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Sequelae of distal humeral fractures

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Summary

Distal humerus fractures (DHF) are rare and complex injuries. Although knowledge of these lesions among surgeons has increased in recent decades, a high rate of complications and unsatisfactory results are still reported. The main complications are ulnar nerve neuropathies, stiffness, heterotopic ossifications, nonunions, malunions, painful hardware and post-traumatic osteoarthritis. Careful pre-operative planning, choosing the correct surgical approach, mini-invasive and tissue-sparing surgery, stable osteosynthesis, correct management of the ulnar nerve and early rehabilitation can improve clinical outcomes by reducing the number of complications. The type of trauma, bone exposure, timing of surgery in polytraumas and varying levels of compliance among patients represent inevitable risk factors for unsatisfactory outcomes. Early and appropriate treatment of complications is associated with better results as it reduces the development of osteoarthritis and avoids a long period of functional disability. The aim of this study is to describe the main complications of DHF and ways of preventing and treating them.

Key words: distal humerus fractures, complications, ulnar nerve neuropathies, stiffness, heterotopic ossifications, nonunion, pseudoarthrosis, malunion, post-traumatic osteoarthritis

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Introduction

Distal humerus fractures (DHF) are considered rare lesions whose prevalence is 0.2-2% of all adult fractures and approximately 30% of elbow fractures. The incidence rate is 5.7/100,000 per year, though this value is likely to increase in next 10 years owing to population aging. These fractures occur in a bimodal distribution, with the first peak in young males, usually following high-energy traumas, and a second peak in elderly women, as a consequence of pathological fractures related to osteoporosis [1].

DHF used to be associated with poor prognosis, poor clinical outcomes and high complication rates, due above all to secondary displacement and joint stiffness. The recent introduction of better surgical techniques, hardware and materials has significantly improved outcomes and reduced failure rates. In the 1980s, A.O. principles introduced the concepts of anatomic reduction, double plate rigid fixation and early mobilization; consequently, minimal osteosynthesis and conservative treatment were progressively abandoned. The further reduction in surgical failure rates in the elderly in recent decades may in part be ascribed to the introduction of prosthetic replacements, which are now considered the treatment of choice in comminuted fractures of the distal humerus in low-demand aged patients.

Nevertheless, the complication rates associated with this type of fracture remain significant, particularly when such lesions are managed by non-expert elbow surgeons. According to the recent literature, the rate of major complications ranges between 19 and 53%,: unsatisfactory outcomes are mainly correlated with severe comminution of fractures, bone defects, open high-energy traumas, poor bone-stock, older age and the timing of surgery [2]. The most common complications in DHF include ulnar neuropathy, joint stiffness, nonunion, olecranon osteotomy-related complications, malunions, osteoarthritis and infections.

Accurate pre-operative planning is mandatory as each kind of complication requires a different management and different surgical procedures. The initial fracture pattern, previous surgical approaches, ulnar nerve position (transposed or not transposed) and function, implant features and articular surface status, as well as the patients' comorbidities and compliance, should always be assessed carefully when planning the timing and type of surgery and post-operative treatment.

Pre-operative planning includes standard radiographs and CT with tridimensional reconstructions and radio-ulnar subtraction; CT is mandatory to evaluate the sequelae of comminuted fractures and to better understand the articular surface involvement, the deformity pattern and the extension and features of any bony defects. MRI is rarely indicated in the acute and chronic settings, though it is recommended to detect or evaluate bone infections, cartilage damage and osteonecrosis. Radiolabeled autologous WBC scintigraphy is frequently used to detect sites of abnormal bone remodeling, e.g. in silent/asymptomatic infections, and to evaluate the effectiveness of antibiotic therapy. Ultrasound, MRI and EMNG may be indicated in post-traumatic neuropathies to better assess the type of injury (neurapraxia, neurotmesis, axonotmesis).

