■ REVIEW ARTICLE

The evolution of functional bracing of fractures

A. Sarmiento,
L. Latta

From the University of Miami School of Medicine, Miami, USA

Functional fracture bracing, described in 1967,[1] was inspired by the patellar-tendon-bearing prosthesis which had recently been developed for below-knee amputees. This prosthesis had eliminated the traditional thigh corset and allowed the transfer of weight-bearing stresses from the soft tissues of the thigh to the patellar tendon and condyles of the proximal tibia. Anticipating that by a similar mechanism, a below-knee weight-bearing cast, moulded like a patellar-tendon-bearing prosthesis, would prevent shortening in axially unstable tibial fractures, the first below-knee functional cast was constructed.[1] Contrary to traditional practice, this new cast allowed full movement of the knee but immobilised the ankle. However, shortly afterwards it was realised that inclusion of the ankle and foot was unnecessary. The ankle was therefore freed and within a short time pre-fabricated plastic braces became an accepted form of treatment.[2] Initial reports indicated a low rate of nonunion, no increase in shortening of the limb and angular deformities which were within acceptable levels.[1,2]

However, doubt was cast on the idea that the patellar tendon and tibial condyles were major weight-bearing areas.

Laboratory studies revealed that neither the patellar tendon nor the tibial condyles participated in the avoidance of shortening. It was then suspected that the soft tissues surrounding the fracture, firmly compressed by the supporting walls of the brace, prevented shortening and angulation by the principle of the incompressibility of fluids.[3-8]

Encouraged by initial successes, the philosophy and technique of functional bracing were extended to other fractures of long bones. The first was fracture of the femoral shaft. At that time, open intramedullary nailing of femoral fractures had been limited to diaphyseal injuries since closed interlocking nailing had not been introduced in the USA. The ischial weight-bearing prosthesis worn by the above-knee amputee suggested that a similarly constructed brace, applied to a patient with a fracture of the femoral shaft, would allow the transfer of weight-bearing stresses to the ischial tuberosity and thereby prevent shortening of the bone. However, success was not consistent. Fractures in the proximal half of the femur tended to angulate into varus. The subsequent introduction of the interlocking nail for the treatment of metaphyseal femoral fractures relegated bracing to unusual situations when nailing could not be used.[9-11]

Extension of fracture bracing to other bones met with varying degrees of success. Pre-fabricated braces were developed for the treatment of diaphyseal humeral fractures and proved to be highly successful. A high rate of union and few complications were documented.[12-14] The indications for bracing widened so that compound fractures with a moderate degree of soft-tissue damage were also braced successfully. However, the premature introduction of active elevation of the arm created excessive movement at the site of the fracture and an increase in the rate of nonunion.[10,11]

Success was also achieved in the treatment of isolated ulnar fractures using pre-fabricated braces which did not immobilise the adjacent joints. The rate of union was high and the final functional results very acceptable.[15,16] Colles' fractures which are stable after manual reduction and are not associated with dislocation of the distal radioulnar joint, can be braced with appliances which stabilise the forearm in a relaxed attitude of supination. They should also allow flexion and extension of the elbow, flexion of the wrist, and prevent pronation and supination of the forearm. Failure to stabilise the forearm in supination can lead to a loss of reduction. The functional results obtained in this way were comparable with those achieved by more aggressive treatments.[7,17-19]

Bracing of fractures of both bones of the forearm encountered technical difficulties which limited its use. However, increased shortening of the limb did not appear to be a problem. Axially unstable fractures maintained their align-

■ A. Sarmiento, MD, Professor and Chairman Emeritus
■ L. Latta, PE, PhD, Professsor and Director of Research
Department of Orthopaedics and Rehabilitation
University of Miami, School of Medicine, PO Box 016960, Miami, Florida, 3310 USA.

Correspondence should be sent to Professor A. Sarmiento; e-mail: asarm@bellsouth.net

doi:10.1302/0301-620X.88B2.16381 $2.00
J Bone Joint Surg [Br] 2006;88-B:141-8.

