

The Pseudarthrosis Oh Fe Humerus: Surgical Treatment, Functional Results and Perspectives

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Abstract

Objectives: Evaluate the results of the surgical treatment of aseptic pseudarthrosis of the humerus by comparing it with the data of literature.

Study Design: Descriptive retrospective.

Methods: This was a study involving 16 patients treated between January 2009 and July 2016 for aseptic pseudarthrosis after diaphyseal fracture of the humerus. The inclusion criterion was the existence of an aseptic diaphyseal pseudarthrosis of the humerus surgically treated, associated or not with a bone graft. Septic pseudarthrosis was excluded, patients who didn't follow-up. Data were collected on standardized questionnaires. Epi-Info version 6 FR was used for data entry and data analysis.

Results: Our study included 10 men and 6 women, an average age of 45.75 ± 15.63 years; the average time for consultation was 12.06 months with extremes of 6 to 39 months. The initial fracture was closed in 87.5% of our patients with 1 case of fracture on pathological bone and 2 cases of radial paralysis during initial trauma. 87.7% of our patients benefited during the treatment of pseudarthrosis of an osteosynthesis using Dynamic Compression Plate with 3 minimum screws on both sides of the fracture site and 12.6% of a centromedullary nailing with proximal locking. 93.7% of our patients progressed towards consolidation in an average time of 4.5 months with an average follow-up of 12 months. Complications were characterized by atrophy of the arm muscles in 12.6% of cases and 25% progressed to an iterative pseudarthrosis and received a second treatment of pseudarthrosis with bone substitute graft in 2 patients and corticocancellous in patients 2 others. Finally, our functional results according to the SOO score with an average follow-up of 5 months, were very good in 43.8%, good in 12.5%, average in 25% and poor in 18.8% of patient.

Conclusions: Pseudarthrosis of the humerus remains one of the most difficult complications of fractures of the humerus due to its frequency, the difficulties of its management and its socio-economic impact. The goal being 100% consolidation, delayed consolidation or pseudarthrosis is often due the surgeon.

Keywords: Pseudarthrosis of the Humerus; Surgical Treatment; CHU HassanII; Maroc

Introduction

Pseudarthrosis is one of the most difficult complications for the orthopedic surgeon to deal with. The choice of treatment should be guided by the location, type of lesion and the extent of bone loss.

Apart from significant bone loss, there is no mention of pseudarthrosis before 6 to 8 months after the initial fracture. Nowadays, pseudarthrosis is defined by the absence of any radiologically significant bone callus [1].

As shown in the literature, the humerus is one of the first non-consolidating sites of long bones at rates of 8 to 12% [2]. Surgical management should be codified. Faced with this "classical" complication of humeral diaphyseal fractures, there is now a wide range of therapeutic options [3]. Whatever the treatments instituted, there seems to be an almost incompressible rate of progress towards pseudarthrosis [4].

Aseptic diaphyseal pseudarthrosis remains a serious affection with functional sequelae especially articular, economic and socio-professional repercussions.

The principles of the treatment are based on stable osteosynthesis and bone graft depending on the case. The aim of this study is to evaluate the results of the surgical treatment of aseptic pseudarthrosis of the humerus by comparing it with the data of literature.

Patient and Method

This was a retrospective study involving 16 patients treated between January 2009 and July 2016 for aseptic pseudarthrosis after diaphyseal fracture of the humerus. The inclusion criterion was the existence of an aseptic diaphyseal pseudarthrosis of the humerus surgically treated, associated or not with a bone graft. Septic pseudarthrosis was excluded, patients who didn't follow-up.

