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• Original Article •

Aseptic Humeral Nonunion: What Went Wrong? What to Do? A Retrospective Analysis of 20 Cases

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Purpose: Due to recent advances in internal fixation techniques, instrumentation and orthopedic implants there is an increasing number of humeral shaft fracture treated operatively. As a consequence, an increased number nonunion after operative fixation are being referred to our center. The aim of this study is to report the common error during osteosynthesis that may have led to nonunion and present a systematic analytical approach for the management of aseptic humeral shaft nonunion.

Methods: In between January 2007 to December 2013, 20 patients with humeral shaft nonunion after operative procedure were treated according to our treatment algorithm. We could analysis x-rays of 12 patients from initial treatment to nonunion. In a subgroup of 12 patients the initial operative procedure were analyzed to determine the error that may have caused nonunion. The following questions were used to examine the cases: 1) Was the fracture biology preserved during the procedure? 2) Does the implant construct have enough stability to allow fracture healing?

Results: In 19 out of 20 patients have showed radiographic evidence of union on follow up. One patient has to undergo reoperation because of the technical error with bone graft placement but eventually healed. There were 2 cases wherein the treatment algorithm was not followed. All patients had problems with mechanical stability, and in 13 patients had biologic problems. In the analysis of the initial operative fixation, only one of 12 patients had biologic problems.

Conclusion: In our analysis, the common preventable error made during operative fixation of humeral shaft fracture is failure to provide adequate stability for bony union to occur. And with these cases we have demonstrated a systematic analytic management approach that may be used to prevent surgeons from reproducing the same fault and reduce the need for bone grafting. [J Trauma Inj 2016; 29: 129-138]

Key Words: Humeral fractures, Fractures, Ununited, Fracture fixation, Internal

I. Introduction

Majority of authors would recommend a non-operative management of most humeral shaft fractures especially because of the high success rate (>90%) of this treatment method.(1-6) However, surgical treatment is indicated in patients whom there is failure to maintain stable alignment and reduction at the fracture site and in patients with severe segmental fractures, open fractures, or fractures associated with bilateral forearm fractures on the same side, polytrauma, progressive neurological deficits, vascular injury or floating shoulder or elbow.(7,8) In recent years, there have been major advances in internal fixation techniques, instrumentation and orthopedic implants which led to the

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expansion of surgical indications for humeral shaft fractures. As a result, there are more humeral shaft fractures being managed surgically today.

The incidence of nonunion after internal fixation ranges from 0-15% in the literature.(9) Causes of nonunion are various including patient's factor such as diabetes, hypothyroidism and vitamin D insufficiency, injury factor such as open fracture and severity of injury and surgeon's factor. Both patient and injury related factors were already decided before the surgical treatment. It could not be altered by surgeon. However, surgeon's factor which could be represented by 'biology' and 'stability' could affect the final result of fracture healing during surgical treatment. This surgeon's factor is the only factor which could be handled by surgical treatment. In majority of nonunion cases which were referred to our center, the causes were related with technical failure which could have be done differently initially.(10) So we tried to analyze the preventable cause of nonunion based on the retrospective reviews. Furthermore, previous studies from literature focus mainly on the result of a standardized treatment for all cases and not with a "problem-based-solution" concept. Hence, this study presents a systematic analytical approach for the management of aseptic humeral shaft nonunion after internal fixation.

II. Materials and Methods

We have searched through our orthopedic trauma database for humeral shaft (AO type 12) fracture nonunion. In between year 2007 to 2013, we have identified 25 patients that were seen in Korea university Guro hospital. Patient data and radiographs were reviewed retrospectively. Inclusion criteria were 1) Radiographic signs of a persistent fracture line, sclerosis at the fracture ends, a gap and hypertrophic or absent callus after 6month follow-up x-rays which had been diagnosed as non-union. 2) The nonunion must have been surgically treated by the author 3) Post-operative and follow-up Radiographs are available. Cases were excluded if 1) Patient has systemic illness (Type I DM, Hypothyroidism, Cushing disease, Vitamin D deficiency) affecting bone metabolism 2) Fracture emanate from a pathological condition 3) Patient has septic nonunion which could be diagnosed by clinical and laboratory findings, such as sinus tracts, redness, heating sense and elevated ESR, CRP. Five patients were removed from the study: two patients refused surgical treatment and three patient have nonunion as a result of infection.

