the Vickers hardness number (VHN).

Results: The mean Vickers hardness number at the mid zone of the drill hole increased from 14,9 VHN after 2 weeks to 28,9 VHN 3 months postoperatively. This correlates with the morphological maturity of bone regenerates. The microhardness shows the highest values in defects filled with autogenous spongiosa followed by spongy HA and granular materials.

Conclusions: The measurement of Vickers microhardness under load provides a quantitative biomechanical evaluation of bone on undecalcified, PMMA embedded, samples without destruction. A differentiation of the mechanical competence of osteoconductive bone regenerates induced by different HA implant materials is possible.

77. Guided bone-defect healing using an absorbable membrane

N Ashammakhi, EA Mäkelä, K Vihtonen, P Rokkanen, P Törmälä

Dept of Orthop and Traumatol, Helsinki Univ Central Hosp, Helsinki, Finland

Guided tissue regeneration principle was developed and applied to control the healing process especially by dentists. The possibility of exploiting absorbable membranes for guided osseous regeneration and effect of healing of bone defects was studied in rabbits.

Materials and methods: The biocompatibility of self-reinforced polyglycolide (SR-PGA) membranes (0.15 mm thick) with cancellous bone was studied in rats. SR-PGA membranes were implanted over distal femoral metaphyses. Animals were killed, specimens examined at 1, 3, 6, 12 and 24 weeks postoperatively. The use of SR-PGA membranes to guide osseous tissue regeneration in metaphyseal bone defects and to prevent fibrous tissue invasion of these defects was studied in 32 New Zealand rabbits. The rabbits were divided into 4 groups: 1) defects grafted with autograft plug, 2) defects grafted with autograft plug and covered with SR-PGA membranes, 3) nongrafted defects, and 4) nongrafted defects covered with SR-PGA membranes. The rabbits were killed and specimens taken after 6, 12 and 24 weeks postoperatively. Radiography, histology, microradiography and oxytetracycline fluorescence were used to evaluate the outcome.

Results: Membranes gave rise to no adverse effects except for fluid accumulation in 4 cases. They were associated with new bone formation and fibrous tissue proliferation that replaced them ultimately leaving behind a fibrous fissure membrane containing remnants of the biomembrane. This biomembrane has prevented the invasion of nongrafted defects by fibrous tissue from outside. Osseous tissue ultimately has filled these defects and healed. Some of nongrafted defects that were not covered by SR-PGA membrane were invaded by fibrous tissue and their healing was compromised. The grafted defects showed no significant difference whether membranes were used or not.

Conclusions: SR-PGA membrane is biocompatible with

metaphyseal bone. It can be successively used in guiding the healing of bone defects in rabbits obviating the need to graft such defects.

78. Fixation of cancellous bone osteotomies on weight-bearing bones with intraosseus self-reinforced poly-L-lactide (SR-PLLA) plates—an experimental study in rabbits

P Rokkanen¹, K Koskikare¹, E Hirvensalo¹, H Päätilä¹, T Pohjonen², P Törmälä², G Lob³

¹Helsinki Univ Central Hosp, Helsinki, ²Tampere Univ of Technology, Tampere, Finland, ³Klinikum Grosshadern, München, Germany

PLLA plates have been placed in the bone in maxillofacial surgery and ankle fractures. The present study is the first report on application of SR-PLLA plates intraosseally to fix experimental osteotomies.

Materials and methods: Horizontal distal femoral osteotomies in 20 adult rabbits were fixed with 2 sagittally intraosseally appicated SR-PLLA plates, which were separated by a 2–5 mm wide bone bridge. The plates were fixed with 2 metallic screws on each side the osteotomy. No external support was used. The follow-up times were 3, 6, 12 and 24 weeks.

Results: Macroscopically a normal postoperative swelling was found, especially at the operated side up to 24 weeks. No foreign-body reactions were observed. Radiographically there were no displacements. Histologically in 12 weeks 2 fixations were broken and in the other the plates too. There was one fibrotic non-union. At 24 weeks full bone consolidation was seen in all except one osteotomy. Microradiographic and oxytetracycline studies confirmed these results.

Conclusions: The present study showed that the SR-PLLA plates were suitable for the fixation of weight-bearing cancellous bone osteotomies in rabbits.

79. Short and long term results of fracture fixation with plastic plates

RHM ten Broeke, AJ Tonino¹

Dept of Orthop Surg, Univ Hosp, Maastricht, ¹Dept of Orthop Surg, De Wever Hosp, Heerlen, The Netherlands

Theoretically in fracture fixation semirigid plates would allow rapid proliferation of callus without the adverse effect of stress protection and bone resorption. Therefore "flexible" plates were developed of polyethersulphone reinforced with carbon fibres (CFRPS) for internal fixation of shaft fractures in men.

Material and methods: Between 1983 and 1987 21 patients with displaced shaft fractures were treated with CFRPS plates (14 forearm, 2 humeral shaft and 5 lower leg

fractures). At the time of plate removal the tissue surrounding the plate was investigated histologically and the plates were retested mechanically. We evaluated the long term results after a mean follow up of 9₊ (7–12) years.

