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Original article

Atrophic pseudarthrosis of humeral diaphyseal fractures: medico-legal implications and methodological analysis of the evaluation.

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Abstract. Humeral shaft fractures account for 1- 3% of all fractures and about 20-27% of those involving the humerus. In the past they were often conservatively treated, with an acceptable consolidation rate. Open reduction and internal fixation (ORIF) is the best choice in polytrauma patients, in complex or pathological fractures and in those associated with vascular injuries. Regardless the type of fixation used, these fractures can evolve into delayed union or pseudarthrosis (PSA). It should be noted that the humeral shaft itself has a high intrinsic healing potential, due to the blood supply provided by the surrounding muscles. The aim of this work is to evaluate whether the causes that led to the development of atrophic pseudarthrosis in a humeral diaphyseal fracture are attributable to inadequate management of this fearful complication and to highlight the possible medico-legal repercussions. We will try to verify whether the currently used forensic evaluation parameters of permanent disability are appropriate and adequate in relation to the complexity of such injuries. This complexity also includes the repercussions on the ergonomic efficiency of the entire limb, the relative possible postural alterations, the inevitable extension of the period of traumatic illness and the relative repercussions on the overall compromised structure of the subject. (www.actabiomedica.it)

Key words: humeral pseudoarthrosis, humeral fractures, medico legal

Introduction

The time required for fracture healing is influenced by various factors, attributable to the patient's characteristics, the type and site of the injury and the method of treatment pursued.

Fracture healing can be considered spontaneous or indirect after bloodless reduction and immobilization, and direct if it occurs after osteosynthesis with interfragmentary compression.

Internal fixation must ensure optimal anatomical reduction and absolute stability of the fracture site, which counteract the deforming forces, minimizing any interfragmentary movement.

In addition to the necessary vascular supply, the optimal compression exerted by the plate plays a significant role in the healing process, preventing movement of the skeletal fragments.

With intramedullary nailing less stability is achieved, especially with regard to torsion and axial

load. The presence, albeit minimal, of interfragmentary stress justifies the formation of the periosteal callus which, associated with the induced callus, leads to the healing of the fracture. The endosteal callus is poorly represented due to the presence of the nail and the methods used to perform the surgery. The reaming of the medullary canal, in fact, determines the destruction of the medullary vascularization, which in the initial stages justifies the absence of the endosteal callus.

Consolidation delays are conditions that can be reversible if identified and treated appropriately. Otherwise, there may be defects of consolidation or evolution in PSA.

Several definitions of pseudarthrosis have been provided in the literature:

- lack of radiographic consolidation at 6 months with the need for revision surgery; radiological healing occurs when there is the presence of callus in at least 3 out of 4 cortices in orthogonal projections (1);
- lack of radiographic consolidation 6-9 months after the traumatic event (2);
- according to the Food and Drug Administration (FDA), the diagnosis of PSA is made after at least 9 months from the trauma with no visible signs of progressive healing for three months (3).

However, as pointed out by Taylor et al., it is difficult to identify a specific time period in the definition of pseudarthrosis and the nine-month interval since the injury cannot be used for every fracture. So, it would be easier to consider a minimum of six months with no improvement towards the union to define pseudarthrosis (3,4).

The incidence of PSA in humeral shaft fractures, from studies dating back 10-15 years ago, is approximately 9-19 % for surgically treated patients (5,6) and 2- 23% for conservative treatment (7,8).

In 2017 Westrick et al. and Harkin et al. showed an incidence of PSA in the conservative treatment of humeral shaft fractures of 23.2% and 33% and an incidence in surgical treatment of 10.2 and 4%, respectively (1,9).

In the study by Harkin et al. the rate of PSA after conservative treatment is higher when dealing with simple and spiral fractures, with localization in the proximal third or distal third of the humeral shaft, assuming that these bony regions have little stability with a functional brace, compromising their healing. Fractures of the middle third, instead, have a higher consolidation rate when treated with a brace. Immediate surgical treatment has a significantly higher rate of bone consolidation than delayed surgery.

Several studies have analyzed the factors that can influence the healing of a humeral shaft fracture and thus guide the therapeutic decision. The etiology of non-consolidation is multifactorial: mechanical, biological, local and systemic and infectious factors can be recognized.

The potential risk factors responsible for fracture healing failure were divided into 4 categories:

- **patient-related factors**, including genetic disorders or systemic disorders (type 1 and type 2 diabetes mellitus, obesity, malnutrition, rheumatoid arthritis, pathological fractures);
- **environmental factors**, such as, consumption of alcohol (10) and tobacco, intake of corticosteroids, chemotherapeutic agents, anticoagulants, NSAIDs; antibiotics (11–16);
- **factors related to the trauma**, above all the force with which the traumatic event develops, at high or low energy. If the injury is at high energy, the bone and surrounding soft tissues are severely affected, producing complex, multi-fragmentary, highly displaced fractures, with more severe damage to soft tissue and the local vascular system (17,18). Local blood support is among the most significant parameters influencing the outcome of fracture healing. Devascularized bone fragments and periosteal stripping can generate necrotic fragments. Open fractures have a higher risk of delayed union and pseudarthrosis than closed fractures (19).
- **factors related to surgical treatment.** It is known that for better healing the bone fragments must be in contact with each other and receive an adequate blood supply. The fracture healing

process will be adversely affected if the soft tissues around the fragments have been damaged during the trauma or during the surgical approach, if there is extensive periosteal stripping, or if there is soft tissue interposition between the bony ends after fracture reduction (20–22).

Other factors associated with an increased risk of nonunion are displacement with diastasis greater than 2 cm (23–25), bone loss in an open fracture (26), contamination and infection (27), implant malposition, soft tissue necrosis (28) and compartment syndrome (29).

Direct bone healing with plate fixation requires absolute fracture stability and the mechanical principles of this type of fixation must be strictly adhered to in order to avoid the onset of pseudarthrosis.

Indirect bone healing with callus formation, which occurs with synthetic means of relative stability, can undergo alteration of the reparative processes due to excessive movement at the level of the fracture fragments, with consequent hypertrophic PSA, or due to excessive rigidity with lack of stimulus for the formation of the callus and consequent atrophic PSA (30).

Delayed weight bearing on the operated limb (31) or early excessive weight bearing could have adverse effects on the response to fracture healing (32).

A first distinction of pseudarthrosis must be made in septic and aseptic forms (33).

Aseptic PSA are divided into "lax" and "stiff", based on the degree of mutual mobility of the fracture stumps. Lax PSA present poor handling of bone fragments with reduced evidence of callus, characterized by a predominant fibrous component, sometimes with bone necrosis and loss of substance. In stiff type, instead, the stumps are aligned or easily aligned, with the presence of fibrocartilaginous callus and sclerosis of the extremities of the fragments.