A total of 20 patients (11 Male, 9 Female) with a mean age of 45 years (range 20 to 69) were managed following our treatment algorithm. Treatment algorithm was based on the two factors which could be controlled by surgeon's hand. Patients' variables and injury variables have been already determined before revision surgery. Biology and Stability, these main factors are only controllable factors during revision procedures. For this reason, we focused on surgeon's controllable treatment algorithm based on systemized analysis of causes of nonunion.

Current 'Biology' of fracture site was evaluated by analyzing the latest radiographs of non-union. Sclerotic bony margin and eroded bony end of fracture were considered as 'Nonviable' non-union. Previous evidences of compromised biology within the radiographs of initial treatment such as periosteal stripping of wedge fragment and excessive opening of fracture site also helped judging of viability of current situation. On the other hand, prominent callus which could not be bridged cross the fracture site was the evidence of 'Viable' nonunion. Previous evidences of preserved biology within the radiographs of initial treatment such as minimally invasive plate osteosynthesis and closed nailing also helped judging of viability of current situation.

Current 'Stability' of fracture site was also evaluated by analyzing the latest radiographs of non-union. 'Unstable' non-union could be classified by evidences with breakage of fixatives, loosening of fixatives and any migration of fixatives. If there were not any signs of instability, current nonunion was classified as 'Stable'. Combined with results of these analysis, 'Viable and Unstable' nonunion could be treated by two options. If nailing have been done at initial treatment, augmentation plating could be tried leaving the nail inside. If there was no room for augmentation plating or previous plating was failed to unstable, revisional compression plating could be treated without any bone graft. 'Nonviable and Unstable'

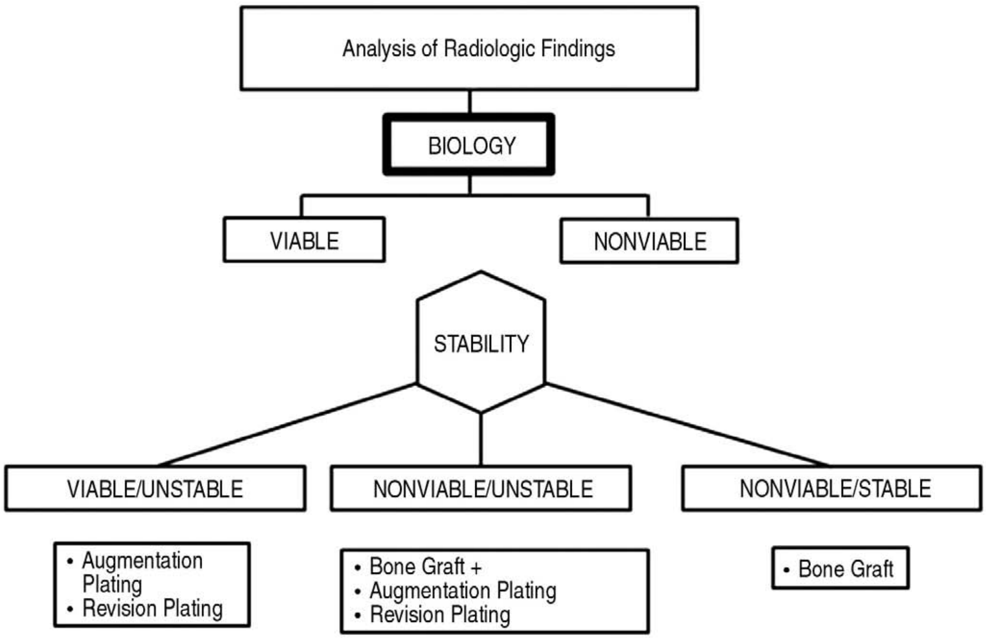

Fig. 1. Treatment Algorithm for Aseptic Nonunion after internal fixation of humeral shaft fracture.
VIABLE - capable of healing (union) without biologic stimulation. e.g. hypertrophic.
(elephant foot, horse hoof)
NONVIABLE - Incapable of healing (union) without biologic stimulation e.g. Oligotrophic, Atrophic
STABLE - Adequate fixation construct:
1) Minimum 6 cortices on each major fragment in conventional plating
2) Minimum 2 interlocking screw on each major fragment in nailing
3) No loosening around the implant
4) Acceptable alignment
UNSTABLE - loosening around the implants; screw pullout; position change of the implant and associated deformity.

nonunion was treated with re-stabilization of fracture site with autogenous bone graft. Finally, 'Nonviable and Stable' nonunion was treated by only autogenous bone grafting leaving the fixative as it is (Fig. 1).

