The concept of locking plates

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Summary
After a short historical review of locking bone plates since their inception more than a century ago to the success of the concept less than 15 years ago with today's plates, the authors present the main locking mechanisms in use. In the two broad categories — plates with fixed angulation and those with variable angulation — the screw head is locked in the plate with a locknut by screwing in a threaded chamber on the plate or by screwing through an adapted ring. The authors then provide a concrete explanation, based on simple mechanical models, of the fundamental differences between conventional bone plates and locking plates and why a locking screw system presents greater resistance at disassembly, detailing the role played by the position and number of screws. The advantages of epiphyseal fixation are then discussed, including in cases of mediocre-quality bone. For teaching purposes, the authors also present assembly with an apple fixed with five locking screws withstanding a 47-kg axial load with no resulting disassembly. The principles of plate placement are detailed for both the epiphysis and diaphysis, including the number and position of screws and respect of the soft tissues, with the greatest success assured by the minimally invasive and even percutaneous techniques. The authors then present the advantages of locking plates in fixation of periprosthetic fractures where conventional osteosynthesis often encounters limited success. Based on simplified theoretical cases, the economic impact in France of this type of implant is discussed, showing that on average it accounts for less than 10% of the overall cost of this pathology to society. Finally, the possible problems of material ablation are discussed as well as the means to remediate these problems.

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Introduction
The locking plate has progressively but especially very recently become part of today's orthopaedic and traumatology surgeon's arsenal of osteosynthesis techniques. However, the concept of the locking plate itself often contin-
ues to be misunderstood and consequently even misjudged. Briefly, the locking plate behaves like an external fixator but without the disadvantages of an external system not only in the transfixion of the soft tissues, but also in terms of its mechanics and the risk for sepsis. It is actually more an "internal fixator" [1].

The change from the conventional nail to the locking nail was a revolution. This is an evolving implant but one that remains within the same conceptual framework, extending its indications. However, the move from a conventional plate to the locking plate is not truly an evolving implant, but rather a change in concept.

We will describe the mechanical and biological implications and their consequences on surgical technique. The differences in relation to the use of a conventional plate are far from intuitive. Even for the well-informed surgeon, a learning period is necessary before the concept can be fully appreciated so that the locking plate is not used as if it were an improved common plate.

History

The earliest ancestor of the locking plate is the monocortical fixator by Carl Hansman in 1886. It rapidly reached its final form in the hands of Paul Reinhold in France in 1931, then fell into oblivion. After the Litos system in 1974 [2], then the Zespol in 1982 [3], the concept progressively cut itself a significant place in the osteosynthesis techniques beginning in 1995. This concept was developed independently and nearly simultaneously by Patrick Sürer with the Surfix® system [4], unchanged since its beginnings, and by the Arbeitsgemeinschaft für Osteosynthesefragen, Association for the Study of Internal Fixation (AO) through many stages. The first version in 2005 was the point contact fixator (PC-fix) [5] followed in 2001 by the Less Invasive Stabilization System (LISS) [6] and the locking compression plate (LCP) [7] with all its versions. In a different approach, the Schuli (literally "small shoe") locking nut systems were proposed in 1998 [8] so that a common screw could be locked in a plate that could be qualified as "normal," preserving certain of today’s interlocking mechanisms.

At the same time as implants were evolving, implantation methods were changing. The extensive approach, injuring periosteaum and blood vessels, became less and less traumatizing to end up as a percutaneous approach [9–12]. From anatomic reduction we moved on to axis restoration. It was understood that the tutor was indeed useful, but that nutrients were fundamental to both bone union and to increasing resistance to infection. We were coming nearer to the closed techniques.

We will present several of the most widely used systems.

Fixed-angle plates

In the Surfix® system (Fig. 1), locking is obtained with the locknut. The screw has a flat head that is locked into the chamber by the locking nut screwed through the plate thickness.

Tornier® has used a similar concept for distal radial epiphysyal plates. The locking nut is replaced with a sort of screwed-in cover that simultaneously locks several screws.

In the AO system (Synthes®) (Fig. 2), the screw head is conical and equipped with a screw thread that locks within the threaded hole. The pitch of the screw head is identical to the pitch of the screw body to prevent compression, but it is smaller, metallic, and lined to provide maximum anchoring. This is in fact a double-threaded screw.

