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Clinical and Experimental Biomechanical Studies Regarding Innovative Implants in Traumatology

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Abstract

Fracture treatment has experienced a fascinating evolution in the last years. The aim of this chapter is to reveal some clinical and biomechanical studies regarding innovative implants. After a short introduction (1), we intend to present our results regarding (2) dynamic condylar screw versus condylar blade plate in complex supra-condylar femoral fractures; (3) biomechanical analysis of four types of implants in humeral fractures; (4) clinical and experimental studies for optimal stabilization of trochanteric fractures: the gliding nail; (5) intramedullary XS nail for pilon and ankle fractures: design, biomechanics, and clinical results; (6) the XS nail for the treatment of patella and olecranon fractures; and (7) plates with polyaxial stability for fractures of distal radius and proximal humerus. In conclusion, the authors highlight the advantages of these innovative implants in difficult trauma cases.

Keywords: fracture treatment, biomechanical, gliding nail, XS nail, polyaxial stability

1. Introduction

Hardship resulted from difficult periarticular fractures and numerous complications following the usage of classic plates and open reduction techniques and determined the development of innovative implants and new types of surgical techniques. The combination of three imperative criteria for fracture treatment (high biomechanical stability, anatomical reduction of the articular surface, and percutaneous insertion with minimal soft tissue damage) has led to the development of a new generation of implants.

The aim of this chapter is to present the advantages of innovative implants in traumatology: dynamic condylar screw (DCS) versus condylar blade plate (CBP) in distal femoral fractures; the optimal implant in humeral fractures; XS nail in ankle, patella, and olecranon fractures; the gliding nail for trochanteric fractures; and plates with polyaxial stability.

2. DCS versus CBP in complex supracondylar femoral fractures:
a biomechanical study

Distal femoral fractures represent a challenge for orthopedic surgeons, and despite numerous biomechanical studies, the optimal implant is still controversial [1–4]. However, while plates with angular stability and retrograde interlocking nails are nowadays the best choice for treatment, CBP and DCS were the most used implants until the development of these innovative implants [5].

In a biomechanical study from 2009, the authors compared the mechanical rigidity of the bone/implant (DCS or CBP) construct in complex supracondylar femoral fractures [5, 6].

Twelve synthetic composite femoral bones were fixed in the distal part with six DCS and six CBP, and then, the authors performed by osteotomy a bone defect of 1.5 cm to simulate a complex supracondylar fracture type A3/AO (**Figure 1**).

The femurs were sectioned in the midshaft, and the proximal part of the distal fragments was fixed in a metallic adapter sleeve. The bone-implant constructs were tested for seven types of loading: (1) internal compression; (2) external compression; (3) anterior compression; (4) posterior compression; (5) axial compression; (6) external torsion; and (7) internal torsion.

The compression tests were realized up to 350 N, and the applied torsion attended 25 Nm. The tests were repeated six times in order to establish the statistic dispersion. All the measurements for DCS were realized with or without compaction screw.

The compression force and loading force were measured by a M221B04 (PCB Piezotronics force transducer), while linear deformation values for the compression were measured using two inductive transducers applied in frontal axis (TD1) and sagittal axis (TD2) (**Figure 2**).

Data acquisition was realized by a six-channel admittance bridge, an interface board, and a digital data acquisition system DAQ1200 connected to a laptop.

According to study measurements, by reporting the loading/unloading force to the transducer (TD1 and TD2) displacement, we represented hysteresis cycles as diagrams for the femur/DCS (with and without compaction screw) and for femur/CBP (**Figure 2**).

By analyzing these measurements and diagrams, the authors obtained preliminary results regarding DCS versus CBP, which were statistically processed by

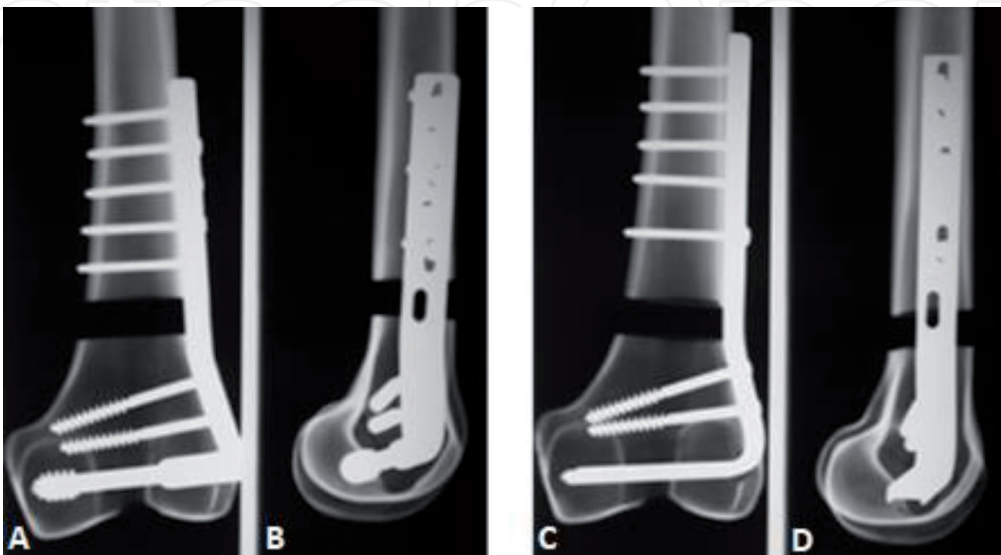


Figure 1.
(A–B) Radiographic aspect of a synthetic composite femur with osteotomy and fixed with DCS and (C–D) radiographic aspect of a synthetic composite femur with osteotomy and fixed with CBP.

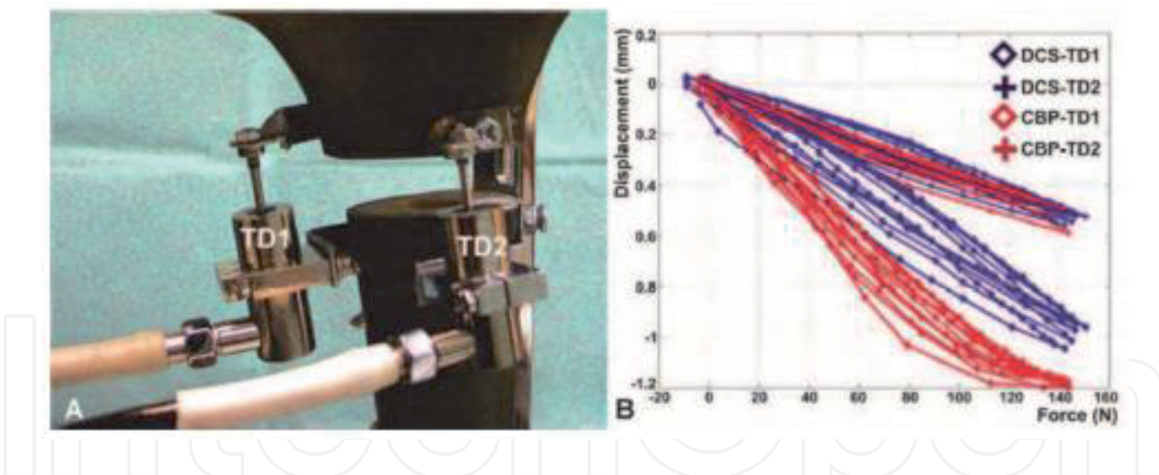


Figure 2.
 (A) Deformation measuring methods. Transducers: TD1—frontal axis; TD2—sagittal axis; (B) internal compression (DCS/CBP). Six loading tests. TD1 deformations, 12–16% higher for CBP than DCS; TD2 deformations, comparable for CBP versus DCS. Negative values (osteotomy closure). Mechanical hysteresis (both implants).

calculating the mean stiffness (square mean error) and the “ p ” value. The stiffness of the two implants differs significantly if $p < 0.05$ (95% reliability).

After the interpretation of the statistical study (DCS with compaction screw/CBP), the authors noticed that the femur-DCS construct is more stable in all compression types except the posterior and axial one, where CBP seems to be more resistant for TD2 transducer.

While, in 2002, Jaakkola et al. [5] found that there is no biomechanical advantage of CBP over DCS on plastic bones, this biomechanical study on synthetic composite femurs suggests that DCS is better than CBP in most loading tests, and the compaction screw for DCS confers an increased stability to the construct.