Fig. 1a

Fig. 1b

Fig. 1c

Fig. 1d

Figure 1a – Radiographs showing closed fractures of the left tibia and fibula stabilised in a functional below-knee brace one week after injury. No attempt was made to regain length. Two screws were placed percutaneously, one above and one below the fracture. The heads of the screws were connected to movement-sensitive devices which transmitted information from weight-bearing activities to a computer. Figure 1b – Photograph showing the patient bearing weight on a force plate. Figure 1c – Radiograph taken after completion of healing. The initial shortening remained the same. Figure 1d – Photograph showing the clinical appearance after union (reproduced with permission from Sarmiento et al.[35])

ment and length in the brace, which also allowed movements of the wrist and elbow. The lessons learned were considerable and shed light on the physiological behaviour of these fractures.[20-22]

Functional bracing of ununited tibial diaphyseal fractures also gave acceptable results in many instances so that its role was established and limitations identified.[8,23]

The concept of fracture bracing was preceded by the popularisation of the rigid immobilisation of fractures and interfragmentary compression using plates, an idea which had first been advanced by Danis in the mid-twentieth century[24] and which was further refined by the AO technique. Basic research findings resulted in rapid acceptance of the method throughout the world.[25,26]

Despite the attraction of fixation by a compression plate, it became evident that some of the scientific concepts on which the technique was based were flawed. Rigid immobilisation of fractures with plates did not enhance healing but delayed it, as well as weakening the underlying cortical bone.[4-7,26,27] This was explained as being a consequence of stress shielding.[28-31] It was concluded that the thick and stiff plates were creating this undesirable phenomenon and changes were made. However, the concept that rigid immobilisation was essential to the success persisted. A lack of

Fig. 2a

Fig. 2b

Photographs showing a) mechanically produced oblique fractures of the tibia and fibula which have left the interosseous membrane intact and b) manual angulation and vertical loading of the specimen. No further shortening occurred and only minimal damage to the interosseous membrane was identified (reproduced with permission from Sarmiento A, Latta LL. *Closed functional treatment of fractures.* Springer-Verlag, 1992.[7])

Fig. 3a

Fig. 3b

Fig. 3c

Figures 3a and 3b – Radiographs showing a) closed, comminuted fractures of the left tibia and fibula with initial displacement but acceptable shortening and b) the healed fractures with preservation of alignment and length. Figure 3c – Photograph showing full healing (reproduced with kind permission of Springer Science and Business Media from Sarmiento A, Latta LL. *Functional fracture bracing: the tibia, humerus and ulna.* Springer-Verlag, 1995.[8])

peripheral callus was regarded as a sign of good healing. More flexible plates were produced and extensively used, but failed to eliminate bone atrophy.[31] It was then suggested that atrophy was created by interference with vascularity under the plate.[32] This led to the manufacture of plates which had projections to reduce the amount of contact between the plate and bone.

Once it was realised that these modifications had not eliminated the adverse changes taking place under the metal implants, it was concluded that absolute rigidity was undesirable and that some movement at the site of the fracture was advantageous to osteogenesis.[32-34]

The philosophy of functional bracing is based upon principles which are totally opposite to those of the AO technique. It maintains that rigid immobilisation of fractures of long bones is unphysiological and that movement at the site of a fracture during functional activities encourages osteogenesis.[3-7,27] The success achieved by intramedullary nail-

