Treatment of diaphyseal fractures of humerus with functional brace

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Abstract

Background: Conservatively treated fractures of the humeral diaphysis have a high rate of union with good functional results. The aim of the current study was to study the outcome of diaphyseal fractures of humerus treated with functional brace.

Materials and Methods: Twenty Seven diaphyseal fractures of humerus were included in this study. The functional brace was applied after the swelling subsided under image intensifier. Bracing was continued for a longer or shorter duration based on each individuals' clinical and radiological finding and progress of healing. Patients were instructed in the performance of pendulum exercises immediately after the application of the initial cast or splint, and the exercises were continued after brace application.

Results: Total 27 patients of mean age 34.14 years, were treated with functional brace. The mean union time was 11.23 weeks. 96.3% patients had union and satisfactory functional results. 3.7% had non-union. The average varus- valgus deformity was 9.3 degrees in our study. The average Antero Posterior deformity was of 6.33 degrees. Average shortening was of 5.55 mm. The brace was removed at an average period of 11.23 weeks. 92.59% patients had near normal – shoulder and elbow range of motion.

Conclusion: The treatment of diaphyseal fracture of humerus with functional brace gives credence to our long-held hypothesis that micro motion at the fracture site is an important factor in osteogenesis. The final angular deviations are cosmetically and functionally acceptable. It remains the treatment of choice, as it offers high union rate and good functional results.

Keywords: Functional Brace, Humeral Diaphysis, Conservative treatment, Humerus fracture, Union

Introduction

Fracture bracing is a philosophy rather than merely the use of orthotic devices, in the treatment of fractures. It is established on the belief that immobilization of the fragments and the joints above and below the fracture are not necessary for fracture healing. It also proposes that the soft tissue of the injured extremity plays a major role in providing the stability necessary to allow incessant osteogenesis. Early function and motion of the joints during treatment of fracture challenges the basic concepts of fracture treatment which emphasizes that rest and fracture immobilization are rudiments for fracture healing. In an effort to explicate these conflicts and gain a better understanding of the working of functional brace, a series of studies have been conducted.[1-4] Fractures of the shaft humerus account for approximately 1-3% of all fractures.[5,6] Although there are several absolute and relative indications for surgical management,[7,8] the general understanding remains that a vast majority of shaft humerus fractures can be treated successfully by conservative methods.[7-9] Non-operative management continues as the mainstay for the treatment of majority of these fractures, with acceptable fracture healing in more than 90% of patients. Surgical treatment is usually reserved for patients with open fractures, ipsilateral humeral diaphysis and forearm fractures, and in patients where the alignment in a functional brace is not maintained.[10-12]

a b c

Fig. 1: Photograph showing (a) Application of brace, (b) After application of Brace, (c) Image of reduction under image intensifier

Functional Bracing has been widely accepted as the best conservative method, and it is considered as the gold standard of humeral shaft fracture treatment by many authors.[13] Functional brace treatment carries many advantages when compared to other conservative methods in terms of range of motion, patient comfort, and cost reduction.[14-20] Augusto Sarmiento and his colleagues[14] were the first to report the successful use of functional bracing for the treatment of fractures of the humeral diaphysis. This method permitted freedom of motion of all joints in the injured extremity. Many other studies have reported a high rate of union and few complications.[14,21-28] Treatment by functional cast brace gives the advantages of mobilization of joints as expected after surgical management without giving its likely complications. The present study has been done to show the effectiveness of functional bracing and evaluate its functional outcome.