A subgroup of 12 patients, which we have the injury data and immediate post-operative radiographs, were analyzed to determine the technical error that may have caused the nonunion (Eight patients were excluded from this subgroup because of incomplete data). The following questions were used as a guide to examine these cases: 1) Was the fracture biology preserve during the procedure? 2) Does the implant construct have enough stability to allow fracture healing? Through these analysis, we tried to report the common errors which might contribute to fail to nonunion during the procedure of initial osteosynthesis.

III. Results

In 19 out of 20 nonunion cases analyzed and treated have radiographic evidence of union at sequential follow up, and only one case failed to unite. Seven patients are 'Viable and Unstable' and treated with augmentation plating or revisional compression plating (no.1, no.3, no.6, no.7, no.12, no.19, no.20). But in two patients (no.6, no.12) of 'Viable and Unstable', the algorithm was not followed. Patient (no.12) had hypertrophic callus formation (elephant foot) but dissection thru the callus had to be done in order to correct the malalignment. Patient (no.6) had socioeconomic concerns and the need for an accelerated healing persuaded the surgeon to do bone grafting. Thirteen Patients are 'Nonviable and Unstable' who treated with re-stabilization of fracture site and autologous bone graft (no.2, no.4, no.5, no.8, no.9, no.10, no.11, no.13, no.14, no.15, no.16, no.17, no.18) (Table 1). One patient (no.18) had to undergo a re-operation because of an error during the procedure but eventually healed (Fig. 2).

In the subgroup of 12 patients, that the operative

Table 1. Patient data

Patient	Age	Sex	Ao	Site	Procedure/s	Biology	Stability	Treatment	Outcome
1	53	M	A3	Mid	OR Plating	Viable (Elephant foot)	Unstable Screw pullout; loss of reduction	Revision plating	Union
2	27	M	B2	Mid	CR IMN (retrograde)	Nonvioable	Unstable Windshield wiper effect osteolysis around the distal screw	Augmentation plating	Nonunion
3	61	F	A2	Mid	CR IMN	Viable (Horse hoof)	Unstable 1 distal interlocking screw windshield wiper effect	Augmentation plating	Union
4	41	M	B3	D1/3	OR Plating	Nonvioable	Unstable Only 4 cortices on the distal main fragment	Augmentation plating+Bone graft	Union
5 (Fig. 3)	69	F	B1	Mid	1) OR Plating 2) OR IMN	Nonvioable	Unstable no distal interlocking screw windshield wiper effect	Revision plating+Bone graft	Union
6	31	M	A1	D1/3	CR IMN (2 Elastic Nail)	Viable	Unstable Rotation and axial instability	**Revision plating+Bone graft	Union
7	27	M	A3	D1/3	CR IMN	Viable (Horse hoof)	Unstable 1 distal interlocking screw windshield wiper effect osteolysis around the distal screw	Augmentation Plating	Union
8 (Fig. 4)	53	F	B2	P1/3	1) CR IMN 2) Autologous Implantation	Nonvioable	Unstable 1 distal interlocking screw windshield wiper effect	Augmentation Plating+Bone Graft	Union
9	60	F	B3	Segmental	1) CR IMN 2) OR Plating	Nonvioable	Unstable Screw pullout	Revision Plating+Bone Graft	Union
10	54	F	B2	Mid	CR IMN `	Nonvioable	Unstable 1 distal interlocking screw windshield wiper effect osteolysis around the distal screw	Augmentation Plating+Bone Graft	Union
11	26	F	B3	D1/3	OR Plating	Nonvioable	Unstable Osteolysis around the screws	Revision Plating+Bone Graft	Union
12	56	F	A3	Mid	OR Plating	Viable (Elephant foot)	Unstable Screw pullout; loss of reduction	**Revision Plating+Bone Graft	Union
13	25	F	B1	D1/3	OR IMN+Wiring+ Lag screw	Nonvioable	Unstable Rotationally unstable	Revision Plating+Bone Graft	Union