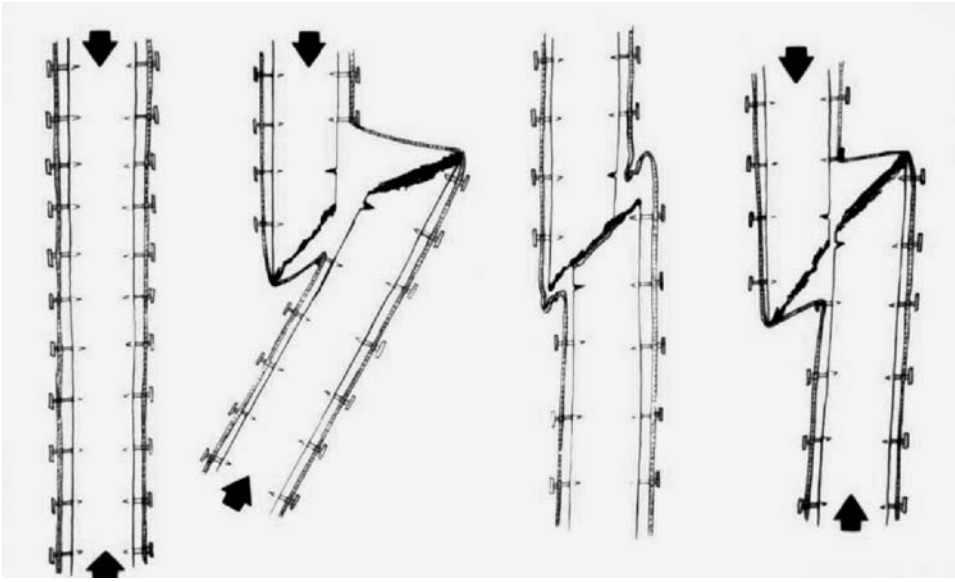

Fig. 4a Fig. 4b Fig. 4c Fig. 4d

Diagrams of the likely mechanism which prevents shortening beyond that seen at the time of the initial injury. They show a) the uninjured limb, b) damage to the soft tissues which are attached to the bone and shortening of the limb with the remaining intact tissues becoming a tether which prevents further shortening, c) traction which restores length, and d) weight-bearing which shortens the limb but no more than that seen initially, as the intact tissues act as a tethering device (reproduced with kind permission of Springer Science and Business Media from Sarmiento A, Latta LL. *Closed functional treatment of fractures.* Springer-Verlag, 1992.[7])

ing further supports the concept that movement at the site of the fracture is desirable.

As with the AO technique and other methods of internal fixation of fractures, functional bracing has evolved. One of the most important features identified during this development was the finding that in closed fractures of two-bone segments of the body, the initial shortening did not increase despite the introduction of early activity and weight-bearing.[3,5-7,11,14,35] The degree of movement which takes place at a fracture during physiologically-controlled weight-bearing is considerable with axial displacement of as much as 0.5 cm being recorded (Fig. 1).[3,33] The interosseous membrane and the surrounding soft tissues provide a tethering mechanism which prevents additional shortening of the fractured bone (Fig. 2). The firm compression of the soft tissues which is provided by the adjustable brace stiffens the area and controls alignment (Fig. 3).[6,8,11] Regaining the length of a fractured bone by traction, in the case of an axially unstable fracture, results in the return of the initial shortening when weight-bearing begins. This suggests that such fractures of the tibia with unacceptable shortening on the initial post-injury radiographs should not be braced (Fig. 4). Once it was recognised that the shortening seen in closed diaphyseal fractures remained the same throughout the healing process it was realised that the main function of the brace was to prevent angular deformity. A review of 1000 closed diaphyseal tibial fractures treated by a functional below-knee brace showed a final varus angulation in 322 (32%) fractures. Of these, 90% healed with angulation of < 6° and 95% with angulation of < 8°. The mean final varus angulation for this group was 4.8° (SD 2.9°).[36] As the initial swelling which accompanies all fractures subsides, so the desirable snugness of the braces decreases, making the limb subject to angular deformities. This risk can be reduced by repeated tightening of the adjustable straps (Fig. 5).

Compliance is not always obtained, and therefore angular deformities may be seen. This remains the most important issue confronting functional bracing, particularly of tibial fractures, and is currently being addressed by the development of a system to ensure permanent, firm compression of the soft tissues.

Equally important in the evolution of fracture bracing was the confirmation that the strength of the callus which forms at the site of a fracture where movement occurs is greater than that seen after rigid immobilisation (Fig. 6).[5-8,26,27,34]

The local irritation of the soft tissues surrounding a fracture produces a vascular invasion which is ultimately responsible for the greater degree of osteogenesis (Fig. 7).[4,7,26,37] This invasion does not occur in the presence of rigid immobilisation. Studies[27,29] have also suggested that when a diaphyseal fracture is treated by plate fixation, the medullary blood supply, which is seriously disrupted by injury, rapidly returns to normal.