The choice of surgical procedures for DHF sequelae should take into account the possible need to use devices for hardware removal, new internal fixation and/or prosthetic replacement. Patient positioning should be carefully assessed when auxiliary surgical fields are required for bone/tendon graft harvesting. The availability of equipment such as image intensifier, surgical microscope and electro-neuro-stimulator should be considered in selected cases. Lastly, alternative surgical strategies aimed at avoiding or overcoming intraoperative complications should be discussed.

The aim of this study is to describe the main complications of DHF as well as their prevention and treatment.

Neuropathies

Neurological lesions are a common complication in DHF. The ulnar nerve is most commonly involved, though the radial and median nerves might also be affected. Nerves lesions directly due to trauma are reported in between 0% and 26% of cases, while late-onset chronic post-traumatic neuropathies are reported in between 0% and 17% of cases; the latter affect the ulnar nerve in the majority of cases.

Ulnar nerve damage is frequently observed in the first days after surgery and is mainly caused by intraoperative compression, stretch, contusion or transection, devascularization, bony or hardware impingement or inadequate anterior transposition at the end of surgery; this clinical finding may also be due to misdiagnosed preexisting damage caused directly by the trauma [3].

Late-onset neuropathies are often related to adhesions or compression by a medial plate, excessive callus or scar formation, nerve instability, nonunion and malunions with significant deformities, medial heterotopic ossifications (HO) and hardware malpositioning or failure).

The severity of nerve injuries ranges between low-grade parasthesiae, which frequently resolve spontaneously within 2-4 weeks of the injury, to complete sensitive/motor palsy, although isolated sensitive deficits are more common. Pre-operative traumatic lesions are treated with decompression and transposition while neurotmesis, a rare injury, is repaired by suture or graft. In mild late-onset neuropathies, conservative treatment is the first effective option, especially if anterior transposition was performed at the time of DHF primary surgery and yields good outcomes in the majority of cases within 2-4 months. Nerve function in patients treated conservatively should be periodically assessed by means of a clinical examination and EMNG. If conservative treatment with anti-inflammatory/neurotrophic drugs and physical therapy fails and nerve deterioration occurs, ulnar neurolysis and anterior transposition need to be performed quickly to avoid permanent damage.

Heterotopic ossifications

Heterotopic ossifications (HO), whose estimated incidence is 0-21% [4,5], are more common in polytrauma patients [6] with extended soft-tissue and neurovascular damage [7], concomitant central nervous system injury, delayed surgical treatment and prolonged immobilization after surgery [8]. Furthermore, HO seem to be more common when a transolecranon approach is used: Chen et al. observed a 12% HO rate with the transolecranon approach and a 0% HO rate with the Brian-Morrey approach [9].

The clinical severity of HO varies depending on their location and size. In 1994, Hastings introduced a classification designed for clinical practice: it divides HO in Type I (asymptomatic), Type IIA (symptomatic HO with stiffness in E/F), Type IIB (symptomatic HO with stiffness in P/S) and Type IIC (symptomatic HO with combined stiffness in E/F and P/S). Type IIIA, IIIB e IIIC are used for ankylosis of the elbow joint in E/F, P/S and combined, respectively. Surgical treatment is recommended in Types II and III, or whenever neurological compression symptoms occur.

The optimal timing for excision surgery of HO has not been established: some authors have suggested that the biological activity of HO should be monitored by CT, X-rays, serum alkaline phosphatase or bone scintigraphy and that surgery should only be performed after the full maturation of HO (approx. 6-12 months) in order to avoid recurrences [10]; however, none of the aforementioned examinations has displayed a high sensitivity or specificity [11]. The evaluation of radiographic features (well-defined rounded margins with clear trabeculae and cortical bone) of HO remain the most widely used method to evaluate the maturation of HO [12], a process that usually ends within 6 months. In recent years, several surgeons have recommended the early excision of HO to avoid a long period of functional impairment, with satisfactory clinical results and a low recurrence rate being reported. Excessively delayed treatment (> 12 months) is associated with a high failure rate due to soft tissue contractures and degenerative development of the joint [13].