Atrophic PSA have some common characteristics, such as osteoporosis of fracture fragments, reduced or absent production of callus and the presence of thin shoots of loose fibrous tissue in the interfragmentary space. It can be both lax and stiff, depending on the degree of atrophy, loss of substance and characteristics of the interfragmentary tissue, although in the majority of cases they appear lax.

Hypertrophic PSA, also referred to as hypervascular, is generally due to instability of the fracture fragments, abnormal axial alignment or early loading. These conditions cause an abundant synthesis of reparative callus, resulting in a reduction in the partial pressure of oxygen in the central region of the fracture site, which makes the stem cells unable to differentiate into osteoblasts, which are metabolically dependent on the supply of oxygen. For this reason, the fibrous callus does not ossify. In place of normal bone tissue, abundant non-mineralized fibrocartilage tissue forms which separates the bone stumps and obliterates the medullary canal at the extremities.

The surgical treatment of humeral shaft PSA require the complete removal of the interposed necrotic tissue, the remodeling of the bone fragments and the restoration of the fracture focus stability.

Osteosynthesis with a plate, applied with axial compression mechanism, is the best choice for most surgeons. The association of cortico-cancellous grafts can increase the possibility of consolidation, as it increases the mechanical stability of the synthesis (34,35). To ensure total immobility of the fragments, in some cases two plates mounted parallel can be used (36). Open reduction and internal fixation with a long compression plate combined with autologous bone graft is the treatment of choice, even in osteoporotic patients with reduced bone quality (37,38). However, it is not free from complications, such as transient radial paresis, persistence of non-union and reduced joint function of the shoulder and elbow, with an overall incidence of 5-8% (39).

For this reason, it is suggested to reserve particular attention to the planning of the therapeutic protocol, after an adequate information process and direct involvement of the patient who will have to know the possible risks and complications related to the procedure, often foreseeable but not always easily preventable and/or avoidable. It will be necessary to remember that information and informed consent are not just the same thing. Information is only part of the communication process, which help to prepare the patient for the expression of a free and informed consent.

Communication does not only mean giving information, but it involves listening to the patient, answering his questions, verifying that he has understood

what he has been told. Consent is the basis of the relationship of care that is established between doctor and patient, and which involves other health professionals in teamwork. Information and consent can be compared to two sides of the same coin which coincide and unify giving content to the medical responsibility in terms of freedom and dignity of the person: on one side, there is the phase of acquiring consent, preceded by a correct and sincere information, interpreted and deciphered as an important phase and essential indicator of good medical-professional conduct and diligence; on the other side, the consent itself directly conceived as an obligation aimed at fully respecting the right to self-determination, independence and autonomy of the patient seen as a person. During the expert assessment, the task of the medico-legal doctor, carried out in collegial association with an orthopedic-traumatologist specialist as required by the recent Gelli-Bianco law, will be to clarify whether the failure of the surgical result may be related to an inadequate choice and execution of the surgical procedure or to a predictable but not otherwise preventable complication. It should be noted, then, that every complication does not necessarily equate to a defect: the perfect result is taken for granted, but this does not correspond to reality. Whoever judges must know the problems of daily practice, must be able to distinguish between failure and error. There are only two types of surgeons who have no complications: those who lie and those who do not operate. The patient must follow the instructions provided by the specialist and feel an active part in the healing process.

Medico-legal considerations and presentation of three clinical cases

The treatment of humeral shaft PSA is characterized by significant technical difficulties, which inevitably also affect the final therapeutic result.

The review of the literature highlights that the pseudoarthrosic evolution of humeral shaft fractures is a relatively rare event compared to other anatomical districts, since this specific segment has a high healing potential due to the blood supply provided by the abundant surrounding muscles.

Scientific studies have focused on identifying factors that can negatively influence the primary osteosynthesis of shaft fractures, identifying four determining elements: the type of fracture, the degree of exposure, the comminution of fragments and the mechanical instability of the synthesis. It also emerges that the risk of delayed consolidation depends significantly on the surgical choice and the Operator's knowledge of the type of fracture, reduction techniques and fixation devices. Moreover, the possibility of a therapeutic failure does not seem to be related to the choice of the surgical technique (intramedullary nail; plate and screws; etc.), but to its concrete execution, to the quality of the reduction and the stability of the synthesis. Therefore, an intramedullary nail must have the right caliber, the locking screws must have adequate length and be positioned correctly, in order to counteract axial and rotational movements that are detrimental to the healing process. Using a plate and screws system, the characteristics of work, material and geometry must be taken into account. If a relative stability technique is used, the right plate length is critical to achieving optimal interfragmentary motion to ensure fracture consolidation; its under-dimensioning, instead, could lead to a lack of consolidation, possible exhaustion of the metal implant and its breakage. Therefore, it will be understood how the judgment of the PSA evolution of a humeral diaphyseal fracture will necessarily require a medico-legal analysis aimed at identifying the causes and consequently the predictability and preventability of the event.

In this regard, it is considered useful to report three of the various clinical cases that have come to our personal observations, all with pre-existing pathological features involving the same anatomical district.

The first case concerns a 38-year-old woman, ex-volleyball player, with previous multiple shoulder dislocation episodes, but no noteworthy pathologies or history of smoking. After an accidental fall, she had reported a right multi-fragmentary displaced humeral shaft fracture (Fig. 1). Three days after hospitalization in another hospital, she underwent to reduction and fixation surgery with an intramedullary nail. However, during the reaming of the medullary canal and the insertion of the nail, a further comminution of the fracture site was determined, which required a

necessary stabilization with an external fixator (Fig. 2). The postoperative course was also complicated by a severe suffering of the radial nerve in correspondence of the distal 1/3 of the arm, confirmed by the neurophysiological examination. Subsequent radiographic checks confirmed the non-consolidation of the fracture. About 5 months after the previous surgery, the patient arrived at our hospital and underwent further surgery to remove the axial external fixator, to release of the radial nerve, and to perform a new synthesis with LCP plate and screws after a bone graft placing. Four months later, radiographic bone consolidation and an optimal anatomical result were noted (Fig. 3).

Upon the definitive stabilization of the clinical picture, there remained a painful symptomatology in the right shoulder, as well as an appreciable deficit of the articular excursion on all planes of movement, in a dominant limb, associated with the results of the neurological lesion consisting in an alteration of sensitivity and a motor deficit of the wrist and first finger. Instead, the extension of the other fingers was recovered within 6 weeks from the radial nerve release. During this period neurotrophic drugs were administered to the patient.

Although of specific interest, the forensic and orthopedic collegial evaluation of the surgical conduct pursued in the initial treatment of the fracture, allowed to recognize critical elements, specifically represented by a superficial operative planning, from which the non-optimal alignment of the fragments of fracture during reduction and stabilization with external fixator is derived.