3. Biomechanical analysis of four different types of implants in humeral shaft fractures

The surgical treatment for humeral shaft fractures is still debatable as long as, according to comparable rate of union, the “nailers” sustain a close intramedullary technique (despite an increased risk of shoulder pain), while the “platers” emphasize the advantages of the open reduction internal fixation (ORIF; with no shoulder morbidity, despite the risk of radial nerve injury) [7, 8]. Some studies in the literature advocate the mechanical advantages of intramedullary nails [9], while other authors enhance the advantages of weight bearing on crutches with plate fixation for patients with associated lower limb fractures [10].

The aim of a biomechanical study from 2010 was to evaluate the mechanical behavior of four different types of implants used for internal fixation of comminuted humeral shaft fractures [11].

In 12 synthetic composite bones, the authors simulated a comminution in the middle third of diaphysis by removing a 38-mm thick fragment. The bones were separated in four groups, and the fractures were instrumented with four types of implants: (1) a locked compression plate (LCP; Synthes®) with six holes; (2) an intramedullary static locked (Medimetal®) nail inserted in a retrograde manner; (3) a long monoaxial locked plate type AxSOS (Stryker®) fixed with four screws (with a longer “working length”); and (4) a classic 13 holes long dynamic compression plate (DCP) with six cortical screws (**Figure 3**).

The mechanical tests were performed on a loading machine LLOYD LRX 5kN (UK), which allows traction-compression tests with forces up to 5000 N, on

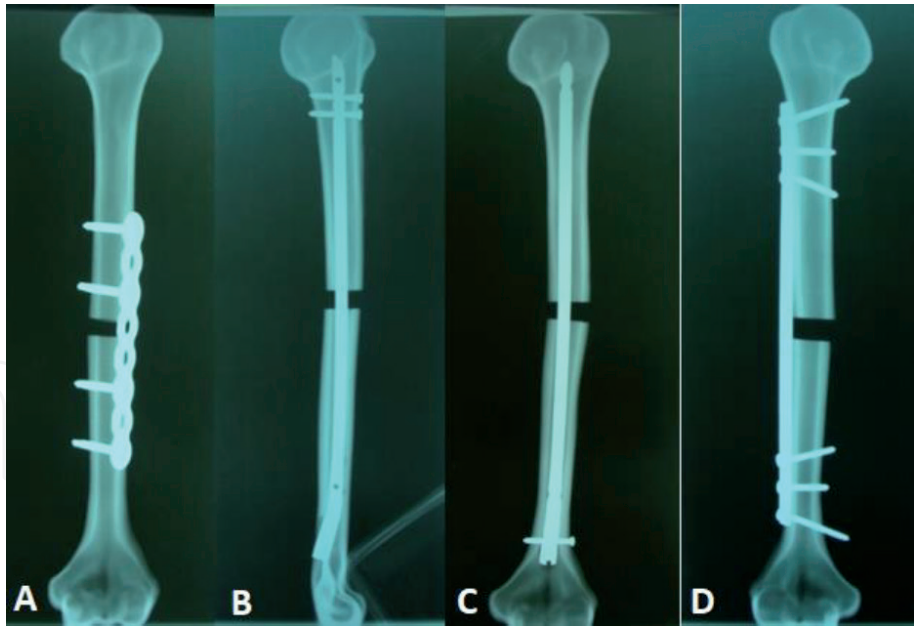


Figure 3.
(A) Locked plate; (B and C) locked nail; and (D) DCP-buttress plate.

variable speeds (0.01–800 mm/min) and an accuracy of minimum 0.2%. The compression forces were measured using the force cell of the machine (0.01% precision), and the deformations were measured with a resolution of 0.1 microns. For the testing trials, we used the Nexygen and Ondio producer provided software. All of the constructs were submitted to torsion essays in external and internal rotation as to obtain the same amount of torque [11].

According to the measured values, the authors obtained load-deformation diagrams corresponding to the four types of implants and two types of torsion loading (**Figure 4**).

The load-deformation diagrams were compared and statistically analyzed for each type of implant.

The shorter LCP proved to be the most rigid implant for each type of loading essay, the mean values of the loading being the highest in the entire group. This construct with a short angular stable plate and a small working length is unfortunately a stiff device that concentrates stress at the bone-screw interface.

The intramedullary locked nail showed to be the most elastic implant of all types of loading but, at the same time, the less rigid implant in torsion.

The classic DCP demonstrated, surprisingly, in all types of torsional loading, a mechanical behavior close to the AxSOS angular stable plate; this result is related to the fact that by using longer plates with few screws placed far from fracture site

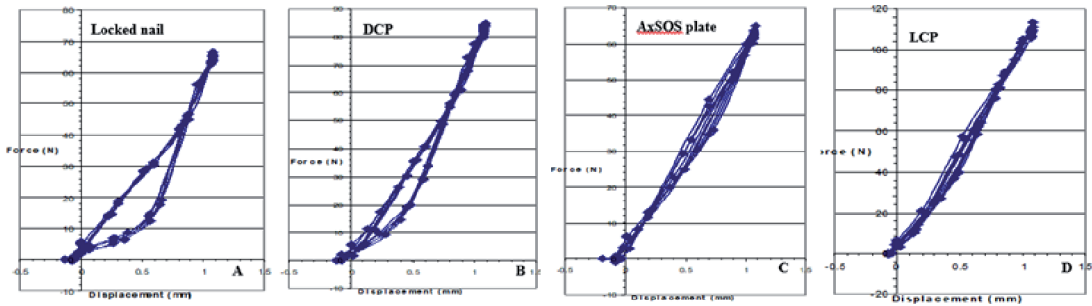


Figure 4.
Load-deformation diagrams corresponding to the four types of metallic implants loaded in external rotation: (a) locked nail; (B) DCP; (C) AxSOS plate; and (D) LCP.

(bigger working length), the torsional stress is distributed more evenly on the entire length of the plate, the mechanical stress between bone and screws is reduced, and the entire construct became an elastic one.

4. Clinical and experimental studies for optimal stabilization of trochanteric fractures: the gliding nail

The high incidence of osteoporosis in the elderly population and the high mechanical load on the proximal femur make the trochanteric region a common fracture site.

Due to the different types of fracture patterns, each with its own characteristics, a universally applicable implant is very difficult to set. The fixation strength for a per-trochanteric fracture is determined by different variables such as bone quality, bone fragment geometry, fracture reduction, implant design, and implant placement [12].

Numerous studies show that the implant used, as well as its placement, is very important for a successful outcome [13–15].

Depending on the implant position, the types of implants used can be extramedullary or intramedullary.

The dynamic hip screw (DHS) and the blade plate are commonly used implants in pertrochanteric fractures. Due to the longer length of the lever arm, they are subjected to a higher bending stress, making the risk of fatigue fractures or cutout higher than intramedullary implants (**Figure 5**). Moreover, the placement of such an implant requires large incisions with soft tissue damage and deperiostation. In these conditions, the local vascularization is greatly impaired, and the risk of local complications is higher.

Furthermore, immediate restoration of weight bearing is not entirely possible, and considering the mean age of the patients, this is of vital importance.

Intramedullary implants existed since the development of the Y-profile Küntscher nail and due to the implant position in the medullary canal, they all share a less bending force compared to extramedullary implants. Also, the surgical technique required for their implantation minimizes the soft tissue damage [16].

The most common intramedullary implants are the gamma nail and the proximal femoral nail (PFN). Since 1994, extensive clinical and experimental investigations conducted in Germany have led to the development of an intramedullary gliding nail (GN). This system has the biomechanical advantages of an intramedullary locked implant, and because of the double-T angle blade profile, the gliding screw system creates an increased resistance [17] (**Figure 6**).

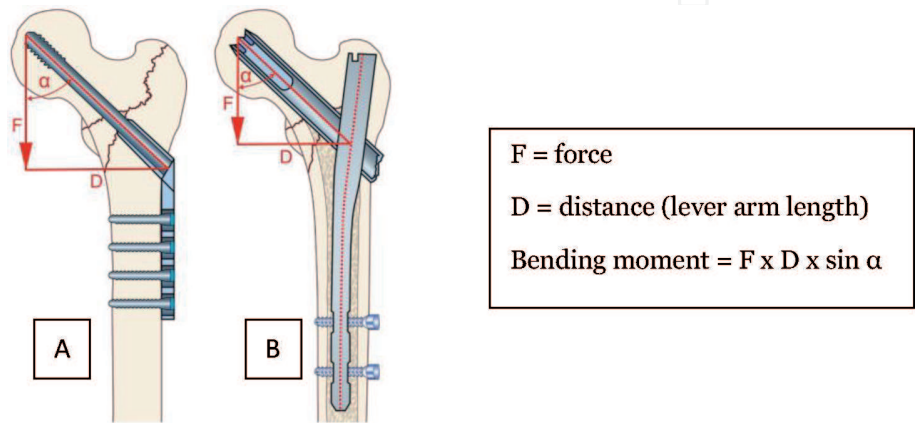


Figure 5.
(A) Extramedullary DHS system and (B) intramedullary GN system.