Plates with variable angulation

The mechanism retained by Newclip® (Fig. 3) and Stryker® includes an expansion ring in which the screw head can be screwed into lock inside a cone with up to 10° clearance.

In the Biotech® mechanism (Fig. 4), the conical and self-tapping screw headlocks with the selected angulation in a polyaryletherketones (PEEK) insert set in the plate. The Zimmer® system (Fig. 5) includes a locknut, which covers the spherical screw head for locking with up to 15° clearance.

The last of these systems, the AO (Synthes®) variable-angle screw system (Fig. 6), was inspired from the fixed-angle screw locking mechanism. The screw head is threaded but is spherical in shape and is screwed inside its pilot hole in four separate threaded flanges.

Figure 1 Surfix® system; the screw head is locked by a threaded locknut.
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Figure 2  AO interlocking system. A. The screw head is threaded and screws into the plate. B. There is a double-thread on the head but the pitch is constant.

Figure 3  Newclip® locking system with an expansion ring.

Figure 4  Biotech® locking plate system. The screw head is screwed into a PEEK insert.

Figure 5  Zimmer® locking plate system with a locknut on a spherical head.

Figure 6  AO variable angulation locking plate system with threaded spherical head.

Mechanical components

We will not present the results of the widely published complex biomechanical tests here [13]. Common sense and simple concrete examples, much more than theoretical numbers, will elucidate the mechanical value of locking plates and the errors to avoid in their use.
Figure 7  A. The role of screw compression can be replaced by a clamp. B. The assembly is not very effective if there is substantial axial compression.

Figure 8  A. More complete model with screw not tightened. B. Resistance to axial compression is better.

Figure 9  A. Effect of compression on the overall thread in contact with the bone. B. Shearing effect only on the proximal side of the screw.

**Plates with conventional screws**

Fixation with the conventional screw plate compresses the plate against the bone. On an experimental model with a piece of balsa wood, the compression applied by the screw can be replaced with a clamp (Fig. 7). The fixation is sturdy but substantial axial stress such as an axial impact can cause sliding under the plate. On the other hand, with a more complete model including a loose screw (with compression from a clamp), greater axial force must be applied for sliding to occur (Fig. 8). This demonstrates the second mechanical component of the working of the screw: shearing.

Let us now examine the details of the model (Fig. 9). One can easily see the effect compression has on the thread of the screw in contact with bone, but that the effect of controlling shearing is above all caused by the part of the
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Figure 10  Greater resistance to shearing with locking screw.

Figure 11  A locking screw resists shearing along its entire length.

Figure 12  A locking screw is subjected to flexion force.

Figure 13  A. Representation of a conventional screw and a locking screw. B. The diameter of the locking screw is greater and its thread finer.

From Wagner M, Frigg R [1], with authorization of the AO International.

screw in contact with the bone below the plate. The tip of the screw in the cortical bone works almost solely in relation to the pullout forces.

Plates with locking screws

An experimental model shows that resistance to shearing is much greater than in the preceding image (Fig. 10). The inset shows that the shearing force is exerted on the entire length of the screw (Fig. 11) and therefore is much more effective. It can also be seen that the body of the screw is working in flexion (Fig. 12).

Screw characteristics

The example of these two types of screw by the same manufacturer shows how screws are adapted to their different functions (Fig. 13). The conventional screw has a wide, asymmetrical thread to resist pullout. The locking screw has a fine-pitched thread designed to make it advance into the bone; it is symmetrical so that it forces equally in pullout and advancement. The diameter of the conventional screw shaft is relatively small to allow room for wide pitch, whereas for
Osteosynthesis failure

During stress, the disassembly mechanism is different for the two types of fixation. In conventional plate osteosynthesis, the screws are sequentially pulled out one after another (Fig. 14). In locking screw fixation, a monobloc effect is produced, with all the screws forcing at the same time (Fig. 15). The latter osteosynthesis method is therefore much sturdier, as seen in an experimental assembly in balsa wood, where the sequential pullout of common screws occurs very easily, whereas the forces on the locking plate have induced fracture of the balsa wood fragment above the plate (Fig. 16).

During pure pullout stresses in the screw axis, it is clear that assembly with screws in different directions provides greater resistance to pullout than an assembly comprising parallel screws. This is one of the reasons why most epiphyseal implants have screws placed in different directions, particularly in the shoulder where the quality of the bone is often mediocre.