Materials and Methods

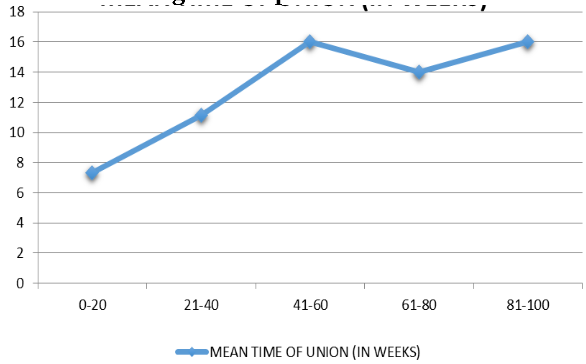
Twenty seven patients (Male 18, Female 9) were included in this study between September 2014 and August 2016. The average age of the patients was 34.14 years (Range, 3 – 93years). The cases with diaphyseal humeral fractures without radial nerve palsy were included in the study. Also the fractures with stable compound injuries (Gustillo – Anderson Grade I) were included. Open fractures with higher grade, Fractures with radial nerve palsy, Floating elbow and patients non-compliant for bracing were excluded from this study. Ethical clearance was obtained from a competent authority. In standardised format data concerning included patients' history and clinical symptoms were collected. The type of fracture, site of fracture and angulations were noted in the antero-posterior and lateral radiographs. Initially the fracture was stabilised with a Plaster of Paris (POP) 'U' arm splint till subsidence of swelling, approximately 7 days. The measurements for the brace were taken by the Orthotic Technician and the brace was made with two plastic sleeves and foam in the interior with two Velcro straps. The functional brace was applied after the swelling subsided. It is difficult to reduce and maintain the diaphyseal humerus fracture in supine position, so in our study the fracture was reduced in sitting position in an awake patient. Closed reduction under image intensifier was done in the operation theatre and functional brace was applied. After tightening of Velcro straps, the reduction was checked in the image. A cuff and collar sling was given to the patient.

Patients were advised to cover the brace with a plastic while bathing. The patients were guided how to adjust the Velcro straps of the brace by tightening it several times a day to adapt to the changes in the girth of the extremity. Patients were instructed in the performance of pendulum exercises immediately after the application of the initial cast or splint, and the exercises were continued after the application of the brace. The collar-and cuff sling was taken off for a few minutes several times a day to permit combined active and passive exercises of the elbow to regain full extension of the joint at the earliest. Active elevation and abduction of the shoulder were not allowed, since such exercises could lead to angular deformity. The patients also were instructed not to lean the elbow on the arm of a chair, a table, or their lap, as leaning on the elbow of a fractured extremity during the early stages of healing may cause varus angulation. The cuff and collar sling was continued for four weeks after which it was recommended only at night. In the treatment of open fractures of the humerus, the functional brace was applied after subsidence of acute symptoms and frequent change of wound dressings were done after adjusting and removing the brace. The brace was discontinued based on clinical and radiographic examination, after adequate fracture healing was confirmed. Bracing was continued for a longer or shorter duration based on each individuals' clinical and radiological finding and progress of healing. The brace used consisted of two plastic sleeves which were attached to Velcro straps. The brace extended medially from 2.5 cm beneath the axilla to 1 cm proximal to the medial epicondyle. On the lateral aspect of the arm, the brace was placed such that it spanned from just below the lateral acromion to a point just above the lateral epicondyle. Two Adjustable Velcro straps that were fashioned around the brace were tightened periodically as the swelling subsided to maintain the constant compressive environment during the reparative process. Adequate placement of the orthosis provided unhindered range of motion of the shoulder and elbow. The patients were followed up at 1 week, 4 weeks, 8 weeks, 12 weeks, 16 weeks and 24 weeks. Patients were seen one week after application of brace and the radiograph was taken to evaluate the position of the fracture. Once full extension of the elbow had been achieved, the collar-and-cuff sling was discontinued during walking. During the next four weeks, patients increased the frequency and intensity of exercises involving passive flexion of the shoulder and active flexion and extension of the elbow.[29] The local skin condition was inspected, tenderness at the fracture site assessed, and abnormal mobility was also checked. Besides, Shoulder Range of motion (Abduction, Flexion, Internal and External Rotations) and Elbow Range of motion (Flexion and Extension) were assessed. Fracture angulation and shortening were noted in each follow up. The angulation (Varus or Valgus) and apex (posterior or anterior) were measured on the PACS (Picture Archiving and Communication System) software with the help of the angle measuring tool and the readings were recorded upon each follow up of the patient. At the end of 24 weeks, Disability of the Arm, Shoulder and Hand (DASH) scoring[30] was done for each patient, to study the functional outcome of the patient. Statistical Analysis was done by using descriptive and inferential statistics using Chi square test and $p < 0.05$ was considered as level of significance.

