© Med Sci Monit, 2007; 13(5): BR125-130
PMID: 17476191

Received: 2006.12.29
Accepted: 2007.03.15
Published: 2007.05.04

Biomechanical comparison of callus over a locked intramedullary nail in various segmental bone defects in a sheep model

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

Minos Tyllianakis[1ABDEG], Despina Deligianni[2CDEF], Andreas Panagopoulos[1ABCDEF], Michael Pappas[3ABD], Efrosini Sourgiadaki[4D], Demosthenis Mavrilas[2DF], Andreas Papadopoulos[3ABD]

[1] Orthopedic Department, Patras University Hospital, Patras, Greece
[2] Department of Mechanical Engineering and Aeronautics, Laboratory of Biomechanics & Biomedical Engineering, Patras University, Patras, Greece
[3] Orthopedic Surgeon, Olympion Hospital, General Clinic S.A., Kato Sihena, Patras, Greece
[4] Department of Anesthesiology, Patras University Hospital, Patras, Greece

Source of support: Departmental sources

Summary

Background: Little has been written about the size of a bone defect that can be restored with one-stage lengthening over a reamed intramedullary nail.

Material/Methods: Sixteen adult female sheep were divided into four main groups: a simple osteotomy group (group I) and three segmental defect groups (1-, 2-, and 3-cm gaps, groups II–IV). One intact left tibia from each group was also used as the non-osteotomized intact control group (group V). In all cases, the osteotomy was fixed with an interlocked Universal Humeral Nail after reaming to 7 mm. Healing of the osteotomies was evaluated after 16 weeks by biomechanical testing. The examined parameters were torsional stiffness, shear stress, and angle of torsion at the time of fracture.

Results: The regenerate bone obvious in x-rays in the groups with 1- and 2-cm gaps had considerable mechanical properties. Torsional stiffness in these two groups was nearly equal and its value was about 60% of the stiffness of the simple osteotomy group. Gradually decreasing stiffness was observed as the osteotomy gap increased. No significant differences were found among the angles of torsion at fracture for the various osteotomies or the intact bone. These results showed that the group with 1-cm gap had 65% of the shear stress at failure of the simple osteotomy group.

Conclusions: The authors believe that there is evidence indicating that intramedullary nailing could be a reasonable option when one-stage lengthening of a long bone by 1 or 2 cm is contemplated.

key words: **limb lengthening • osteotomy model • intramedullary nailing • bone healing • biomechanical properties of callus**

Full-text PDF: http://www.medscimonit.com/fulltxt.php?IDMAN=10011

Word count: 2828
Tables: 1
Figures: 7
References: 37

Author's address: Andreas Panagopoulos, MD, Ph.D, Associated Consultant, Patras University Hospital, Orthopedic Department, 26504 Rio-Patras, Greece, e-mail: andpan21@medscape.com

Background

Traumatic or iatrogenic bone defects in the lower limbs are frequently encountered by orthopedic surgeons. Most authors advocate the Ilizarov principles of distraction osteogenesis to fill the gap using either circular external fixation devices or monolateral external fixation systems [1–6]. Nevertheless, external fixation systems are cumbersome and some patients often tolerate the consolidation period poorly, and complications such as pin-tract infections, articular cartilage damage, muscle shortening, and stiffness of the joint may develop [7–10]. In addition, if the external fixator is removed too early, the regenerated bone fractures can result in deformity, shortening, or nonunion [11,12].

Locked Reamed Intramedullary Nailing (LRIN), either solely or in combination with external fixation, has been used for the treatment of segmental bone defects in long bones since it secures both axial and rotational alignment and bone length [13–16]. The latter is accomplished even if comminution exists at the fracture site and fragments are not in close contact to each other provided that periosteal vascularization is not violated [17–20]. In 1997, Paley et al. described the technique of bone lengthening using an intramedullary nail to provide a more tolerated distraction process, shorter external fixation period, and internal bracing of the regenerated bone [9]. This technique has been tested in animal [21] and clinical studies and has gained wide acceptance because of the improvement in patient comfort and lesser risks of stiffness and malunion [22–24]. On the other hand, Kristiansen and Steen reported encountering a high rate of serious complications with lengthening using nails, leading them to their abandonment this technique and a return to the classic Ilizarov method [25]. One-stage distraction with intramedullary nails augmented by autogenous cancellous bone or BMP composite grafts has been successfully used for femoral mal- and non-unions. The mean gap bridged ranged from 2 to 4 cm [26,27]. Alternatively, fully implantable motorized nails or the Albizzia technique for gradual limb lengthening without an external device can treat leg length discrepancies of up to 7 cm and 8.4 cm on average, respectively, without major complications [28,29].

