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Tibial shaft fractures: an experience-based 10-step pathway for treatment

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Summary

Tibial shaft fractures are a heterogeneous group of lesions, the treatment of which requires adequate knowledge of managing both soft tissues and bony injuries for optimal outcome. The incidence of tibial shaft fractures has been recently quoted around 16.9/100,000 year, with an incidence among males almost twice that in women. Surgical or conservative treatment should always turn to accurate soft tissue management to reduce wound problems and avoid infections, together with fracture management to stabilize the lower limb, aiming at fracture healing and restoring good function, possibly with a quick return to everyday activities. In order to achieve these goals, the vast majority of adult tibial shaft fractures are treated surgically. The gold standard has been intramedullary nailing for several years, and this is probably the best treatment for most patients and fractures, but there are still some patterns that can require a different approach. The authors' aim is to produce a simple 10-step pathway that can be used as a decision making from the initial fracture pattern and soft tissue status evaluation in emergency department, passing across the choice of surgical or conservative treatment, to the final stage of tailoring the operative procedure.

Key words: tibial shaft fractures, operative treatment, external fixation, intramedullary nailing, plate fixation

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Introduction

Despite their relatively low incidence (cumulative 16.9/100,000/year, 21.5/100,000/year in males and 12.3/100,000/year in women), tibial shaft fractures show an high rate of non union or malunion. Literature reports nonunion rates from 12% to 19%, with a two-fold incidence of non unions in open fractures [1].

Tibial shaft fractures can result from a low energy trauma (fall, twist or direct penetrating trauma) usually in women, or a high-energy trauma (motor vehicle accident, crush injury, direct blunt trauma, fall from a height), more often in young men. The most common fracture type is 42-A1, accounting for one-third of all lesions. The energy of trauma is also responsible for soft tissue damage that is negligible in low energy trauma; on the other hand, it is of paramount importance in a high energy mechanism, prevailing in decision making about fracture treatment, such as if a compartment syndrome occurs [2].

The line "bone has its roots in the soft tissues" is absolutely true for the tibial shaft, in which soft tissues are often skinny and compromised from previous comorbidity or the trauma itself. Poor soft tissue conditions result in a high incidence of nonunion, up to 1 in 4 [3]. In growing skeletons, non-operative management may be safely preferred for closed tibia shaft fractures with an initial shortening less than

1 cm and an angulation less than 5° in any plane, keeping in mind the potential disadvantages, such as late reduction loss, malunion, knee and ankle stiffness, prolonged immobilization and residual minimal leg length difference.
By contrast, in adults operative treatment is mandatory to achieve a solid bone union and early mobilization of the patient, thus reducing reoperation rates. Three surgical techniques are commonly used: external fixation, intramedullary nailing and open reduction and internal fixation. Each technique has its pros and cons. Which is the most suitable and complications-free for any type of shaft fractures is still controversial [4].