In detail, the anatomo-pathological characteristics of the bone lesion (as evident at the first radiographic examinations), related to the patient's age and functional needs, required the use of different surgical techniques, favoring the choice of a reduction and synthesis with internal fixation (AO plate or, alternatively, synthesis with intramedullary nail), as a method concretely suitable for guaranteeing the restoration of a satisfactory district anatomy and therefore the favorable evolution of the reparative process. In the case in question, an initial attempt at fixation with a blocked intramedullary nail was actually carried out, however

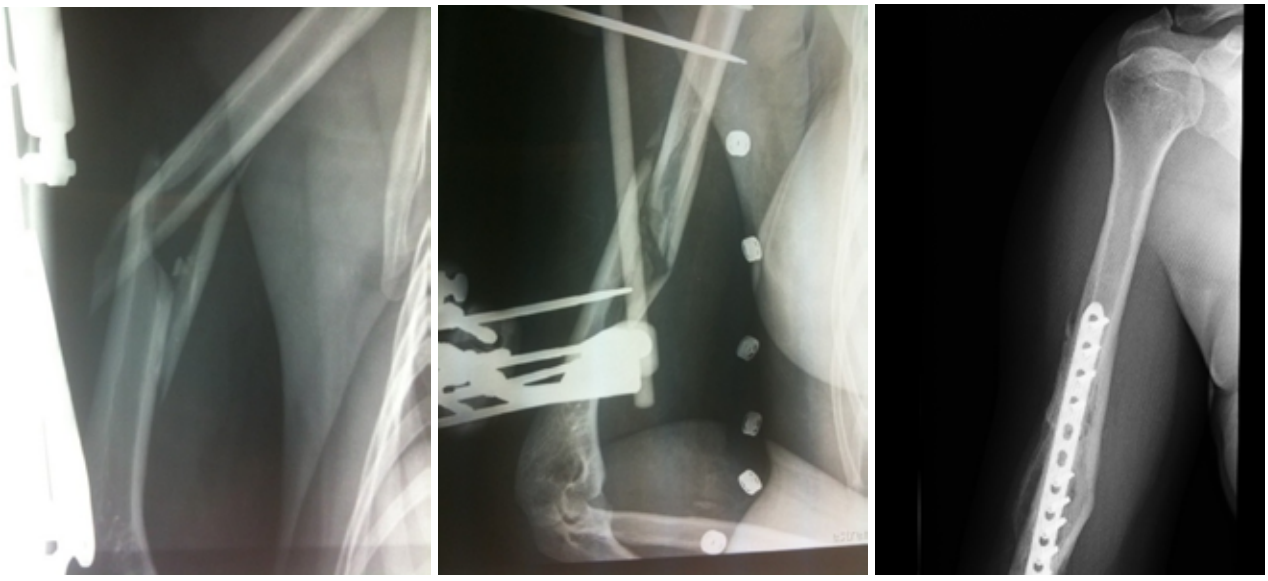


Figure 1. First clinical case: X-Ray image of right multi-fragmentary displaced humeral shaft fracture in a 38-year-old woman, ex-volleyball player after an accidental fall.
Figure 2. First clinical case: X-Ray image after a further comminution of the fracture site occurred during the reaming of the medullary canal and the insertion of the nail, which required a necessary stabilization with an external fixator.
Figure 3. First clinical case: X-ray image 4 months after further surgery to remove the axial external fixator, to release of the radial nerve, and to perform a new synthesis with LCP plate and screws after a bone graft placing. Radiographic bone consolidation and an optimal anatomical result were noted.

this resulted in a further comminution of the fracture and subsequent stabilization with an external fixator, which proved to be inadequate to guarantee the correct alignment of the bone fragments. During the surgery, an axonotmesic lesion of the radial nerve was also determined (not present in the pre-operative phase), which in the absence of ascertained anomalies in its course will be related to the lack of isolation and protection of the nerve.

Therefore, in the case in question, underlining the difficulties in the surgical treatment of complex humeral shaft fractures, the objectionable technical execution of the surgery was responsible for an injury to the healing process, not fully amended by the subsequent revision.

The second case concerns a 64-year-old male patient, a construction contractor, non-smoker and suffering only from arterial hypertension, who had undergone acromionplasty surgery and rotator cuff repair in the past, with a middle-proximal third humeral shaft fracture, treated conservatively with a Desault bandage for 60 days and then with arm sling for further 60 days.

A pseudoarthrosis occurred as shown in x-Ray and CT images (Fig. 4, 5, 6), which required a revision surgery with plate and screws without bone graft (Fig.7), which healed, as detectable by radiographic verification at 20 months (Fig.8).

The third case concerns a 75-year-old male patient, a musician-composer, suffering from arterial hypertension and without a history of smoking, who had already undergone an acromionplasty in glenohumeral arthrosis. This patient was affected by a PSA localized to the proximal third of humeral shaft after treatment with an intramedullary nail for a fracture. The nail was removed (Fig. 9) since it was proved to be unsuccessful, and the local situation had required a revision surgery with plate and screws associated with cortico-cancellous bone graft (Fig. 10), which then healed, as detectable at radiographic verification at about 27 months after the first trauma (Fig. 11).

Medical-Legal Discussion

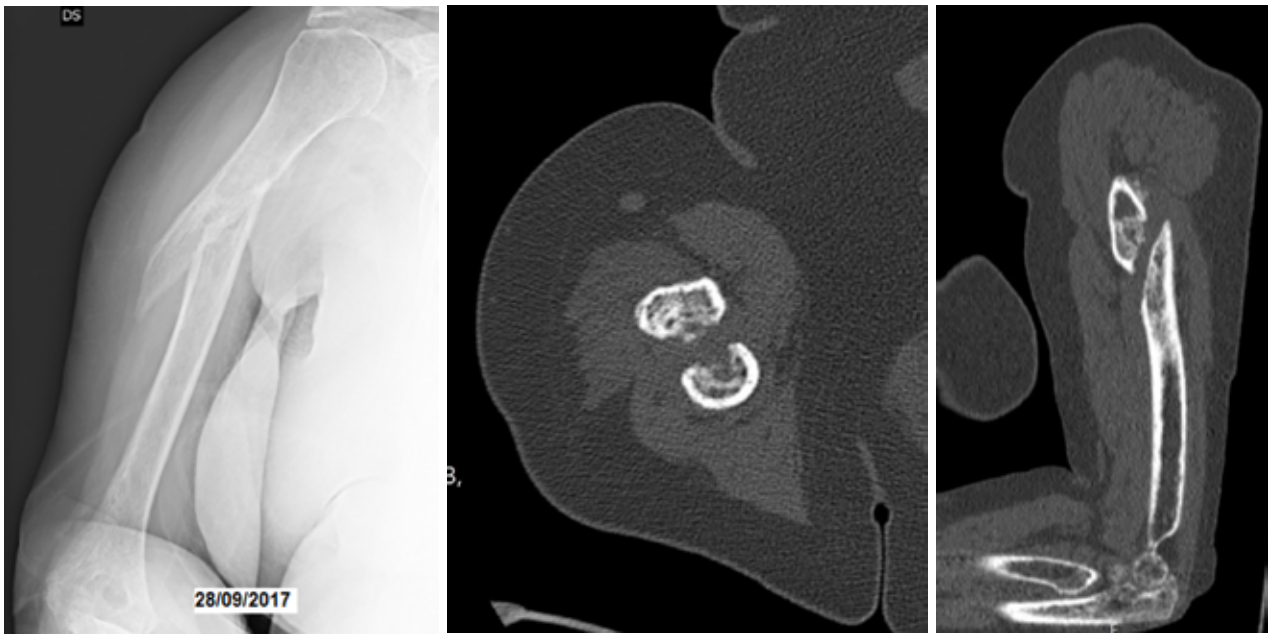
The cases presented allow us to formulate some considerations regarding the medico-legal evaluation methodology to be pursued for the definition of the impairing sequelae derived from the humeral diaphyseal fracture, taking into account the pre-existing pathological conditions, the damage caused to the healing process from the initial treatment pursued and the "Greater damage" residual compared to that expected in case of correct technical execution and optimal *ab initio* healing. Moreover, it should be duly noted that the value of the damage indicated represented the overall result of the effects of an intervention (surgical in two cases and conservative in the other one) not carried out *lege artis*, performed on subjects with concurrent "natural" pre-existences, taking into account the anatomical-functional repercussions representative of the share of permanent biological anatomo-functional compromise, "naturally" pre-existing the intervention in question, "not eliminable" / "not reducible", even in the case of unexceptionable sanitary conduct.