Clinical examination of the arm sought pain assessed on an analog scale (from no pain to permanent pain) and/or mobility of the fracture; the examination of the fracture region sought paralysis of the radial nerve and measured the amplitudes of the shoulder and elbow joints of the two upper limbs (The mobility assessment was made on the angular deficit in each sector of mobility compared to that of the opposite side). We used on the initial radiographs the classification of the association of Francophone Orthopedic (AO) determining the type of fracture line and the Hackethal classification modified by Caffinière determining the site of the fracture [5]. These radiological images were also investigated for possible technical errors or factors favoring pseudarthrosis. The surgical indications were based on the existence of clinical signs of pseudarthrosis and radiological signs at three months from the beginning of the treatment of the fracture of the humerus. The surgical treatment consisted of stable osteosynthesis associated with or without a bone graft.

The patient was placed in a half-sitting position, lateral or supine position, the upper limb concerned in the operative field, as well as the homolateral iliac crest. The approaches used were lateral, anterolateral or posterior of the arm. The first surgical act consisted of the removal of the osteosynthesis material previously put in place in the cases of surgical treatment, after marking and neurolysis of the radial nerve.

The pseudarthrosis region was cleaned of all interposition fibrosis tissue associated with repermeabilization of the medullary canals with bacteriological sampling if necessary and an osteomuscular decortication. Sometimes a bone shortening was performed according to the vitality of the bone, and it was also possible to correct certain axis defects. Stable osteosynthesis was established after manual compression of the pseudarthrosis area. The optimal mounting included four screws on either side of the pseudarthrosis area. A spongy or cortico-spongy graft from the ipsilateral iliac crest or the bone substitute was placed opposite the pseudarthrosis area. The upper limb was immobilized in a thoraco-brachial bandage for 45 days and antibioprohylaxis was done for 48 hours. Functional rehabilitation was systematic.

All patients were reviewed 3 weeks postoperatively for the 1st control, then at 1 month intervals for 3 months and then every 3 months. The control criteria were clinical and radiological. We used the score “SOO” this is the score set up by the Western France Orthopedic Society 1997 during the round table on humeral fractures [6]. The collection of data was done through: - hospital records of head of nursing in the department, - the operating reports - evaluation of the SOO score in external consultation of the department, - patient records - Individual patient survey forms. The data collected were entered on Word and Excel and analyzed on the Epi-info 7 software.

Satisfaction	
Very happy-happy	3
Disappointed-very disappoint	0
Pain	
Absent ou meteorological	6
Minimal effort	4
Excessive effort	2
Permanent	0
Antepulsion	
> 120°	1.5
90/120°	1
< 90°	0
Abduction	
> 120°	1.5
90/120°	1
< 90°	0
External Rotation	
Normal	1.5
Reduced	0
Internal Rotation	
Normal	1.5
Reduced	0
Deficit in Extension of Elbow	
< 20°	1.5
20/40°	1
> 40°	0
Flexion of elbow	
> 130°	1.5
110/130°	1
< 110°	0
Radiography	
Anatomical	2
Cal > 20°	0

Table 1: Functional score of the Western Orthopedic Society.