Surgical treatment of HO is often based on the lateral and/or the medial column procedure, which consists in excising ectopic bone and scar tissues; neurolysis in situ or anterior transposition of the ulnar nerve is often associated with this procedure. Late treatment (> 12 months) associated with cartilage injury and anterior HO is a negative prognostic factor in this type of surgery [14].

The administration of indomethacin for HO prophylaxis remains a controversial issue, with the literature available on this topic being very limited. Although the most recent literature does not provide unequivocal evidence of its benefits in HO prophylaxis, several elbow surgeons have stated that they routinely use indomethacin (50-100 mg/daily for 4 weeks) in clinical practice, especially in traumatic and post-traumatic conditions. Mini-invasive and tissue sparing surgery, as well as early and gentle rehabilitation, are considered other factors that help to prevent HO formation.

Elbow stiffness

The incidence of severe stiffness is estimated to be 10%-20%, though it is higher in elderly patients [15,75]. Highly comminuted and displaced fractures and extended post-operative immobilization are negative prognostic factors for the development of a stiff elbow [16,17]. Pathoanatomic features include soft tissue retraction, periarticular osteophytosis, hypertrophic callus formation, HO, nonunions, malunions and hardware impingement.

Surgery is indicated when conservative treatment fails in extrinsic stiffness (> 4/6 months) and in all cases of intrinsic stiffness with significant pain or limitations in daily activities. Extrinsic stiffness requires open arthrolysis with capsular-ligamentous release (bicolumn procedure), HO and osteophyte excision and, occasionally, implant removal. The treatment of intrinsic stiffness treatment is more complex owing to the presence of joint deformities. Prosthetic replacement is recommended in elderly patients affected by malunions and intra-articular nonunions, with good outcomes expected in the majority of cases. By contrast, the treatment of intrinsic contractures in younger patients is often challenging as it requires corrective osteotomies, interposition arthroplasty, nonunion debridement with autologous bone grafting and new fixation. These procedures should be considered as better options than prosthetic replacement in young adults.

Transolecranon osteotomy-related complications

The transolecranon approach is the most common procedure in DHF osteosynthesis [18]. However, the complication rate associated with this procedure is high: hardware failure with secondary displacement, delayed union and nonunion are described in 0-31% of cases [4,19-21]. Olecranon healing failure has been more commonly observed when a dynamic tension band or an intramedullary screw rather than plate-screw fixation are used [19,22]. CT scan is indispensable to evaluate the grade and extension of the nonunion. No surgical treatment should be considered in asymptomatic patients when partial bone healing occurs and the proximal fragment is stable.

The correct timing of treatment is essential to avoid excessive resorption of the olecranon: whenever delayed healing is observed, one or two cycles of shockwave therapy should be administered. Early surgical intervention is recommended if physical treatment fails. The type of treatment depends on the location and the extension of the nonunion. In case of bony resorption of the olecranon tip, the excision of the latter and tricipital reinsertion is the first-choice procedure: these cases are often caused by an osteotomy that has been performed too proximally or an excessive time interval between nonunion onset and surgical treatment.

In other cases with large proximal olecranon fragment, pseudoarthrosis debridement, autologous bone grafting and internal fixation with plate is indicated. The main goal of surgery is to maintain the dimensions of the greater sigmoid notch: this may be achieved by positioning a tricortical bone graft along the iliac crest after debridement of the nonunion. Compression with a stable ORIF is mandatory in such cases to ensure bone graft integration and healing.

Delayed union/nonunion of distal humerus

Despite a significant reduction in the incidence of nonunions in DHF over the past 30 years, the failure to heal is still reported in as many as 10% of cases [23,24].