Consequently, the explanation that cortical atrophy after plate immobilisation is the result of compromise to the blood supply becomes unsupportable because the medul-

Fig. 5a

Fig. 5b Fig. 5c

Radiographs showing a) a comminuted fracture of the left humeral diaphysis produced by a low-velocity bullet which was treated by a functional brace and b) and c) full healing three months later (reproduced with kind permission of Springer Science and Business Media from Sarmiento A, Latta LL. *Functional fracture bracing: the tibia, humerus and ulna.* Springer-Verlag, 1995.[8])

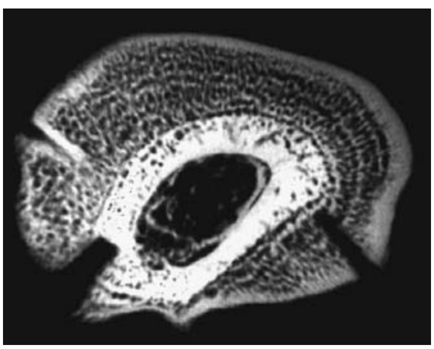

Fig. 6a

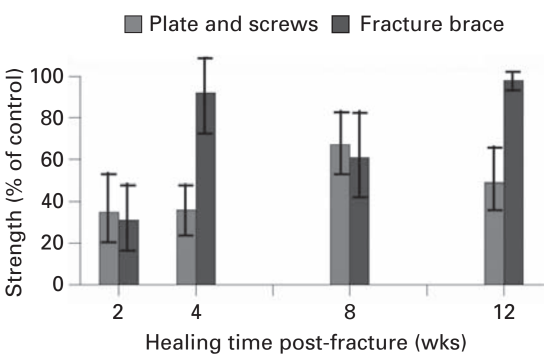

Fig. 6b

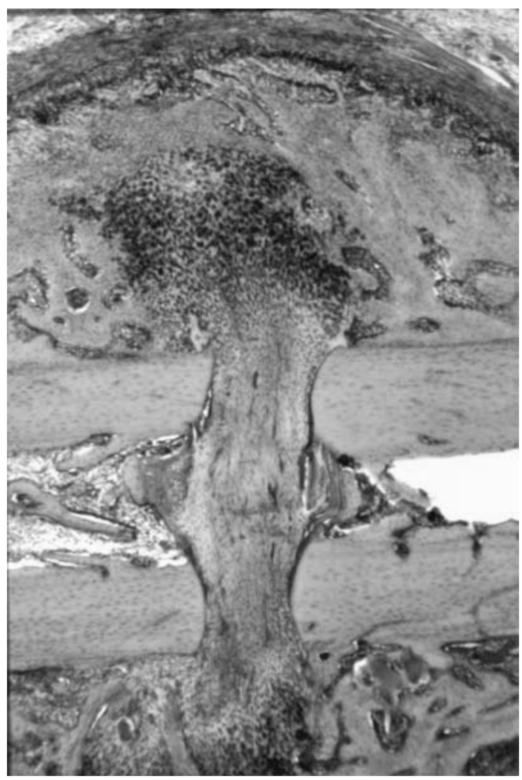

Fig. 6c

Figure 6a – Microradiograph of the peripheral callus which forms when there is movement at the site of the fracture. The large diameter of the callus increases the strength of the bone. Figure 6b – Bar graph indicating the increase in strength of callus formed in the presence of motion between the fragments compared with that of the immobilised fragments; Figure 6c – Photomicrograph of a healing fracture in a rabbit showing the abundant peripheral callus. The fracture is healing in the presence of movement at the site of the fracture. There is no evidence that the haematoma plays a role in osteogenesis (reproduced with kind permission of Springer Science and Business Media from Sarmiento A, Latta LL. *Closed functional treatment of fractures.* Springer-Verlag, 1992 (Figs 2.15B, 2.27, 5.15B). Figure 6c is a reproduction of Fig. 1.15A in Sarmiento A, Latta L. *Functional fracture bracing*. Springer-Verlag, 1995.