Continue

Table 1. Patient data

Patient	Age	Sex	Ao	Site	Procedure/s	Biology	Stability	Treatment	Outcome
14	51	M	B2	Mid	OR Plating	Nonvioable	Unstable Screw pullout; loss of reduction	Revision Plating+Bone Graft	Union
15	61	F	A2	Mid	1) OR Plating 2) Revision Plating 3) OR IMN (2 Elastic Nails)	Nonvioable	Unstable Rotation and axial instability	Revision Plating+Bone Graft	Union
16	20	M	B2	D1/3	OR Plating	Nonvioable	Unstable Osteolysis around the screws	Revision Plating+Bone Graft	Union
17	56	M	B3	P1/3	OR Plating	Nonvioable	Unstable Screw pullout; loss of reduction	Revision Plating+Bone Graft	Union
18 (Fig. 2)	57	M	B2	Mid	CR IMN	Nonvioable	Unstable 1 proximal and distal interlocking screw Windshield wiper effect	Revision Plating+Bone Graft	Union
19	30	M	A3	Mid	CR IMN (retrograde)	Viable (Elephant foot)	Unstable 1 proximal and distal interlocking screw	Augmentation Plating	Union
20	42	M	A3	Mid	OR Plating	Viable (Horse hoof)	Unstable Screw pull out; loss of reduction	Revision Plating	Union

OR: open reduction
CR IMN: closed reduction intramedullary nailing
** treatment algorithm not followed.

procedure/s was analyzed as to preservation of the fracture biology and mechanical stability of the construct, all of 12 patients had problems with mechanical stability. Most instability arises from using a 1) Short plate (no.3, no.16) which does not allow sufficient cortical fixation above and below the fracture. 2) Intramedullary nail (no.4) with insufficient interlocking screws. 3) No interfragmentary compression (no.5) after an attempt to achieve absolute stability (Fig. 3). One patients (no. 16) showed technical error of preserving biology during plate osteosynthesis. Wedge fragment was manipulated and devitalized during initial surgical procedure that ended up non-union (Table 2).

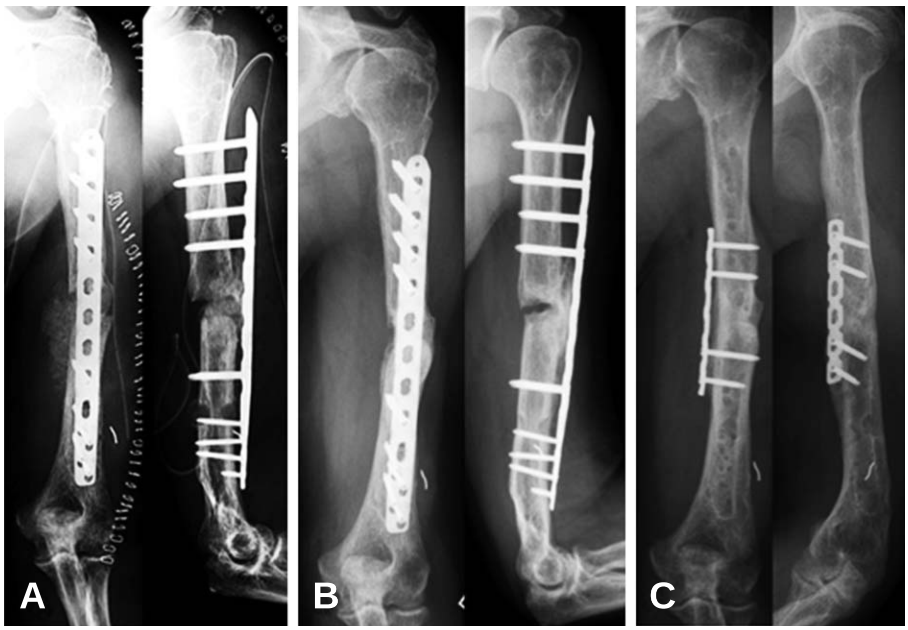

Fig. 2. (**A**) 57-year-old male s/p revision plating+bone grafting. There was incomplete dissection of fibrous tissue thru the nonunion site and as a result no bone graft placed on the posterior cortex. (**B**) 11 months post revision plating+bone grafting x-ray shows union occurs only on the anterior cortex. Reoperation was done bone graft was placed on the posterior cortex and plate was replaced with a smaller plate because complain of pain over the proximal part of the old plate. (**C**) 16 months post-op.