Discussion

Each of the following steps focuses on key clinical parameters; AO/OTA classification method and recommendations are used [5].
When treating a tibial shaft fracture, it is always necessary to focus on the patient and, in case of multiple trauma, the quote "save life, save limb, save function" have to be applied. The **step first** of tibial shaft fractures management consists in clinically evaluating the patient, following the ATLS (Advanced Trauma Life Support) principles. Associated lesions that can represent a serious risk for patient's life, as major chest, abdominal, and head injuries, should be recognized and addressed. Standard resuscitation, if necessary, begins with continuous monitoring of the patient's response. Once the patient has been stabilized, or in case of isolate limb fracture, definitive evaluation of lower limb injury and soft tissue disruptions has to be achieved, assessing potential neurovascular compromises or limb-threatening conditions. Emergencies like compartment syndrome, open fractures, neurovascular lesions, should be treated as soon as possible. Compartment syndrome is addressed according the BOAST criteria (British Orthopaedic Association Standards for Trauma) with a two incision, four-compartment fasciotomy. This includes an anterolateral and posteromedial incision. The incision is 15-18 cm long. The anterolateral incision is made 2 cm lateral to the anterior border of the tibia; its aim is to decompress the anterior and peroneal compartments of lower limb. The superficial peroneal nerve is identified and protected. The fasciotomy of the anterior compartment is performed 1 cm in front of the intermuscular septum and that of the lateral compartment is performed 1 cm behind the intermuscular septum. The posteromedial incision is made 1-2 cm medial to the posterior tibial border. The saphenous vein and nerve are protected and the superficial compartment is incised. The soleal bridge is detached from the posterior aspect of the tibia to adequately decompress the deep posterior compartment [6].
Together with decompression, if underlying fractures are present, rigid fixation should be considered as it also protects soft tissues and makes access to the wound easier. Accurate planning of surgical incision positioning is mandatory. The medial incision should be anterior to the posterior tibial artery to avoid injury to the network of perforating vessels that supply the skin paddle, which are potentially useful for flaps. The medial 10 cm perforator is the most reliable and constant, so care must be taken to avoid this vessel.
Open fractures can be addressed similarly to closed ones in Gustilo Grade I or II and Grade IIIA, but only in selected cases. By contrast, they are treated with temporary external fixation in higher grades and definitive fixation is delayed to performing definitive wound closure [7].
Potential vascular injury should be evaluated as well as neurological status. In case of pulseless, deformed limb, the fracture should be re-aligned and any bone dislocations reduced under appropriate sedation or anaesthesia. The limb should be then splinted, neurovascular examination repeated and documented, and a final and appropriate radiological imaging obtained.
In many patients, circulation to the lower limb will be restored. A non-vascularized limb requires urgent surgical exploration, which should be delayed only to manage life-threatening injuries. Warm ischemia for over 3-4 hours results in irreversible tissue damage and an increasing risk of amputation. Among the risks of a delayed revascularization, myoglobinuria has to be included because of it may be associated with an increased mortality.
In case of arterial damage, usually limb perfusion should be restored using temporary shunts, followed by viability assessment. Skeletal stabilization should be performed, then definitive vascular reconstruction with autologous vein grafts. Because of the high risk of compartment syndrome after limb reperfusion, standard fasciotomy should be associated with the aforementioned procedures. The ultimate goal is to save limb and function, thus reducing potential sequelae, like infection, late amputation or claw toe deformity as a result of muscles ischemia and fibrosis.
The **step second** is complete formal assessment of the patient (general health status, previous surgery, medications, level of occupation) and a precise description of the injury, which is mandatory to correctly understand its nature, determine the right pathway of treatment and prevent complications. Comorbidities, such as diabetes, vascular pathologies, smoking habit must be recorded for their association with an increasing complication rate.
Classification of soft tissues disruptions represents the **step third**. This includes the recognition of a closed or open fracture, the evaluation of soft tissues, paying attention to the presence of wounds, especially if there are signs of possible contamination, but also contusions, contained hematomas or soft tissues damage. Dealing with open fractures, the definitive grading can be assigned only after adequate surgical debridement, because soft tissue damage can be more severe and widespread than previously evaluated. The importance of classification shows up in good inter-observer communication,