Observations and Results

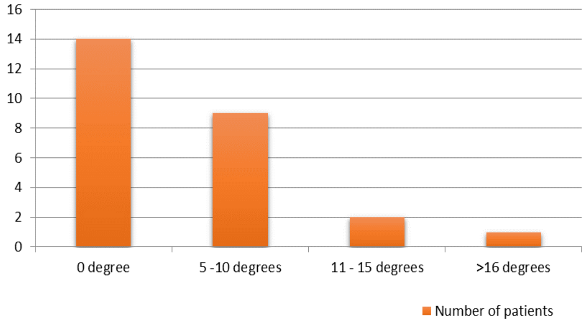
In our study, out of 27 patients, 18 patients were male and 9 were female. The average age of patient in our study was 34.14 years (3 – 93 years) at the time of injury. 16 (59.3%) patients had fracture in the right humerus and 11 (40.7%) patients had fracture in the left humerus. 26 (96.3%) fractures were closed and 1 (3.7%) fracture was open fracture (Gustilo Type I). 13 had mid shaft humerus fracture, 8 had distal third humerus fracture and 6 patients had proximal third fracture humerus. 11 patients had simple transverse fractures, 10 had oblique fractures and 6 patients had comminuted diaphyseal humeral fractures. 3 patients had valgus angulation and 24 patients had varus angulation. In 3 patients, the brace was discontinued at four weeks as fracture had clinically and radiographically united by then. We were able to follow all 27 patients up to six months. Only 1 patient (3.7%) had irregular follow up, who came directly came at 6 month follow up after the first follow up and also used the brace irregularly and had incomplete healing of fracture (Non Union), with no clear radiological evidence of fracture healing. Large number of patients had discontinued their visit to Out-patient department as soon as the injured extremity became painless and functional (Union of fracture). The average period of union (radiographic and clinical) of the fracture in our study was 11.23 weeks (4 to 24 weeks). (Table 1)