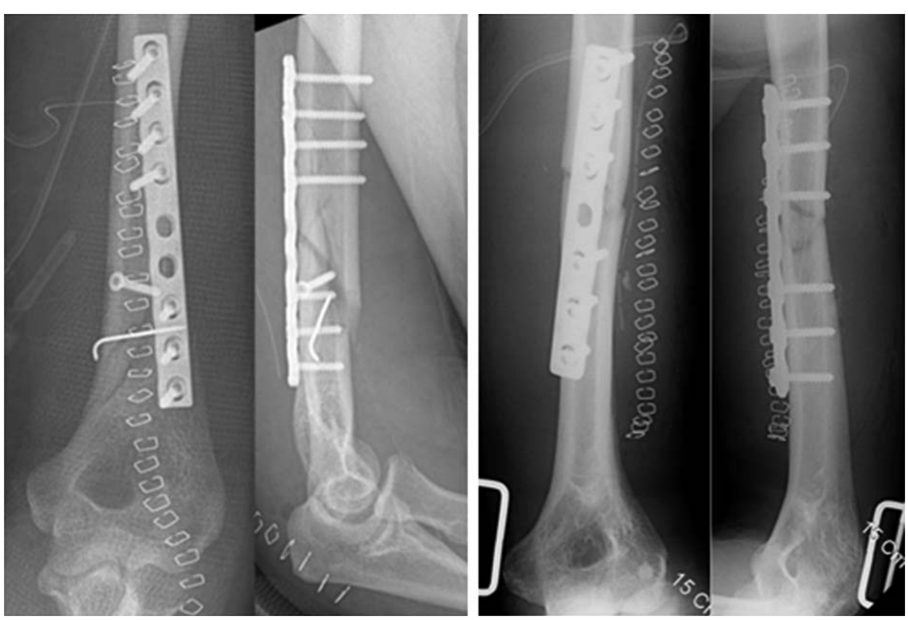

Fig. 3. Failure to achieve interfragmentary compression after open reduction internal fixation.

Table 2. Subgroup of patients that the operative procedures was analyze for preservation of fracture biology and mechanical stability of the construct.

Patient	Age	Sex	Ao	Site	Procedure	Objective (Relative/ Absolute)	Biology	Stability Problem
2	27	M	B2	Mid	CR IMN	Relative		Small diameter nail
4	41	M	B3	D1/3	OR PLATING	Absolute		No interfragmentary compression; only 4 cortical fixation on the distal fragment
5	69	F	B1	Mid	1) OR plating	Absolute		Short plate; no cortical fixation above and below the fracture
					2) Revision IMN	Relative		1 proximal and distal interlocking screw
					3) Removal of distal interlocking screw	Relative		Further increased instability
6	31	M	A1	D1/3	CR IMN (Elastic Nail)	Relative		Rotation and axial instability
8	53	F	B2	P1/3	CR IMN	Relative		1 distal interlocking screw
10	54	F	B2	Mid	CR IMN	Relative		1 distal interlocking screw; iatrogenic fracture at the distal main fragment
11	26	F	B3	D1/3	OR plating	Absolute		4 cortical fixation on the distal main fragment
15	61	F	A2	Mid	1) OR plating	Absolute		No interfragmentary compression
					2) Revision Plating	Absolute		No intergrafmentary compression
					3) IMN (Elastic Nail)	Relative		Rotational and Axial instability
16	20	M	B2	D1/3	OR plating	Absolute	Devascularization of the wedge fragment during the procedure	Short plate No interfragmentary compression
17	56	M	B3	P1/3	OR plating	Absolute		No interfragmentary compression 4 cortical thickness gap opposite the plate
19	30	M	A3	Mid	CR IMN (retrograde)	Relative		1 proximal and distal interlocking screw
20	42	M	A3	Mid	OR plating	Absolute		No interfragmentary compression 1 cortical thickness gap

CR IMN: closed reduction intramedullary nailing
OR: open reduction

IV. Discussion

"What went wrong"? The main technical failure in the osteosynthesis is that the implant construct failed to adequate stability for fracture healing to occur (11 out of 12). In order to successfully treat humeral shaft fracture with internal fixation, it is important to recognize the following: 1) torsion is the predominant form of mechanical stress 2) being a non-weight bearing bone there is a lack of axial loading and mainly promotes fracture distraction. Several animal studies have demonstrated that by producing interfragmentary compression along the fracture site induces healing by bridging callus. On the other hand, pure translation and shear torsion does not stimulate callus formation for fracture union.(11-14)

Some authors had suggested that intramedullary nail may not fully eliminate torsion(9,15-19) and distraction at the humerus.(9,19) The rotational stiffness of the nail is largely influence by the nail design and number of interlocking screw placed.(15-17) It is recommended that for intramedullary nailing of the humerus to place at least 2 proximal and 2 distal interlocking screws.(20) In our study 11 out of 12 cases of intramedullary nailing were either locked with 1 proximal and distal interlocking screw or 2 proximal and 1 distal interlocking screw. In two cases the single distal interlocking screw was placed on the proximal part of the dynamic hole (Fig. 4). Thus, with the weight of the arm it allows distraction between the major fragments. We believe that these fixation constructs are not stable enough for bone formation to occur.