which is crucial for decision-making and planning a surgical strategy.
Soft tissue involvement can be determined by referring to several classification systems, being the most widely used Gustilo-Anderson (GA) for open fractures and Tscherne for closed ones. The GA classification establishes three degrees of increasing severity in soft tissue lesions, associated with open fractures: I, II and III, with the third degree further divided into types IIIA, IIIB and IIIC. There are 5 criteria that characterize every injury: fracture type, wound dimension, soft tissue damage, degree of contamination, neurovascular compromise.
The risk of infection is directly related to the degree of exposition: the less the area of exposition, the less likely that infection will be. GA grade I includes fractures with the skin wound < 1 cm, usually derived from inside-to-outside injury mechanism, clean, with a simple (spiral, oblique) pattern.
GA grade II fractures are characterized by the following: skin wound > 1 cm, soft tissue damage not extensive, minimal contamination, simple pattern (transverse).
Finally, GA grade III covers fractures with skin wound usually more than 10 cm in width, derived from a high energy trauma, with severe contamination and extensive soft tissue damage, complex pattern (multifragmentary, segmental), as well as lesions denoted by bone loss irrespective of wound size, severe crush and vascular injuries (Tab. I).
Fractures GA type IIIA are associated with extensive soft-tissue damage and periosteal stripping, although adequate soft-tissue coverage, while type IIIB show extensive soft-tissue damage with significant periosteal stripping, thus requiring soft-tissue coverage procedures, like flaps. GA IIIC is the most severe fracture pattern, because of combination with arterial injuries requiring repair (Tab. II).
The Tscherne classification system can be adopted for open or closed fractures; in fact, depending on whether they are open or closed, they are labelled by an "O" or "C".
As regards to closed fractures, associated soft tissue injuries are divided into four categories of increasing severity (Tab. III).
After radiographic evaluation in anteroposterior and lateral view, including proximal and distal joints visualization, with or without CT scan, pattern of bone fracture may be definitively assessed **(step four)**.
The alphanumerical AO/OTA Fracture and Dislocation Classification takes into account the location of the lesion: tibia is marked as bone number 4 and the diaphyseal segment as number 2. Next comes the evaluation of fracture's morphology, distinguishing simple (42A, with single circumferential diaphyseal disruption), wedge (42B, characterized by a third fragment but still possible contact between the main fragments after reduction, usually restoring the normal length of the bone) and multifragmentary (42C, with multiple fracture lines and fragments) fractures.
42A fractures include all the following:

Table I. Gustilo Anderson classification.

Grade	Description
I	▪ Skin wound < 1 cm ▪ Clean ▪ Simple fracture pattern (oblique, spiral) ▪ Usually skin perforation is caused from inside-to-outside mechanism
II	▪ Skin wound > 1 cm ▪ Soft-tissue damage not extensive ▪ Minimal contamination ▪ Simple fracture pattern (transverse)
III	▪ Skin wound usually > 10 cm ▪ High-energy injury ▪ Severe contamination ▪ Extensive soft-tissue damage ▪ Complex fracture (multifragmentary, segmental) ▪ Bone loss irrespective of the size of the wound ▪ Severe crush injuries ▪ Vascular injury requiring repair

Table II. Gustilo-Anderson grade II.

Grade III	Description
IIIA	▪ Extensive soft-tissue damage with minimal periosteal stripping and adequate soft-tissue cover
IIIB	▪ Extensive soft-tissue injury with significant periosteal stripping and bone exposure, requiring soft-tissue coverage procedures
IIIC	▪ Arterial injury requiring repair

- 42A.1: spiral fractures, often as a result of a low-energy indirect trauma;
- 42A.2: oblique fractures, with an angle > 30°;
- 42A.3: transverse fractures, with an angle < 30°, deriving usually from a direct blow trauma.

42B fractures can be further classified in:
- 42B2 (intact wedge);
- 42B3 (fragmentary wedge).

Whereas 42C fractures are divided in:
- 42C2 (intact segmental);
- 42C3 (fragmentary segmental).

The AO classification system has shown a good relationship with prognosis and outcome: for instance, 42A1 fractures are mostly closed with minor soft tissue disruption (except for patterns in which the skin is likely to be tented by the spiroid

Table III. Tscherne classifcation of closed fractures (C).

Grade 0	▪ No or minor soft-tissue injury ▪ Indirect injury ▪ Simple fracture types
Grade 1	▪ Superficial abrasion or skin contusion ▪ Simple or medium severity fractures types
Grade 2	▪ Deeply contaminated abrasions ▪ Localized skin and/or muscle contusions ▪ Direct trauma ▪ Transverse or complex fracture types ▪ Imminent compartment syndrome
Grade 3	▪ Extensive skin contusion ▪ Crush injury with severe damage to underlying muscle ▪ Degloving ▪ Complex fracture patterns ▪ Vascular injuries ▪ Manifest compartment syndrome

fragment). By contrast, 42C fractures are frequently open or associated with a high grade of soft tissues damage (Tab. IV). As a result of the first four treatment steps, the so-called 'personality' of the injury is obtained, that is influenced by: the patient, the fracture and last but not least soft-tissue status [5].