Table 1: Age of the patient to time to union

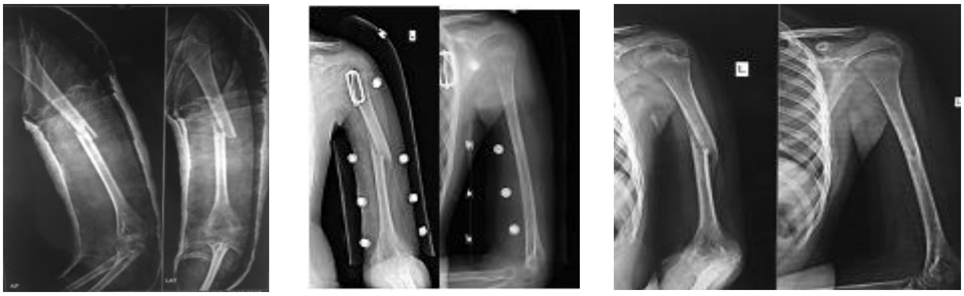


The 11 Transverse fractures healed in an average of 10.9 degrees of varus angulation; 9 oblique fractures in an average of 8.8 degrees; and 6 comminuted fractures in an average of 7 degrees. There was non-union in only 1 patient (3.7%). 2 (7.4%) patients had delayed union, in both the cases the fracture united at 24 weeks. 1 (3.7%) patient had 20 degrees of varus angulation, 3 (11.11%) patients had 15 degrees of varus angulation, 2 (7.4%) patients had 12 degrees of varus angulation, 6 (22.22%) patients had 10 degrees of varus angulation, 2 (7.4%) patients had 7 degrees of varus angulation, and 9 (33.33%) patients had 5 degrees of varus angulation. 2 (7.4%) patients had Valgus deformities of 5 and 15 degrees respectively. In sagittal plane, apex anterior deformity was noted in 4 (14.81%) patients. However, apex posterior deformity was noted in 22 (81.48%) patients, out of this 1 (4.54%) patient had 3 degrees, 14 (63.63%) patients had 5 degrees, 4 (18.18%) patients had 7 degrees, 3 (13.63%) patients had 10 degrees apex posterior deformity. Residual joint stiffness is as important as union and deformity in estimating the efficacy of functional bracing as a method of treating diaphyseal fractures.[31]

Table 2: Loss of Shoulder range of motion compared to normal side



14 (53.84%) patients had full shoulder range of motion at 24 weeks follow up.(Table 2) 3 (11.5%) patients had deficit greater than 10 degrees concerning elbow flexion and 1 (3.84%) patient concerning elbow extension.



a b c

Fig. 2: Radiographs of a patient- (a) Before bracing, (b) 1 week after bracing, (c) At 4 weeks

Disability of the Arm, Shoulder and hand scoring was done at the end of 24 weeks of bracing. The Mean Dash score in our study was 14.55 (Range, 2.7 – 48.3).

Fig. 3: Photograph showing a pressure sore over the arm of the patient

In our study 2 (7.4%) patients developed pressure sores, which were superficial and healed subsequently with daily dressing. In our study, none of the patients developed post reduction radial nerve palsy.

Functional Bracing didn't restore anatomical alignment of the fracture, but the final angular deviations were cosmetically and physiologically acceptable.[19,22-25,32]

Discussion

Non Operative management still remains the treatment of choice for most fractures of the humeral diaphysis.[25,33] A high rate of union and satisfactory functional results has given credence to this method.[14,21-25,32] In our study, the mean union time was 11.23 weeks (4 – 24 weeks). Time to union in most of the series in the literature is reported to vary between 3 – 40 weeks. This was consistent with Sarmiento et al[29] mean union time of 11.5 weeks (5-22 weeks). However in various other series, the mean union time reported is 10.7 weeks (6.5 – 22 weeks).[14,16,17,21,23,26,29,31,34,35,36,37,38] In the present study 26 (96.3%) patients had union and satisfactory functional results. Similar results were found in other studies – Sarmiento et al[14] (98%), Balfour et al (97.6%), Zagorski et al[21] (98.2%), Wallny et al[17] (95.5%), and Rosenberg et al[39] (100%).

3.7% (1 patient out of 27) had non-union. In this patient the non-union can be attributed to non compliance of the patient rather than technique, as the patient discontinued functional brace frequently, and also had irregular follow ups. It was statistically significant (p value < 0.05). Ostermann et al.[25] and Zagorski et al.[21] reported non-union of 2 percent. Similarly in other studies Naver and Aalberg et al,[34] Fjalestad et al,[36] Koch et al,[31] Rosenberg et al,[39] Ekholm et al,[41] and Rutgers et al,[37] the non union rate was less than 7 percent. Toivanen et al[15] reported the highest non union rate 22.6%, their decision of abandoning functional brace after 6 weeks time even if there were no radiological or clinical signs of consolidation, could partially explain this.[15]

In our study, 2 (7.4%) patients had delayed union. Pehlivan et al[16] defined delayed union as failure to unite within 4 months but in presence of clinical and radiological signs of healing. It was statistically not significant (p value > 0.05). Balfour et al[26] reported delayed union rate of 2.4%, Ricciardi-Pollini and Falez et al[28] reported delayed union rate of 7.1%, Leung et al[35] reported delayed union rate of 3.4% and Koch et al[31] reported delayed union rate of 1%.