The method of one-stage distraction using intramedullary nailing has been sporadically used in our department with promising results in patients having 2–3 cm post-traumatic shortening, but to our knowledge no conclusive information is available in the literature regarding the maximum amount of bone length that can be achieved using an LRIN in one stage. We therefore undertook the present experimental study in order to examine the mechanical properties of the callus created at gaps of various sizes in sheep tibiae treated with LRIN.

Material and Methods

Sixteen adult female sheep of the same age (16 to 20 months) weighing 30–35 kg were divided into four groups. All animal experiments were carried out according to the policies and principles established by the National Institutes of Health Guide for the Care and Use of Laboratory Animals. The design of the surgical procedures was critically reviewed and observed by an experienced veterinary surgeon. The study was approved by the Ethics Committee of our hospital.

In all sheep, the procedure was performed on the right tibia with the animal under general anesthesia (administered by 2.5% pentothal solution) and lying on its left side. The insertion point for the nails was on the anterior part of the tibial plateau, with an approach medial to the patellar tendon, without opening of the knee capsule. The diaphysis was osteotomized with use of an air-oscillating saw through an anteromedial incision 4–6 cm below the knee joint. After blunt periosteal elevation over the circumference of the bone, two transverse and exactly parallel osteotomies were done to create different gaps (1, 2, and 3 cm: groups II, III, and IV) in the shaft; exact measurement was achieved using a ruler blanking out the thickness of the saw teeth (0.7 mm) (Figure 1A,B). In the osteotomy control group, a simple osteotomy without gap was performed (group I). Since all the sheep were of the same race, age, and weight, one intact left tibia from each group was used after the sacrifice as the non-osteotomized intact control group (group V). The bone cylinder was removed thereafter and split longitudinally in half; its half was temporarily re-inserted into the gap in order to accommodate the insertion of the nail and to maintain the gap during the locking procedure (Figure 1C).

A Universal Humeral Nail (UHN-Protek-Synthes) 6.8 mm in diameter and 190 mm in length was used in all cases. For the insertion of the nail, a longitudinal incision just medial to the midline was made over the knee. The patellar tendon was split in the middle. An inlet hole was created at the level of the tibial tuberosity, and the canal was reamed with a power reamer to a diameter of 7 mm. All nails were locked with mediolateral bolts, two proximal and two distal. The locking bolts were inserted proximally with the standard aiming device and distally with a custom-made aiming device accommodated to the distal part of the standard device (Figure 1D,E). In two cases, distal interlocking was achieved with the free-hand technique under fluoroscopic control. Careful attention was paid to the restoration of the physiological rotation of the tibia.

All wounds were closed in layers including the periosteum (Figure 1F) and were covered with sterile compresses and woolen bandages. The limb was protected with a long soft cast for five weeks postoperatively. Finally, anteroposterior and lateral radiographs were made immediately postoperatively. The animals were caged separately for the first three days after surgery; thereafter they were pastured together. Pain control was managed by i.m. paracetamol and antibiotic prophylaxis by three subsequent doses of i.m. Cefuroxime 750 mg.

Radiographies were obtained at 4, 8, and 16 weeks postoperatively, in the last case immediately after sacrifice of the animals. Radiological evaluation showed solid callus formation in all cases with simple osteotomies and 1-cm gap, adequate healing in the 2-cm gap group, and poor callus formation in all cases with the 3-cm gap (Figure 2). There were no cases with mechanical failure of the nail, but we noticed screw breakage in three cases; in two of these cases, healing of the fracture was achieved despite the breakage. No cases of screw loosening or migration were identified.