Figure 14  Sequential pullout of conventional screws.

Figure 15  *En bloc* pullout of an interlocking screw system.

Position of the screws

With a simple mechanical model (Fig. 17), it is easy to understand that assembly with screws grouped at the end of the plate is not as sturdy as when the screws are distributed over a greater length.

Number of screws

For identical reasons, we understand intuitively that an additional screw, for example, will have a greater effect on the assembly over a greater length than if the screws are grouped over a short distance (Fig. 18). However, one must trust the published mechanical tests [13] and accept that beyond three screws, adding a fourth screw has little effect on axial stability. On the other hand, this fourth screw slightly improves stability in torsion.

It can be concluded that for a diaphyseal fracture, three or four locking screws are sufficient.

Epiphysial fixation

At this level, conventional screws often only contribute mediocre stability. Compression of cancellous bone against the plate is not very effective, particularly if the bone quality is not good and/or there is a multifragment fracture. Use of interlocking screws in the plate alleviates this compression of the bone against the plate. The example of the hayfork is demonstrative. The fork can easily withstand a heavy load despite the mediocre-quality of the material lifted (Fig. 19).

Another simple and accessible mechanical example shows the value of locking plates. When an apple is attached to a plate with a locking screw, the angular stability of the

Figure 16  A. Easy pullout of conventional screws in balsa wood. B. Rupture of the fragment during attempt to pull out locking screws.
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Figure 17  A. Assembly with screws grouped at the end of the plate (B) is weaker than (C) if the screws were distributed over a greater length.

Figure 18  Beyond two screws, adding another screw (A) is more effective on a long working assembly than (B) if the screws are grouped over a short distance.

assembly is clear (Fig. 20). On the other hand, this stability is only acquired with a conventional screw by compression of the apple against the plate. Obviously, this is not compatible with maintaining periosteal vascularization intact.

In the interlocking screw assembly, primary stability is increased without losing reduction by adding a second locking screw (Fig. 21). In the conventional screw assembly, if the plate is not molded to the epiphysis, the compression induced by a second conventional screw produces a primary loss of reduction.

Loading tests on our apple fixed with two screws give spectacular results (Fig. 22). In the assembly with two locking screws, it is possible to load the apple axially with 25 kg without disassembly, whereas in the assembly with two common screws, displacement began with a 3-kg load and the assembly collapsed at 5 kg.

Taking these results into account, we pursued the experiment with fixation of the apple with five interlocking screws on a plate for the distal femur. The assembly withstood the complete load of a 47-kg woman with no alteration of the apple or assembly displacement (Fig. 23). This test obviously has no scientific value but it nevertheless clearly and simply demonstrates the quality of the epiphyseal fixation obtained with the locking plate, even on bone whose quality is mediocre.

Conventional plate versus interlocking plate antinomy

There is antinomy between the two fixation modes: the locking plate versus the conventional plate [1,14]. Conventional plate osteosynthesis seeks to obtain maximum stability with a rigid plate and if possible compression of the fracture fragments. Locking plate fixation, on the other hand, seeks to maintain a certain elasticity to stimulate bone healing. Locking plates are generally less rigid than conventional plates.

In conventional plate osteosynthesis, anatomic reduction is sought because it increases stability, whereas in locking plate osteosynthesis the quality of the reduction is less vital, provided that the local soft tissues (and therefore vascularization of the fragments) are maintained intact. The objectives are closer to the objectives of nailing than conventional plate fixation.

For the same reasons, the callus obtained with a locking plate is a stress callus, secondary, as in nailed osteosynthe-
Figure 20 Fixation of an apple on a plate. A. With a locking screw, the assembly is stable. B. With an untightened common screw, the assembly is unstable. C. Compression is necessary against the plate.

Figure 21 A. Assembly using one locking screw. B. A second locking screw does not displace the assembly. C. Assembly with a conventional screw on an unadapted plate. D. A second conventional screw displaces the assembly.

Figure 22 Loading test of the assembly. A. Apple fixed by two locking screws. B. Apple fixed by two common screws.
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However, the usual elasticity of locking plate osteosynthesis makes it at least a theoretical contraindication in cases of devascularized or necrotic bone; hard callus is not obtained.

