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Evolution of fracture treatment with bone plates

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ABSTRACT

Internal fixation of bone fractures by plate osteosynthesis has continuously evolved for more than 100 years. The aim of internal fracture fixation has always been to restore the functional capacity of the broken bone. The principal requirements of operative fracture management, those being anatomical fracture reduction, durable fixation, preservation of biology, promotion of fracture healing and early patient mobilization, have always been crucial but were accomplished to different extents depending on the focus of the specific fracture fixation principle employed. The first successful approach for internal fracture fixation was anatomic open reduction and interfragmentary compression. This secured the fracture fragments, maintained alignment and enabled direct healing of the fracture fragments. However, the highly invasive approach inflicted an immense amount of biologic stress to the area surrounding the fracture site. Modern preferably anatomically pre-contoured locking plates with relative stability of the bone-implant construct enable durable fixation while allowing a less invasive approach that preserves the biology at the fracture site. In contrast to conventional plating, locked plating provides a certain amount of flexibility, which is required to induce the formation of periosteal callus through interfragmentary motion. Most recently the concept of dynamic plating was introduced, which aims to induce more controlled interfragmentary motion and active stimulation of periosteal callus formation. This review article describes the historic development of plating from conventional plating to locked and dynamic plating.

History of fracture treatment by plates

The internal fixation of broken bones only became possible after the introduction of aseptic techniques for open reduction of fractures and direct fixation with metallic hardware. It was Joseph Lister (1827–1912), a British surgeon who promoted the idea of sterile surgical intervention by using carbolic acid (phenol) to sterilise surgical instruments and to clean wounds [1]. This enabled Lister to successfully open closed fractures of the patella and fix them by wiring without causing wound infection and sepsis [2]. Not much later, by the end of the 19th century, the concept of fracture fixation using screws and plates was introduced by several European surgeons, including Carl Hansmann (1853–1917), William Arbuthnot Lane (1856–1943) and Albin Lambotte (1866–1956). Hansmann introduced the concept of temporary internal fixation with nickel coated steel plates [3]. The plates provided a sort of handle which penetrated the skin and was used for percutaneous removal after the fractures were consolidated. William Lane's strict adherence to sterile, no touch procedures enabled him to pioneer the technique of open reduction and internal fixation (ORIF). He employed a variety of steel plates, screws and cables for the stable fixation of fractures if possible with interfragmentary compression to maintain fracture alignment [4]. Lambotte further increased the variety of fractures he treated and the types of implants he used, leading to the inception of contemporary "osteosynthesis", as formulated in 1912: "…the most certain way to obtain a good functional result is to secure a good anatomical result." [5,6] Nevertheless, all the implants used in these times were doomed to fail through metal corrosion and were thus required to be removed soon after completion of fracture healing. Developing implants from corrosion resistant metal alloys which provided sufficient strength and holding power for plates, screws, pins, and cables required engineering knowledge [7]. This eventually led to introduction of the nonferrous steel alloy of cobalt with chromium and molybdenum as well as titanium and its alloys [8,9].

With the availability of more biologically inert materials for fracture fixation, further development of ORIF focused on techniques to optimize the fracture healing process. Robert Danis (1880–1962) studied the biology of fracture healing and published in his "Théorie et pratique de l'ostéosynthèse" that "[Callus] should be regarded as a pathological structure whose formation can usually be prevented by internal fixation" [10]. Consequently, his idea of internal fixation was rigid fixation of fractures obtained through axial interfragmentary compression and prevention of any interfragmentary movements. After Danis' formulation of the principle of rigid fixation and compression, various technical solutions were developed that

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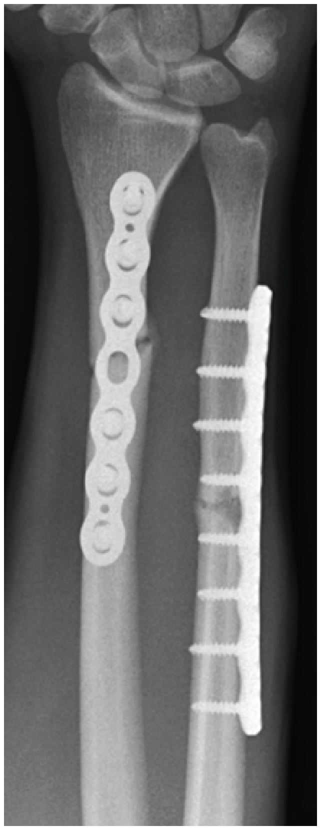