Unstable osteosynthesis, fragment comminution with bone devascularization and infections are the main risk factors in the development of pseudoarthrosis [25]. In 2004, Ali et al. reported that fixation was unstable in 12 (75%) of the 16 cases with a distal humerus nonunion treated by them [26]. Other factors associated with the occurrence of nonunions are smoking habit, immunosuppressive drugs, osteoporosis and extensive

soft tissue injuries, e.g. in open fractures; aggressive surgical techniques with extended periosteum devascularization and dissection of bone fragments from contiguous soft tissues are another important risk factor for nonunions.
The type of nonunions observed in DHF are frequently oligotrophic lesions involving the supracondylar region alone or combined with the intra-articular surface. Typical symptoms include pain (70%), abnormal joint mobility (20%) and stiffness (66%) [27]: surgical treatment is often indicated in such cases. By contrast, asymptomatic nonunions associated with mild functional limitations should not be surgically treated, especially if a single column is involved, or in elderly low-demand patients.
In a young, active population with extra-articular or intra-articular fractures with preserved joint surface, nonunion debridement, internal fixation and autologous bone grafting leads to operative success in over 80% of cases. However, bone healing is not always correlated with satisfactory clinical results because of the high risk of developing significant post-operative stiffness or ulnar neuropathy [25,28]. These complications may be avoided, however, by combining nonunion treatment procedures with capsular release, nerve decompression and transposition. Customized treatment with careful pre-operative evaluation of associated lesions can significantly improve clinical outcomes in over 90% of patients and lead to pain relief and ROM improvement [29,30].
In young patients with nonunions associated with a severely damaged articular surface, one treatment option that has been described is interposition arthroplasty and external fixation; the success rate of this treatment is, however, low, especially in cases of infection, elbow instability, severe deformity or high functional demands. Total elbow arthroplasty (TEA) is the first treatment option in elderly patients because it provides some notable advantages, such as rapid restoration of elbow motion, whilst avoiding complications related to debridement and internal fixation and bone grafting, with satisfactory clinical outcomes being reported in 80-91% of cases [31,32]. TEA can also lead to good clinical outcomes in compliant and low-demand young patients, though such patients should be made aware of the functional limitations and the risk of future implant revisions associated with this option. TEA is contraindicated in infected DHF nonunions, in high-demand patients or in cases with a severe hand function impairment. Although olecranon nonunion is not an absolute contraindication to TEA, the surgical technique required may be more challenging. Distal humerus hemiarthroplasty (DHH) represents another effective option in DHF nonunions. It can be performed in patients with very distally located pseudoarthrosis and severe humeral cartilage impairment; preserved ulnar and radial articular surfaces are required if good functional outcomes are to be achieved. The main advantage of DHH over TEA is the reduced functional limitation associated with the former resulting from the absence of the prosthetic linked hinge. DHH is also indicated in intra-articular malunions and in avascular necrosis of articular fragments, whereas it is not recommended in case of infection, poor medial and/or lateral column bone-stock, unreconstructable collateral ligaments, severe elbow instability and degeneration of radial head and ulnar cartilage.
Long-term outcomes of DHH are as yet unknown, though promising short and mid-term results have been reported. DHH needs to be studied further to shed more light on the true potential and limitations associated with these implants in DHF nonunions.

Malunions

Malunions are a well-known and thoroughly studied complication in pediatric traumatology, whereas very little is known about the incidence, treatment options and expected outcomes in the adult population.
Malunions can be diaphyseal, metaphyseal or intra-articular and are usually related to improper reduction or unstable fixation with secondary displacement. Deformity can occur on different spatial axes, often generating triplanar complex deformities, though varus-valgus and procurvatus-recurvatus defects are more common in the extraarticular region of the distal humerus; in these cases, sagittal deformities cause F/E loss, whereas coronal defects can cause severe aesthetic impairment, joint instability, ulnar neuropathy and secondary osteoarthritis. Intra-articular malunions often cause complex deformities that are clinically associated with pain and stiffness.
There are several surgical strategies worth considering when managing these conditions. Correction osteotomies can restore ROM and correct aesthetic defects, but these are challenging procedures and often contraindicated in case of severe post-traumatic osteoarthritis, poor bone-stock and in aged and/ or non-compliant patients. Osteotomies can be performed at intra or extra-articular sites, with results being better in the latter. Correction of varus-valgus and recurvatus-procurvatus deformities can be achieved by performing full-thickness osteotomies, as humeral shortening is generally well tolerated, or wedge osteotomies, which remain the first-choice technique. Intra-articular osteotomy is performed by realigning each condyle separately together with iliac crest bone autografting. This is a technically challenging surgical procedure with very few indications as it is sometimes nearly impossible to achieve anatomical reconstruction of the articular trochlea. The few studies that do provide data on this technique, such as those by McKee et al. [33], Kazuki et al. [34] and Marti et al. [35], report good overall clinical and functional outcomes. Malunions due to shear fractures are corrected by coronal osteotomies that pass through the fracture plane; bone grafting may be required in such cases to restore the articular shape.
Prosthetic joint replacement, whether it be TEA or DHH, is indicated in elderly and low-demand patients, as well as in all cases with associated severe osteoarthritis, even though further