The preceding discussion shows that the concept of the locking plate is much closer to nailing or external fixators than to conventional plates. Despite the appearances, a locking plate is therefore not a plate in the classical sense of the term, but rather an internal fixator [1]. This is an essential concept, far from intuitive for a surgeon who is familiar with classical means of osteosynthesis. Even a surgeon who is well-informed of the fundamental conceptual differences must generally adapt and accept to reconsider what he or she has learned about classical osteosynthesis so as to use the locking plate optimally.

Another important aspect to take into account is the fundamental difference in behavior of the two types of osteosynthesis in terms of infection. According to Perren [14], the foreign body effect that reduces resistance to

Figure 23  A. Assembly with apple fixed with five locking screws on a distal femur plate. B. Loading test.

Figure 24  Infected pseudarthrosis of a humerus operated several times. A. Radiological aspect. B. Fistula. C. Interlocking plate fixation. D. Follow-up x-ray at 15 months.

Figure 25  A. Comminution fracture of the distal end of the femur. B. Reduction assisted by positioning the epiphyseal screws parallel to the joint space.
Figure 26  A. Comminution fracture of the tibial plateau. B. Reduction assisted by positioning the epiphyseal screws parallel to the joint space.

Figure 27  Comminution fracture of the navicular. A. Plain x-rays. B. 3D CT reconstruction. C. Interlocking plate fixation. D. The screws risk conflicting because of bone convexity.

Infection is less caused by the foreign material than by necrosis (induced by the implant) and the dead space effect. In conventional plate osteosynthesis, necrosis of the cortical bone compressed under the plate is produced systematically. In contrast, locking plate fixation does not result in bone necrosis.

In addition, titanium, the material generally used in locking plates, does not form a foreign body membrane and therefore does not create a dead space effect with the implant.

In an experimental rabbit study, the ratio of the quantity of Staphylococcus aureus necessary to obtain infection in osteosynthesis was 1/450 for conventional stainless steel plate fixation versus titanium locking plate fixation [14].

As a clinical example, we can present the case of an 82-year-old patient who presented suppurating fistulized malunion of the humerus after multiple interventions (Fig. 24). The bacterium was multidrug-resistant Staphylococcus epidermis. After excision and lavage, osteosynthesis was provided by a locking plate in titanium. Adapted antibiotics were maintained until the lab tests normalized. Union was obtained without incident.

Principles of plate placement

Epiphysis

Reduction
The basic principle of anatomic reduction of a joint fracture remains valid with locking plate osteosynthesis.

Screw direction
Screw direction is imposed on classical locking plates, but more and more materials are being developed that provide a locking system with variable-angles. This concept, often advanced by the manufacturers, corresponds more or less to an intuitive request from surgeons, but with experience the question can also be raised as to whether this was a misconceived idea.
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Figure 28  Assembly error: with locking screws in the epiphysis, it is not useful to risk excess length because it is generally poorly tolerated.

In a premodeled epiphyseal plate, the imposed screw direction was studied to solve three potential problems: to avoid joint penetration, a conflict between screws, or extra-articular conflict, if the plate is properly placed on the epiphysis. This is particularly true to avoid screw penetration in the intercondylar fossa of the distal femur, for example. The last detail to take into consideration is that in certain areas such as the knee, screw direction provides valuable assistance in controlling bone axes. In cases of metaphyseal comminution fracture, positioning the juxta-articular screws parallel to the femorotibial joint space makes it possible to prevent axis misalignment in the frontal plane (Figs. 25 and 26).

The need for a variable-angle system is often implicitly accepted as being able to adapt to different fracture types to provide fixation for a particular fragment. Actually, this notion is valid first and foremost for conventional screws that must provide good bone purchase in the different fragments brought in contact with the plate. Locking screws work differently by providing a sort of grid that supports the reduced fragments. The direction of fixed-angle screws has generally been studied so that they provide maximum support of joint surface given the shape of the plate.

In addition, the variable-angle locking systems require thicker implants, which is generally not desirable near a joint. Finally, even though the results of the in vitro mechanical tests announced by the manufacturers are good, to our knowledge no norms have been defined and a certain clinical experience is necessary before the stability of one mecha-

Figure 29  A. Interlocking screw that is too short to fix the posterior fragment of the tibial pilon. B. Secondary displacement.

Figure 30  CT view of a fracture of the humerus head in an elderly female patient. The cancellous bone is reduced to a thin subchondral layer.
nism or another can be assessed, however ingenious it may be, compared to the reference fixed-angle systems.