The tibiae were denuded thereafter and firmly embedded at their ends in epoxy resin. All animals survived to the 16th

BR

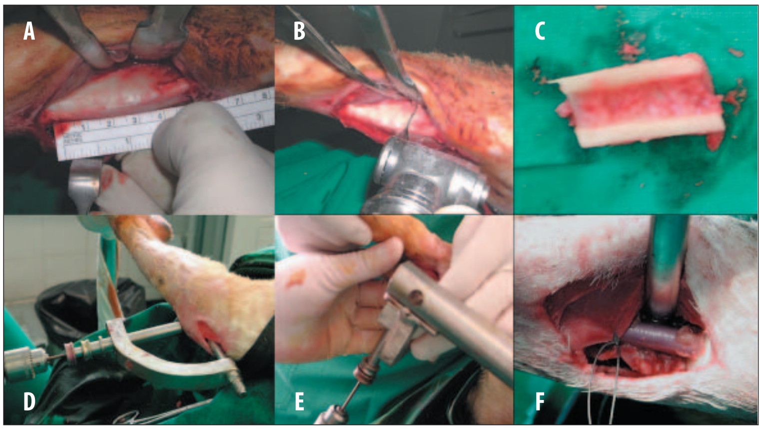

Figure 1. Surgical technique: (**A**): approach to the tibia and accurate measurement of the gap, (**B**) osteotomy, (**C**) splitting of the bone cylinder and re-insertion into the gap, (**D**) application of the nail and proximal locking using the standard aiming device, (**E**) distal locking using a custom-made aiming device, and (**F**) closure with periosteum preservation.

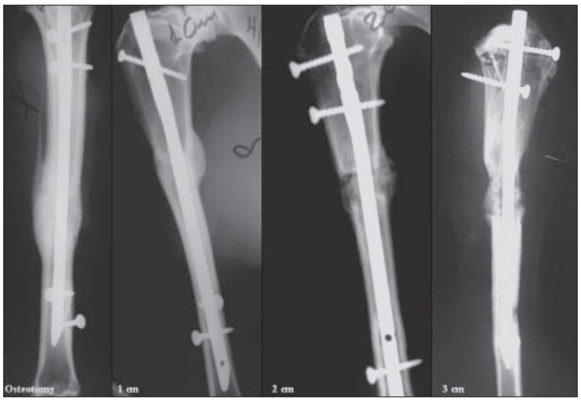

Figure 2. Radiological evaluation of healing among different osteotomized groups. Solid callus formation is seen in both the simple osteotomy and 1-cm gap group.

week except one with a 2-cm gap that died in the 11th postoperative week because of infection at the tibia and was replaced by another animal. One left tibia from each group was explanted as well to serve as the intact control group (group V).

Healing of the osteotomies was evaluated by biomechanical testing after nail removal. The mechanical test was a static application of torsion moment. It was applied using a computer-controlled torsion testing machine at a rate of 0.5° per second to failure (Figure 3). A strain gage reaction torque sensor (Lebow 2121-1K, Troy, Michigan, USA) was used to measure the applied torsion moment. The angle of rotation was measured via a device based on the variable potential divider principle. By a precise and highly linear 10-turn potentiometer connected to a Wheatstone bridge and turned during rotation due to proper mechanical engagement, a linear transformation of the rotational angle to voltage change was achieved. Each sample was tested a total of three times. The first two tests conditioned the sample and the last test was used to calculate torsional stiffness. The applied torsion moment (Nm) versus angular displacement (degrees) was recorded online. From the torsion moment and the dimensions of the tibial shaft cross-section in the middle of the fracture site of each sample measured after mechanical testing, the torsional shear stress τ was calculated by the formula:

$$t = T * r/I_0 \quad \text{where} \quad I0 = I0 = \frac{\pi}{2}(R_0^4 - R_i^4)$$

T is the torsion moment, I_0 the polar moment of inertia, r the radius at which the torsional stress was calculated, and R_0, R_i the outer and the inner radii of the cylindrical shaft of the tibia. Because of the tapered shape of the cross section, half of the mean value of six measurements of the diameter taken at six points every 15 degrees in the periphery of the cross-section, was considered as the outer radius. The slope of the graph of the mean shear stress (in the middle of the bone shaft cross-section at the fracture site) versus angle of torsion is defined as torsional stiffness. The mode and area of failure of each specimen was recorded (direct observation, photography). Mean values and standard deviations for torsional stiffness and shear stress at failure are shown in Figures 4 and 5, respectively.

Statistical analysis

The data were interpreted with the Mann-Whitney *U* test. Possible correlations were examined with use of the Spearman ρ test. SPSS 11.0 for Windows software (SPSS, Chicago, Illinois) was used for the statistical analysis. To determine statistical differences between the four groups with regard to torsional properties, a two-factorial analysis of variance for repeated measurements was performed. The level of significance was set at $p<0.05$.