Results

Our study included 10 men and 6 women, an average age of 45.75 ± 15.63 years; the average time for consultation was 12.06 months with extremes of 6 to 39 months. 81.2% of our patients were doing manual work with 43.8% housewives and 68.8% of our patients resided in the region of Fez. 87.5% of our patients were right-handed with 43.8% of fractures involving the right side. The initial fracture was closed in 87.5% of our patients with 1 case of fracture on pathological bone and 2 cases of radial paralysis during initial trauma. 56.3% of our patients suffered a fall following a domestic accident, 31.3% victim of a road accident et 12.5% were the victims of an industrial accident. All our patients had persistence of pain at admission associated with partial functional impotence in 43.8% of cases. Physical examination found persistence of palpation pain in all of our patients with persistent mobility in 31.3%, an apparent deformation in 81.4%, and a shortening in 6.3% of our patients. 81.7% of patients were initially treated in our department with 37.5% having received a centromedullary nailing, 37.5% osteosynthesis with Dynamic Compression Plate. The initial radiological lesion according to the AO classification was 37.5% type AIII, 12.5% type BII et 12.5% AI. Atrophic pseudarthrosis was the predominant radiological diagnosis with 62.5% versus 37.5% hypertrophic. General anesthesia was used in all our patients in supine or lateral decubitus. All our patients had antibioprohylaxis for 48 hours. The lateral approach of the arm was used most with 68.8% and the posterior arm approach in 12.5% of cases. 87.7% of our patients benefited during the treatment of pseudarthrosis of an osteosynthesis using Dynamic Compression Plate with 3 minimum screws on both sides of the fracture site and 12.6% of a centromedullary nailing with proximal locking. Radial nerve exploration was systematic in all cases of plate osteosynthesis, 2 cases of nerve bruises were found during the initial management, which regressed spontaneously before the treatment of pseudarthrosis. All our patients have systematically benefited from a revival of the banks, re-permeabilization of the medullary canal and osteomuscular decortication. 87.7% benefited from a graft at the fracture side: by bone substitute in 43.7% of cases, corticocancellous from the ipsilateral crest in 31.3% of cases and spongy 12.5% of patients. 93.7% of our patients progressed towards consolidation in an average time of 4.5 months with an average follow-up of 12 months. Complications were characterized by atrophy of the arm muscles in 12.6% of cases and 25% progressed to an iterative pseudarthrosis and received a second treatment of pseudarthrosis with bone substitute graft in 2 patients and corticocancellous in patients 2 others. These iterative pseudarthrosis consolidated after an average delay of 5 months and one patient presented a vicious consolidation without functional disability with an angulation ≤ 10°. No patient showed signs of radial paralysis in the treatment of pseudarthrosis. In our series only one patient did not consolidate it was a patient of 76 years initially operated by locked intramedullary nailing having evolved towards an absence of consolidation with a septic episode. Finally, our functional results according to the SOO score with an average follow-up of 5 months, were very good in 43.8%, good in 12.5%, average in 25% and poor in 18.8% of patients.

Age	Sex	Profession	Dominant side	Timelimit for consultation/months	etiology	Initial Fracture	ATCD	Initial treatment	Type of lesion (AO)	Radiological diagnostic	Cure chirurgical	SA	Evolution
52	m	Unemployed	Right	8	DA	Closed	N	T	AIII	Atrophic	SO+SG+DCP	Ext A	BAD
42	m	unemployed	Right	6	DA	Closed	N	T	AIII	Atrophic	SO+SBG+DCP	Ext A	Good
26	m	labourer	Right	8	DA	Closed	N	LIN	BII	Atrophic	SO+SBG+ECMV	Ext A	Good
74	m	Driver	Left	12	DA	Closed	N	LIN	BII	Hypertrophic	SO+SBG+DCP	Ext A	BAD
52	f	Housewife	Right	8	RA	Closed	N	LIN	AI	Atrophic	SO+DCP	Post A	Good
54	f	Housewife	Right	12	DA	Closed	N	AP	AIII	Atrophic	SO+CCG+AP	Ext A	BAD
60	f	Housewife	Right	24	DA	Closed	N	LIN	AIII	Hypertrophic	SO+SBG+DCP	Ext A	Good
50	m	Housewife	Right	9	RA	Closed	N	DCP	BI	Atrophic	SO+CCG+DCP	Ext A	Good
35	m	Labourer	Right	6	I A	Open	RP	LIN	AIII	Hypertrophic	SO+CCG+DCP	Ext A	BAD
46	f	Housewife	Right	8	DA	Closed	PB	Neg	AIII	Atrophic	SO+ECMV	Ext A	Good
26	m	Labourer	Right	39	IA	Closed	N	LIN	AIII	Hypertrophic	SO+CCG+DCP	Ext A	Good
29	m	Driver	Right	15	RA	Open	RP	DCP	AIII	Hypertrophic	SO+SBG+DCP	Ext A	Good
68	f	Housewife	Left	11	DA	Closed	N	LIN	AIII	Hypertrophic	SO+SBG+DCP	Post A	Good
34	m	Labourer	Right	12	RA	Closed	N	LP	AI	Atrophic	SO+SBG+LP	Post A	BAD
24	m	Student	Right	8	RA	Closed	N	DCP	CIII	Atrophic	SO+SG+DCP	Post A	Good
60	f	driver	Right	7	DA	Closed	N	AP	CIII	Atrophic	SO+CCG+AP	Ext A	Good