studies are needed to shed more light on the long-term clinical outcomes following this procedure. In this regard, humeral deformities have been known to significantly complicate the positioning of prosthetic implants and to be associated with a high risk of early implant mobilization and failure because of stem loosening and bushing wear. Arthrodesis may be considered in aged non-compliant patients or in high-demand patients who are not prepared to tolerate the limitations imposed by a prosthesis.

Post-traumatic osteoarthritis (PTOA)

Post-traumatic osteoarthritis, which results from damage to the cartilage layer, is a common complication in all elbow fractures, whether it is caused by the trauma itself or by the chronic consequences of an inadequate fracture reduction and/or joint instability. Intra-articular loose fragments, osteonecrosis and hardware impingement are other risk factors associated with PTOA.

The onset of PTOA may occur either gradually or rapidly and may have varying clinical consequences. TEA represents a good treatment option, with a positive outcome expected, in elderly low-demand patients with pain and stiffness [36,37].

In younger patients, TEA is associated with a higher rate of late complications and reinterventions (37%) that are due to the improper use of the arm and may lead to long-term failure [38]. Interposition arthroplasty may be an adequate treatment option in high-demand patients, especially in the absence of marked deformity, though it should be borne in mind that some authors have reported high failure rates when they adopted this technique (61-66%) [39,40]. This procedure should thus be considered as a "bridge solution" to postpone TEA as long as possible while preserving bone-stock and relieving pain and stiffness.

Wound complications and infections

The thin soft tissues envelope at the elbow places this joint at risk for major post-operative wound complications and secondary deep infections. Wound complications can lead to significant comorbidity with the need for further surgical procedures, and may influence the outcomes of the initial treatment of DHF. Although wound problems in DHF are well-known, it is surprising to observe that only one study directly focused on this topic [41]: Lawrence et al. studied 89 DHF treated with ORIF. Fourteen patients (15.7%) developed a major wound complication requiring on average 2.5 (range, 1-6) additional surgical procedures. Six patients required plastic surgical soft tissue coverage with flexor carpi ulnaris flap or radial forearm flap. The great majority of wound complications in this study were successfully treated with debridement and primary or delayed wound closure. All 14 fractures complicated by wound problems healed. In this study, minor self-resolving wound complications, occurred much less frequently (3%). Fracture healing rates and elbow range of motion did not appear to be affected by wound complications when they were rapidly and properly managed. The authors also highlighted that an olecranon osteotomy approach and plate fixation increases the risk of major wound complications by 13 times.

When major wound complications are neglected, deep soft tissues and bone infection may occur, thus affecting the final outcomes. Indeed, these cases require surgical treatments consisting of premature hardware removing, wide tissue debridement and intravenous antibiotics; in these patients nonunion frequently occurs and further surgical procedures are required.

In the last decade, negative pressure wound therapy (NPWT) efficacy emerged, simplifying management of wound complications and avoiding more complex surgical procedures. A recent review [42] including 404 upper extremities cases, reported good results in 90% of cases, highlighting that NPWT could be considered not only a temporary management tool but even a definitive treatment in selected patients. Minor and some major wound complications are nowadays best treated with oral antibiotics associated with NPWT: this treatment can resolve the majority of cases, often avoiding premature hardware removal.