Figure 6. (A) Axial view of the double-T blade profile inside the femoral head (sawbone); (B) lateral view of the GN in three sizes; and (C) 3D view of the gliding nail.

The double-T profile has a higher stiffness due to its rotational stability and due to its reduced risk of damage in osteoporotic bone. The nail curvature of 6° in frontal plane and straight in sagittal plane allows the entry point on the tip of the trochanter (thus having a lower risk of circulatory disorders to the femoral head than opening the piriformis fossa) (**Figure 7**).

Another important characteristic is the dynamic impaction possibility in the femoral neck direction with dynamic stability in the femoral shaft direction (**Figure 8**).

The first study from 1996 [18], which compared the gliding nail system with the gamma nail, showed better intraoperative and postoperative results for the GN. The rate of intraoperative complications for the GN was 2.7%, while for the gamma nail, it was between 17.2 and 42.2%. The difference in outcome is highlighted by the long-term results, where the gliding nail had only 3.9% rate of complications, while the gamma nail had 6–13.8% [18].

Following the promising results, a biomechanical study from 1998 showed the importance of the blade geometry for the stability of fixation in proximal femoral fractures. The alternating load examinations on Sawbone femoral heads revealed no instability of the implant after 100,000 cycles at a load of 2000 N. The displacement of the double-T blade after 1000 cycles at 1500 N was 1–4 mm, while for the 10 mm, screw of the gamma nail was 4–8 mm [19].

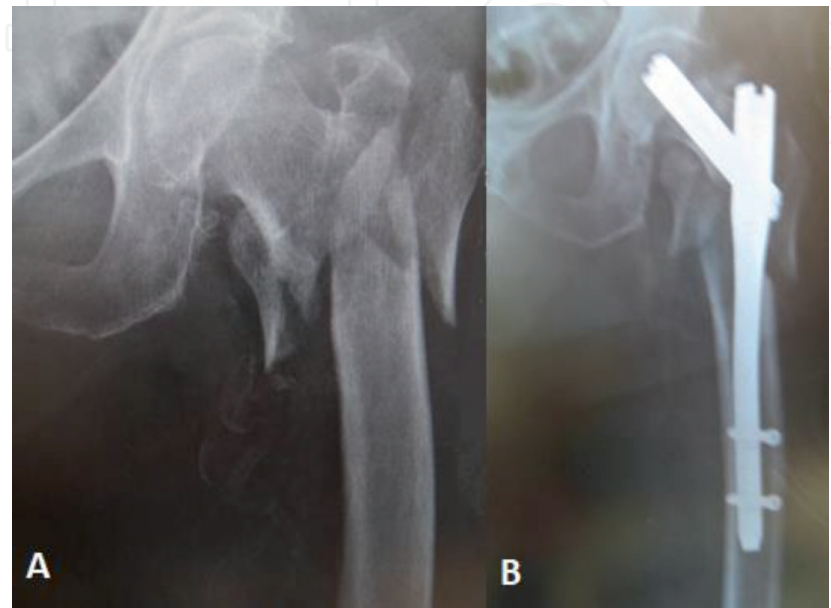


Figure 7. (A) AO/OTA A3.3 pertrochanteric fracture and (B) osteosynthesis with gliding nail.

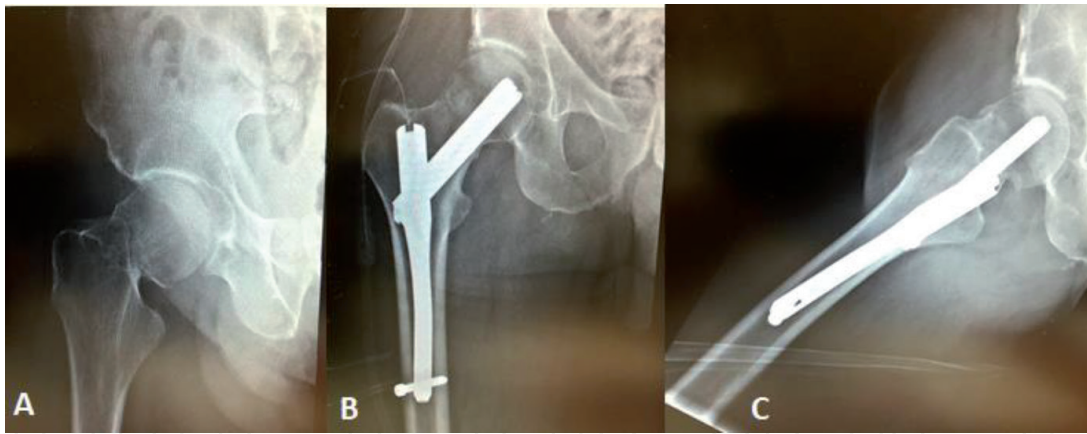


Figure 8.
 (A) Garden IV femoral neck fracture and (B and C) closed reduction and osteosynthesis with gliding nail.

In 1998, Friedl et al. published a study on 186 patients with pertrochanteric fractures treated with gliding nail; the authors revealed a very good outcome with low complication rate, especially for intraoperative complications (1.1%) and late local complications (4.9%) [20].

The superiority of the gliding nail system over the DHS or gamma nail was highlighted by the authors in a series of clinical and biomechanical studies.

The most recent study published in 2009 carried out over a period of 5 years and studied 501 patients with trochanteric and subtrochanteric fractures operated only with the GN system and immediate weight bearing. The results revealed that local complications of these difficult fractures like cutout or severe impaction can be avoided by using the gliding nail system [21].

5. Locked intramedullary XS nail for ankle and pilon fractures: design, biomechanics, and clinical results

Fractures around the ankle are very frequent injuries, and the aim of the treatment is reconstruction of the anatomy with stable and minimally invasive osteosynthesis techniques [22, 23] while avoiding further trauma of soft tissue in a local region with anatomical peculiarities: the skin is thin, with limited mobility, with almost nonexistent skin excess, a very poorly represented subcutaneous soft tissue, and poor blood supply [24, 25].

Plate osteosynthesis is the “gold standard” procedure for distal fibula, pilon, and lower leg fractures, but Zaghoul et al. reported a rate of 21.5% complications, with 2% infections and 10.8% operative revisions [26].

The severe wound complications associated with an extramedullary implant due to the compromised blood supply (arterial occlusion diseases, diabetes, and post-thrombotic sequelae) and the thin soft tissue envelope require removal of the plate (with secondary stability impairment) and additional challenging reconstructive technical solutions including split-thickness skin grafts and local or locoregional flaps [27–29]. With regard to the use of split-thickness skin grafts, they are often impossible to use in the case of soft part defects in the ankle, due to bone or tendinous exposure. Lately, a solution worthy of consideration is the use of negative pressure therapy, so that a good, vascularized bed can be created, which will allow the use of a split-thickness skin graft (**Figure 9**).

Intramedullary implants had biomechanical advantages over plates by reducing the lever arm and increasing the stability of the construct [27, 30]. The limitations of simple wires, intramedullary pins, and distally locked flexible nails,



Figure 9.
Wound complication after fibular plate osteosynthesis; (A) necrosis and exposure of the osteosynthesis material; (B) soft tissue defect after debridement; (C) granular bed after negative pressure therapy; and (D) granular bed covered with skin graft.

regarding no maintenance of length and rotation, prompted the surgeons to look for alternative techniques for osteosynthesis; the crucial requirements were minimally invasive approaches with less soft tissue irritation and high biomechanical stability. When a soft tissue problem occurs, the treatment is much easier because there is no implant on the bone surface, so that only excision and split skin graft can be performed.

From 1999, some investigators in Germany [27, 30] started to use a novel intramedullary cannulated small-diameter straight locked nail system for the fibula osteosynthesis, which was primarily designed for the treatment of fractures under tension: the XS nail. The intramedullary device length was improved to the needs of the fibula osteosynthesis (**Figure 10**). The advantages of this nail allowed their use for fractures of the fibula and tibial pilon.