Table 3: Results of various studies on functional bracing

Study	Study Design	Fractures (n)	Follow Up n (%)	Union n (%)	Non Union n (%)	Delayed Union n (%)	Time of Brace application in weeks (range)
Our Study	Prospective	27	27 (100)	26(96.3)	3.7	2 (7.4)	11.24 (4-24)
Sarmiento et al	Retrospective	51	51 (100)	50 (98)	2	-	8.5 (3–22.5)
Balfour et al	Prospective	74	42(57)	51(97.6)	2.4	1 (2.4)	7.5 (4–15)
Ricciardi-Pollini and Falez	Retrospective	14	14 (100)	14 (100)	0	1 (7.1)	- (8–13)
Naver and Aalberg	Prospective	20	20 (100)	18 (90)	10	-	6.5(4–24)
Zagorski et al	Retrospective	233	170 (73)	167(98.2)	1.8	-	10.6 (5–20)
Leung et al	Retrospective	29	29 (100)	29 (100)	0	1 (3.4)	7 (4–18)
Wallny et al	Retrospective	79	79 (100)	74 (93.7)	6.3	-	8.7 (4–17)
Sarmiento et al	Retrospective	922	620 (67)	604(97.4)	2.6	-	11.5 (5–22)
Fjalestad et al	Retrospective	67	67 (100)	61 (91.1)	8.9	-	12 (6–25)
Koch et al	Retrospective	74	67(91)	58 (86.6)	13.4	1 (1.4)	10 (5–36)
Toivanen et al	Retrospective	93	93 (100)	72 (77.4)	22.6	-	Not specified

Rosenberg et al	Prospective	15	15 (100)	15 (100)	0	-	22 (10–40)
Ekholm et al	Retrospective/ Prospective	78	78/50 (100/64)	70 (89.7)	10.3	-	Not specified
Rutgers et al	Retrospective	52	49 (94)	44 (89.8)	10.2	-	-
Pehlivan	Prospective	25	21 (84)	21 (100)	0	3 (14.3)	11.8 (8–30)
Jawa et al	Comparative/ retrospective	21	19 (90)	19 (100)	0	-	9.7 (8–12)

It is generally accepted that the most common deformity is varus angulation.[14,16,17,21,26,31,36] In our study, the Varus – Valgus angulations was less than 10 degrees in 19 (70.37%) patients. It was statistically not significant (p value > 0.05). However, 2 (7.4 %) patients had an angulation of 20 degrees. The average varus- Valgus deformity was 9.3 degrees in our study. Sarmiento et al[14] reported Varus – Valgus angulation of less than 5 degrees in a series of 50 patients with an average deformity of 4 degrees with varus – Valgus deformity of more than 20 degrees in 0% patients. Zagorski et al[21] reported Varus – Valgus angulation of less than 8 degrees in a series of 170 patients, with an average deformity of 5 degrees. Ricciardi-Pollini and Falez et al[28] reported Varus – Valgus angulation of less than 5 degrees in a series of 14 patients. Naver and Aalberg[34] reported Varus – Valgus angulation of less than 10 degrees in a series of 18 patients, with an average of 3.3 degrees. In most of the series angulation of less than 10 degrees was found in more than 85 percent of the patients.[14,16,18,21,28,41] Open fractures are the ones which heal slower in an average of 13 – 14 weeks, but in our study we had only 1 case of open injury (Gustilo Type I) which healed in 4 weeks.[21,34]