Results

Fractures produced during the mechanical test were not in the callus zone in all cases. In particular, samples with a simple osteotomy or 1-cm gap were fractured distally to the callus zone, whereas samples with 2- and 3-cm gaps were fractured at the callus zone or at the distal metaphysis. One of the samples with 2-cm osteotomy was fractured at the site of the peripheral screw. Samples with osteotomy of 3 cm did not fractured abruptly. The torsion moment, and in consequence the maximum shear stress, decreased gradually after they had reached their maximum values (Figure 6).

The results of the torsion testing appear in Figures 4–7 and the summary of the mean biomechanical values for each osteotomy group in Table 1. Figure 6 displays the mean for each osteotomy graph of maximum shear stress (developed

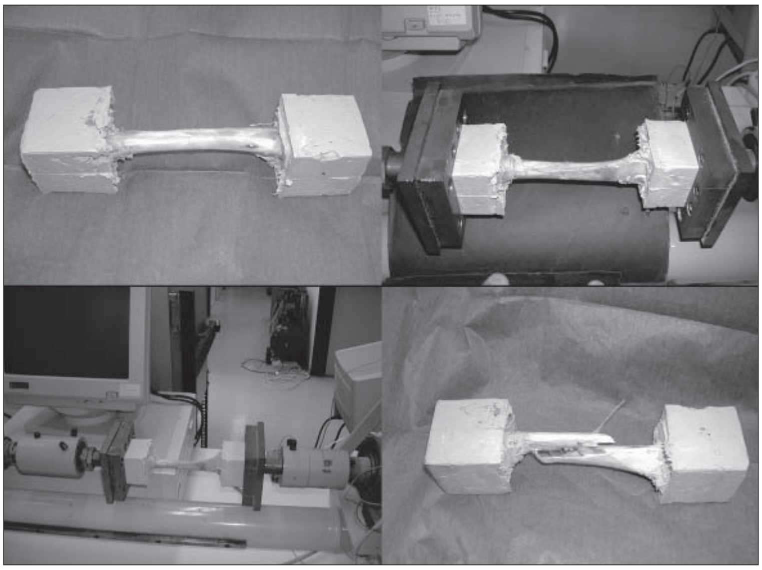

Figure 3. The biomechanical testing device. The denuded tibiae were embedded in epoxin resin. Note the fracture pattern after the application of a torsional moment. This particular case had a 3-cm defect and the fracture was eventuated in the callous zone.

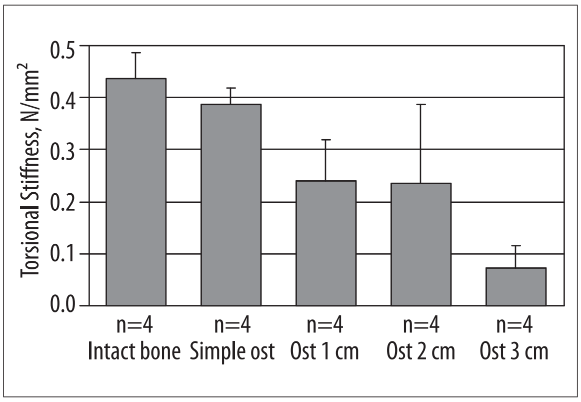

Figure 4. Torsional stiffness for each kind of osteotomy (mean ±*SD*).

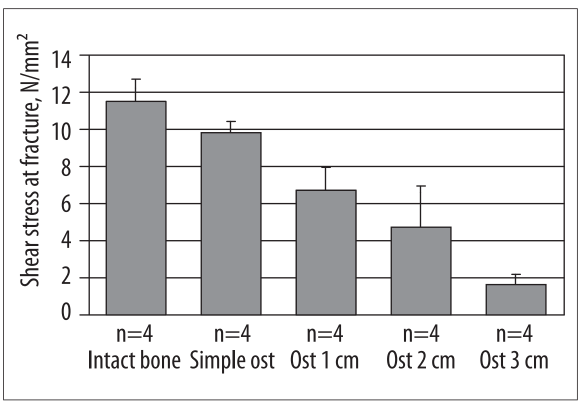

Figure 5. Shear stress at failure for each kind of osteotomy (mean ±*SD*).