The **step fifth** deals with open tibial shaft fractures. Taking a picture of an open fracture at arrival in emergency department is always a good idea and helps in deciding the correct treatment strategy and monitoring changes of the wound and surrounding tissue status.

The management of severe open tibia fractures can be challenging and lead to poor functional outcomes, so that in some settings (blast injuries, extensive and serious vascular lesions, highly comminuted patterns, other life-threatening injuries), primary amputation may be the best solution.

The main targets in treating open fractures are prevention of infection, bone stabilization and adequate soft tissue coverage. Current recommendations suggest starting antibiotic intravenous therapy as soon as possible, within one hour of trauma with 1st generation cephalosporins, adding aminoglycosides and antibiotics against anaerobic bacteria, depending on the degree of contamination. In hard and difficult scenarios (rural lesions, far from hospital), antibiotics may be administered on-site or during transportation [8].

The current guidelines in the authors' department recommend using piperacillin/tazobactam 4.5 gm every eight hours, adding vancomycin 15 mg/kg every 12 hours if reduction, together with osteosynthesis, is performed. In GA types I and II fractures such a treatment has to be continued at least 24 hours after wound closure or application of VAC-therapy, while in GA type III at least 72 hours. Antibiotics against anaerobic bacteria (metronidazole 500 mg every 8 hours) are added, depending on the degree of contamination, and are usually associated with the aforementioned drugs, in case of farmyard injuries.

Concerning the treatment of open shaft fractures, GA type I are mostly addressed with wound management in the emergency room (washing, debridement, suture). If the fracture is considered to be suitable for treatment with an intramedullary nail, a degree I or II of exposition, according to Gustilo, do not represent a contraindication, if adequate antibiotic prophylaxis has been established. Grade III fractures are addressed initially with a temporary external fixator. When soft tissues are suitable to sustain a surgical procedure, healing by secondary intention or performing a flap, as definitive treatment, are both possible solutions, depending on the size, localization and contamination of the area of exposition.

GA Type II fractures are carried to the operating room for a debridement, following the three liters rule: at least three liters of saline solution are used for grade I fractures, six liters for grade II and nine for grade III. A primary wound closure is usually successful, with a low rate of infection (around 4%), and bone lesion being fixed as if it is a closed fracture. If wound closure is impossible to achieve, the use of negative pressure wound therapy (NPWT) is typically the gold standard, till closure by second intention or involvement of plastic surgeons is obtained.

In GA type IIIA fractures, after surgical debridement, delayed closure (2 to 7 days) is performed, while in type IIIB a soft-tissue coverage procedure is needed; on the other hand, vascular repair is required for type IIIC fractures. Apart from a few GA IIIA fractures, which are suitable for intramedullary nailing, and the others are treated with external fixation, temporary or definitive.

Timing is important, and still under discussion. In isolated tibial shaft fractures, the 6 hour rule has been reviewed: grade I open fractures can be correctly treated within 12-24 hours, while type II or type IIIA and IIIB within 12 hours,

Table IV. AO/OTA classification of tibial shaft fractures (42).

Simple fractures (42A)	Spiral (42A.1)	Oblique (42A.2)	Transverse (42A.3)
Wedge fractures (42B)		Intact wedge (42B.2)	Fragmentary wedge (42B.3)
Multifragmentary fractures (42C)		Intact segmental (42C.2)	Fragmentary segmental (42C.3)

provided that a team dedicated to trauma is available, without the functional result being compromised. The indications for emergency surgery still remain open fractures with gross contamination or associated neurovascular injuries.