However, this concept of a variable-angle has become particularly intriguing for adjustable and adaptable epiphyseal plates, as we are beginning to see, notably for the ankle and the foot. If the plate is modeled on a convex bone, which is generally the case, with an imposed screw direction, the screws converge and risk conflicting with each other (Fig. 27). Moreover, if the plate is implanted near a joint, it can be difficult to avoid joint penetration. In this case, the choice of the screw angle becomes an essential criterion.

**Screw length**

Screw length is another point that differentiates interlocking screws from common screws. With a common screw, it is sometimes advantageous to take the opposite cortical bone in an attempt to gain maximum purchase, but this is at times harmful and the source of conflict with the neighboring soft tissues (tendons, ligaments). On the other hand, achieving good purchase in the opposite cortical bone is not necessary with locking screws because there is no pullout force. In practical terms, with a locking screw, the screw never has to be offset (Fig. 28), and a slightly short screw would be better than an overly long screw, avoiding a number of potential problems. The type of fracture must nevertheless be taken into account because a screw that is too short will not stabilize a small fragment at the fracture site (Fig. 29). Fixation at the humeral head poses a specific problem: in the elderly or osteoporotic individual, the quality of the cancellous bone in the humeral head is relatively poor and generally the bony zone in which the screw can achieve acceptable purchase is reduced to a thin layer of subchondral bone less than 1 cm thick (Fig. 30). Screw length is therefore a determining factor in fixation stability. Intraoperatively, one should verify that the screws reach the subchondral bone, at the limit of joint penetration (Fig. 31). For the same reason, the pullout strength of these screws working only at their tip is relatively mediocre and one should therefore prefer osteosynthesis with very different screw directions.

**Bone grafting**

Epiphyseal bone grafting with a mechanical objective is not necessary with locking plates. Stability is obtained with the grid effect of different juxta-articular screws that support and join the bone fragments. However, metaphyseal bone grafting can be advantageous if there is bone loss so that interposition of fibrous tissue does not disturb union. However, this graft can only be used if there is no risk of increasing metaphyseal devascularization.

**Diaphysis**

The practical recommendations based on the above-discussed mechanical conditions are currently being validated in clinical practice. Large series of patients are necessary before conclusions can be drawn.

It should first be noted that locking plates are mechanically less satisfactory than an intramedullary nail because stresses are placed off-center. Locking plates are therefore indicated if nailing is impossible.

**Reduction**

Locking plate fixation does not require anatomic reduction at the diaphysis, as we have seen, and the type of reduction is more similar to that used in nailing, respecting the axes and the length. Nevertheless, there is one important difference in that placing an intramedullary nail necessarily implies a certain quality of “anatomical” reduction when the nail is inserted into the fracture site. Nailing can therefore improve an approximate reduction obtained with external procedures. This is not the case with the locking plate and the objective is not only to achieve fixation of the plate to both bone fragments. Satisfactory reduction of the fracture is necessary. What constitutes a “satisfactory” reduction now remains to be determined and only personal experience and the experience of the orthopaedic community will establish reliable criteria. At the very least, it is clear that if muscle or aponeurotic tissue comes between the two fracture fragments, union cannot be obtained. On the other hand, the experience gained with nailing in a closed procedure shows that fracture union is obtained more easily in severe comminution fractures than in certain simple fractures that require more precise reduction. Finally, the experience acquired with interlocking plates is already sufficient to show that reduction quality should not be obtained at the cost of direct handling of the bone fragments, with the inevitable resulting loss of blood supply. Use of toothed bone holding forceps, in percutaneous procedures or through the muscle mass via a superficial approach, can provide acceptable reduction without compromising bone vitality.

**Plate placement**

Anatomic molding of an interlocking plate is not useful because osteosynthesis does not require close contact between the bone and the implant. Premolded plates are generally shaped so that they can be positioned near the bone to avoid displacement caused by reduction when the screws are inserted. Nevertheless, and particularly during fluoroscopic guidance, the plate edges must be aligned with the diaphysis. It is therefore recommended to begin fixation by the ends of the plate. Use of bone holders should
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Figure 32  Too many screws in the fixation of a fracture in a mentally ill patient.

be avoided if possible, taking care to preserve blood supply to the bone as much as possible. All in all, this should be a “minimally invasive” surgery, even in cases of open surgery.