Table 2: Sociodemographic and clinical data (summary).

m: Masculine; f: Feminine; DA: Domestic Accident; RA: Road Accident ; IT: Industrial Accident; ATCD: Antecedent; N: None; RP: Radial Paralysis ; PB: Pathological Bone; T: Traditional Treatment; LIN: Locked Intramedullary Nailing; BP: Bone plate; LP: Lecestre Plate; AP: Anatomical Plate; Neg: Neglected; SO: Stimulation Of Osteogenesis; SG: Spongy Graft; SBG: Substitute Bone Graft; CCG: Corticocancellous Graft; DCP: Dynamic Compression Plate, Ext: External; A: Arm; Post: Posterieur; E: Elbow; S: Shoulder; NG: No Graft, H: Hackethal, Ca: Caffinière; SA: Surgical Appraoch

Initial Displacement of fracture	Fractured side	Soo/points	Graft	Aspect of Calus	Second surgery	Site of graft sample	Type According to H et C	Time limit/months
Angulation	Right	10	SG	Loose		Iliac crest	D4	
Translation	Right	17	SG	Tight		Iliac crest	D4	
Rotation	Right	17	SBG	Tight			D4	
Angulation	Left	4	SBG	Loose	SO+ CCG +SBG+DCP	humerus	D4	12
Overlapping	Left	19	NG	Tight			D5	
Rotation	Right	5	CCG	Tight	SO+SBG+DCP	Iliac crest	D3	36
Angulation	Right	18	SBG	Loose			D4	
Rotation	Left	17	CCG	Loose		Iliac crest	D4	
Angulation	Left	9	CCG	Loose	SO+ CCG +DCP	Iliac crest	D4	9
Non displaced	Right	13	NG	Tight			D4	
Overlapping	Left	19	CCG	Tight		Iliac crest	D4	
Angulation	Left	14	SBG	Tight			D5	
Overlapping	Left	10	CCG	Tight		Iliac crest	D5	
Overlapping	Right	5	CCG	Loose	SO+SBG+LP	Iliac crest	D5	36
Angulation	Left	9	NG	Tight			D5	
Angulation	Left	19	CCG	Loose			D3	

Table 3: Clinical Data (continued).