Figure 10.
Ankle fracture before and after XS nail osteosynthesis.

The XS(L) nail used in the treatment of malleolar fractures has a rounded figure and a width varying from 4.5 to 3.5 mm in the case of XXS(L) nail [27, 28, 30]. The type of fracture dictates the number of locking holes needed, with an availability between 4–11 spaced (9 mm) locking holes and 3, 4, 6, 8, or 10 locking holes for the smaller XXS(L) nail (**Figure 11**). Two holes closest to the fixation have a longitudinal oval alignment. For XSL long nails, there are available lengths of up to 272 mm, and 197 mm for the XXSL nails [28].

Before starting with the clinical application of this innovative implant, experimental tests were performed comparing a standard plate and compression screw with the XS nail in fibula osteotomies [27, 31].

Eighteen sawbones were used to create Weber type B, type C, and suprasyndesmotic fractures by resection osteotomy. In each group, three sawbones were “treated” by plate and compression screw, and three with XS nail. Load was applied in 1000 cycles of 40–100 N with a frequency of 1 Hz using a MTS® machine (www.mts.com). Both plastic and total deformations were recorded. The tests showed that the nail group showed a lower deformation and higher stability.

Based on these promising results, from May 2000 to January 2002, the surgeon designers operated 194 ankle joint fractures (one-third bimalleolar injuries) using the innovative XS nail [27, 30]. The results (according to Olerud score) were encouraging (excellent outcome—58.6%, a good one—33.3%, a fair one—5.5%, and an unsatisfactory outcome—2.5%), with very few soft tissue problems and only one nonunion.

The nail insertion is realized after open fracture reduction in displaced ankle fractures (**Figure 12**) and percutaneously for pilon and lower leg fractures (with extraarticular involvement) [27, 28, 30]. The preoperative planning is crucial including the analysis of diameter of the medullary canal up to the optimal level of stabilization. XS nail is not indicated in rare cases when the canal is too narrow, and for a very thin medullary space, the XXS nail should be used. It is essential that the medullary canal must have a diameter of at least 3 mm in case of XS nail osteosynthesis [27, 28, 30]. The nail insertion requires the division of the retinaculum distal to the fibula and retraction of the peroneal tendons.

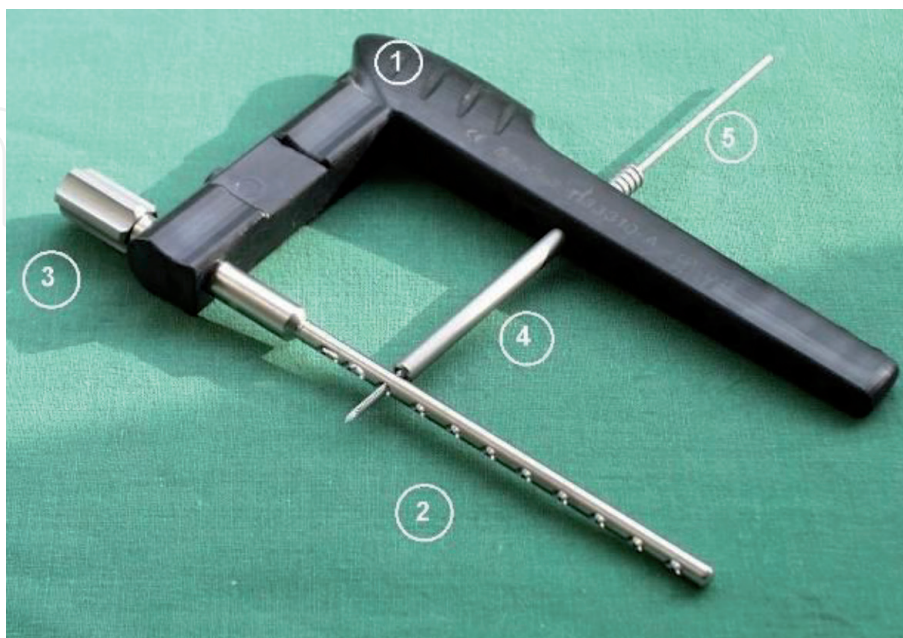


Figure 11.
Standard XS nail with aiming device: (1) X-ray transparent carbon aiming device; (2) XS standard (4–5 mm) nail, here 12-hole nail; (3) adapter for the nail on the aiming device; (4) lateral drill sleeve for the locking wires; and (5) cross-locking threaded K wire.

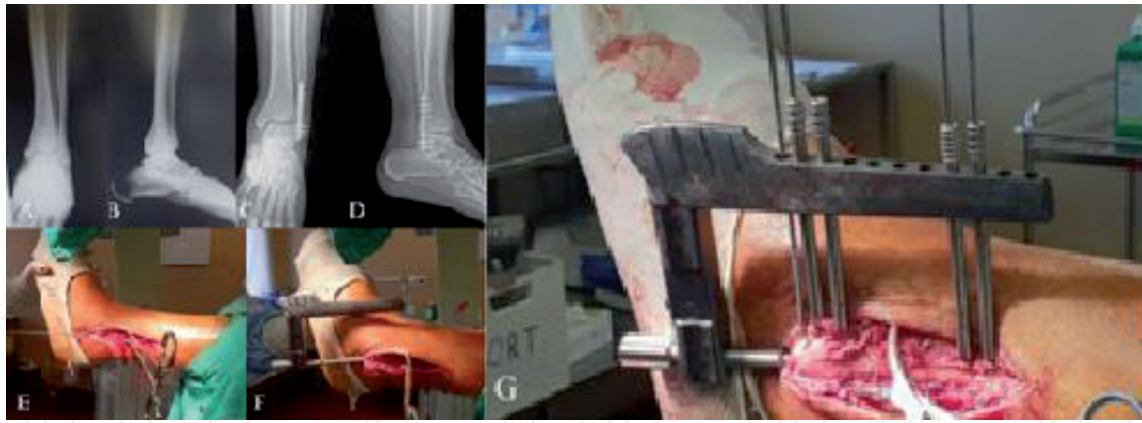


Figure 12.

XS nail osteosynthesis for a left distal fibula fracture; (A and B) preoperative X-rays; (C and D) postoperative X-rays; (E) insertion of the guiding wire; (F) insertion of the nail with the aiming device; and (G) locking with transfixing threaded wires.

After open reduction of distal fibular fracture and compression with a reduction forceps, a guide wire (1.6–2 mm thickness) is inserted under fluoroscopic control in the medullary canal. The position of the wire is verified in two radiological views, and a cannulated drill is used to the desired length of the nail, using the same diameter. The best stability is obtained by placing a nail, which is at least 2.7 cm (3 holes) longer than the fracture site.

A crucial step is to choose the biggest nail diameter fitting into the medullary canal, in order to obtain the stability of the syndesmosis without fibulotibial set screw [27, 28].

The radiolucent aiming device is used to place the nail tightly in the canal, and afterward, cross-locking is realized with threaded K wires at 90°; 2.4 or 2.0 mm wires are used depending on the type of nail (XS or XXS). Maximum stability is obtained by securing the nail with two proximal and two distal wires. The hole diameter is 0.2 mm smaller and ensures an angle stable locking for the wires. Additional inter-fragmentary compression can be achieved in transverse or short oblique fracture by placing a compression screw after the removal of the aiming device. For oblique or comminuted fracture, the compression realized with reposition forceps can be preserved by threaded wires that cross the fracture site [27, 28, 30]. In type C fractures, with a larger medullar canal than the nail diameter, an additional fibulotibial set screw must be used in order to ensure a stable syndesmosis [28].

At the end of the surgery, the threaded wires are cut with a special device, in order to minimize the implant over the bone surface.

The XS nail can additionally be used in percutaneous technique for concomitant fractures of the fibula in distal metaphyseal fractures of the lower leg, pilon fractures and for fixation of the tibia following joint reconstruction [28, 32, 33]. A perfect anatomical reduction of the fibula is not needed, so no additional damage will compromise the thin soft tissue and impaired blood supply (**Figure 13**).

The percutaneous osteosynthesis with an XS nail is first performed for the fibular fracture and then tibia is fixed with one XS nail introduced from the medial malleolus to the proximal lateral cortical bone; if it is necessary, a second XS nail is inserted from the distal lateral tibia aiming at the proximal medial cortical bone [28, 32, 33].

The minimally invasive osteosynthesis of pilon fracture using the XS nail, as well as the absence of plates on the bone surface, reduces significantly the healing problems and the rate of complication for these difficult fractures [33].