Number of screws
The most common error when beginning to use this technique is placing all the screws (Fig. 32). At first it is difficult to shed this habit acquired with classical osteosynthesis materials. Independently of the cost, which is not insignificant, we have seen that the solidity of an assembly that is generally sufficient with three screws in “normal” bone shows practically no increase beyond four screws per diaphyseal fragment. However, we have also seen that the quality of the fixation increases as the implant length increases. In practice, a sufficiently long implant is used so that one out of two holes can be left free in diaphyseal fixation (Fig. 33).

Figure 33  A. Excessive number of diaphyseal screws in tibial plateau osteosynthesis. B. Three sufficiently spaced diaphyseal screws in normal-quality bone. C. Four spaced diaphyseal screws are indicated in osteoporotic bone.

Position of screws in relation to fracture focus
In simple fractures (Fig. 34), it is recommended to leave three holes free at the fracture zone to increase the system’s elasticity (and thus promote union aiming for “biological” synthesis) and avoid excessive stress on the small part of the implant, which may lead to premature breakage.

In comminution fractures (Fig. 35) or those extended over a greater height, screws can be placed near the focus so that the fixation has adequate stiffness, while avoiding excessive stress on the implant (Fig. 36). From a scientific point of view, it is even possible to establish a screw density index in relation to the number of holes [1,15]. This should be 50% at the diaphyseal fixation, 0 at the fracture zone, and can be higher at the epiphysis, which does not follow the same principles, with the essential point being to obtain a perfectly stable fixation.

Minimally invasive technique
We have seen that to obtain optimal fixation, a long plate is necessary. This is not a problem with locking plates, and if in doubt a longer plate should be preferred over...
Figure 35  Comminution fracture. A. Assembly with screws nearer the fracture zone. B. Limits excess mobility without overloading the plate. 
From Wagner M, Frigg R [1], with authorization of the AO International.

Thus it is possible (Fig. 37) to slide a plate against the bone through a small opening, somewhat as in the nailing technique, and if need be to make a counter incision to verify plate position and fixation. Although requiring some experience, this technique is not a technical feat and can be used in certain locations depending on the regional anatomic conditions.

The location on the humeral diaphysis illustrated in this example proximally maintains the stresses of the classical transdeltoid approach and distally the approach allows one to position the plate in the lateral bicipital groove medially to the radial nerve, which does not need to be folded back or lifted. The technique’s main advantage is not the size of the incisions, but rather maintaining the soft tissues intact. Christoph Sommer (cited in [1], p. 46) has even stated that “the skin protects the fracture from the surgeon”.

The medial side of the tibia is accessible to a purely transcutaneous technique, particularly for fractures of the distal quarter. After reduction, with assistance if necessary from a traction device or an external fixator, the plate is slid under the skin and screwed percutaneously (Fig. 38); this is a good alternative to nailing for very distal fractures (Fig. 39).

Extending this concept to less directly accessible sites has incited the AO to develop the ancillary instrumentation for the LISS technique for the distal end of the femur [6].

Figure 36  Fracture of the distal end of the femur. A. Initial x-ray with third fragment. B. Postoperative follow-up. C. Union at 3 months.

Figure 37  A 68-year-old woman with a complex fracture of the humerus. A. Initial x-ray. B. Intraoperative view with two limited openings. C. Postoperative x-ray. D. X-ray at 10 months. E. Clinical aspect at 10 months.
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and the proximal end of the tibia. Equipped with an aiming device, the plate is inserted through a short incision near the joint (Fig. 40), possibly with reduction of a joint fracture. The diaphyseal fixation is performed using the aiming arm as a nail locking system.

Periprosthetic fractures

In periprosthetic fractures with a particularly severe prognosis with complications in 30% of cases [16], the interlocking plate concept shows its greatest advantages. At the level of the stem, fixation can be obtained with monocortical screws, possibly associated with a cerclage system to prevent pullout (Fig. 41). These fractures usually occur on poor-quality bone in which the fixation obtained with a locking plate is much more solid than with a conventional plate. In most cases, the LISS technique makes it possible not to use an extended opening that may be particularly aggressive (Fig. 42). The ancillary designed for this purpose for the distal end of the femur can also be used for the proximal femur.

Figure 38  Percutaneous osteosynthesis of the distal tibia. A. Supramalleolar incision. B. The plate is slid under the skin of the medial side of the tibia. D. The screws are placed through counter incisions.