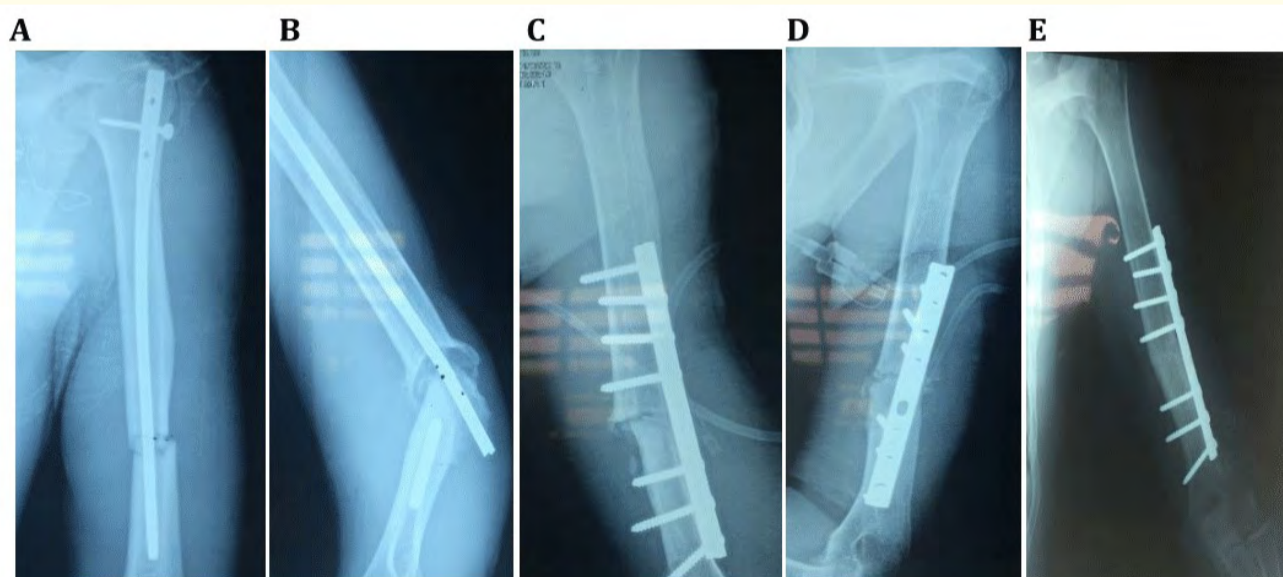
	Evolution			univariate analysis	P value
	Consolidation n (%)	Treatment failure (%)	Total %		
Sex					
Feminine	5 (83.3)	1 (16.7)	37.5		0.59
Masculine	6 (60.0)	4 (40.0)	62.5		
Initiale fracture					
Closed	10 (71.4)	4 (28.6)	87.5		1.00
Open	1 (50.0)	1 (50.0)	12.5		
Radiological type					
Atrophic	7 (70.0)	3 (30.0)	62.5		1.00
Hypertrophic	4 (66.7)	2 (33.3)	37.5		
Surgical Technique					1.04
Bone plate	9 (64.3)	5 (35.7)	87.5		
Nailing	1 (100.0)	0 (0.0)	6.3		
Orthopedic	1 (100)	0 (0.0)	6.3		
Graft					
No	3 (100)	0 (0.0)	18.8		0.51
yes	8 (61.5)	5 (38.5)	81.3		
Age (years)	43,91 ± 15,71	49,80 ± 16,41			0.50
Time limit of consultation	13 ± 10,03	10 ± 2,83			0.52

Discussion

Aseptic pseudarthrosis of the humerus is the most difficult late complication of fractures of the humerus, for the surgeon and for the patient with difficulties of treatment, huge socio-economic burden and the duration of temporary incapacity or autonomy generated by its treatment. Literature reports a rate of pseudarthrosis varying 0 to 10% for fractures of the humerus [7,8]. This prevalence of the pseudarthrosis of the humerus is largely explained by the biomechanical characteristics of the upper limb. Nowadays, a wide range of therapies exists for the treatment of aseptic pseudarthrosis without any real consensus on the most appropriate technique. This therapeutic decision must be preceded by clinical, radiological and biological diagnostics and depending on several factors influencing the onset of pseudarthrosis that are more or less in agreement with literature [9]. The epidemiological variables of our series have no peculiarities and can be superimposed on those of the literature. It confirms that the aseptic diaphyseal pseudarthrosis of the humerus can occur at any age with a male predominance in most series [10-12]. In addition to the usual factors related to the terrain (obesity, smoking, alcoholism, osteoporosis, corticosteroid therapy) the initial opening of the fracture site, initial trauma, initial fracture comminutions, loss of bone matter and therapeutic errors are listed as pseudarthrogens in most series [13-15].