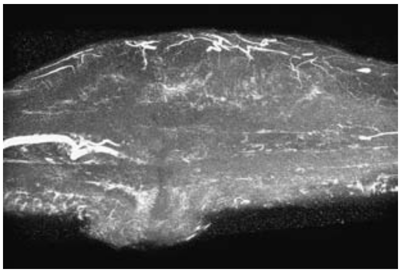

Fig. 7a

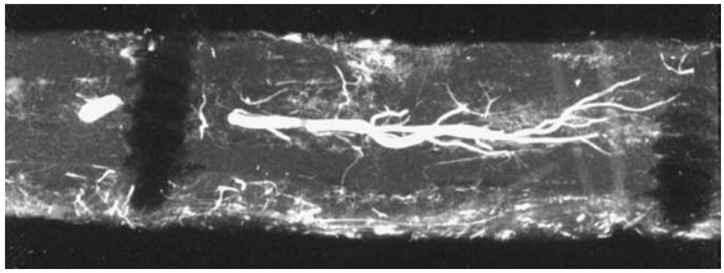

Fig. 7b

Photomicrograph showing a) massive invasion of capillaries into the site of the fracture when there is movement there and b) without movement there is no vascular contribution from the soft tissues. Reproduced with kind permission of Springer Science and Business Media from Sarmiento A, Latta LL. *Closed functional treatment of fractures*, Springer Verlag, 1992[7] (Figs. 2.1A and 2.28B).

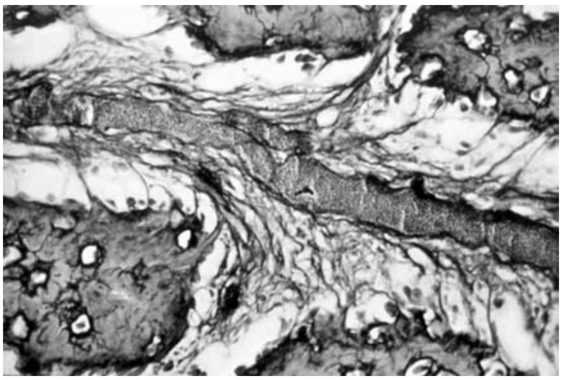

Fig. 8a

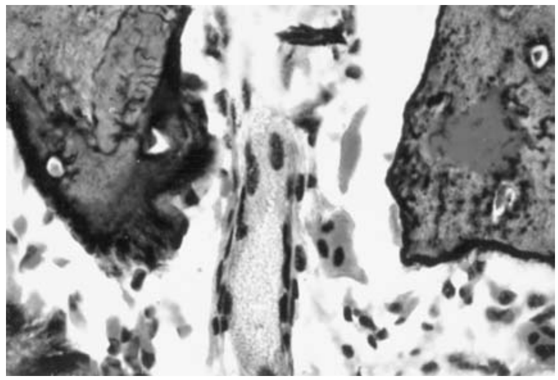

Fig. 8b

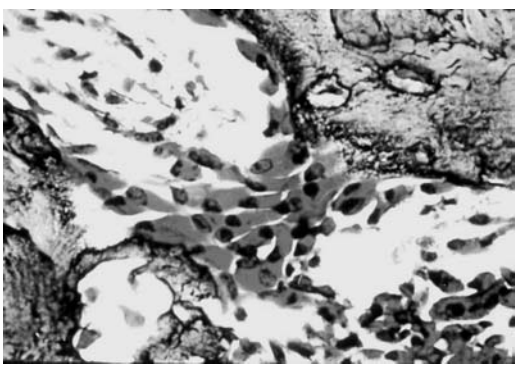

Fig. 8c

Photomicrographs of a fracture treated with movement at its site showing a) capillaries arising from the surrounding soft tissues and the osteoid bone around it, b) osteoblasts arising from metaplasia of cells which form the walls of the capillaries, and c) osteoblastic activity at the site of the fracture. Reproduced with kind permission of Springer Science and Business Media from Sarmiento A, Latta LL. *Closed functional treatment of fractures*. Springer-Verlag, 1992[7] (Figs. 2.2B, 2.3B, 2.4).

lary vessels nourish between 66% and 90% of the cortex of long bones. The remaining cortical bone is nourished by periosteal vessels.[4,7-9,37] In addition, there is strong evidence that the osteogenic capillaries arise primarily from the surrounding soft tissues and to a less extent, from the periosteal vessels. For reasons which are currently unclear, the endothelial and perithelial cells which form part of the invading capillaries, undergo metaplasia and become osteoblasts (Fig. 8).[4,7-9] It can therefore be concluded that the greater the number of capillaries at the site of a fracture the greater is the degree of osteogenesis.