In sagittal plane (Antero-Posterior deformity), the results are equally satisfying if not better.[14,16,17,21,23,26,28,29,31,34,38] In our study the Antero Posterior deformity was less than 7 degrees with an average deformity of 6.33 degrees. Naver and Aalberg,[34] Sarmiento et al,[14] Wallny et al[17] and Koch et al[31] reported anterior – posterior deformity of 10 degrees in 13.9% patients,[16,17,23,28,29,31,34] 20 degrees in 2% of patients[14,15,16,23,34,37,38] and an average angulation was 3.7 degrees.[14,16,21,23,26,39,41,42,43] Sarmiento et al,[29] Pehlivan et al[16] and Jawa et al[38] reported Anterior – Posterior deformity of more than 20 degrees in 5.8%, 0% and 10.5% respectively. In our study, average shortening was of 5.55 mm. Similarly, Zagorski et al,[21] Naver et al,[34] Sarmiento et al,[29] Pehlivan et al[16] reported shortening of 4mm, 0mm, 1.8mm and 1.9mm respectively. Rotational deformity is difficult to report on plain radiographs and its incidence is seldom reported. Pehlivan et al,[16] Sarmiento et al,[14] Zagorski et al[21] observed in their study that there was no significant radiological or clinical deformity. Fjalestad T et al[36] were the only ones to examine the degress of malrotation with a CT scan. They correlated it with loss of external rotation of the shoulder. They believe that early fracture stabilisation by a functional brace may reduce this malrotation and that the sling should be discarded soon in order not to inhibit the fracture during muscle activity. The brace was removed at an average period of 11.23 weeks (4 – 24 weeks) after the initial injury. Similarly, in study by Sarmiento et al the brace was removed at 11.5 weeks (4-22 weeks) after the initial injury.[33] In present study, 25 (92.59%) patients had near normal – shoulder and elbow range of motion. In our study, more than 10 degrees loss of abduction of the shoulder was found in 1 (3.84%) patient, more than 10 degrees of loss of external rotation found in 1 (3.84%) patient. However, full range of motion in shoulder joint was found in 14 (53.84%) of patients and more than 10 degrees of loss of flexion of shoulder was found in 3 (11.5%) patients. However in elbow joint, more than 10 degrees of loss of flexion was found in 11.5% of patients, whereas more than 10 degrees of loss of extension was found in 3.84% of patients.

Conclusion

The high prevalence of union (96.3 percent) in this study gives credence to our long-held hypothesis that micro motion at the fracture site is an important factor in osteogenesis.[44,45] The final angular deviations are cosmetically and functionally acceptable.[19,22,23,24,25,32]

The elbow and shoulder range of motion are restored early in almost 80 percent of the patients due to early mobilization of the joints.[13] Functional bracing remains the first treatment of choice for humeral shaft fractures as it offers high union rate, good functional results, patient comfort and cost reduction while avoiding the possible complications of an operative treatment.[13]

References

1. Kinman, P. B., Sarmiento, A., and Cohen, J.: Experimental tibial condylar fractures, J. Bone Joint Surg. 57A:576, 1975.
2. Sarmiento, A, Latta, L. L., Zilioli, A, and Sinclair, W. F.: The role of soft tissues in fracture stability, Clin. Ortho 105:106,1975.
3. Sarmiento, A., and Latta, L. L.: Factors controlling the behavior of tibial fractures: A correlation of clinical and laboratory studies. Abstract of Kappa Delta Award Paper, J. Bone Joint Surg. 58A:724, 1976; Orthop. Digest, 1976.
4. Sarmiento, A., Schaeffer, J., Beckerman, L., Latta, L. L., and Enis, J.: Fracture healing in rat femora as effected by functional weight-bearing, J. Bone Joint Surg. 59A:369,1977.