In plating, it is agreed upon that a certain number of screws must be used in order to prevent mechanical failure. For the humerus, 3 to 4 screws on either side should be used as rotational forces predominate in these bones.(20,21) In our analysis, the main reason for nonunion after plate fixation is the mechanical instability brought about by the inadequate number of screws on the proximal and distal main fragment. It is sometimes difficult to attain adequate fixation on the distal humerus because the bone here becomes wide and flat. In such situations, we recommend the use of dual plating technique or use a plate (anatomically contoured plates) that allows more screws to be placed distally.

"What to do" in humeral shaft aseptic nonunion after internal fixation? Each case should be analyzed by asking these 2 clinical questions: 1) Is it capable of healing (union) without biologic stimulation? 2) Is the construct stable enough to allow healing (union)? Based on these, we were able identify what is the inadequate and planned an appropriate treatment for 20 cases of humeral shaft nonunion. If the fracture site is Viable and the construct is Unstable, Augmentation or Revisional plating is done. The Augmentation compression plating is used around the nail for increasing stability. And revisional plating is applied to loosened implants. If the fracture site is Nonviable and the construct is Unstable, then cancellous bone graft-

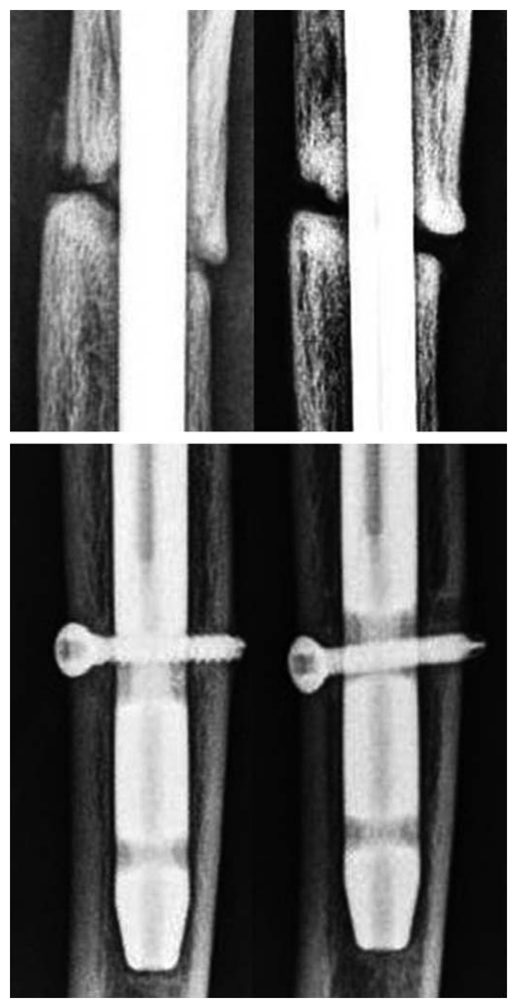

Fig. 4. Placing the single interlocking screw on the proximal part of the dynamic hole allows distraction at the fracture site.

ing is added with augmentation or revision plating (Fig. 1). In all cases, we preferred the use of a locking plate due to the following reasons: 1) its advantage on osteoporotic bone, because in most cases of nonunion there is presence of some degree of osteopenia resulting from disuse 2) as an internal fixator it can be placed via minimally invasive approach and précised plate contouring is not needed. We have refrained from using exchange intramedullary nailing by cause of its poor union rate even after multiple attempts.(22)

Several studies have reported their success in the treatment of aseptic humeral nonunion.(23-27) These studies only showed a stereotyped pattern of treatment and mostly described the results of plating with bone grafting. In contrast, we have applied an analytical approach to treatment of nonunion and based our treatment only on "what is necessary". With this concept we are not clichéd into doing bone grafting routinely. As shown in this study, 3 out 4 of patients had successful fracture union, simply by resolving the problem on mechanical instability and we have avoided the added morbidity with autologous bone grafting (Fig. 5).

There are several limitations in this study and some are inherent to its retrospective design. Pertinent data like initial clinical photos, smoking as well as medication history were not completely retrieved in all cases. Consequently all patient factors could not be considered in the study. But we tried to minimize the interfering effect by excluding the patients who had the underlying disease which might affect normal healing potential. The follow up schedule of patients was irregular making the determination of "time to union" impossible. The small number of patients that had undergone operative treatment without bone graft makes it difficult to prove that this procedure is effective. We therefore recommend a prospective study with more number of cases to validate our findings.