It has also been observed that the osteoblasts which form in non-immobilised fractures show greater activity.[7,8] The haematoma which forms at the site of a fracture after the initial injury, rather than being a helpful participant in the healing process, appears to delay it.[27] Histological examination of healing non-immobilised fractures, has shown resorption of the haematoma which is normally seen around bony fragments before enchondral ossification takes place and questions the popular belief that the haematoma plays an important role in healing. Because it was inevitable that treatment of diaphyseal fractures by functional braces might lead to some permanent angular deformities, studies were conducted to determine if these deformities had a harmful effect on the adjacent joints. The data obtained indicated that minor angular deformities in weight-bearing bones altered the distribution of pressure on the articular cartilage in the proximal and distal joints to a minimal extent.[38-44]

The fact that some minimally displaced intra-articular fractures might be associated with diaphyseal fractures prompted studies to determine whether permanent degenerative arthritis was unavoidable. These investigations indicated that minor articular incongruity did not necessarily produce progressive arthritis.[45] By contrast, incongruity associated with instability of a joint was more likely to result in late degenerative change.[46]

There will always be limitations to the use of bracing techniques in the management of fractures of long bones. Currently, bracing is primarily used in closed, axially unstable tibial fractures which show an acceptable degree of shortening, and have an angular deformity which can be manually corrected to within a few degrees of normal. Included in this group are transverse fractures which can be successfully reduced and rendered mechanically stable.[1,2,7,11,35,47] Regaining length by traction and manipulation in axially unstable fractures which had originally demonstrated unacceptable shortening can lead to a loss of any length gained and a return to the initial shortening. Failure to recognise this has led some to discard functional bracing as a treatment option. Axially unstable fractures of the tibia which show initial, unacceptable shortening should not be treated by functional bracing, unless there are strong mitigating circumstances. Functional bracing of open fractures is limited, because most show unacceptable shortening, and the damage to the soft-tissue envelope prevents the effective role of the incompressible soft tissues around the site of the fracture.

Internal fixation of diaphyseal and metaphyseal fractures of long bones will remain the treatment of choice in many cases. Systems of intramedullary nailing and external fixation have progressed considerably in recent years. However, intramedullary nailing of diaphyseal tibial fractures may frequently be associated with chronic knee pain, which often fails to resolve after removal of the implant.[48] Although the plating of fractures now has fewer indications, it is still an option in the management of metaphyseal fractures and fractures of flat bones. Functional bracing continues to evolve in a way which makes future predictions difficult. However, the lessions learned over the past decades from the use of old and new methods of treatment, strongly suggest that a balanced approach to the management of fractures is essential. The recognition of the indications and contra-indications for each method of treatment must be clearly learned by those responsible for the care of the traumatised patient. In addition, the economic factors surrounding the care of fractures must also be seriously considered.