Figure 39  A 37-year-old woman with bilateral fractures of the distal tibias. A. Initial x-rays. B. Cutaneous condition on the 4th day. C. X-rays at 6 months. D. Clinical aspect at 6 months.

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Figure 40  Osteosynthesis of the distal femur using the Less Invasive Stabilization System (LISS) technique. A. Limited juxtaepiphyseal approach. B. Diaphyseal locking using the aiming arm.

Figure 41  A. Periprosthetic fracture of the proximal femur. B. Interlocking plate fixation with trochanter screws, monocortical screws, and cerclage.

Economic impact

One of the main obstacles to the use of locking plates is their high cost, or at least this is the main argument advanced to limit their use. We have therefore undertaken a study of theoretical cases stemming from actual representative cases to provide a concrete assessment of the price of the material in France in terms of the overall cost to society of the disease. We used simplified cases with no comorbidity to facilitate comprehension. For each case, we collected the data on the hospitalization costs, postsurgical care (bandages, medical treatments, follow-up consultations and radiographs, and physical therapy sessions), sick leave and compensation, and on the loss of earnings for the health and social services, and/or hospitalization for convalescence. The price of the implant (average price billed to a hospital by the manufacturer) was compared to the total (Table 1).

Case No. 1 was a 53-year-old female teacher who presented a fracture of the distal end of the radius with the

Figure 42  Periprosthetic fracture of the distal femur. A. Initial x-ray. B. Postoperative x-ray with immediate weight bearing. C. Follow-up x-ray at 5 months. D, E. Clinical result at 5 months.
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### Table 1  Simplified cost estimated of six illustrative cases.

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<th>Postoperative care (€)</th>
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<th>Price of material (€)</th>
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</tbody>
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The "hospitalization" column is the price of the Groupe homogène de malades (GHM) provided by the paying organization. The "postoperative care" column includes the price of bandages, medical treatments, follow-up consultations and radiographs, and physical therapy sessions. The "other costs" column covers sick leave and compensation, the loss of earnings for the health and social services, and/or hospitalization for convalescence. The "price of material" column is the average price billed to a hospital by the manufacturer.

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**Figure 43**  Fracture of the distal radius. A. Initial x-ray. B. Interlocking plate osteosynthesis.

The fracture osteosynthesized using a locking plate (Fig. 43). The material accounted for 8% of the overall cost in this case and the total cost of the injury was estimated at €9840.

Case No. 2 involves a 57-year-old woman who worked in upper management in a bank, presenting a fracture of the proximal humerus, osteosynthesized with a locking plate (Fig. 44). The material accounted for 4% of the total cost estimated at €18,800.

Case No. 3 was a 72-year-old retired woman living autonomously in her home, who presented a supra- and intercondylar fracture of the distal end of the humerus osteosynthesized with a double locking plate (Fig. 45). The material accounted for 11% of the overall cost estimated at €14,800.

Case No. 4 involved a 68-year-old male patient who had had a total hip replacement 8 years before. He fell from a height and presented a periprosthetic fracture that was osteosynthesized with a minimally invasive locking plate (Fig. 46). The material accounted for 7% of the overall cost estimated at €20,600.

Case No. 5 was a 25-year-old mechanic whose traffic accident resulted in a lateral Gustilo 2 open fracture of the tibial plateau tibial osteosynthesized with a locking plate (Fig. 47). The material accounted for 6% of the overall cost estimated at €13,800.

Case No. 6 was a 35-year-old roofer who presented a complex fracture of the tibial pilon osteosynthesized with a locking plate following a work accident (Fig. 48). The
Figure 45  Fracture of the distal humerus. A. Initial x-ray. B. Interlocking plate fixation.

Figure 46  Periprosthetic fracture of the proximal femur. A. Initial x-ray. B. Interlocking plate fixation.

Figure 47  Fracture of the tibial plateau. A. Initial x-ray. B. Interlocking plate fixation.

Material ablation is a highly debated subject, as shown by the 2005 SOFCOT teaching conference [17]. Ablation of locking plates seems to be the most feared. The problem is material accounted for 5% of the overall cost estimated at €23,420.