In conclusion, we have demonstrated that the prevalent technical lapse in operative fixations of humeral shaft fractures is the failure to provide adequate stability. The minimum number of screws/interlocking screws during plating and/or nailing must be strictly accomplished and an interfragmentary compression during ORIF is of paramount importance to achieve absolute stability. On the other hand, when dealing with humeral shaft nonunion an analytical approach

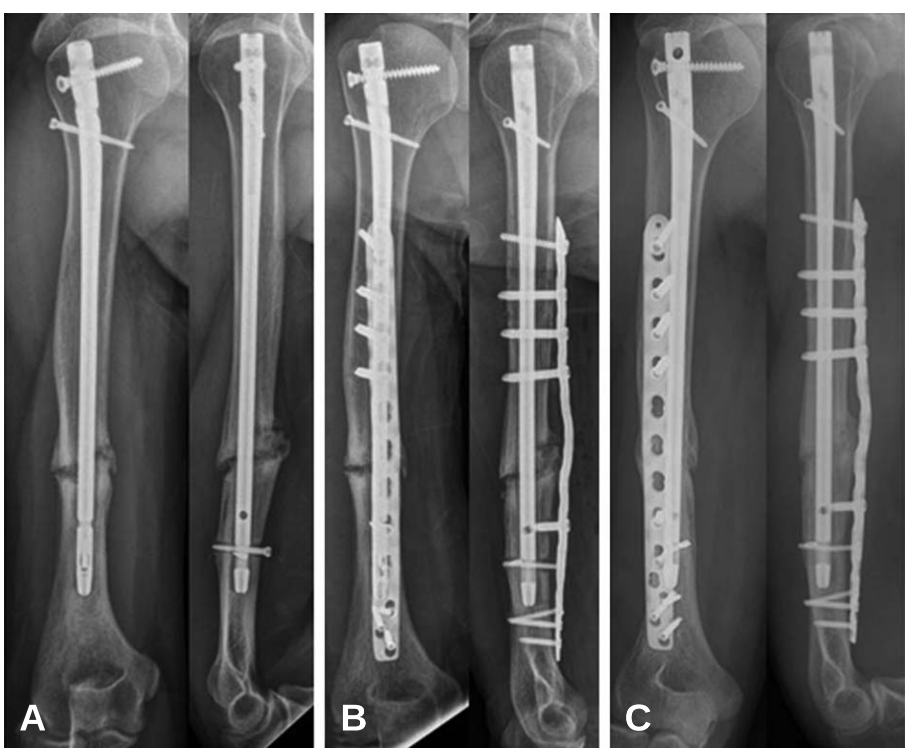

Fig. 5. (**A**) 27-year-old male with Hypertrophic Nonunion after CR IMN (**B**) Increased Stability with Augmentation Plating (4.5 LC DCP) (**C**) Radiographic Union at 6 months after Augmentation Plating.

to treatment is critical. This can prevent surgeons from reproducing the same fault, provide what is only necessary for healing and reduce the need for bone grafting.