All the clinical and biomechanical studies enhanced that XS and XXS nails are important alternatives to classic plate osteosynthesis for distal fibula, pilon, or



Figure 13.
Distal metaphyseal lower leg fracture and XS nail osteosynthesis.

lower leg fractures while avoiding soft tissue complications and ensuring a stable fracture fixation with a higher weight bearing tolerance.

These advantages highlight the XS nail as an “ideal” implant for patients with poor bone and soft tissue healing problems due to vascular conditions, diabetes, or trauma.

6. The XS nail for the treatment of fractures under tension: patella and olecranon

In patella fractures, the surgical treatment with the AO tension belt osteosynthesis system is the golden standard today, but the results are not always good on the long term. Dislocation and functional deficit (limited mobility) can be as high as 20–50% of all cases [34].

One explanation is that the tendon insertions and the retinaculum create a gap between the tension-band wires and the bone, thus a very tight fixation cannot be achieved; because of this, loosening occurs after loading [35].

Moreover, due to the fact that the AO tension band is placed on the anterior surface of the patella, there is a distraction in the fracture site on the articular surface, which causes fracture gaps, dislocations, nonunion, and finally implant failure (**Figure 14**).

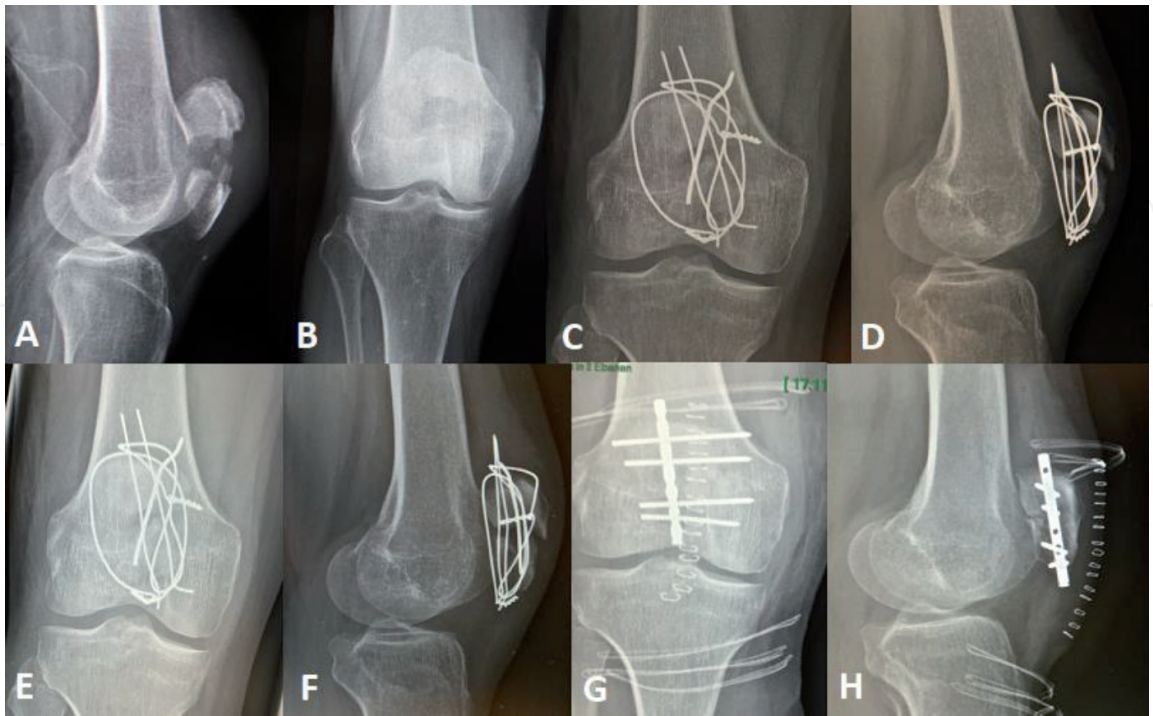


Figure 14.
(A and B) AO 34-C1 fracture of the patella; (C and D) internal fixation with tension band and cerclage wire; (E and F) failure of the construct tension band and cerclage wire; and (G and H) revision surgery with XS nail osteosynthesis.

As a result, an implant that allows compression of the entire fracture surface was needed. To achieve this, the XS nail entitled Tension Band Compression Nail (TCN) was developed and placed centrally in the patella; this implant allows equally distributed compression on the whole surface by muscular distraction [35] (**Figure 15**).

In a biomechanical study, the authors divided 30 sawbone patellas into four types of fractures. Proximal third, middle, distal third, and Y-pattern fractures were obtained by osteotomy. Osteosynthesis was carried out using one XS nail, two XS nails, and standard AO tension band. The three-part Y-pattern fractures were fixed with an additional circular wire system (cerclage) in the AO tension band group (**Figure 16**).

Plastic and total deformations were recorded, while the sawbone patellas were submitted to a force of 250 and 500 N at 30°. The batch with XS nail sets the lowest value in the entire lot. The highest deformation occurred in the AO tension band group, and a significant gap appeared between the fragments. No gap was registered in the XS-nail group.

Smaller differences were recorded in the Y-pattern group based on the strength of the circular wire put in close contact with the bone that was added to the tension band group. We must mention that in real clinical cases this is not possible because of the soft tissue interposition.

The experimental data show that the XS nail system is a viable alternative to the AO tension band due to its good fixation of the fragments and less deformation under physiological loading. This implant's characteristics will allow patients to recover faster and with better long-term results.

Tension band wiring of olecranon fractures has been the standard choice since 1963. However, migrations of the Kirschner wires and cerclage failure were reported in up to 80% of the cases [36]. Even a numerical model of the tension band wiring technique proved that high von Mises stresses were seen at the bridge between two fragments connected by the Kirschner wire [37].

The plate osteosynthesis alternative may aggravate a soft tissue lesion, usually caused by direct trauma.

The intramedullary XS nail is a new form of osteosynthesis that allows uniform compression of the fracture surfaces by central positioning the implant. Moreover, increased fixation in the cortical bone can be obtained by locking the 4.5 mm nail with threaded 2.4 mm wires. The surgical technique is easy and protective for the soft tissues due to the intramedullary position.

In a clinical study from 2006, 80 olecranon fractures were treated with XS nail osteosynthesis, and after a follow-up period of 16 months, the results were good in 93.2% of the cases [38] (**Figure 17**).

The XS nail represents, in our opinion, a future possibility in the treatment of olecranon fractures, especially in the elderly population, where bone quality is deficient.

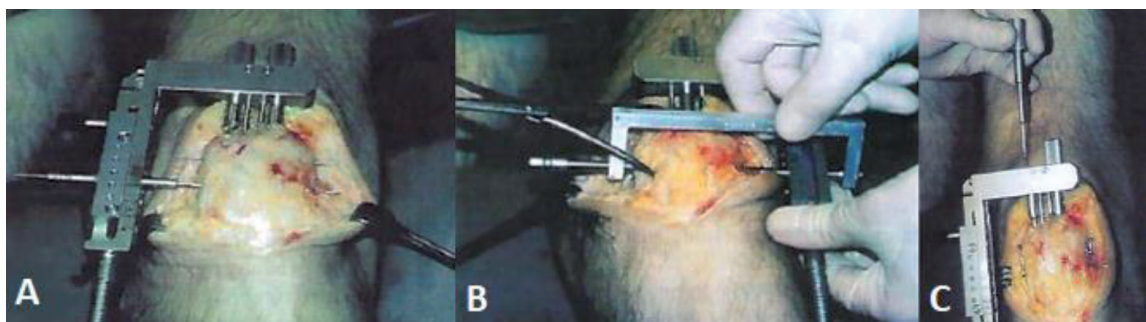


Figure 15.

(A) TCN with locking aiming device; (B) Kirschner wire aiming device; and (C) compression screw placement.