In closed fractures and in some patients conservative treatment may play a role **(sixth step)**. In our experience, the place for this treatment is limited to:

- fracture adequately reduced with closed means: tibia can tolerate valgus angulation less than 5°, posterior/anterior angulation less than 5°, rotational deformity less than 10° and preferably in external rotation, shortening less than 1 cm, but usually do not tolerate varus angulation;
- non-displaced fractures;
- patients (independently of their age) with very-high surgical risk because of medical conditions;
- patients with open growth-plates and fracture suitable for closed reduction.

This treatment may not be comfortable for the patient, and includes risk of malunion (varus deformity), nonunion and delayed union, and is also correlated with soft-tissue injuries (sores), deep venous thrombosis and algodystrophy.

As repeatedly stated, current surgical options vary from external fixation, intramedullary nailing and plate fixation.

External fixation **(step seven)** is considered the gold standard in the following clinical settings:

- fractures with severe soft tissue damage or contusion;
- polytraumatized patients, according to DCO (damage control orthopedics) principles (Fig. 1);
- medical contraindications to intramedullary nailing (lung diseases, thoracic trauma);
- open growth-plate;
- narrow diaphyseal medullary canals;
- previous deformity with impossibility to place a straight nail.

External fixation has a role in the treatment of potential complications of other implant osteosynthesis such as malunion and nonunion; circular external fixators (Ilizarov technique or Hexapodalic fixators) are very useful to correct these kind of deformities, avoiding further soft-tissue injury.

Closed reduction with locked intramedullary nailing **(step eight)** has proven to be efficient in the treatment of the vast majority of displaced tibia shaft fractures in adults; therefore it is the most popular and widely used method of fixation [9]. Two major advantages: preservation of blood supply to the fracture site, with minimal soft tissue envelope damage and mechanical stability with adequate locking in different planes (coronal, sagittal). By contrast, knee pain is reported as one of the most common complications, especially in young and active patients, together with nonunion and malunion. Anterior knee pain is probably due to the choice of surgical approach: using the transpatellar approach it is more likely to occur, as a result of the incision through tendon fibers and the retro-tendinous highly innervated fat pad injury. Therefore, we usually recommend a medial parapatellar approach without entering the tendon, although there is no evidence that strongly supports this position in the current literature. Another significant reason for knee pain might be proximal tibiofibular joint violation as a result of oblique locking screws penetration.

Figure 1. DCO with external fixator. A 17-year-old woman involved in a motor-vehicle injury, with an open tibial shaft fracture (AO 42B2, GA IIIA) of her left leg. Pre-operative X-rays and post-operative X-rays.

When using an intramedullary nail, reduction is achieved by traction and closed manipulation or, if an acceptable fracture alignment cannot be obtained, by using pointed forceps at the fracture site. Reduction aids as Poller screws, temporary reduction plates for open fractures and application of a femoral distractor can play a critical role in obtaining and ensuring the final anatomical reduction. It is well known that in diaphyseal fractures, length, rotation and alignment are more important than anatomical reduction, but anatomical reduction means that these goals have been achieved.

With the knee flexed at 90°, the guide wire, properly pre-bended, is inserted into the medullary canal until it passes the fracture line. Reaming has proven to be beneficial in reducing the rates of nonunion in closed fractures, while in open ones definitive evidence is still lacking. Limb length is the key to correct reduction and should be restored as the first step. Fibular fractures are usually not addressed in intramedullary nailing if at the similar level. When the fibula is fractured near the ankle, however, it has to be treated as an independent pattern of lesion.

Nails can also be used in:

- fractures with distal extra-articular extension, once proven that the fracture line is more than 4-6 cm (depending on the nail used) away from the tibial plafond (a pre-operatively CT scan is mandatory to evaluate how far from ankle joint is from the most distal point of fracture line). Fracture reduction and nailing fixation in this area can result technically challenging, owing to the discrepancy between the large metaphyseal diameter of the intramedullary canal and the relatively short distal fragment. A triplane screw fixation should be used (Fig. 2);
- fractures with proximal metaphyseal extension are amenable to IM using a suprapatellar approach and using reduction aids (Fig. 3);
- open fractures, GA grade I or II;
- floating knee (one single surgical access allows the management of both tibia and femoral fractures);
- bilateral tibia fractures.