Infective complications range between 0 [43] and 22% [44] and correlate with type of fractures (close vs open), grade of exposure, soft tissue involvement and general health status of patients. Robinson et al. [1] found an overall incidence of infection of 4.7%, but only 1.6% developed deep sepsis. Sanchez-Sotelo et al. [45] found wound complication in 6% and deep infection in 3%. In a recent case-report including 62 patients with DHF and treated with ORIF, Somerson et al. [46] reported a wound dehiscence and infection rate in 14.5%. Kundel et al. [47] documented higher infection rates in open fractures (14%) compared with the closed injuries (8%). Grade III open fractures were associated with a higher risk of infections. Furthermore, the use of a plate construct to stabilize the olecranon osteotomy is considered to be another significant risk factor for wound complications and secondary infections.

Few studies have investigated the management of this uncommon but severe complication in DHF. Open fractures present additional challenges to the surgeon and frequently require a staged approach involving an initial irrigation, debridement and external fixation followed by delayed definitive ORIF when the soft tissues are deemed satisfactory and infections excluded. Infection should be suspected in any patient with persistent drainage and delayed union or nonunion of the DHF as well as in patients with significant night pain and stiffness. In unclear cases, when subacute infection is suspected, MRI, autologous WBC radiolabeled scintigraphy and incisional biopsy may be useful. Specific antibiotic therapy, serial debridements with preservation of internal fixation are

Table I. DHF complications rates: review of the literature.

Author (year)	Patients N/mean age	Follow-up (mean)	Complication type
Henley et al. [53] (1987)	33/32	18 months	9 Olecranon osteotomy complications 2 Heterotopic ossifications 2 Infections 2 Nonunions
Kundel et al. [8] (1996)	98/54	40 months	29 Heterotopic ossifications 26 Ulnar neuropathies 10 Deep infections 10 Nonunions 8 Wound infections 4 Hardware failures 1 Avascular necrosis
McKee et al. [48] (2000)	26/44	51 months	4 Delayed unions 2 Wound infections 2 Symptomatic hardware 1 Deep infection 1 Radial neuropathy
McKee et al. [49] (2000)	25/47	37 months	3 Hardware impingements 3 Ulnar neuropathies 2 Stiffness 1 Wound infection 1 Radial neuropathy 1 Nonunion (hardware failure) 1 Malunion
Gupta et al. [70] (2002)	55/39	48 months	5 Hardware failures 3 Ulnar neuropathies 3 Heterotopic ossifications 2 Deep infections 1 Wound complications 1 Malunion
Pajarinen et al. [23] (2002)	21/44	25 months	2 Nonunion 1 Deep infection 1 Olecranon osteotomy complication
Ring et al. [30] (2003)	21/50	40 months	6 Stiffness 2 Ulnar neuropathies 1 Symptomatic hardware 1 Hardware failure
Gofton et al. [4] (2003)	23/53	45 months	7 Heterotopic ossifications 3 Stiffness 2 Olecranon osteotomy complications 1 Hardware impingement 1 Wound infection 1 Deep infection 1 Avascular necrosis
Frankle et al. [57] (2003)	12/74	57 months	3 Hardware failure 1 Infection 1 Stiffness 1 Heterotopic ossifications