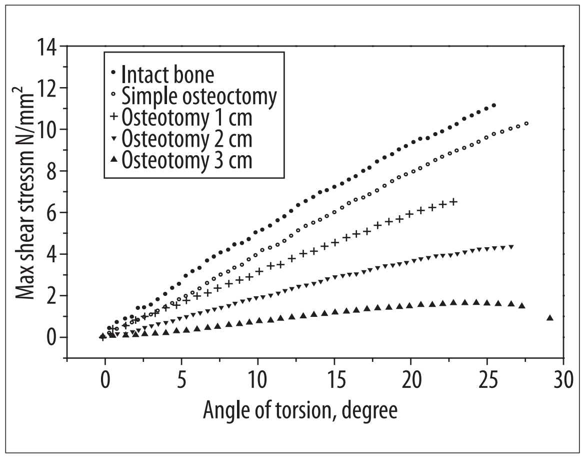

Figure 6. Graphs of maximum shear stress (on the outer surface of the bone shaft in the middle of the fracture site) versus angle of torsion, typical for each osteotomy.

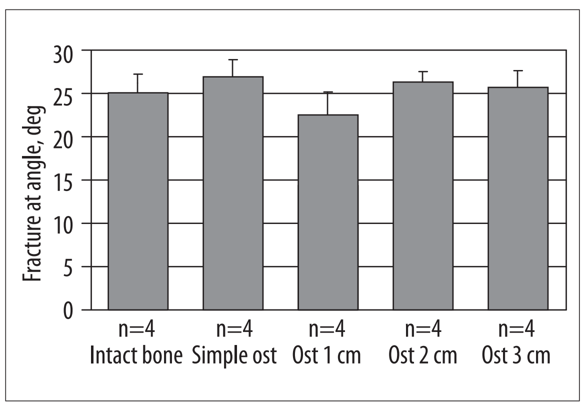

Figure 7. Angle of fracture, in degrees, for each kind of osteotomy (mean ±*SD*).

on the outer surface of the bone shaft in the middle of the fracture site) versus the angle of torsion. The slope of each graph represents the torsional stiffness. A gradually decreasing stiffness was observed as the osteotomy gap increased. Osteotomies without gap displayed the maximum stiffness, which was lower than that of intact bone. The development of torsional rigidity, although weak in osteotomies with larger gaps, provides proof that some bony bridging of the osteotomy fragments occurred in all osteotomies. Among the samples with 2-cm osteotomies there were differences resulting in large standard deviations in torsional stiffness.

Table 1. Mean biomechanical values for each osteotomy group.

	Torsional stiffness (N/mm²/deg)	Max shear stress (N/mm²)	Angle of fracture (degrees)
Intact bone (group V)	0.437	11.51	25.1
Simple osteotomy (Group I)	0.386	9.88	27.8
Osteotomy 1 cm (Group II)	0.240	6.63	23.4
Osteotomy 2 cm (Group III)	0.236	4.85	23.1
Osteotomy 3 cm (Group IV)	0.071	1.65	25.9

Figures 4 and 5 display respectively the torsional stiffness and the maximum shear stress at fracture, which occurs on the outer surface of the bone shafts at the fracture site, at the section of the gap, for each kind of osteotomy. There was a decrease in maximum shear stress from simple osteotomy to osteotomy with a fracture gap of 3 cm. No significant differences ($p<0.05$) were found among the angles of torsion at fracture for the various osteotomies or the intact bone (Figure 7).

Discussion

In the literature there are three methods of treatment of bone defects with an intramedullary nail: progressive lengthening with an external fixation device using an intramedullary nail, gradual limb lengthening with the Albizzia technique, and one-stage lengthening using an intramedullary nail [2,9,21–23,25–29,30–32]. In the last mentioned, the bridging of such a gap is not based on the principles of progressive distraction osteogenesis, which is a method well documented and widely accepted. This raises the question concerning the quality of the callus. Therefore the existence of callus per se and the mechanical properties of such callus would be worth investigation.

Bone defects in sheep tibiae is a model documented in the literature [21,33–35]. In a previous publication we described our surgical technique of intramedullary nailing of a sheep tibia [32]. In this study we followed the technique described by den Boer et al. [33] with a slight modification: we used half of the removed bone cylinder as a temporary spacer in order to maintain the gap during nail insertion and locking instead of a specially designed device used by the above-mentioned authors.