Nails can be locked in a static or a dynamic way depending the stability and obliquity of the fracture line. For a long period of time ORIF **(step nine)** has been used and suggested in the orthopedic literature. ORIF is associated with anatomic or nearly anatomic reduction and stable osteosynthesis, preventing fracture malunion. Indeed, soft tissue complications, like wound dehiscence and breakdown or infection, implant subcutaneous prominence and vascular envelope disruption, might negatively affect fracture healing. The problem of soft tissue contusion still remains unresolved, even with the popularity of minimally invasive percutaneous plate osteosynthesis (MIPO), which uses indirect reduction, sliding over the periosteum and does not affect fracture site vascularization and hematoma [10].

The main indications for plate fixation are:

- proximal meta-diaphyseal fractures (the suprapatellar nailing technique with the knee in semi-extension can be very useful in this situation, avoiding the classic deformity of extension and valgus of the proximal tibial fragment);
- distal meta-diaphyseal fractures (especially when the fracture rhyme is less than 5 cm away from the ankle joint) (Fig. 4);
- patients with narrow or skewed intramedullary canals or with knee prosthesis or other orthopedic implants that prevent the surgeon from using intramedullary nailing;

Figure 2. Intramedullary nailing with standard technique. A 36-year-old man who sustained a motorcycle injury, resulting in open tibial shaft injury (AO 42A1, GA I). Pre-operative X-rays and post-operative X-rays after 20 weeks.

- open growth plate, when reduction with external fixation is not easy to achieve.

Plating can also be used as a salvage technique in case of nonunion and malunion following other kinds of osteosynthesis [8].

During the post-operative period **(step ten),** the patient is encouraged to molilize the knee and ankle joints, with particular attention to equinus deformity at the ankle and extension lag at the knee.

When intramedullary nailing has been used, progressive weight bearing with crutches is permitted from day 2 post-operative to allow compression at the site of the fracture.

When a plate has been used, weight bearing is not allowed for the first 4/6 weeks, then partial weight bearing is allowed with bearing as tolerated at around 10 weeks post-operatively.