5. Brinker MR, O'Connor DP. The incidence of fractures and dislocations referred for orthopaedic services in a capitated population. J Bone Joint Surg [Am] 2004;86:290–7.
6. Shao YC, Harwood P, Grotz MRW, et al. Radial nerve palsy associated with fractures of the shaft of the humerus. A systematic review. J Bone Joint Surg [Br] 2005;87-B:1647–52.
7. McKee MD. Fractures of the shaft of the humerus. In: Rockwood CA, Green DP, Bucholz RW, editors. Sixth edition, Rockwood and Green's fractures in adults, vol. 1, Sixth edition Philadelphia: Lippincott Williams & Wilkins; 2006. p. 1118.
8. Schemitsch EH, Bhandari M. Fractures of the diaphyseal humerus. In: Browner BD, Jupiter JB, Levine AM, Trafton PG, editors. Skeletal trauma. 3rd ed., Toronto: WB Saunders; 2001. p. 1481–511.
9. Charnley J. The closed treatment of common fractures, 3rd ed., Edinburgh and London: E. and S. Livingstone; 1968.
10. Epps CH Jr, Grant RE. Fractures of the shaft of the humerus. In: Rockwood CA Jr, Green DP, Bucholz RW, editors. Rockwood and Green's fractures in adults. 3rd ed. Philadelphia: Lippincott Williams & Williams; 1991.
11. Browner BD, Levine AM, Jupiter JB, Trafton PG. Skeletal trauma. Philadelphia: Saunders; 1998.
12. Sarmiento A, Waddell JP, Latta LL. Diaphyseal humeral fractures: treatment options. Instr Course Lect 2002;51:257-69.
13. Papasoulis E, Drosos GI, Ververidis AN, Verettas D-A. Functional bracing of humeral shaft fractures. A review of clinical studies. Injury. 2010 Jul 1;41(7):e21–7.
14. Sarmiento A, Kinman PB, Calvin EG, et al. Functional bracing of fractures of the shaft of the humerus. J Bone Joint Surg [Am] 1977;59:596–601.
15. Toivanen JA, Nieminen J, Laine HJ, et al. Functional treatment of closed humeral shaft fractures. Int Orthop 2005;29:10–3.
16. Pehlivan O. Functional treatment of the distal third humeral shaft fractures. Arch Orthop Trauma Surg 2002;122:390–5.
17. Wallny T, Sagebiel C, Westerman K, et al. Comparative results of bracing and interlocking nailing in the treatment of humeral shaft fractures. Int Orthop1997;21:374–9.
18. Wallny T, Westermann K, Sagebiel C, et al. Functional treatment of humeral shaft fractures: indications and results. J Orthop Trauma 1997;11:283–7.
19. Zagorski JB, Latta LL, Zych GA, Finnieston AR. Diaphyseal fractures of the humerus. Treatment with prefabricated braces. J Bone Joint Surg [Am] 1988;70:607.
20. Camden P, Nade S. Fracture bracing the humerus. Injury 1992;23(4):245–8.
21. Zagorski JB, Latta LL, Zych GA, Finnieston AR. Diaphyseal fractures of the humerus. Treatment with prefabricated braces. J Bone Joint Surg [Am] 1988;70:607–10.
22. Klestil, T.; Rangger, C.; Kathrein, B.; Huber, B.; and Waldegger, M.: Sarmiento bracing of humeral shaft fractures — a comparative study. SOT, 20, 1997.
23. Sarmiento, A.; Horowitch, A.; Aboulafia, A.; and Vangsness, C. T., Jr.: Functional bracing for comminuted extra-articular fractures of the distal third of the humerus. J. Bone and Joint Surg., 72-B(2): 283-287, 1990.
24. Sharma, V. K.; Jain, A. K.; Gupta, R. K.; Tyagi, A. K.; and Sethi, P. K.: Non-operative treatment of fractures of the humeral shaft: a comparative study. J. Indian Med. Assn., 89:157-160, 1991.
25. Ostermann, P. A. W.; Ekkernkamp, A.; and Muhr, G.: Functional bracing of shaft fractures of the humerus — an analysis of 195 cases. Orthop. Trans., 17:937,1993-1994.