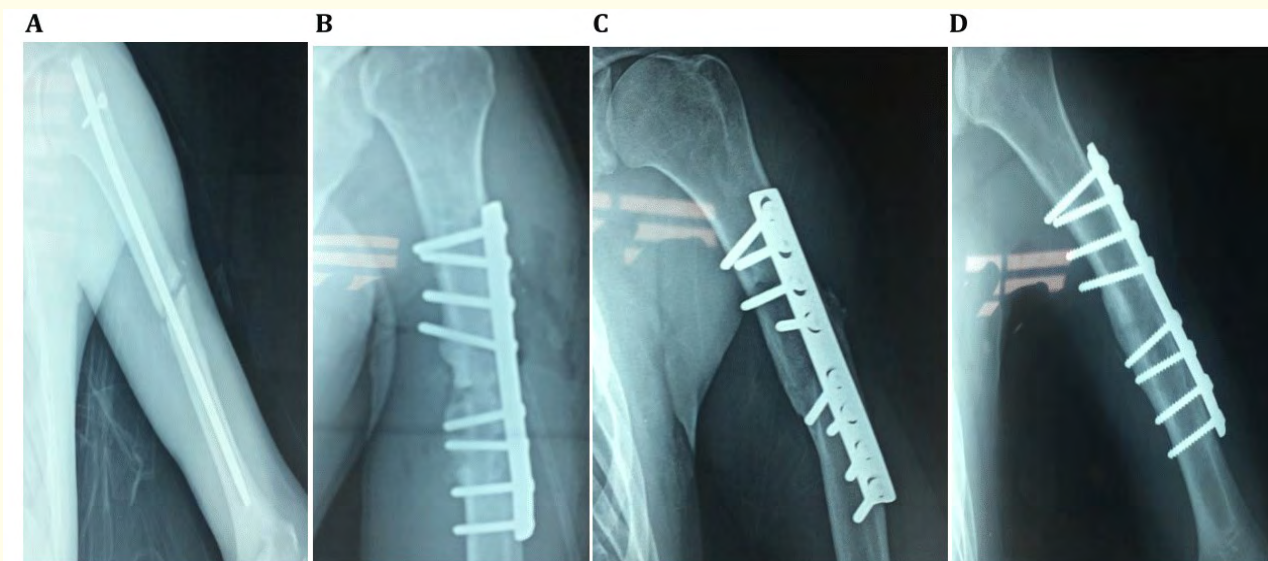
In our series, analytical tests looking for prognostic factors did not give statistically significant results. This could be explained by the small size of our sample, as opposed to some series reporting influencing factors such as infection and links between the site of the lesion and the statistically significant functional repercussions [16].

The average time to admission, which defines the time between initial surgical treatment and the treatment of pseudarthrosis in our series, is similar to that of M Tall., *et al* [17]. This average could be explained by the lack of information from our patients, and the rather heavy cost of this surgery. The predominance of pseudarthrosis occurring in the middle third of the humeral diaphysis in our series is in accordance with the data of the literature for this location most often implicated [18,19]; the incidence of pseudarthrosis of this location would be mainly due to the particular anatomy of this zone by the presence of the main nourishing artery of the humerus [20]; unlike other series of literature combining a predominance of seat junction middle third-upper third, distal quarter or proximal third [12,13,17]. The radiological type of atrophic pseudarthrosis was the most frequent in our series as corroborated most of the series of literature [17,21]. These radiological types of pseudarthrosis define also the most adequate surgical technique, some authors advocate strictly a simple immobilization in hypertrophic pseudarthrosis seeing the good vascularization of the fracture tips, contrary to a necessity of osteogenic stimulation in the atrophic pseudarthrosis. The constant improvement of the osteosynthesis techniques and of the osteogenic stimulation in the treatment of the pseudarthrosis of the humerus yields very promising results with a consolidation rate of 95 to 100%, whatever the technique used [8,22-25] despite the disadvantages associated with each technique. In our series, the consolidation rate was 93.75% with an average follow-up of 12 months. Despite this satisfactory result, all the fractures of the humerus whatever the surgical or orthopedic techniques used can evolve towards a pseudarthrosis. This pejorative evolution may be related to a failure of realization of the surgical technique as reported by these authors [3,11,12] cases of pseudarthrosis attributed to initial osteosynthesis defects were recorded in our series: a short plate, a screw on the fracture site and a lack of distal locking in all our cases centromedullary nailing (icono3). The graft of the fracture site was predominant in our series, either cortispongious or spongy from the iliac crest or by bone substitute. The certain role of this graft for consolidation being reported in the recent publications [9,11,12].