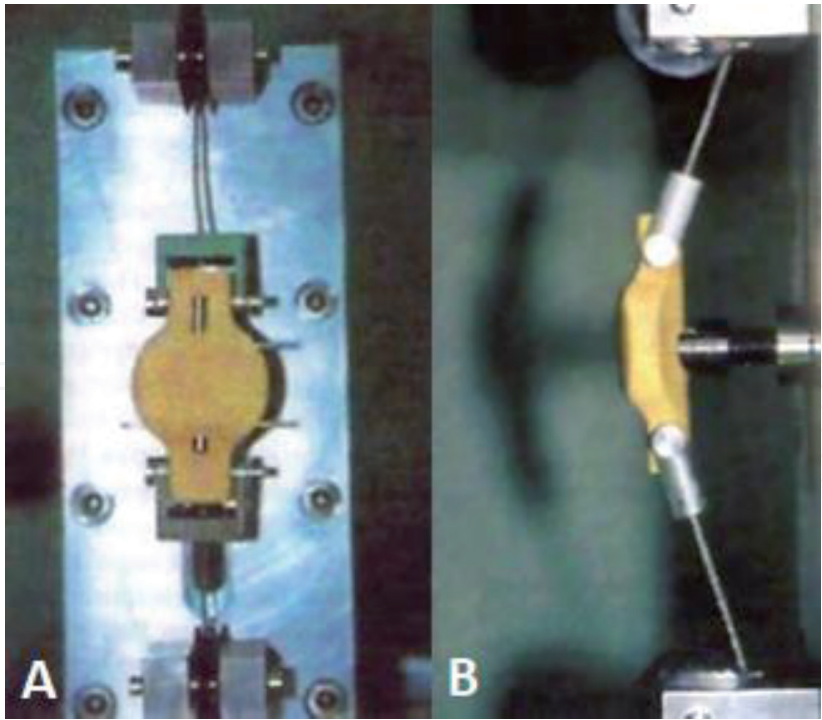


Figure 16.
Patella test without osteotomy in the hydraulic machine: (A) frontal view and (B) lateral view.

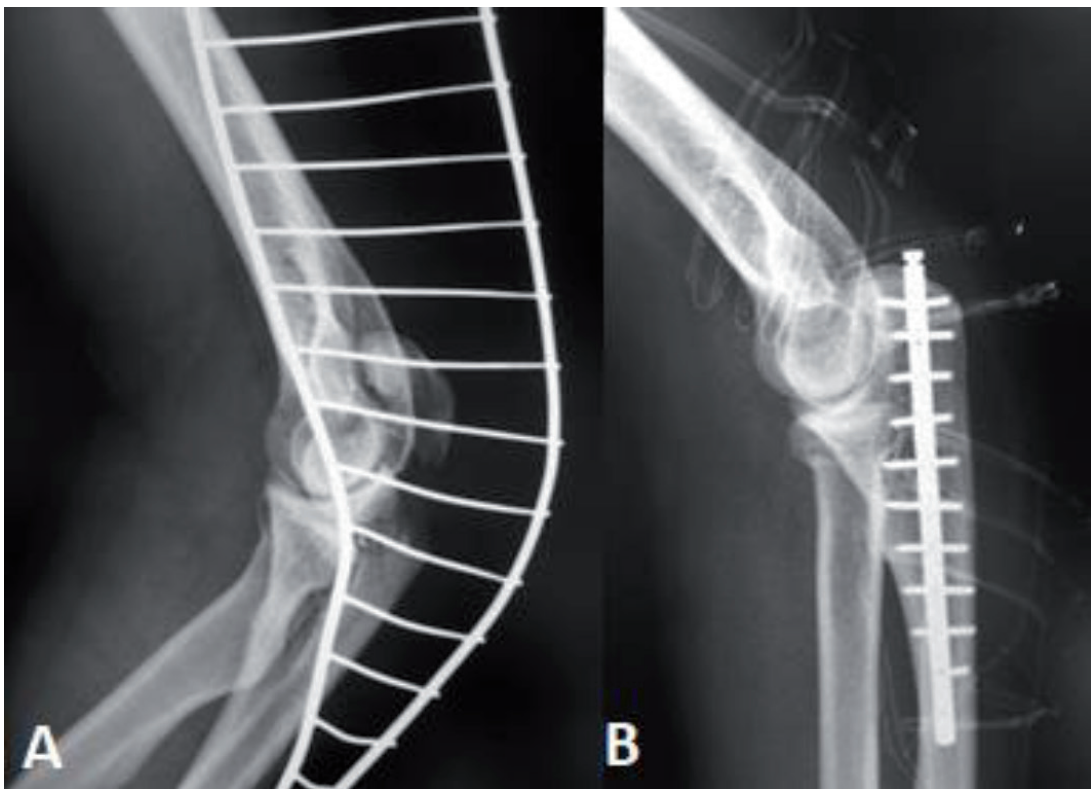


Figure 17.
(A) Displaced fracture of the olecranon and (B) osteosynthesis with XS nail.

7. Clinical and biomechanical studies regarding plates with polyaxial stability for fractures of distal radius and proximal humerus

Among the elderly, distal radius is the second most common fracture location after hip fractures. Mauck et al. [39] presented a wide variety of fracture patterns. Dorsal and metaphyseal radius fractures are usually treated with closed reduction

and cast immobilization or K-wire fixation. However, the fracture is most often unstable, and the reduction is not always maintained. Therefore, all unstable fractures or articular fractures have to be treated surgically. Due to the stability deficiency of the osteosynthesis with standard plates, depending on the type of fracture, an additional ventral, dorsal, or even radial fixation with a high degree of complexity is necessary. Studies showed that this type of osteosynthesis was accompanied by complications related to tendons lesions and a high risk of secondary dislocation or angulation.

Since the 1990s, plates with angular stability started to be used more often in the treatment of distal radius fractures. Initially being used for simple metaphyseal fractures, angular stability plates were later used in complex fractures depending on the fracture pattern. Different types of screws had to be adapted to the different articular fragments, which needed to be fixed. Moreover, an articular positioning of the screws had to be avoided, and this was followed by unavoidable issues regarding stability [40].

Thus, multidirectional (polyaxial) plates with multiple angulation possibilities were developed. The screws can be inserted perpendicularly on the plate surface or at an angle of 10° distal/proximal, medial, or lateral, offering the possibility for insertion at plate level in positions very close to the articular surface. Depending on the bone structure and the multiple fracture trajectories, fixation of fracture fragments is always possible in the adequate position (**Figure 18**).

Because these implants require large incisions with soft tissue damage and deperiostation, a new type of implant was developed [41]. The XS radius (XSR) nail is a 4.5- or 3.5-mm straight nail that is introduced after drilling and inserting a guide wire inside the medullary canal. It is then locked using threaded wires in three different directions (**Figures 19 and 20**).

The authors tested the osteosynthesis with angular stable plate and XS nail on 16 osteotomized sawbones that replicate AO/A3 fractures of the distal radius. We registered the deformation after we subjected them to 1000 alternating load cycles from 20 to 200 N (**Figures 21 and 22**).

The experimental study showed a reduced deformation of the XS nail system compared to the plates with angular stability. The deformation amplitude was only 0.31 mm in the XS nail system compared to 0.42 mm in the angular stability plate [41].

Although both implants showed good biomechanical results, the deformation recorded in the XS group proved to be 20% lower than the plate group. The XS nail has the advantages of a simple operation technique, the intraosseous positioning, and saving the pronator quadrates; however, very comminuted fractures are better treated with multidirectional (angular) locking plate [40, 41].

To date, no consensus has been reached regarding the optimal treatment of proximal humerus fractures [42]. Instability and fragment displacement usually require surgical treatment for a better quality of life. Highly comminuted fractures

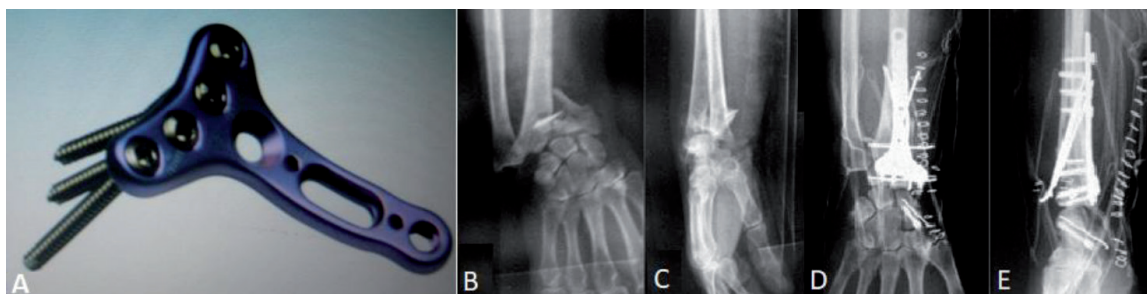


Figure 18.