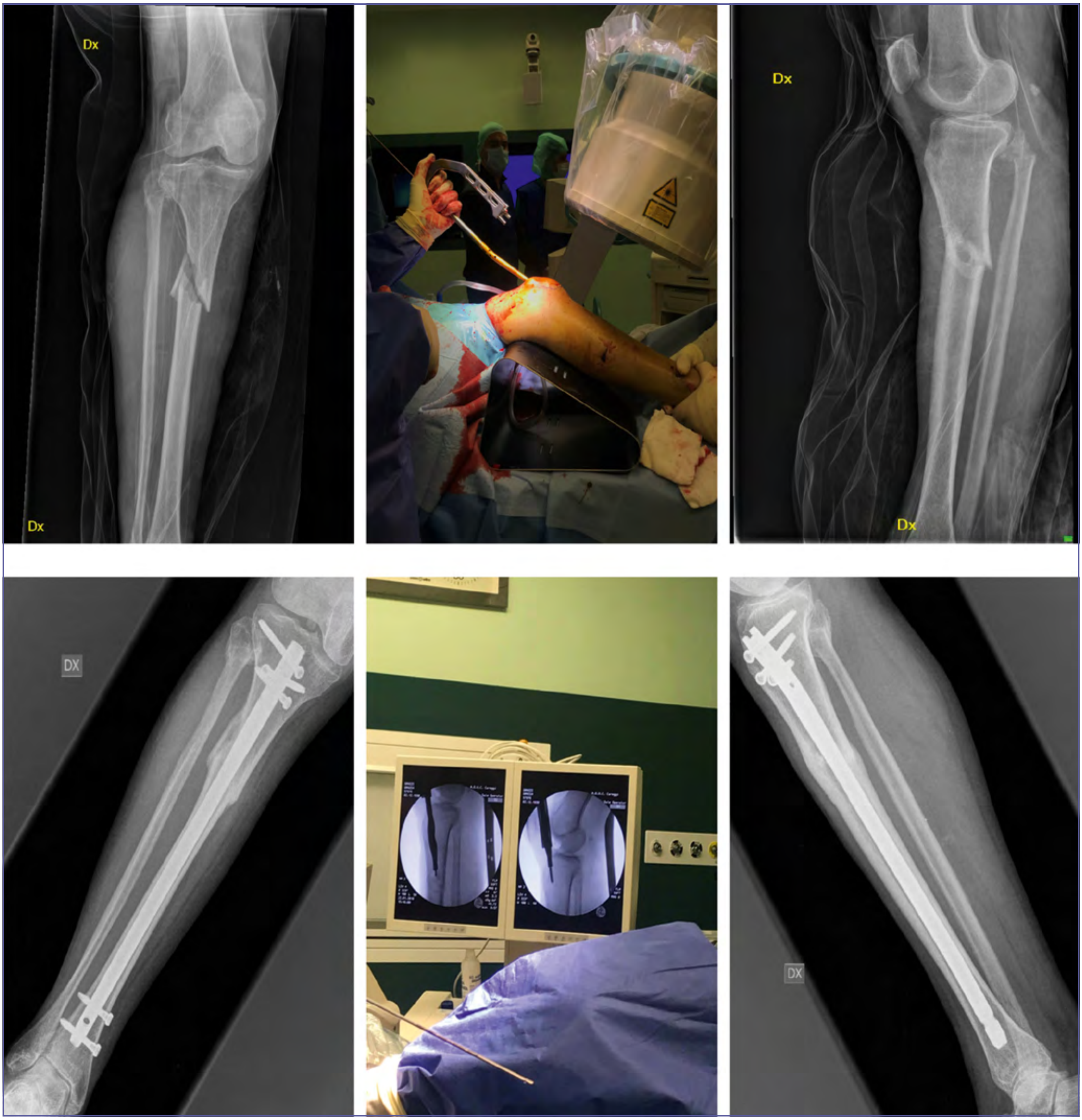

Figure 3. Intramedullary nailing with supra-patellar nailing (SPN) technique. A 79-year-old woman involved in a motor-vehicle injury, resulting in closed tibial shaft injury (AO 42B2, GA I). Pre-operative X-rays, intra-operative photos and post-operative X-rays at 32 weeks.

External fixation usually allows immediate partial weight bearing, gradually increased following radiological signs of consolidation; circular frames are designed to allow immediate weight bearing as tolerated.

Figure 4. Plating fixation. A 80-year-old man involved in a work injury, resulting in open tibial shaft injury (AO 42A1, GA I). Pre-operative X-rays and post-operative X-rays at 12 weeks.

Conclusions

According to the authors' clinical and surgical experience, a practical guideline in **10 steps** has been produced, which can be used for correct assessment of tibial shaft fractures, with the aim of helping surgeons in the decision-making process (Tab. V). At the beginning, attention should focus on correctly assess the patient's conditions and limb status, then on the fracture itself and osteosynthesis devices. Damage control is extensively used in the authors' practice, together with a wide range of indications for intramedullary nailing both in the acute phase and in the conversion setting.

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Table V. Flow-chart. A 10-step experience-based pathway for the treatment of tibial shaft fractures.

Step 1: identify life threatening and limb-risk conditions and manage them
Step 2: assessment of patient's medical history and injury mechanism
Step 3: open VS closed fractures and evaluation of associated soft-tissue injuries (Tscherne classification for closed/ Gustilo Anderson classification for open fractures)
Step 4: classify the fracture, according to AO/OTA classification
Step 5: open fractures: adequate management for each grade of GA
Step 6: closed fractures, indications for conservative treatment
Step 7: closed fracture, when to use external fixation
Step 8: closed fracture, when to use intramedullary nailing
Step 9: closed fracture, when to use plate fixation
Step 10: post-operative care, avoiding complications