This study has no statistical value but provides an idea of the cost of the implant compared to the overall cost of managing the injury. The high cost of this implant should be relativized as it generally accounts for less than 10% of the overall cost. We purposely did not take into consideration the comorbidities that are frequently part of managing these patients, resulting in a much higher overall cost. Only a large comparative study could provide a realistic idea of the economic impact of using locking plates. Be that as it may, given the clear substantial clinical benefit for a large number of applications, the cost/benefit ratio is undoubtedly highly favorable.

The problem of material ablation

Material ablation is a highly debated subject, as shown by the 2005 SOFCOT teaching conference [17]. Ablation of locking plates seems to be the most feared. The problem is
The concept of locking plates

locking screws jamming in the plate, called "cold welding." However, no fusion has been found and the term "jamming" is more appropriate.

Publications on this subject are rare. The frequency of ablation problems varies from 0% [18] to 4.25% [11] and 17% [19] for 5-mm-diameter screws, and from 8.6% for 3.5-mm-diameter screws (versus 0.5% for nonlocking screws) [18]. Thus, even if in the a single comparative study [18] 3.5-mm-diameter screws seem to be implicated, higher-diameter screws are not exempt from problems.

If a problem occurs, one must first attempt to remove the screw using other means, because the screw head is the first thing to lose its shape. Pattison et al. [20] proposed an unconvincing trick to improve the congruence between the screw driver and the screw head: envelop the tip of the screw driver with the metallic wrapping for surgical suture. A conical reverse-pitch extraction device [18,19], called a tap wrench, would be more effective. This instrument is made of an extremely hard material and breaks easily [19]. It must therefore be used precisely in the axis of the screw to prevent any flexion stress.

It is also possible to attempt to loosen the screw from the plate en bloc, either twisting the plate using it as a handle, with, however, the risk of iatrogenic fracture [18], or with the plate intact if the location is appropriate.

In case of failure, the screw must be separated from the rest of the plate either by destroying the head [21] or by cutting the plate around the screw [18,19]. The screw head can be destroyed by drilling. A few technical points are important. It is not necessary to destroy the entire head with a large drill, but it must be separated from the shaft by drilling into the head down to the root. A perfectly adapted disposable drill is necessary, with the same diameter as the screw shaft, for optimal cutting. The most misunderstood detail is rotation speed. One must drill very slowly, applying firm pressure and constant wet drilling. This way the drill penetrates easily, raising large spiral shavings. In contrast, a drill speed that is too fast is not effective and rapidly overheats, destroying the drill tip.

Metallic debris can be contained by maintaining compresses or with surgical wax.

It should be emphasized that whatever implant is used, material removal begins the day the plate is implanted by respecting proper technique. In the present case, aiming arms must be used to center the screw properly, tightening it properly with a torque-limiting screwdriver and using screwdriver tips that are in good condition.

As for determining which models are at risk, rare problems have been reported with Synthes® plates. However, it must be stressed that this is an older material, a priori the most widely used plate, and certainly the subject of the most publications. Certain competing manufacturers explain this problem by the type of locking or the shape of the screw head (conical), but these references did not get beyond peer review.

As for the material used, titanium is regularly blamed, particularly for the Synthes® material. The above comments also apply to the impact of this argument concerning the Synthes® brand. However, titanium seems to favor jamming, particularly since problems unscrewing end caps for intramedullary nails have also been reported with this type of material [22,23].

No problems have been reported with the Surfix® material. Here again a screwdriver for this purpose should be used so that the screw and locknut are not unscrewed together.
Conclusion

The history of locking plates in its current use is still quite recent. It is a revolution, but, like all revolutions it now needs to stand the test of time. The practical recommendations initially based on experimental theoretical considerations are being validated and refined by daily clinical experience. We are still far from the notions validated by decades of experience in conventional osteosynthesis techniques, but already this new type of fixation has demonstrated their limits. One of the most spectacular is undoubtedly fixation of complex epiphyseal fractures (Fig. 49).

Conflict of interest statement

Patrick Cronier: Ex-member of the Foot and Ankle Expert Group of the AO-ASIF; Unpaid consultant of AO International; Conferences: invitations as a speaker for AO International.

Guy Piétu, Nicolas Bigorre, Florian Ducellier: Invitation as an auditor in AO International courses, travel expenses paid by Synthes®.

Romain Gérard: Invitation as a speaker for AO International courses.

Colin Dujardin: Occasional interventions as a consultant paid by Synthes® France; conferences: invitations as a speaker for AO International courses.

References