Having made this necessary premise, it will be possible to examine the various orientations for the prospect of a coherent medico-legal evaluation.

In this regard, it is our opinion that, in civil proceedings (therefore, in a completely different context from special cases, concerning the "labor" process, as well as private insurance litigation) the regulatory reference of the "concurrence of lawsuits" persists as ex art. 41 c.p.

In fact, the aforementioned rule not only states that "*the concurrence of cause. . . pre-existing. . . does not exclude the causal relationship between the action or omission and the even*t", but also states "*even if independent of the action or omission of the guilty party*" and still explicit that "*the previous provisions are also applied when the pre-existing or simultaneous or supervening cause consists in the unlawful act of others*".

The reading of the aforementioned article by the medico-legal doctrine obviously entailed its application, including civil law (either for the provision ex Article 185 of the Criminal Code, or for the natural extension of the notion of "concurrence of causes" to civil law for the unitary teleological genesis of the codes, either for the cogency of the art. 2043 C.C.) not only as regards the identification / specification of responsibility but also for a fair proposal regarding the quantification of the damage.



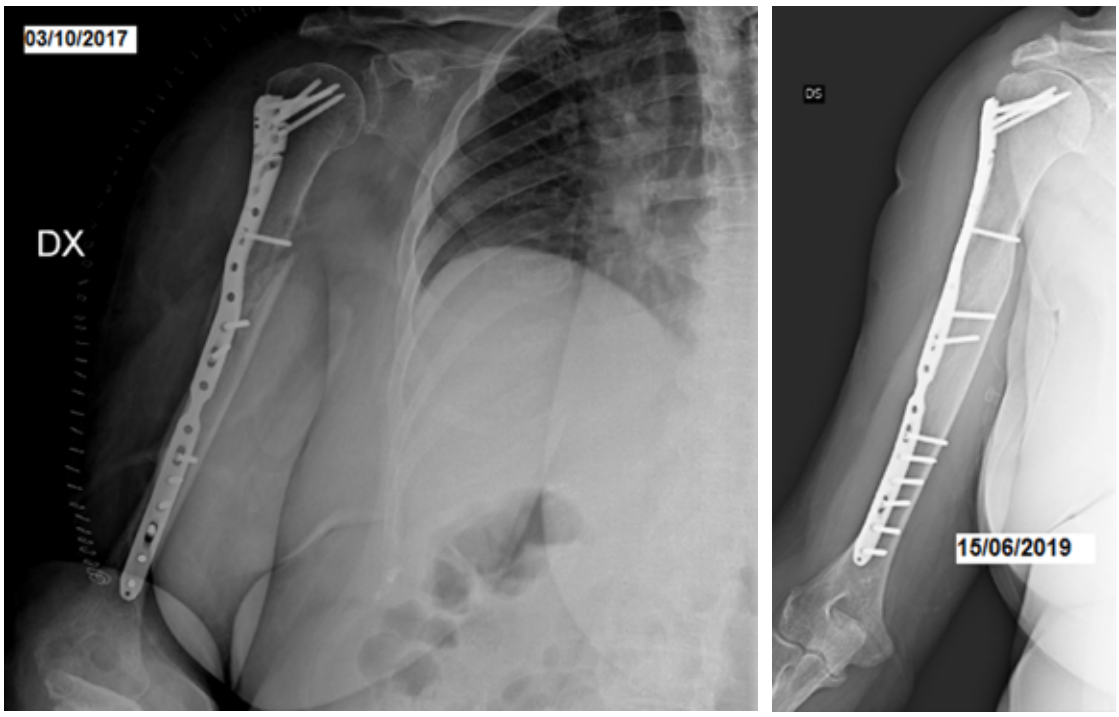


Figure 4. Second clinical case: X-Ray image of pseudoarthrosis occurred after a middle-proximal third humeral shaft fracture in a 64-year-old male patient conservatively treated.
Figure 5. Second clinical case: CT image in transversal plane of pseudoarthrosis occurred after a middle-proximal third humeral shaft fracture in a 64-year-old male patient conservatively treated.
Figure 6. Second clinical case: CT image in coronal plane of pseudoarthrosis occurred after a middle-proximal third humeral shaft fracture in a 64-year-old male patient conservatively treated.
Figure 7. Second clinical case: X-Ray image after revision surgery with plate and screws without bone graft.
Figure 8. Second clinical case: X-Ray image where bone healing can be detected 20 months after after revision surgery with plate and screws without bone graft.