The healing of bones was evaluated by torsion testing. The examined parameters were torsional stiffness, shear stress, and angle of torsion at the time of fracture. Our decision to use only mechanical test and no histology or DEXA was based on the main principle of any fracture healing process: the restoration of mechanical strength of the bone.

The callus created in the simple osteotomy group was also very strong in our series, as other authors have shown in their series [36,37]. Samples with osteotomy without a gap were fractured distally to the osteotomy zone at a site roughly coinciding with the middle of the tibia, which was the site where the intact tibiae were fractured. This was not the case with samples with osteotomies of 2-cm or 3-cm gap, which were fractured at the callus zone or at the distal metaphysis. The callus in the 3-cm gap group was very weak in all tests.

In the tibial model described by den Boer et al. [33], two of six tibiae with 3-cm bone defects were healed. They give no information regarding the postoperative mobilization. The authors argue that closure of the periosteum could be a possible explanation for callus formation in these cases. We nevertheless did not notice adequate callus formation although we also did meticulous closure of the periosteum. A likely cause could have been the better mechanical stability they obtained with three screws proximally and three distally compared with two proximally and two distally in our study). Regauer et al. [35] created a critical defect (5 cm) in sheep tibiae that was filled with different osteoinductive factors, including autogenous cancellous bone and Osteogenic Protein-1. After 12 weeks they used 3D-CT volumetry to evaluate fracture healing, but there were no significant differences between the different combinations of growth factors. New bone formation by autogenous cancellous bone was better than any other factor. According to our findings, we think that healing of a 3-cm bone defect is not certain unless bone graft or bone substitute is applied. Den Boer et al. [33] noticed efficient healing in 7/8 defects (3 cm) in the group that was treated with autologous bone graft.

Maximum shear stress on the outer surface of the bone at the fracture site at the time of failure was noted in the intact bone. The various groups had progressively lower values than the intact bone, the highest being that with the simple osteotomy and the lowest that with the 3-cm gap. The group with the 3-cm gap had small resistance in torsion, thus emphasizing the weakness of the callus. The regenerate bone obvious in x-rays in the groups with 1-cm and 2-cm gaps had considerable mechanical properties. Torsional stiffness in these two groups was nearly equal and its value was about 60% of the stiffness of the simple osteotomy group. It was interesting that the group with the 2-cm gap, i.e. twice the gap size of the group with 1 cm, had the same torsional stiffness as the former. However, the wide range in values in the latter shows that further investigation is required. A more even distribution of values was noted regarding shear stress at failure. A gradually decreasing shear stress was observed as the osteotomy gap increased. Our results showed that the group with the 1-cm gap had 65% of the shear stress at failure of the simple osteotomy group.

The weak point of this study was the short period of time over which the experiment was developed. It is unknown whether the callus would further mature in the groups with the various gaps after the period of 16 weeks and what the time required for that would be. The increase in torsional resistance of the callus would probably be faster and sounder in the group with the 1-cm gap, but at the same time one could reasonably hypothesize that the callus in the 2-cm group would finally be equal in terms of torsional stiffness to that of 1-cm gap. The length of time per se for callus formation in intramedullary nailing is not a problem for patients because their only restriction is partial weight bearing over the prescribed period of time. The authors acknowledge these weak points, but they had to finish the study prematurely for reasons beyond their control.

CONCLUSIONS

We believe that there is evidence indicating that intramedullary nailing would be a reasonable option when one-stage lengthening of a long bone of 1 or 2 cm is contemplated. However, a longitudinal study of healing of acutely distracted bones is necessary to draw firm conclusions.

Acknowledgements

The authors wish to thank Mr. Takis Katsoulos, veterinary surgeon, Aristoteleio University of Thessalonica, for his assistance regarding anesthesia prescription and design of the surgical approach and Mrs. Ioanna Bagioneta, nurse, for surgical assistance. The authors express their appreciation to Protek-Synthes Hellas for their donation of the intramedullary nails we used in the study.