26. Balfour G, Mooney V, Ashby M. Diaphyseal fractures of the humerus treated with a ready-made fracture brace. J Bone Joint Surg Am 1982;64:11-3.
27. Kujat R, Tscherne H. [Indications and technic of functional fracture treatment with the Sarmiento brace]. Zentralbl Chir. 1984;109(22):1417–23.
28. Ricciardi-Pollini PT, Falez F. The treatment of diaphyseal fractures by functional bracing. Results in 36 cases. Ital J Orthop Traumatol. 1985 Jun;11(2):199–205.
29. Sarmiento A, Zagorski JB, Zych GA, et al. Functional bracing for the treatment of fractures of the humeral diaphysis. J Bone Joint Surg [Am] 2000;82:478–86.
30. Hudak PL, Amadio PC, Bombardier C. Development of an upper extremity outcome measure: the DASH (disabilities of the arm, shoulder and hand) [corrected]. The Upper Extremity Collaborative Group (UECG). Am J Ind Med. 1996 Jun;29(6):602–8.
31. Koch PP, Gross DF, Gerber C. The results of functional (Sarmiento) bracing of humeral shaft fractures. J Shoulder Elbow Surg. 2002 Mar-Apr;11(2):143-50.
32. Robinson, C. M.; Bell, K. M.; Court-Brown, C. M.; and McQueen, M. M.: Locked nailing of humeral shaft fractures. Experience in Edinburgh over a two-year period. J. Bone and Joint Surg., 74-B(4): 558-562, 1992.
33. Sarmiento, A., and Latta, L. L.: Closed Functional Treatment of Fractures, pp. 497-545. New York, Springer, 1981.
34. Naver L, Aalberg JR. Humeral shaft fractures treated with a ready-made fracture brace. Arch Orthop Trauma Surg 1986;106:20–2.
35. Leung KS, Kwan M, Wong J, et al. Therapeutic functional bracing in upper limb fracture-dislocations. J Orthop Trauma 1988;2(4):308–13.
36. Fjalestad T, Stromsoe K, Salvesen P, Rostad B. Functional results of braced humeral diaphyseal fractures: why do 38% lose external rotation of the shoulder? Arch Orthop Trauma Surg 2000;120:281–5.
37. Rutgers M, Ring D. Treatment of diaphyseal fractures of the humerus using a functional brace. J Orthop Trauma 2006;20:597-601. doi:10.1097/01. bot.0000249423.48074.82.
38. Jawa A, McCarty P, Doornberg J, et al. Extra-articular distal-third diaphyseal fractures of the humerus. A comparison of functional bracing and plate fixation. J Bone Joint Surg [Am] 2006;88(November (11)):2343–7.
39. Rosenberg N, Soudry M. Shoulder impairment following treatment of diaphyseal fractures of humerus by functional brace. Arch Orthop Trauma Surg 2006;126:437–40.
40. Ekholm R, Tidermark J, T? Rnkvist H, Adami J, Ponzer S. Outcome after Closed Functional Treatment of Humeral Shaft Fractures: Journal of Orthopaedic Trauma. 2006 Oct;20(9):591–6.
41. Meyer C, Alt V, Kraus R, Giebel G, Koebke J, Schnettler R. The arteries of the humerus and their relevance in fracture treatment [in German]. Zentralbl Chir 2005;130:562-7.
42. Sarmiento A. A functional below-the-knee brace for tibial fractures. J Bone Joint Surg [Am] 1967;49: 855–75.
43. Sarmiento A, Latta L. The evolution of functional bracing of fractures. J Bone Joint Surg [Br] 2006;88(2):141–8.
44. Sarmiento, A.; Latta, L. L.; and Tarr, R. R.: Principles of fracture healing. Part II. The effects of function on fracture healing and stability. In Instructional Course Lectures, the American Academy of Orthopaedic

Surgeons. Vol. 33, pp. 83-106. St. Louis, C. V. Mosby, 1984.
45. Sarmiento, A., and Latta, L. L.: Functional Fracture Bracing: Tibia, Humerus, and Ulna. New York, Springer,1995.