References

1. **Sarmiento A.** A functional below-knee cast for tibial fractures. *J Bone Joint Surg [Am]* 1967;49-A:855-75.
2. **Sarmiento A.** A functional below-knee brace for tibial fractures: a report on its use in one hundred thirty-five cases. *J Bone Joint Surg [Am]* 1970;52-A:295-311.
3. **Sarmiento A, Latta L, Zilioli A, Sinclair W.** The role of soft tissue in the stabilization of tibial fractures. *Clin Orthop* 1974;105:116-29.
4. **Sarmiento A, Latta LL, Tarr R.** The effects of function in fracture healing and stability. In: Murray JA, ed. *Instructional course lectures*. St. Louis: C.V. Mosby Co., 1984: 83-106.
5. **Latta LL, Sarmiento A, Tarr RR.** The rationale of functional bracing of fractures. *Clin Orthop* 1980;146:28-36.
6. **Latta LL, Sarmiento A, Zynch GA.** Principles of non-operative fracture treatment. In: Browner BD, Jupiter JB, Levine MM, Trafton PG, eds. *Skeletal trauma: basic science management and reconstruction*. Philadelphia: Saunders, 1998:237-66.
7. **Sarmiento A, Latta LL.** *The closed functional treatment of fractures*. Berlin: Springer-Verlag, 1981:1-59.
8. **Sarmiento Z, Latta LL.** *Functional fracture bracing: the tibia, humerus and ulna*. Berlin: Springer-Verlag, 1995:231-78.
9. **Sarmiento A.** Functional bracing of tibial and femoral shaft fractures. *Clin Orthop* 1972;82:2-13.
10. **Sarmiento A.** Complications from functional bracing. In: Epps CH Jr, ed. *Complications in orthopaedic surgery*. Philadelphia: J.B. Lippincott Co., 1994.
11. **Sarmiento A, Latta LL.** *Functional fracture bracing: a manual*. Philadelphia: Lippincott, Williams & Wilkins, 2002.
12. **Sarmiento A, Kinman PB, Galvin EG, Schmitt RH, Phillips PG.** Functional bracing of fractures of the shaft of the humerus. *J Bone Joint Surg [Am]* 1977;59-A:596-601.
13. **Sarmiento A, Horowitch A, Aboulafia A, Vangsness CT Jr.** Functional bracing for comminuted extra-articular fractures of the distal third of the humerus. *J Bone Joint Surg [Br]* 1990;72-B:283-7.
14. **Sarmiento A, Zagorski J, Zych G, Latta LL, Capps C.** Functional bracing of humeral shaft fractures. *J Bone Joint Surg [Am]* 2000;82-A:478-86.
15. **Sarmiento A, Kinman PB, Murphy RB, Phillips JG.** Treatment of ulnar fractures by functional bracing. *J Bone Joint Surg [Am]* 1976;58-A:1104-7.
16. **Sarmiento A, Latta LL, Zych G, McKeever, Zagorsky J.** Isolated ulnar shaft fractures treated with functional braces. *J Orthop Trauma* 1998;12:420-4.
17. **Sarmiento A, Pratt GW, Berry NC, Sinclair WF.** Colles' fractures: functional bracing in supination. *J Bone Joint Surg [Am]* 1975;57-A:311-17.
18. **Sarmiento A, Zagorski JB, Sinclair W.** Functional bracing of Colles' fractures: a prospective study of immobilization in supination versus pronation. *Clin Orthop* 1980; 146:175-87.
19. **Sarmiento A.** *Closed treatment of distal radius fractures: techniques in orthopaedics*. Philadelphia: Lippincott, Williams & Wilkins, 2000:299-304.
20. **Sarmiento A, Cooper JS, Sinclair WF.** Forearm fractures: early functional bracing. *J Bone Joint Surg [Am]* 1975;57-A:297-304.
21. **Sarmiento A, Ebramazadeh E, Brys D, Tarr R.** Angular deformities and forearm function. *J Orthop Res* 1992;10:121-33.
22. **Tarr RR, Garfinkel AI, Sarmiento A.** The effects of angular and rotational deformities of both bones of the forearm: an in vitro study. *J Bone Joint Surg [Br]* 1984;66-B:65-70.
23. **Sarmiento A, Burkhalter M, Latta LL.** Functional bracing in the treatment of delayed union and nonunion of the tibia. *Int Orthop* 2003;27:26-9.
24. **Danis R.** *Theorie et practique de l'osteosynthèse*. Paris: Mason & Cie Editeurs, 1994.
25. **Schlitch T.** *Surgery, science and industry: a revolution in fracture care, 1950-1990s*. Basingstoke: Palgrave MacMillan, 2002.
26. **Sarmiento A, Latta LL.** Periosteal fracture callus mechanics. In: Moore TM, ed. *AAOS Symposium on trauma to the leg and its sequelae*. St. Louis: C.V. Mosby Co., 1981:75-86.
27. **Sarmiento A, Mullis D, Latta LL, Alvarez R.** A quantitave comparative analysis of fracture healing under the influence of compression plating versus closed weight bearing treatment. *Clin Orthop* 1980;232:232-9.
28. **Perren SM.** The concept of biological plating using the limited contact-dynamic compression plate (L.C-DCP): scientific background, design and application. *Injury* 1991;22 (Suppl 1):1-42.
29. **Perren S, Russernberger M, Steinemann S, Muller M, Allgower M.** A dynamic compression plate. *Acta Orthop Scand Suppl* 1969;125:31-41.
30. **Uhthoff H, Dubuc FL.** Bone structure changes in the dog under rigid internal fixation. *Clin Orthop* 1971;91:165-70.
31. **Woo S, Akenson W, Coutts R, et al.** A comparison of cortical bone atrophy secondary to fixation with plates with large differences in bending stiffness. *J Bone Joint Surg [Am]* 1976;58-A:190-5.
32. **Perren S.** Evolution of the internal fixation of long bone fractures. *J Bone Joint Surg [Br]* 2002;84-B:1093-110.