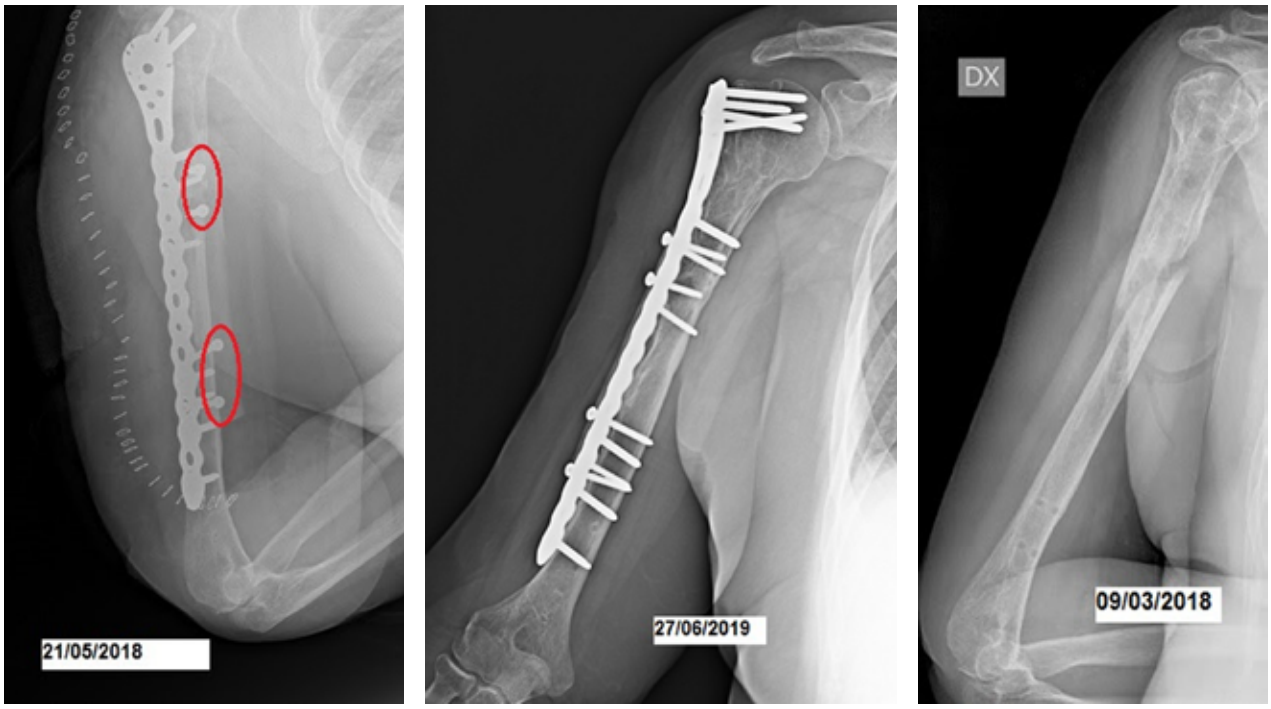


Figure 9. Third clinical case: X-Ray image after nail removal which show a PSA localized to the proximal third of humeral shaft after treatment with an intramedullary nail for a fracture.
Figure 10. Third clinical case: post-operative X-Ray after revision surgery with plate and screws associated with cortico-cancellous bone graft. The red circles identified the screws blocking the bone grafting.
Figure 11. Third clinical case: X-Ray image at about 27 months after the first trauma showed bone healing and integration of bone graft.

In fact, it has consistently been held in the medical-legal context that the provision ex art. 41 of the Criminal Code, aimed at the maximum protection of the citizen with respect to the minimum of harmful conduct, also determines the absolute civil protection, with reference to the "natural" (canonical or variously compromised for "natural" / "non-violent" causes) original psycho-physical condition of the person subsequently injured / disabled (classic example: recognizing the compensation connected to the loss of the sense of sight to the person, previously single-eyed) (40).

The injurious / impairing insult is therefore posed as an "aggravating" event, so that, where the nature of the offense / non-fulfillment of the conduct is ascertained, as well as the psychological causal incidence (fault; intention; malice), the resulting impairing it cannot fail to include and reabsorb, as a whole, in its quantification also any pre-existing pathology "independent of the action / omission" of third parties, as it is considered as "unfairly" "aggravated". The only limit could be set in the event of real duplication of compensation, in the event that the pre-existing impairment derives from illegal activities of third parties already recognized and satisfied monetarily. This approach is consistent with the notion of "biological damage", which, notoriously, identifies the damage with respect to the "original psycho-physical condition of the person", invariant and undifferentiated, conventionally assumed to be equal to 100.

In this methodological projection, a proposal for a percentage assessment of permanent biological damage has been made. It was then considered necessary to advance a clarification of "damage" (rectius, "absolute" percentage assessment, released from third part activities) of the pathology pre-existing at / (object of) surgery (censored as it was not correctly performed and immediately productive of worse outcome than the pre-existence). The above is fully consistent with the Cass case law. Civ. Section 3, no. 28896/2019 (published 11 November 2019). Moreover, in advance of

the presentation of various technical application solutions, it is believed to specify:

a) the jurisprudential acquisition of the Supreme Court, aimed at guiding the civil law determination of the damage by the Judge of merit, of the concept of "differential damage" seems to assume a notion originally of a purely social insurance nature (RD May 13, 1929, n.929; RD 5 October 1934, no. 1565; Presidential Decree 30 June 1965, no. 1124 and subsequent amendments), accrued and deemed relevant for the purposes also of private insurance contractual protection;

b) the formal writing of the Cassation sentence. Civ. Section 3 n. 28896/2019 further considers, in our opinion, the "degree of permanent disability" as a "measure" of the damage. The point is that "validity" (as indeed "ability") does not constitute an invariant, descriptive and characterizing parameter of the "undifferentiated person" subject to "damage". The notion of "biological damage" was (laboriously) proposed by the medical-legal practitioners precisely in order to update "according to the Constitution" and harmonize the perception/assessment of the individual impairment (almost as a "effect"/"consequence"/"damage" base) on any individual (independently, in the first instance, from considerations on gender, age, activity), leaving the technician with the commitment/duty of illustration / quantification (either for the static component, which, in a necessary perspective of personalization, for the dynamic-relational component). The medico-legal quantification of "biological damage" is given by the reference, for conventionally defined points, to the "compromise of the psycho-physical condition" (which only depending on particular areas of protection can refer to "validity"/"ability") proper to the person, considered "in itself", prior to the injurious / crippling vulnus. In this sense, again, the overcoming of the concept of "generic work capacity", introduced prior to the 1942-43 code, in the pre-constitutional era, by the doctrine and medico-legal practice as a useful picklock for the positive procedural resolution of appetite compensation (it is repeated, in the period preceding the new code of law of 1942-43);

c) it seems that we can / should also point out that the "*single percentage degree of permanent disability*" (rectius, of "*permanent biological damage*", PBD) corresponds to the "*percentage point of disability*" (rectius, PBD), it constitutes a factor / indicator that the forensic specialist makes available in order to provide for the "*monetization of disability*" (rectius, of the PBD). This procedure does not determine the risk of "double assessment", functionally pursuing absolutely very different purposes in the process:
   1. the percentage assessment of biological damage by the medical-legal specialist concerns the highlighting of the decrease in the "psycho-physical condition" (not the integrity, attention, wrong terminology, used by inertia, unfortunately, in the doctrinal context and even more automatically in the legislative and jurisprudential) proper to the injured party;
   2. the degree of the decrease expressed by percentage number in points also concerns the base on which the monetary sanctioning parameters of specific competence will be applied autonomously, at discretion;

d) question, not secondary to the technical consultancy / medical-legal specialist activity, emerges from the reference in sentence by the Court of Cassation to the law of March 5, 2001, no. 57; to the Ministerial Decree July 3, 2003; to Legislative Decree 7 September 2005, n. 209, which, "*stricto sensu*", seem to consider the private contractual insurance sector (in fact, they concern "*provisions on the opening and regulation of markets*", "claims resulting from the circulation of motor vehicles- nd cc.tt.u .: excluding pedal bicycles? including pedal assisted bicycles and scooters? - and boats - here, fortunately, there is no distinction between paddle, sail and motor "-), on which, however (art. 165 DL vo 209/2005), unless explicitly provided otherwise, the civil code always prevails.