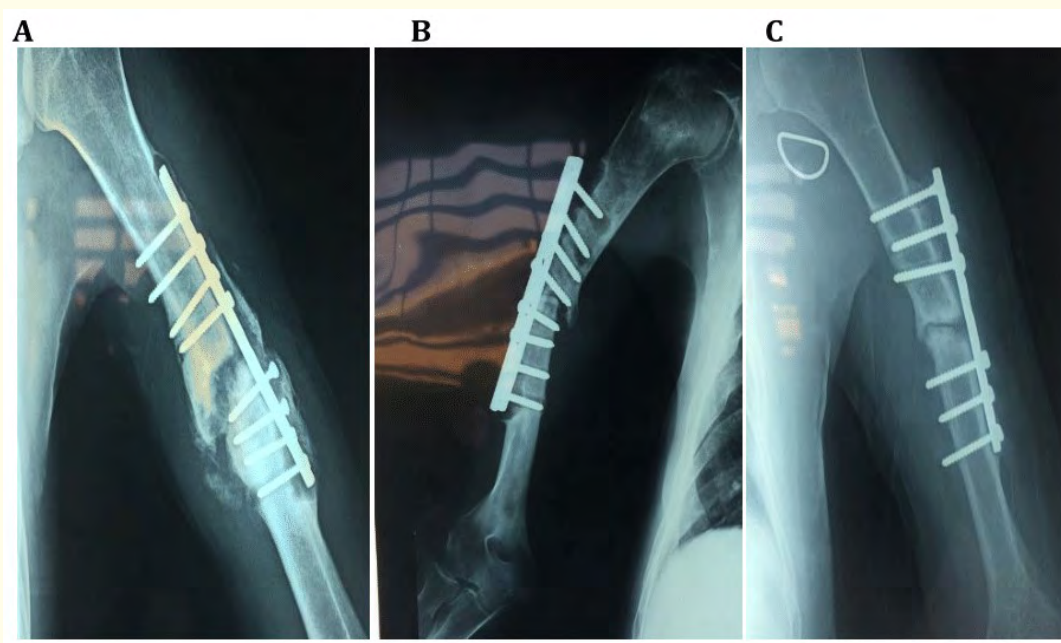
Patient 1

- A: Medioclavicular fracture treated by locked intramedullary nailing
- B: Pseudarthrosis with breaking of nail
- C: Treatment of pseudarthrosis + DCP 9 holes (immediate post op control front incidence)
- D: Post op image lateral incidence
- E: Consolidation after 6mois



Patient 2

- A: Initial locked intramedullary nailing
- B: Immediate post op image
- C: Consolidation after 6months lateral incidence
- D: Front incidence



Some defects of osteosynthesis

- A: Pseudarthrogen screws
- B: Pseudarthrogen screws
- C: Short plate with only 3 screws either side of the fracture

Conclusion

Pseudarthrosis of the humerus remains one of the most difficult complications of fractures of the humerus due to its frequency, the difficulties of its management and its socio-economic impact. The goal being 100% consolidation, delayed consolidation or pseudarthrosis is often due the surgeon. However, this treatment is subject to several predictive factors, hence the need for a dynamic study taking into account these multiple aspects on a more substantial sample making it possible to identify these potential factors which could contribute to the objective of complete consolidation.

Rh-BMP-7/matrice collagène (OP-1), the use of biphasic phosphocalcic ceramics and the injection of bone marrow remains possible prospects to improve our treatment.

Conflict of Interests

None.