REFERENCES

1) Böhler L. Conservative treatment of fresh closed fractures of the shaft of the humerus. Journal of Trauma-Injury, Infection, and Critical Care 1965; 5: 464-8.
2) Mast JW, Spiegel PG, HARVEY JP, Harrison C. Fractures of the Humeral Shaft A Retrospective Study of 240 Adult Fractures. Clinical orthopaedics and related research 1975; 112: 254-62.
3) Balfour G, Mooney V, Ashby M. Diaphyseal fractures of the humerus treated with a ready-made fracture. J Bone Joint Surg Am 1982; 64: 11-3.
4) Edward AP. Chapter 57: Fractures of the Humeral Shaft. In: Canale ST, Beaty JH. Campbell's operative orthopaedics. Vol. 3. 12th ed. Philadelphia: Mosby 2013: 2852-69.
5) Sarmiento A, Waddell JP, Latta LL. Diaphyseal humeral fractures: treatment options. The Journal of Bone & Joint Surgery 2001; 83: 1566-79.
6) Court-Brown CM, Heckman JD, McQueen MM, Ricci WM, Tornetta PI. Humerus Shaft Fractures. In: McKee MD. Rockwood and Green's fractures in adults. Vol. 1. 8th ed. Philadelphia: Wolters Kluwer Health 2015: 1298-1301.
7) Robinson C, Bell K, McQueen M. Locked nailing of humeral shaft fractures. Experience in Edinburgh over a two-year period. Journal of Bone & Joint Surgery, British Volume 1992; 74: 558-62.
8) Mulier T, Seligson D, Sioen W, Van Den Bergh J, Reynaert P. Operative treatment of humeral shaft fractures. Acta Orthop Belg 1997; 63: 170-7.
9) Marti RK, Kloen P. Concepts and cases in nonunion treatment. 1st ed. New York: Thieme, 2011.
10) Swanson EA, Garrard EC, O'Connor DP, Brinker MR. Results of a systematic approach to exchange nailing for the treatment of aseptic tibial nonunions. J Orthop Trauma 2015; 29: 28-35.
11) Park S-H, O'CONNOR K, McKellop H, Sarmiento A. The Influence of Active Shear or Compressive Motion on Fracture-Healing*. The Journal of Bone & Joint Surgery 1998; 80: 868-78.
12) Augat P, Burger J, Schorlemmer S, Henke T, Peraus M, Claes L. Shear movement at the fracture site delays healing in a diaphyseal fracture model. Journal of orthopaedic research 2003; 21: 1011-7.
13) Bishop N, Van Rhijn M, Tami I, Corveleijn R, Schneider E, Ito K. Shear does not necessarily inhibit bone healing. Clinical orthopaedics and related research 2006; 443: 307-14.
14) Steiner M, Claes L, Ignatius A, Simon U, Wehner T. Disadvantages of interfragmentary shear on fracture healing-mechanical insights through numerical simulation. Journal of Orthopaedic Research 2014; 32: 865-72.
15) Schopfer A, Hearn T, Malisano L, Powell J, Kellam J. Comparison of torsional strength of humeral intramedullary nailing: a cadaveric study. Journal of orthopaedic trauma 1994; 8: 414-21.
16) Dalton JE, Salkeld SL, Satterwhite YE, Cook SD. A biomechanical comparison of intramedullary nailing systems for the humerus. Journal of orthopaedic trauma 1993; 7: 367-74.
17) Blum J, Machemer H, Högner M, Baumgart F, Schlegel U, Wahl D, et al. [Biomechanics of interlocked nailing in humeral shaft fractures. Comparison of 2 nail systems and the effect of interfragmentary compression with the unreamed humeral nail]. Der Unfallchirurg 2000; 103: 183-90.
18) Mølster A, Gjerdet NR, Strand RM, Hole RM, Hove LM. Intramedullary nailing in humeral shaft fractures. Archives of orthopaedic and trauma surgery 2001; 121: 554-6.
19) Garnavos C. Diaphyseal humeral fractures and intramedullary nailing: Can we improve outcomes? Indian journal of orthopaedics 2011; 45: 208.
20) Ruedi TP, Murphy WM. AO principles of fracture management: Ao Publishing; 2007.
21) Stoffel K, Dieter U, Stachowiak G, Gächter A, Kuster MS. Biomechanical testing of the LCP-how can stability in locked internal fixators be controlled? Injury 2003; 34: 11-9.
22) Flinkkilä T, Ristiniemi J, Hämäläinen M. Nonunion after intramedullary nailing of humeral shaft fractures. Journal of Trauma and Acute Care Surgery 2001; 50: 540-4.
23) Devnani A. Simple approach to the management of aseptic non-union of the shaft of long bones. Singapore medical journal 2001; 42: 20-5.
24) Khan MS, Sahibzada AS, Khan MA, Sultan S, Younas M, Khan AZ. Outcome of plating, bone grafting and shortening of non-union humeral diaphyseal fracture. J Ayub Med Coll Abbottabad 2005; 17: 44-6.
25) Hsu T-L, Chiu F-Y, Chen C-M, Chen T-H. Treatment of nonunion of humeral shaft fracture with dynamic compression plate and cancellous bone graft. Journal of the Chinese Medical Association 2005; 68: 73-6.
26) Lin C-L, Fang C-K, Chiu F-Y, Chen C-M, Chen T-H. Revision with dynamic compression plate and cancellous bone graft for aseptic nonunion after surgical treatment of humeral shaft fracture. Journal of Trauma and Acute Care Surgery 2009; 67: 1393-6.
27) Hierholzer C, Sama D, Toro JB, Peterson M, Helfet DL. Plate fixation of ununited humeral shaft fractures: effect of type of bone graft on healing. The Journal of Bone & Joint Surgery 2006; 88: 1442-7.