Coming to the expert case and abstracting from various method considerations, it is considered useful to offer the following information, possibly usable for the purpose of the percentage sanctioning clarification of the impairment (and the related permanent biological damage), as well as its actuarial / monetary quantification. The Cassation Civ. Section 3 n. 28896/2019 requires:

a) the estimate "in percentage points of the total disability of the individual" following the jurisdictionally censured conduct and corresponding monetary conversion;
b) the estimate "in percentage points of the theoretically pre-existing disability" and the corresponding monetary conversion;
c) the monetary "quantification" of the damage, deriving from the subtraction c = (a-b).

The aforementioned jurisprudential approach does not seem to consider as a priority, consequently, the clarification of the biological presupposition of the variation, obviously decreasing, of the "psycho-physical condition" of the individual to be compensated. It seems, in particular, to be more sensitive in highlighting the mechanism for automatically matching the monetary quantum to the impairment percentage, thus "forgetting" the necessary personalization and full recognition of the damage.

The proposed methodology, by corollary consideration, avoids (since it is based on the monetary "subtraction" and not on the "subtraction" of "psycho-physical compromise") the compensation distortions determined by the actuarial system currently prevailing, which does not combine I point to a "fixed" / "standard" monetary "quantum" but recognizes its "heaviness" to varying degrees "by bands". In this sense, the proposal is not directly, exclusively reductive "by subtraction of impairment", seeking to achieve the substantial equity of the compensation through the artifice of "monetary subtraction".

Moreover, the proposal in question does not seem to be a useful tool (despite what is stated in the judgment) general application, as it is inconsistent with the concept of biological damage, invariant with respect to the person, except for specific dynamic-relational aspects, as well as, again, not even, in hindsight, useful in the hypothesis of "concurrence" of injury / impairment, because it cannot (this time yes, abstractly) differentiate this case from the hypothesis of coexistence of injury / impairment. The latter are not irrelevant in civil law, as they are likely to influence the dynamic-relational component and the productive one, obviously, it is repeated, essential for the necessary / required personalization of the damage. Incidentally, in fact, we allow ourselves to observe that the "classic" distinction between "coexisting vs competing" anatomical-functional systems must be considered substantially superseded in the scientific context (eg renal impairment can no longer be considered coexistent with lesion / impairment cardiovascular, as it synergistically affects the regulation of blood pressure, etc.).

However, the following technical information has been expressed, based on the classic descriptive scheme to be used as a basis for the "monetary" processing of the compensation / penalty:

a) the "final overall impairment", an expression of "permanent biological damage" (resulting from the pre-existing "psycho-physical impairment" and that caused by the surgical activity examined) identifiable in each of the Examined;
b) the "actual impairment" (not "theoretically" according to simplistic terminology of the Supreme Court) in the three distinct ones examined, prior to the surgery for which it is the cause, expression of the pathology subjected to censored orthopedic surgery.

It should be noted that the medico-legal information does not consider, for manifest disciplinary non-competence, the procedures for the attribution of the monetary value to the point of damage.

Only, again, we allow ourselves to repeat, in this regard, that the monetary definition "a priori", for "bands", appears to us inconsistent and contradictory with respect to the concept, acquired by technical medico-legal suggestion and accepted by constitutional orientation, of "biological damage".

For the purpose of possible comparison, it is therefore considered necessary to specify that:

A) the pre-existing pathological (but "natural") "competition", considered independently of the iatrogenic technicality that determines the dissent, has been evaluated, in percentage terms of "biological" anatomo-functional decrease, the degree of impairment of which must be monetarily calculated in a completely autonomous way, as well as (adhering to the Cass. Civ. Section III n. 28986/2019 of 11 November 2019) setting, the monetary determination of the "final" / "overall" permanent biological damage will have to be set. The determination of the relief may result from the "monetary" subtraction of the quantum connected to the "pre-existing" / "non iatrogenic" biological compromise from the total quantum connected to the final permanent biological damage ascertained. Ultimately, it seems that the sentence of Cass. cited makes its own, partially but substantially, one of the different approaches already subject to the medico-legal proposal - the so-called "innovative method", actually "monetary reduction"(41).

B) the "concurrence" of impairments (regardless of the methods / times of production / verification of the pre-existing "psycho-physical impairment" due to "natural" pathogenesis -) is, classically, reabsorbed in the overall determination of the damage (psycho-physical; functional) to the person from civilly appreciable and sanctioned offense / breach.

In this way, the sanctioning decision is arranged by appreciating the final functional impairment ascertained by the medico-legal specialist, according to the company methodological indications. It is the medical-legal technical opinion of the writer that the only limitation to The proposed method can be identified in the event that the pre-existing "pathological" but "natural" condition has already been subject to monetary consideration (obviously having to avoid any additions of refreshment for fairness).

C) The pre-existing "compromise" can be considered, according to another medico-legal approach, specifically, more explicitly attentive to the transfer to civil law of the equally classic private insurance approach, with the adoption of a purely "reductive" approach, not only for the monetary aspect but also for the preliminary one of determining the degree of "biological damage". This is the so-called "traditional method", actually "arithmetic reductive of the impairment".

In these terms the proposal was justified: ". . .The most suitable percentage to represent the extent of the damage - in a subject with pre-existence - is to be identified in the arithmetic difference obtained by subtracting from the global assessment after the damaging event that relating to the impairment in progress before the accident itself"(42).

D) Further approaches could be cited.

1. The first is applied in the social insurance field (INAIL) where, notoriously, "invalidity" (but, today, following the Legislative Decree 23 February 2000, n. 38, more correctly to be denoted as psycho-physical compromising conditions the person - ergo, expression of "biological damage -)" functionally concurrent "heterogeneous are evaluated (whether pre-existing, whether" subsequent "/" supervening ") by means of the well-known" proportionalistic "formula of Magnus - Groenouw - Gabrielli - Balthazard (G).
2. The latest evaluation proposal, sensitive to the concrete functional permanent vulnus, applicable both in the case of concurrent and coexisting, heterogeneous or even homogeneous pre-existences, is based on the analytical percentage of psycho-organic compromises elaborated by AMA (American Medical Association), whose setting also takes into account (from the 2nd Edition of 2008) not only the classification of morbid forms according to DRE (Diagnosis Related Estimates model) but also the international classification of disabilities (ICF: International Classification of Functioning, Disability and Health).