(A) Polyaxial stability plate; (B and C) AO/C2 type distal radius fracture, carpal scaphoid fracture; (front and lateral view); (D and E) reduction and osteosynthesis of radius fracture with polyaxial stability plate + additional K wires and osteosynthesis of the carpal scaphoid fracture with Herbert screw + K wire.

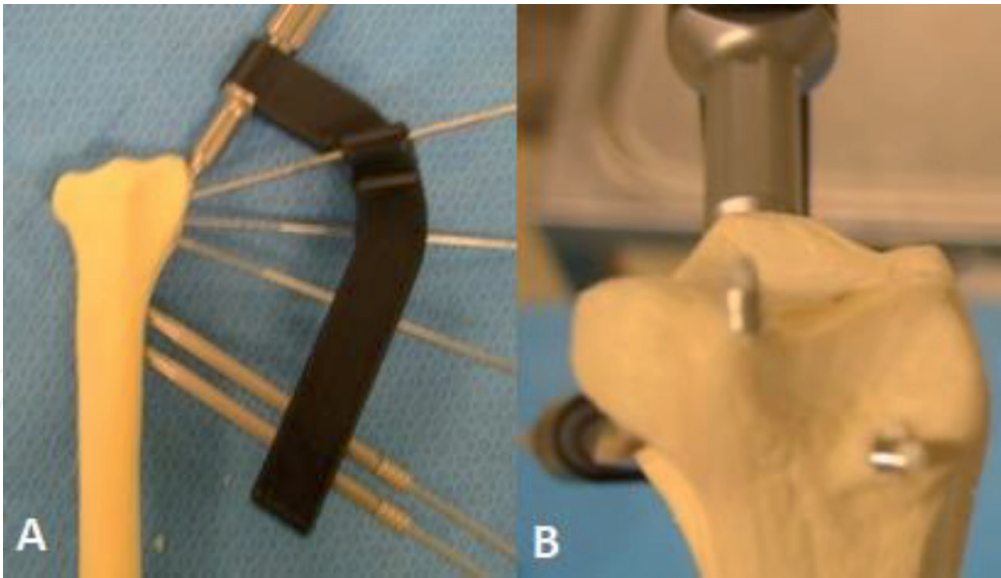


Figure 19.
(A) XS nail in sawbone with aiming device and (B) multidirectional locking of the XS nail with threaded K wires.



Figure 20.
(A) X-ray view of AO/A3 proximal radius fracture and (B) reduction and osteosynthesis with XS nail.

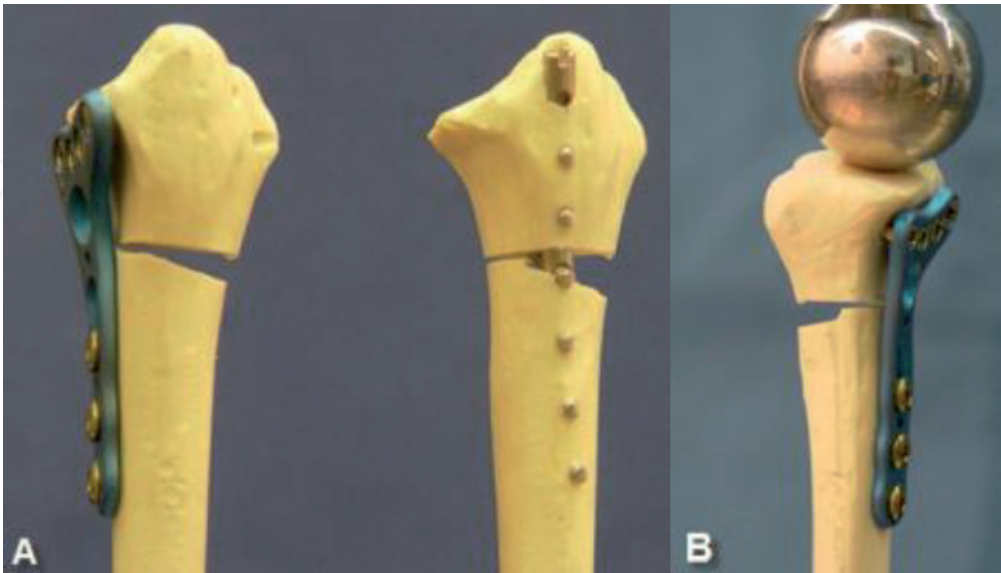


Figure 21.
(A) Angular stable plate and XS nail osteosynthesis and (B) alternating load test.

will necessitate hemi or total shoulder arthroplasty, but the vast majority of fractures can be treated by osteosynthesis with multidirectional angular stability plates or other types of plates (**Figures 23 and 24**).

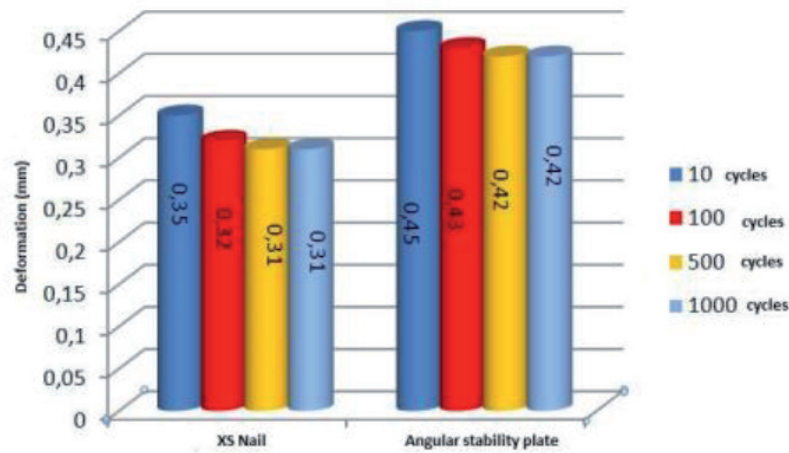


Figure 22.
Deformation values under load are higher for the plate than the XS nail.



Figure 23.
Locked polyaxial plate for proximal humerus.

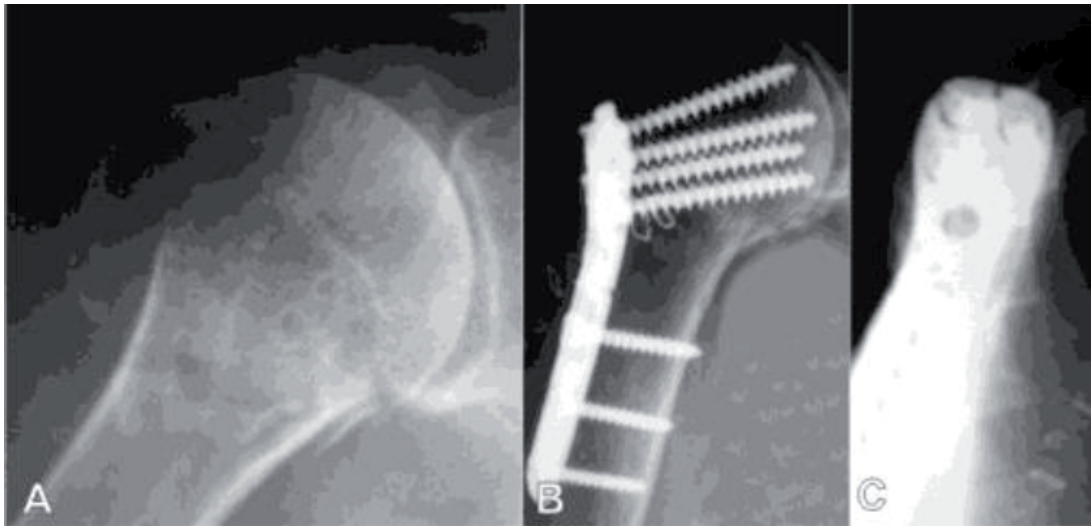


Figure 24.
(A) Proximal humerus fracture type AO 11-B1 and (B and C) locked polyaxial plate fixation.

The angular stable fixation of proximal humerus fractures has significantly improved the possibilities of anatomical reconstruction and postsurgical rehabilitation. Optimal screw positioning is hard to be achieved using classic T plates or monoaxial locked plates, especially in large bone defects or osteoporotic bones (**Figures 25 and 26**).

In a biomechanical study from 2006, the authors [43] compared on 18 sawbones the efficiency of osteosynthesis with multidirectional angular stability plate versus



Figure 25.
(A) Proximal humerus fracture type AO 11-B3 and (B) fixation with polyaxial stability plate.