33. **Park SH, O'Connor K, McKellop H, Sarmiento A.** The influence of active shear or compressive motion on fracture-healing. *J Bone Joint Surg [Am]* 1998;80-A:868-78.

34. **Kenwright J, Goodship A, Kelly D, et al.** Effect of controlled axial micromotion on healing of tibial fractures. *Lancet* 1986;2:1185-7.

35. **Sarmiento A, McKellop H, Llinas A, et al.** Effect of loading and fracture motions on diaphyseal tibial fractures. *J Orthop Res* 1996;14:80-4.

36. **Sarmiento A, Sharpe F, Ebramzadeh E, Norman P, Shankwiler J.** Factors influencing the outcome of closed tibial fractures treated with functional bracing. *Clin Orthop* 1995;315:8-24.

37. **Trueta J.** The role of vessels in osteogenesis. *J Bone Joint Surg [Br]* 1963;45-B:402-18.

38. **Tarr RR, Resnick RT, Wagner KW, Sarmiento A.** Changes in tibiotalar joint contact areas following experimentally induced tibial angular deformities. *Clin Orthop* 1985;199:72-80.

39. **Wagner KS, Tarr RR, Resnick C, Sarmiento A.** The effect of simulated tibial deformities on the ankle joint during the gait cycle. *Foot Ankle* 1984;5:131-41.

40. **McKellop HA, Sigholm G, Redfern FC, et al.** The effect of simulated fracture-angulation of the tibia on cartilage pressures in the knee joint. *J Bone Joint Surg [Am]* 1991;73-A:1382-90.

41. **Merchant TC, Dietz FR.** Long-term follow-up after fractures of the tibial and fibular shafts. *J Bone Joint Surg [Am]* 1989;71-A:599-606.

42. **Kristensen KD, Kiaer T, Blicher J.** No arthrosis of the ankle 20 years after malaligned tibial-shaft fracture. *Acta Orthop Scand* 1989;60:208-9.

43. **Milner S, Davis TR, Muir KR, Greenwood DC, Doherty M.** Long term outcome after tibial shaft fracture: is malunion important? *J Bone Joint Surg [Am]* 2002;84-A:971-80.

44. **Lovasz G, Llinas A, Benya P, et al.** Effects of valgus tibial angulation on cartilage degeneration in the rabbit knee. *J Orthop Res* 1995;13:846-53.

45. **Llinas A, McKellop H, Marshall J, et al.** Healing and remodelling of articular incongruities in a rabbit fracture model. *J Bone Joint Surg [Am]* 1993;75-A:1508-23.

46. **Lovasz G, Park SH, Ebramzadeh E, et al.** Characteristics of degeneration in an unstable knee with a coronal surface step-off. *J Bone Joint Surg [Br]* 2001;82-B:428-3.

47. **Martinez A, Latta LL, Sarmiento A.** Functional bracing of fractures of the proximal tibia. *Clin Orthop* 2003;47:293-302.

48. **Court-Brown, Gustilo T, Shaw AD.** Knee pain after intramedullary nailing of proximal third tibia fractures. *J Orthop Trauma* 1997;11:103-5.