Conclusion

Atrophic pseudarthrosis of the humeral shaft represents a disabling pathological condition for the patient and difficult to treat for the surgeon. While we are aware that there is still no universal gold standard in the revision treatment of atrophic humeral shaft PSA, certainly the experience of the surgeon is a fundamental requirement for the resolution of the disease.

In preoperative planning, it will be necessary to understand the mechanical, biological or mixed causes that led to delayed consolidation or PSA and look back to the initial surgical planning to identify any possible errors in the reduction and synthesis employed.

During the appraisal operations, the coroner with the orthopedic specialist, will have to clarify the possible causes of the failure of the surgical procedure performed, taking into account all the biomechanical requirements for the healing of the original fracture and for the success of the surgical revision in case of PSA evolution.

In the orthopedic field, it has been highlighted that debridement, the production of a biologically active fracture, the formation of vital bone fragments placed in compression are the essential moments during the revision surgery of the pseudarthrosis. Particular attention should be paid to the bone tissue still available and whether the healing potential can only be based on residual local tissue, or if it requires bone grafting. The synthesis technique consists in interfragmentary compression with plate, choosing an appropriate plate size and positioning of the screws, in order to obtain absolute mechanical stability, thanks to which it will be possible to start an early rehabilitation program and obtain an optimal functional result.

From a medico-legal point of view, it has been shown that the healing process of a displaced humeral shaft fracture cannot be separated from its correct classification and surgical treatment. Often at the basis of the non-union of the fracture site there is an questionable technical execution of the surgical procedure. This can lead to an aggravation, even significant, of the impairment connected to the bone lesion and its surgical treatment, subject to civil compensation.

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References

1. Westrick E, Hamilton B, Toogood P, Henley B, Firoozabadi R. Humeral shaft fractures: results of operative and non-operative treatment. IntOrthop 2017 Feb;41(2):385-395. doi: 10.1007/s00264-016-3210-7. Epub 2016 May 6. PMID: 27150488.
2. Fayaz HC, Giannoudis PV, Vrahas MS, Smith RM, Moran C, Pape HC, et al. The role of stem cells in fracture healing and nonunion. Int Orthop 2011 Nov;35(11):1587-97. doi: 10.1007/s00264-011-1338-z. Epub 2011 Aug 24. PMID: 21863226; PMCID: PMC3193959.
3. Frölke JPM, Patka P. Definition and classification of fracture non-unions. Injury 2007 May;38 Suppl2:S19-22. doi: 10.1016/s0020-1383(07)80005-2.
4. Taylor JC. Delayed union and nonunion in fractures. Campbell's Operative Orthopaedics 1992; 2:1287–345.
5. Denard A, Richards JE, Obremskey WT, Tucker MC, Floyd M, Herzog GA. Outcome of nonoperative vs operative treatment of humeral shaft fractures: a retrospective study of 213 patients. Orthopedics 2010 Aug 11;33(8). doi: 10.3928/01477447-20100625-16. PMID: 20704103.
6. Mahabier KC, Vogels LM, Punt BJ, Roukema GR, Patka P, Van Lieshout EM. Humeral shaft fractures: retrospective results of non-operative and operative treatment of 186 patients. Injury 2013 Apr;44(4):427-30. doi: 10.1016/j.injury.2012.08.003. Epub 2012 Aug 29. PMID: 22938959.
7. Sarmiento A, Zagorski JB, Zych GA, Latta LL, Capps CA. Functional bracing for the treatment of fractures of the humeral diaphysis. J Bone Joint Surg Am 2000 Apr;82(4):478-86. doi: 10.2106/00004623-200004000-00003. PMID: 10761938.
8. Toivanen JA, Nieminen J, Laine HJ, Honkonen SE, Järvinen MJ. Functional treatment of closed humeral shaft fractures. Int Orthop 2005 Feb;29(1):10-3. doi: 10.1007/s00264-004-0612-8. Epub 2004 Dec 21. PMID: 15611875; PMCID: PMC3456948.
9. Harkin FE, Large RJ. Humeral shaft fractures: union outcomes in a large cohort. J Shoulder Elbow Surg 2017 Nov;26(11):1881-1888. doi: 10.1016/j.jse.2017.07.001. PMID: 29054684.
10. Pugh DM, McKee MD. Advances in the management of humeral nonunion. J Am Acad Orthop Surg 2003 Jan-Feb;11(1):48-59. doi: 10.5435/00124635-200301000-00007. PMID: 12699371.
11. Chen YJ, Kuo YR, Yang KD, Wang CJ, Sheen Chen SM, Huang HC, et al. Activation of extracellular signal-regulated kinase (ERK) and p38 kinase in shock wave-promoted bone formation of segmental defect in rats. Bone