Bibliography

1. H Van Cauwenberge, *et al.* "Actualités dans le traitement des pseudarthroses aseptiques". *Revue Medicale De Liege* 62.5-6 (2007): 344-351.
2. Marti RK, *et al.* "Humeral Shaft non-union: evaluation of uniform surgical repair in fifty one patients". *Journal of Orthopaedic Trauma* 16.2 (2002): 108-115.
3. Béguin JM, *et al.* "Considérations à propos du traitement des pseudarthroses de l'humérus". *Acta Orthopædica Belgica* 57 (1991): 114-122.
4. Jupiter JB. "Complex non-union of the humeral diaphysis". *Journal of Bone and Joint Surgery* 72.5 (1990): 701-707.
5. CB Diémé, *et al.* "Embrochage centromédullaire ascendant des fractures diaphysaires de l'humérus de l'adulte. Évaluation des résultats anatomiques et fonctionnels à propos de 63 cas". *Chirurgie de la main* 24.2 (2005) 92-98.
6. Nieto H. "Les fractures de la diaphyse humérale. Table ronde sous la direction de Nieto H. Société d'orthopédie de l'ouest". *Ann Orthop Ouest* 29 (1997): 129-159.
7. Chantelot C, *et al.* "Traitement des fractures de l'humérus par le clou de Marchetti". *Annales de Chirurgie de la Main* 17 (1998): 165-174.
8. Osman N, *et al.* "Results of non-operative and operative treatment of humeral shaft fractures. A series of 104 cases". *Annales de Chirurgie de la Main* 17.3 (1998): 195-206.
9. J Brillhault and L Favard. "Traitement chirurgical des pseudarthroses diaphysaires aseptiques". *EMC-Rhumatologie Orthopédie* 2.3 (2005): 217-247.
10. R Bernard de Domsure, *et al.* "Non-consolidation aseptique de la diaphyse humérale". Elsevier Masson SAS. Tous droits réservés (2010).
11. Dahmani, *et al.* "Pseudarthrose aseptique de la diaphyse humérale traitée par plaque vissée et autogreffe osseuse (à propos de 20 cas)". *Chirurgie de la main* 32.2 (2013): 85-91.

12. C Chantelot, *et al.* "Étude rétrospective des résultats du traitement chirurgical de 21 pseudarthroses de l'humérus". *Chirurgie de la main* 24.2 (2005): 84-91.
13. Lemaire R. "Management of nonunions: an overview, in Duparc J (ed)". *Surgical Techniques in Orthopaedics and Traumatology*. Elsevier, Paris (2000).
14. Lammens J, *et al.* "Treatment of non-union of the humerus using the Ilizarov external fixator". *Clinical Orthopaedics and Related Research* 353 (1998): 223-230.
15. Panagiotis M. "Classification of non-union". *Injury* 36.4 (2005): S30-S37.
16. VR Patel, *et al.* "Nonunion of the humerus after failure of surgical treatment". *Journal of Bone and Joint Surgery* 82-B (2000): 977-983.
17. M Tall, *et al.* "Traitement des pseudarthroses diaphysaires des os longs sur fracture négligée par décortication ostéomusculaire". *Revue de chirurgie orthopédique et traumatologique* 100.6S (2014): S145-S150.
18. Gerard Y, *et al.* "Pseudarthroses deladiaphyse humérale". *Chirurgie* 117 (1991): 263-269.
19. Salanne P and Aribit F. "Conduite à tenir devant une pseudarthrose de la diaphyse humérale". *Ann Orthop Ouest* 29 (1997): 148-151.
20. Caroll SE. "A study of the nutrient foramina of the humeral diaphysis". *Journal of Bone and Joint Surgery* 45B (1963): 176-181.
21. Segonds JM, *et al.* "Pseudarthroses et retards de consolidation aseptiques de la diaphyse humérale, à propos de 30 cas traités par plaque et autogreffe osseuse". *Revue de Chirurgie Orthopédique* 89.2 (2003): 107-114.
22. Heim D, *et al.* "Surgical treatment of the humeral shaft fractures, the Basel experience". *Journal of Trauma* 35.2 (1993): 226-232.
23. LE Gayet, *et al.* "Traitement chirurgical: l'embrochage fasciculé".
24. Dujardin FH, *et al.* "Échec de l'enclouage centromédullaire verrouillé des pseudarthroses de la diaphyse humérale". *Revue de Chirurgie Orthopédique* 86 (2000): 773-780.
25. Koutalos A, *et al.* "Operative management of humeral non-unions. Factors that influence the outcome". *Acta Orthopædica Belgica* 81.3 (2015): 501-510.

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