REFERENCES:

1. Aronson J: Current Concepts Review: Limb-Lengthening, Skeletal reconstruction, and bone transport with the Ilizarov method. J Bone Joint Surg Am, 1997; 79: 1243–1258
2. Dal Monte A, Donzelli O: Comparison of different methods of leg lengthening. J Pediat Orthop, 1988; 8: 62–64
3. Ilizarov GA: The tension-stress effect on the genesis and growth of tissues. Part II. The influence of the rate and frequency of distraction. Clin Orthop Relat Res, 1989; 239: 263–85
4. Noonan K, Leyes M, Forriol F, Canadell J: Distraction osteogenesis of the lower extremity with use of monolateral external fixation. A study of two hundred and sixty-one femora and tibiae. J Bone Joint Surg Am, 1998; 80: 793–806
5. Regauer M, Jurgens I, Kotsianos D et al: New-bone formation by osteogenic protein-1 and autogenic bone marrow in a critical tibial defect model in sheep. Zentralbl Chir, 2005; 30: 338–45
6. Wu CC, Lee ZL: One-stage lengthening using a locked nailing technique for distal femoral shaft nonunions associated with shortening. J Orthop Trauma, 2004; 18: 75–80
7. Gasser B, Boman B, Wyder D, Schneider E: Stiffness characteristics of the circular Ilizarov device as opposed to conventional external fixators. J Biomech Eng, 1990; 112: 15–21
8. Giannikas K, Maganaris C, Karski M et al: Functional outcome following bone transport reconstruction of distal tibial defects. J Bone Joint Surg Am, 2005; 87: 145–52
9. Papadopoulos AX, Tyllianakis, M, Karageorgos E et al: Exchange intramedullary nailing for external fixation device in the stabilization phase in bone lengthening process. J Bone Joint Surg Br, 2004; 86(Suppl.III), 273–74
10. Tornetta P III, Bergman M, Watnik N et al: Treatment of grade-IIIb open tibial fractures. A prospective randomised comparison of external fixation and non-reamed locked nailing. J Bone Joint Surg Br, 1994; 76: 13–19
11. Luke DL, Schoenecker PL, Blair VP III, Capelli AM: Fractures after Wagner limb lengthening. J Pediatr Orthop, 1992; 12: 20–24
12. Simpson AHRW, Cole AS, Kenwright J: Leg lengthening over an intramedullary nail. J Bone Joint Surg Br, 1999; 81: 1041–45
13. Bhandari M, Guyatt GH, Tornetta P III et al: Current practice in the intramedullary nailing of tibial shaft fractures: an international survey. J Trauma, 2002; 53: 725–32
14. Bhandari M, Guyatt GH, Tong D et al: Reamed versus nonreamed intramedullary nailing of lower extremity long bone fractures: a systematic overview and meta-analysis. J Orthop Trauma, 2000; 14: 2–9
15. Finkemeier CG, Schmidt AH, Kyle RF et al: A prospective, randomized study of intramedullary nails inserted with and without reaming for the treatment of open and closed fractures of the tibial shaft. J Orthop Trauma, 2000; 14: 187–93
16. Nowotarski P, Brumback RJ: Immediate interlocking nailing of fractures of the femur caused by low- to mid-velocity gunshots. J Orthop Trauma, 1994; 8: 134–41
17. Anastopoulos G, Asimakopoulos A, Exarchou E, Pantazopoulos T: Closed interlocked nailing in comminuted and segmental femoral shaft fractures. J Trauma, 1993; 35: 772–75
18. Brumback RJ, Toal TR Jr, Murphy-Zane MS et al: Immediate weightbearing after treatment of a comminuted fracture of the femoral shaft with a statically locked intramedullary nail. J Bone Joint Surg Am, 1999; 81: 1538–44
19. Vecsei V, Heinz T: The interlocking nail for long comminuted and compound fractures of the femur and tibia. Technique and results. Unfallchirurg, 1990; 93: 512–18
20. Wagner H: Surgical lengthening or shortening of the femur and tibia. Technique and indications. In: Hungerford DS, editor. Progress in orthopaedic surgery. Leg length discrepancy. The injured knee. New York: Springer, 1977; 71–94
21. Lin CC, Huang SC, Liu, TK, Chapman M: Limb lengthening over an intramedullary nail: An animal study and clinical report. Clin Orthop Relat Res, 1996; 330: 208–16
22. Gorden JE, Goldfarb CA, Luhmann SJ et al: Femoral lengthening over a humeral intramedullary nail in preadolescent children. J Bone Joint Surg Am, 2002; 84: 930–37
23. Kocaoglu M, Eralp L, Kilicoglu O et al: Complications encountered during lengthening over an intramedullary nail. J Bone Joint Surg Am, 2004; 86: 2406–11
24. Stanitski DF: The effect of limb lengthening of articular cartilage. An experimental study. Clin Orthop Relat Res, 1994; 301: 68–72
25. Kristiansen LP, Steen H: Lengthening of the tibia over an intramedullary nail, using the Ilizarov external fixator. Acta Orthop Scand, 1999; 70: 271–74
26. Johnson EE, Uris MR: One-Stage Lengthening of Femoral Nonunion Augmented With Human Bone Morphogenetic Protein. Clin Orthop Relat Res, 1998; 347: 105–16
27. Paley D: Problems, obstacles, and complications of limb lengthening by the Ilizarov technique. Clin Orthop Relat Res, 1990; 250: 81–104
28. Baumgart R, Betz A, Schweiberer L: A Fully implantable motorized intramedullary nail for limb lengthening and bone transport. Clin Orthop Relat Res, 1997; 343: 135–43
29. Guichet JM, Deromedis B, Donnan LT et al: Gradual femoral lengthening with the Albizzia intramedullary nail. J Bone Joint Surg Am, 2003; 85: 838–48
30. Murray DW, Kambouroglou G, Kenwright J: One-stage lengthening for femoral shortening with associated deformity. J Bone Joint Surg Br, 1993; 75: 566–71
31. Paley D, Herzenberg JE, Paremain G, Brave A: Femoral lengthening over an intramedullary nail: a matched-case comparison with Ilizarov femoral lengthening. J Bone Joint Surg Am, 1997; 79: 1464–80
32. Price CT, Mann JW: Experience with the Orthofix device for limb lengthening. Orthop Clin North Am, 1991; 22: 651–61
33. den Boer FC, Patka P, Bakker FC et al: New segmental long bone defect model in sheep: quantitative analysis of healing with dual energy x-ray absorptiometry. J Orthop Res, 1999; 17: 654–60
34. Kaspar K, Schell H, Seebeck P et al: Angle stable locking reduces interfragmentary movements and promotes healing after unreamed nailing. Study of a displaced osteotomy model in sheep tibiae. J Bone Joint Surg Am, 2005; 87: 2028–2037
35. Simpson AHRW, Kenwright J: Fracture after distraction osteogenesis. J Bone Joint Surg Br, 2000; 82: 659–65
36. Augat P, Burger J, Schorlemmer S et al: Shear movement at the fracture site delays healing in a diaphyseal fracture model. J Orthop Res, 2003; 21: 1011–17
37. Claes L, Eckert-Hubner K, Augat P: The fracture gap size influences the local vascularization and tissue differentiation in callus healing. Langenbecks Arch Surg, 2003; 388: 316–22