2004 Mar;34(3):466-77. doi: 10.1016/j.bone.2003.11.013. PMID: 15003794. 7.
12. Delius M, Draenert K, Al Diek Y, Draenert Y. Biological effects of shock waves: in vivo effect of high energy pulses on rabbit bone. Ultrasound Med Biol 1995;21(9):1219–25 doi: 10.1016/0301-5629(95)00030-5. PMID: 8849836.
13. Martini L, Giavaresi G, Fini M, Borsari V, Torricelli P, Giardino R. Early effects of extracorporeal shock wave treatment on osteoblast-like cells: a comparative study between electromagnetic and electrohydraulic devices. J Trauma 2006 Nov;61(5):1198-206. doi: 10.1097/01.ta.0000203575.96896.34. PMID: 17099529.
14. Schaden W, Fischer A, Sailler A. Extracorporeal shock wave therapy of nonunion or delayed osseous union. Clin Orthop Relat Res 2001 Jun;(387):90-4. doi: 10.1097/00003086-200106000-00012. PMID: 11400900.
15. Wang CJ, Chen HS, Chen CE, Yang KD. Treatment of nonunions of long bone fractures with shock waves. Clin Orthop Relat Res 2001 Jun;(387):95-101. doi: 10.1097/00003086-200106000-00013. PMID: 11400901.
16. Xu ZH, Jiang Q, Chen DY, Xiong J, Shi DQ, Yuan T, et al. Extracorporeal shock wave treatment in nonunions of long bone fractures. Int Orthop 2009 Jun;33(3):789-93. doi: 10.1007/s00264-008-0553-8. Epub 2008 Apr 25. PMID: 18437381; PMCID: PMC2903117.
17. Kiran M, Jee R. Ilizarov's method for treatment of nonunion of diaphyseal fractures of the humerus. Indian J Orthop 2010 Oct;44(4):444-7. doi: 10.4103/0019-5413.69319. PMID: 20924488; PMCID: PMC2947734.
18. Kumar MN, Ravindranath VP, Ravishankar M. Outcome of locking compression plates in humeral shaft nonunions. Indian J Orthop. 2013 Mar;47(2):150-5. doi: 10.4103/0019-5413.108899. PMID: 23682176; PMCID: PMC3654464
19. Segonds JM, Alnot JY, Masmejean E. Pseudarthroses et retards de consolidation aseptiques de la diaphyse humérale: à propos de 30 cas traités par plaque et autogreffe osseuse (Aseptic non-union of humeral shaft fractures treated by plating and bone grafting). Rev Chir Orthop Reparatrice Appar Mot 2003 Apr;89(2):107-14. French. PMID: 12844054
20. Cox G, Jones E, McGonagle D, Giannoudis PV. Reamer-irrigator-aspirator indications and clinical results: a systematic review. Int Orthop 2011 Jul;35(7):951-6. doi: 10.1007/s00264-010-1189-z. Epub 2011 Jan 18. PMID: 21243358; PMCID: PMC3167404
21. Dawson J, Kiner D, Gardner W, Swafford R, Nowotarski PJ. The reamer-irrigator-aspirator as a device for harvesting bone graft compared with iliac crest bone graft: union rates and complications. J Orthop Trauma 2014 Oct;28(10):584-90. doi: 10.1097/BOT.0000000000000086. PMID: 24625833.
22. Khan SN, Cammisa FP Jr, Sandhu HS, Diwan AD, Girardi FP, Lane JM. The biology of bone grafting. J Am AcadOrthop Surg 2005 Jan-Feb;13(1):77-86. PMID: 15712985.
23. Kanakaris NK, Morell D, Gudipati S, Britten S, Giannoudis PV. Reaming Irrigator Aspirator system: early experience of its multipurpose use. Injury 2011 Sep;42 Suppl4:S28-34. doi: 10.1016/S0020-1383(11)70009-2. PMID: 21939800.
24. Sagi HC, Young ML, Gerstenfeld L, Einhorn TA, Tornetta P. Qualitative and quantitative differences between bone graft obtained from the medullary canal (with a Reamer/Irrigator/Aspirator) and the iliac crest of the same patient. J Bone Joint Surg Am 2012 Dec 5;94(23):2128-35. doi: 10.2106/JBJS.L.00159. PMID: 23224383.
25. Tomić S, Bumbasirević M, Lesić A, Mitković M, Atkinson HDE. Ilizarov frame fixation without bone graft for atrophic humeral shaft nonunion: 28 patients with a minimum 2-year follow-up. J Orthop Trauma 2007 Sep;21(8):549-56. doi: 10.1097/BOT.0b013e31814612c8. PMID: 17805022.
26. Bajaj SK, Mohan NR, Kumar CS. Supracondylar Femoral Nail in the management of non-union of humeral shaft fractures. Injury 2004 May;35(5):523-7. doi: 10.1016/S0020-1383(03)00199-2. PMID: 15081332.
27. Han F, Peter L, Lau ET, Thambiah J, Murphy D, Kagda FH. Reamer Irrigator Aspirator bone graft harvesting: complications and outcomes in an Asian population. Injury 2015 Oct;46(10):2042-51. doi: 10.1016/j.injury.2015.07.027. Epub 2015 Jul 29. PMID: 26253387.
28. Jakma TSC, Röling MA, Punt B, Reynders-Frederix P. More adverse events than expected in the outcome after use of the reamer-irrigator-aspirator. Eur J Trauma Emerg Surg 2014 Jun;40(3):337-41. doi: 10.1007/s00068-013-0345-8. Epub 2013 Oct 22. PMID: 26816069.
29. Emara KM, Diab RA, Emara AK. Recent biological trends in management of fracture non-union. World J Orthop 2015 Sep 18;6(8):623-8. doi: 10.5312/wjo.v6.i8.623. PMID: 26396938; PMCID: PMC4573506.
30. Liu JW, Chao LH, Su LH, Wang JW, Wang CJ. Experience with a bone bank operation and allograft bone infection in recipients at a medical centre in southern Taiwan. J Hosp Infect 2002 Apr;50(4):293-7. doi: 10.1053/jhin.2002.1192. PMID: 12014903.
31. Wozney JM, Rosen V, Celeste AJ, Mitsock LM, Whitters MJ, Kriz RW, et al. Novel regulators of bone formation: molecular clones and activities. Science 1988 Dec 16;242(4885):1528-34. doi: 10.1126/science.3201241. PMID: 3201241.
32. EMEA. European Public Assessment Report. Procedure n. EMEA/H/C/293. (2000).
33. Rosen H. The treatment of nonunions and pseudarthroses of the humeral shaft. Orthop Clin North Am ottobre 1990 Oct;21(4):725-42. PMID: 2216404.
34. Marti RK, Verheyen CC, Besselaar PP. Humeral shaft nonunion: evaluation of uniform surgical repair in fifty-one patients. J Orthop Trauma 2002 Feb;16(2):108-15. doi: 10.1097/00005131-200202000-00007. PMID: 11818806.
35. Rubel IF, Kloen P, Campbell D, Schwartz M, Liew A, Myers E, et al. Open reduction and internal fixation of humeral nonunions: a biomechanical and clinical study. J Bone Joint

Surg Am 2002 Aug;84(8):1315-22. doi: 10.2106/00004623-200208000-00004. PMID: 12177259.
36. Ring D, Perey BH, Jupiter JB. The functional outcome of operative treatment of ununited fractures of the humeral diaphysis in older patients. J Bone Joint Surg Am 1999 Feb;81(2):177-90. doi: 10.2106/00004623-199902000-00005. PMID: 10073581.
37. Foster RJ, Dixon GL, Bach AW, Appleyard RW, Green TM. Internal fixation of fractures and non-unions of the humeral shaft. Indications and results in a multi-center study. J Bone Joint Surg Am 1985 Jul;67(6):857-64. PMID: 4019533.
38. Murray WR, Lucas DB, Inman VT. Treatment of Non-Union of Fractures of the long Bones by The Two-Plate Method. J Bone Joint SurgAm. 1964 Jul;46:1027-48. PMID: 14192498
39. Maresca A, Sangiovanni P, Cerbasi S, Politano R, Fantasia R, Commessatti M, et al. Why a surgically treated humeral shaft fracture became a nonunion: review of 11 years in two trauma centers. Musculoskelet Surg 2017 Dec;101(Suppl 2):105-112. doi: 10.1007/s12306-017-0509-5. Epub 2017 Oct 19. PMID: 29052035.
40. Giolla P. Valutazione del danno alla persona in responsabilità civile, Giuffrè, Milano, 1968
41. Ronchi E, Morini O. Reflections on the subject of an earlier state in the assessment of biological damage, It. Journal of Legal Medicine 14, 574, 1992
42. Grandi M, Farneti A, Mangili F. Food for thought on the subject of biological and property damage, Study Days on Damage to Health, Pisa 12-13 May 1989, CEDAM, pp. 193 -197, 1990.

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