Results: After mean 12 (6–18) weeks all fractures showed bony union and full consolidation after 20 (12–36) weeks. The plates were removed at 8 (5–13) months. There were no delayed or non unions. In a minority of cases some small particles of carbon fibre could be detected around the screw holes with only a mild foreign body reaction. Long term evaluation showed no toxic effects of the implant. At retesting no alteration of mechanical data could be detected. In 94 % of patients there was swift and complete functional recovery and radiologically a normal bone mass in all patients.

Conclusions: CFRPS plates enable callus formation and early consolidation to allow early and safe removal of plates without refractures. This can probably be attributed to less stress protection of the bone by these semirigid implants.

Posters: Miscellaneous

80. Peripheral nerve reconstruction with a silicone tube in 6 patients

VV Viljanen

Med School, Inst of Med Technology, Univ of Tampere, Tampere, Finland

The technique of entubulation in peripheral nerve repair utilizes the principles of neurotropism and guided tissue regeneration and creates a physiological milieu between the nerve ends by means of a non-collapsing tube. To date, nerve defects of >3 cm have been repaired with success with artificial tube conduits, while the results in longer gaps have been unsatisfactory.

Patients and methods: 6 patients were treated by resection of neuroma or lacerated nerve tissue and entubulation with a silicone tube leaving a gap between the nerve ends inside the tube (Figure). The true gaps in 4 digital nerves were 10, 10, 25 and 30 mm. 2–7 and 15 mm gaps were measured in median nerves, the former being a 4/5 thickness partial laceration and the only fresh injury. The delays in the others were 5 months – 3 years. The patients were instructed in a sensory re-education program as soon as initial sensibility returned. Functional sensory recovery was graded based on static and moving 2PD measurements (Dellon and MacKinnon 1990). Excellent static 2PD result was ≤6 mm and good ≤12. The f/u time was 5–7 months.

Results: Excellent and good moving 2PD results were ≤4mm and ≤8 mm, respectively.

The result was poor in 2 cases (gaps of 30 and 25 mm). In the former, replacement of a 3-cm-long nerve graft with a tube gave better sensory recovery in 3 months without any

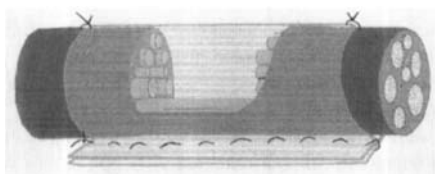


Figure 80.1.

neuroma pain than the earlier graft operation after a follow-up of 1 year (without sensory recovery). In the another patient direct end-to-end repair of RDN and entubulation of the same level (and same finger) UDN lesion gave equally good functional sensory recoveries.

Conclusion: Recovery after tubulization seems to be superior to the results with nerve grafting in cases where the nerve gap does not exceed 2 cm. Superiority is attributed to of using a silicone tube and postoperative sensory re-education program together. A partial-thickness nerve injury with delayed diagnosis or where a considerable amount of nerve tissue has to be sacrificed because of laceration is proposed as a special indication for the tubulization technique (Figure). The disadvantage of using silicone or other nonresorbable material is the need for tube removal after 2–5 months depending on the case.

81. A critical comparison of the Regnauld and Magerl hallux valgus operation

S Rehart

Orthop Univ Hosp, D-60528 Frankfurt am Main, Germany

In the Regnauld procedure, often preferred in older patients, the base of the proximal phalanx of the great toe is osteotomized and, after shaping, reimpacted under reasonable shortening to correct the deformity. In the Magerl procedure, often used in younger patients, the metatarsal head is osteotomized, rotated and shortened, then lateralised and plantarised and fixed with a screw.

Patients and methods: From 6/88 to 12/93 118 patients underwent the Regnauld procedure (105 females, 13 males, mean age 51 (27–78) years, while 50 Magerl operations were performed (48 females, 2 males, mean age 30 (12–60) years. In the age group of 30 to 50 years we found 25 patients with 38 Regnauld operations and 28 patients with 33 Magerl operations with a mean follow up of 24 (16–38) months.

Results: 20 Regnauld patients with 30 operated feet and 24 Magerl patients with 28 operated feet could be examined. The results are given Regnauld (feet)/ Magerl(feet).

Subjective results: No problems in sports 24/20, Walking distance free 16/20, no pain 24/24, cosmetically good 26/23, satisfied 25/23.

Objective results: Normal gait 30/23, free range of motion 26/25, free toe standing 28/26, cosmetically fine 25/26, very good to good 26/25 feet. Radiographic hallux valgus angles were 32°/26° prior to surgery and 15°/12° postoperatively.

Conclusions: The comparison of the Regnauld and Magerl hallux valgus procedures shows no significant differences in results in a 30 to 50 year old compatible population. Both procedures provide good results.