Table I *(continue)*

Author (year)	Patients N/mean age	Follow-up (mean)	Complication type
Tyllianakis et al. [54] (2004)	26/46	70 months	4 Olecranon osteotomy complications 3 Heterotopic ossifications 3 Symptomatic hardware 2 Hardware failures 1 Delayed union 1 Deep infection 1 Wound infection 1 Ulnar neuropathy 1 Wound infection
Soon et al. [60] (2004)	15/43	12 months	4 Stiffness 3 Hardware failures 2 Ulnar neuropathies 1 Wound infection 1 Nonunion
Korner et al. [71] (2005)	45/73	87 months	32 Post-traumatic osteoarthritis 12 Implant failures 6 Ulnar neuropathies 2 Wound infections
Huang et al. [72] (2005)	19/72	96 months	15 Post-traumatic osteoarthritis 1 Wound infection 1 Ulnar neuropathy
Srinivasan et al. [73] (2005)	28/85	42 months	3 Wound complications 2 Nonunions 1 Olecranon osteotomy complication 1 Deep infection 1 Heterotopic ossifications
Sanchez-Sotelo et al. [45] (2007)	32/58	24 months	5 Heterotopic ossifications 2 Wound infections 2 Post-traumatic osteoarthritis 2 Ulnar neuropathies 1 Deep infection 1 Nonunions
Liu et al. [74] (2009)	32/68.7	25 months	7 Heterotopic ossifications 2 Wound infections 2 Ulnar neuropathies
Atalar et al. [61] (2009)	21/47	28 months	7 Heterotopic ossifications 1 Deep infection 1 Post-traumatic osteoarthritis
McKee et al. [59] (2009)	32/69	24 months	2 Stiffness 1 Ulnar neuropathy 1 Nonunion
Shin et al. [51] (2010)	35/54	31 months	11 Symptomatic hardware 6 Ulnar neuropathy 4 Heterotopic ossifications 2 Stiffness 2 Nonunions

Table I *(continue)*

Author (year)	Patients N/mean age	Follow-up (mean)	Complication type
Singh et al. [64] (2010)	14/33	58 months	-
Mighell et al. [66] (2010)	18/45	26 months	5 Post-traumatic osteoarthritis 3 avascular necrosis 3 Heterotopic ossifications 1 Stiffness 1 Wound infection
Giannicola et al. [65] (2010)	15/47	29 months	2 Post-traumatic osteoarthritis 1 Radial neuropathy 1 Wound infection 1 Nonunion
Huang et al. [71] (2011)	14/76.8	51 months	2 Post-traumatic osteoarthritis 1 Hardware failure 1 Stiffness 1 Heterotopic ossifications
Egol et al. [58] (2011)	11/76	13 months	2 Stiffness 1 Nonunion
Brouwer et al. [67] (2011)	30/49	34 months	8 Nonunions 3 Infections
Erpelding et al. [50] (2012)	24/47	27 months	5 stiffness 2 Ulnar neuropathy 1 Post-traumatic osteoarthritis
Schmidt-Horloe et al. [62] (2012)	31/50	12 months	10 Post-traumatic osteoarthritis 7 Olecranon osteotomy complications 4 Heterotopic ossifications 2 Symptomatic hardware
Heck et al. [68] (2012)	15/36	59 months	8 Post-traumatic osteoarthritis
Ducrot et al. [56] (2013)	43/80	25 months	6 Ulnar neuropathies 4 Heterotopic ossifications 4 Symptomatic hardware 2 Infection 2 Nonunion 1 Hardware failure
Bilsel et al. [69] (2013)	18/45	44 months	1 Heterotopic ossifications 1 Olecranon osteotomy complication 1 Stiffness
Lee et al. [52] (2014)	67/56	30 months	21 Symptomatic hardware 5 Heterotopic ossifications 5 Ulnar neuropathies 3 Stiffness 2 Hardware failure 1 Wound infection 1 Olecranon nonunion

Table I *(continue)*

Author (year)	Patients N/mean age	Follow-up (mean)	Complication type
Flinkkila et al. [55] (2014)	47/60	47 months	13 Symptomatic hardware 4 Ulnar neuropathies 3 Infections 2 Nonunions 1 Malunion 1 Olecranon nonunion
Kural et al. [63] (2017)	24/47	28 months	6 Post-traumatic osteoarthritis 2 Olecranon osteotomy complications 1 Infection

an effective treatment for acute non-aggressive infections. However, if multiple debridements and systemic antibiotics fail to treat the infection, implants should be removed and a more thorough debridement should be performed. Further studies are required to better define shared therapeutic algorithms in post-operative DHF infections.

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