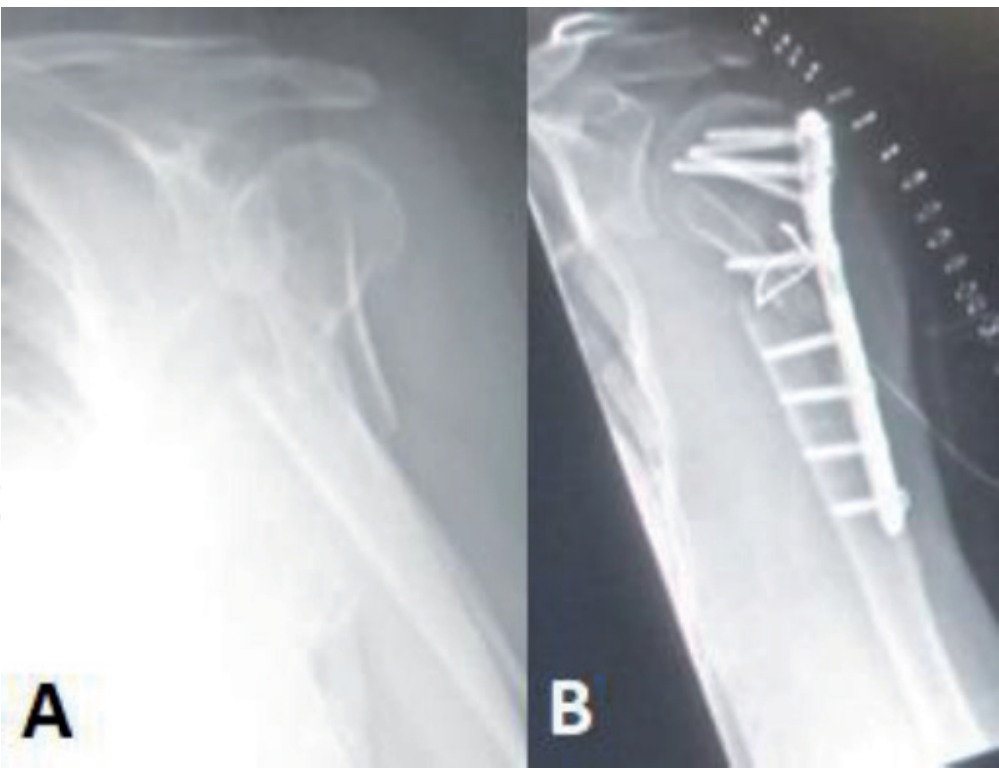


Figure 26.
(A) Proximal humerus fracture type AO 11-B3 fracture and (B) fixation with polyaxial stability plate.

monodirectional angular stability plate and normal (classic) T plate, with the same configuration and thickness. The bone-implant constructs were subjected to an alternating pressure load test of 1000 cycles between 50 and 200 N (**Figures 27 and 28**).

After 1000 cycles, the total deformation was 0.7 mm in the PAS group, 1 mm in the MAS group, and 1.5 mm in the T-plate group. In all the tests, the highest resistance and the lowest deformation were seen in the polyaxial stability plate group.

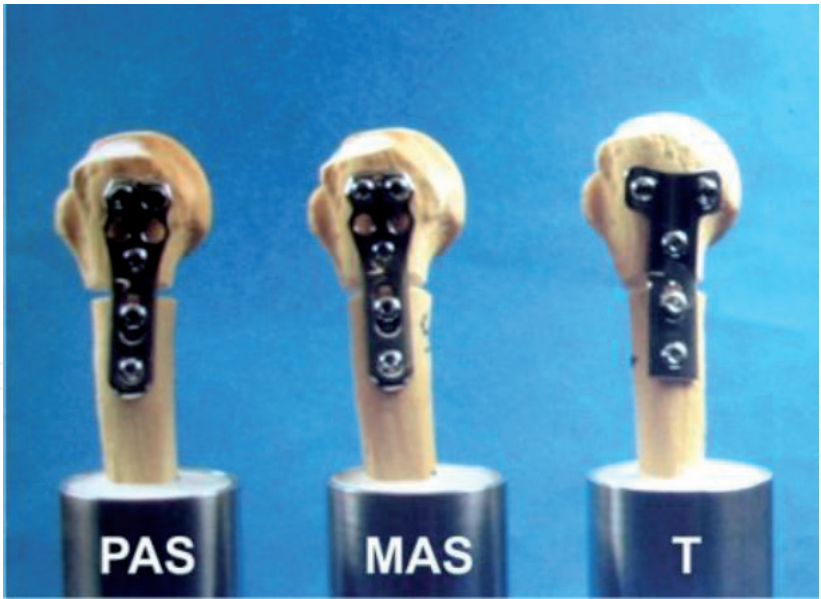


Figure 27.
Sawbones with polyaxial angular stability (PAS) plate, monoaxial plate (MAS), or classic T plate (T).

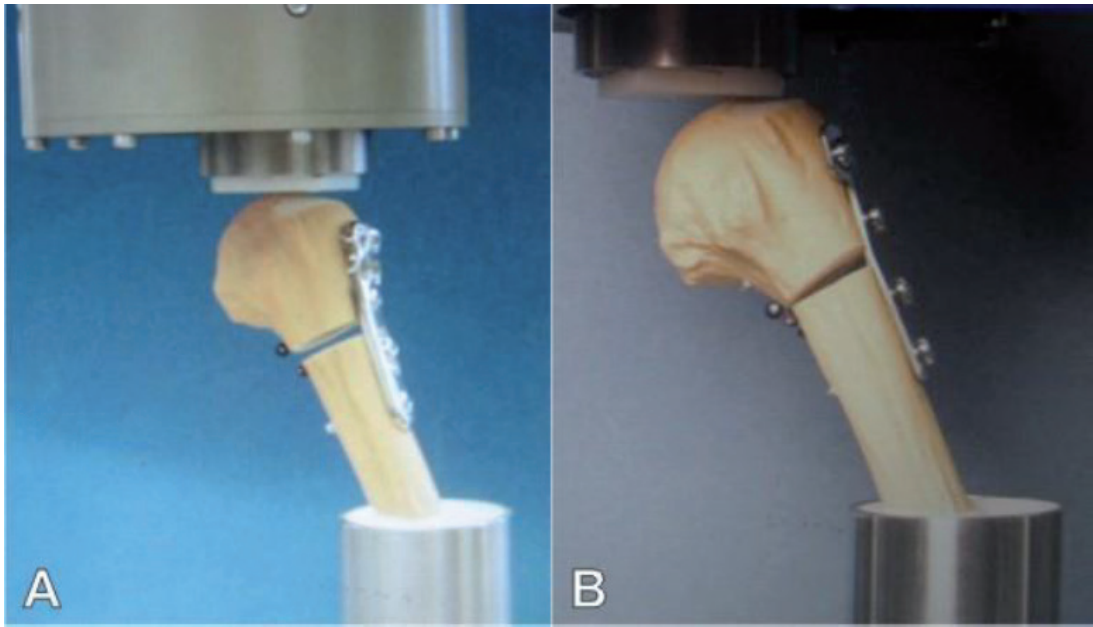


Figure 28.
(A) No deformations at the PAS plate under load and (B) the closing of the osteotomy segment at T plate under load.

In conclusion, the polyaxial angular stability plate offers not only an improved placement option for the screws but also a lower risk of reduction loss than the monoaxial plate or T plate [43].

8. Conclusions

The authors enhance the advantages of these innovative implants for difficult clinical trauma cases. For supracondylar fractures simulated on plastic composite bones, DCS is better than CBP in most loading tests. In complex midshaft humeral fracture, the shorter locked plate (LCP—Synthes) seems to be the most rigid implant; the intramedullary nail proved to be the most elastic, while the DCP

gives surprising values of torsion forces relatively close to the longer locked plate (AxSOS—Stryker). Clinical and biomechanical studies revealed the superiority of intramedullary gliding nail over DHS and gamma nail due to the double-T blade profile. The XS nail is a secure device for ankle and pilon fractures; in osteoporotic bone and difficult soft tissue conditions, it shows significant advantage over the plate fixation. In fractures of the patella and olecranon, the XS nail allows uniform compression of the fracture surface and overcomes the disadvantages of the AO tension band. Clinical and biomechanical tests proved the superiority of the polyaxial locked plates in distal radius and proximal humerus fractures due to the adjustable trajectory of the screws; in distal radius, the XS nail is stronger than the plates.

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