82. Muscle fibre type, capillarization and fibrosis in the deltoid muscle in patients with impingement syndrome compared to normal controls

P Larsson, M Kronberg, L-Å Broström

Dept of Orthop, Umeå Univ Hosp, S-90185 Umeå, Sweden

Subacromial impingement syndrome is a common cause of chronic disability of the shoulder. Pain and decreased range of motion might give inactivation of the deltoid muscle.

Materials and methods: The patient group consists of 5 men, mean age 57 years. All suffered from chronic impingement syndrome with symptom duration >1 year. All were operated on with anterior acromioplasty. The control group consists of 5 men, mean age 25 years. All suffered from traumatic shoulder dislocations planned for surgery, and there was no history of shoulder weakness, muscle hypertrophy or pain. Muscle biopsies from the middle and anterior part of the deltoid were taken at operation for immunohistochemical analysis. Cryostat sections were stained for collagen type III to visualise connective tissue and for laminin to visualise capillaries. Sections were incubated for Ca²⁺-activated myofibril adenosine triphosphate at pH 10.4, 4.6 and 4.3 for assessment of muscle fibre types I, IIA, IIB and IIC. Image analysis was used.

Results: In both parts of the deltoid muscle type I fibres were more numerous ($p < 0.01$) in patients than in controls. In the medial part of the deltoid type IIA and IIB fibres were fewer ($p < 0.05$). There was also a tendency of smaller muscle fibre area in the medial part of the deltoid in patients. No differences in capillarization were found. In the medial part of the deltoid the endomysial connective tissue constituted 15 % (SD 2.3) in patients and 10 % (SD 1.9) in controls ($p < 0.01$), and the perimysial tissue 13 % (SD 5.0) in patients and 5 % (SD 2.3) in controls ($p < 0.01$). In the anterior part of the deltoid the endomysial connective tissue constituted 13 % (SD 1.4) in patients and 10 % (SD 2.0) in controls ($p < 0.01$), but no difference was found for the perimysial connective tissue.

Conclusion: Patients with impingement syndrome had hypotrophy of muscle fibres and an increased amount of connective tissue both in the anterior and middle parts of the deltoid compared with controls. They also had an increased number of type I fibres in both parts of the deltoid as an expression of muscle inactivation due to pain.

83. Apatite–collagen implant in orthopaedic surgery

SD Litvinov, AF Krasnov

Samara State Med Univ, Samara, Russia

The present-day biomaterial for bone tissue prosthetics must conform to the main requirements: biodegradability, nonimmunogenicity, sufficient mechanical strength and economical efficiency. We have attempted to apply these principles in a synthetic implant. One approach to the problem is ensuring a high degree of structural integration of the protein matrix and inorganic salt.

Materials and methods: The implant was produced by speciality precipitation in the collagen body (xenogenous collagen) of calcium hydroxyphosphate. The biotransformation of the implant was investigated on dogs. The bone defect cavity in the shin bone, ribs and in the low jaw was filled with the implant which simulated the bone tissue. 30 animals were used for these experiments. The behavior of the material in the operation zone was checked by summarizing and magnifying X-ray, CT and ^{99m}Tc scintigraphy (in vivo) as well as by X-ray diffraction, differential thermal, morphological analysis and by combination of CT differential thermal analyses (in vitro). The length of the observations ranged from some months to 3 years.

Results: The apatite–collagen implant synthesized by us was used clinically for filling foci of fibrotic dysplasia in the humerus, scaphoid and shin bone as well as for closing defect of skull cap after trepanation. The maximum of accumulation of ^{99m}Tc in the implant biodegradation process fell on the 4th to 5th month (shin bone). The total reduction occurred in 10–12 months.

Conclusion: The results of the biological and clinical investigations show that the biomaterial (apatite–collagen implant) developed can be used in orthopaedic surgery and neurosurgery.

84. A study for evaluating semiautomatic bone resections

M Fadda, M Marcacci, ST Larsen¹, S Zaffagnini, T Wang²

Inst Ortop Rizzoli, Bologna, Italy, ¹Dept of Orthop, Univ Hosp, Lund, Sweden, ²Beijing Univ of Aeronautics and Astronautics, Beijing, China

The need of well finished bone surfaces for implant site preparation have been proved by many authors in the recent past, finding 0.35–0.50 mm for the maximum allowable gap. Previous studies by Larsen demonstrated, however, that the limits proposed are difficult to achieve in the normal clinical practice. Our work aims to demonstrate that such limits are easily achievable by using a milling machine and a robotic tool positioner.

Results: We resected 32 pig bones simulating the tibial resection needed for total knee arthroplasty. Bones were resected using different criteria: depth of the tool cutter inside the bone (2–>5 mm), feed forward speed (2–>10 mm/s), fixed or variable speed, depending on the reaction of the bone, and strategy of scanning (1–2 passes for each segment). Measurements were performed picking up in each bone a grid of surface points 2.5 mm apart using a coordinate measuring machine.

Conclusion: The results demonstrated a maximum gap of 0.3 mm (highest – lowest point in each bone) and showed global reliability of the method because of lower dependency from the scanning variables. The proposed method for performing resections, demonstrates the possibility of positively using such a technique in the clinical practice.