Index Copernicus

Global Scientific Information Systems
for Scientists by Scientists

INDEX COPERNICUS INTERNATIONAL™

www.IndexCopernicus.com

EVALUATION & BENCHMARKING

PROFILED INFORMATION

NETWORKING & COOPERATION

VIRTUAL RESEARCH GROUPS

GRANTS

PATENTS

CLINICAL TRIALS

JOBS

STRATEGIC & FINANCIAL DECISIONS

Index Copernicus integrates

IC Scientists

Effective search tool for collaborators worldwide. Provides easy global networking for scientists. C.V.'s and dossiers on selected scientists available. Increase your professional visibility.

IC Virtual Research Groups [VRG]

Web-based complete research environment which enables researchers to work on one project from distant locations. VRG provides:

- customizable and individually self-tailored electronic research protocols and data capture tools,
- statistical analysis and report creation tools,
- profiled information on literature, publications, grants and patents related to the research project,
- administration tools.

IC Journal Master List

Scientific literature database, including abstracts, full text, and journal ranking. Instructions for authors available from selected journals.

IC Patents

Provides information on patent registration process, patent offices and other legal issues. Provides links to companies that may want to license or purchase a patent.

IC Grant Awareness

Need grant assistance? Step-by-step information on how to apply for a grant. Provides a list of grant institutions and their requirements.

IC Conferences

Effective search tool for worldwide medical conferences and local meetings.

IC Lab & Clinical Trial Register

Provides list of on-going laboratory or clinical trials, including research summaries and calls for co-investigators.