Fig. 1. Internal fixation of a forearm shaft fracture using rigid small fragment compression plates in radius and ulna shaft.

enabled the application of compression to a fractured bone. These included the coapteur of Danis, a compression clasp by Venable [11], the tensioner by Müller and the compression plate by Bagby [12] which was the predecessor of the dynamic compression plates (DCP) by the Arbeitsgemeinschaft für Osteosynthesefragen (AO). In 1950, Maurice E. Müller, who was a student of Danis, gathered a group of Swiss surgeons and formed the AO group with the purpose of conducting research in bone healing, with particular emphasis on the influence of the mechanical environment of the fracture upon its healing pattern. The AO group agreed that effective treatment of fractures should include anatomical reduction, rigid internal fixation, atraumatic techniques and early active mobilization of the injured extremity [13]. An excellent and much more detailed description of the historic development of internal fixation with plates can be found in a historic review article by Philippe Hernigou [14].

Conventional plating

The foundation of the AO and later the constitution of the AO Foundation in 1984 heralded the era of fracture fixation with bone plating. Bone plating fulfils various mechanical functions. Firstly, it transmits forces from one end of the bone to the other and thus enables load transfer and/or load bearing. Secondly, it maintains the mechanical alignment of the fracture fragments. And thirdly, it stabilizes the fracture zone and protects it from overloading, thus eventually enabling the fracture healing process [15]. Conventional bone plating (in contrast to locked plating) relies on absolute stability of the fracture and aims to avoid any relative movement between the fracture fragments (Fig. 1). This stable fixation promotes direct healing of the fracture gap without any callus formation. This process of primary healing is related to remodelling of the fractured zone by intramembraneous bone healing [16] and has been adequately phrased by Danis [10] as “autogenous welding”. Direct healing of fractures can occur by contact healing or by gap healing. Contact healing requires the surfaces of the fractured bone to be in direct contact to each other and leads to remodelling of the fracture zone by newly formed osteons [17]. If the fracture ends are not in direct contact but form a small gap not wider than 0.5mm, woven bone infiltrates the gap before osteonal remodelling can begin

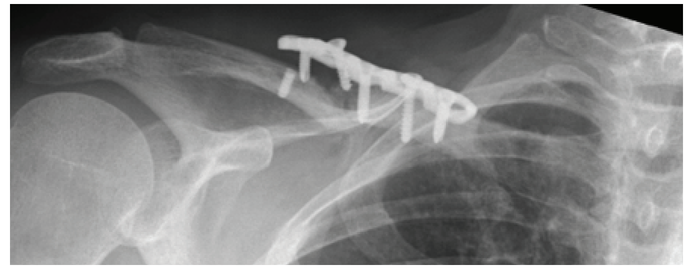

Fig. 2. Secondary metal loosening of bone plate and screw breakage with development of non-union based most likely to be caused by the use of a too short and too thin plate.

The mechanical stability in conventional plating is generated by pressing the plate on to the surface of the bone (Fig. 1). The load transfer of axial forces from the bone to the plate and back to the bone is provided by the friction from the compression of the plate onto the bone surface. The compression between plate and bone is generated by screws, which engage bicortically in the bone. The rounded screw head is free to toggle in the plate hole and therefore pulls the plate tight to the bone surface. The compressional force is directly produced by the tightening torque of the screws. Depending on the frictional coefficient between screw and plate as well as screw and bone, a tightening torque of 2 Nm can easily exceed compressional forces of 1000 N, equivalent to approximately 100 kg load [18]. In order to increase the load which can be transferred by the plate, the friction between bone and plate can be increased by contouring the plate to match the bone surface and also by increasing the tightening screw torque. In particular, increasing the screw torque generates considerable compressional strain on the bone surface and also tension in the cortical bone around the screw threads. Thus, the weakest element in conventional plating is usually the bone at the screw-bone interface. The bone at this interface is already pre-strained by screw tightening and experiences further shear strains if it is loaded during patient activities. Each screw is loaded individually at the screw-bone interface and the outer screws tend to experience the largest interface loads [18]. Not surprisingly, a major clinical failure scenario in conventional plating is screw failure as a result of screw loosening or pull-out (Fig. 2).

The stability of fracture fixation in conventional plating can be further enhanced if the fracture ends are compressed. Interfragmentary compression firstly restores anatomical alignment of the bone and secondly reduces the interfragmentary strain by pre-compression of the fracture fragments. Interfragmentary compression can be obtained by an externally applied compression device, pre-bending of the plate or special design of the holes in the plate which force the bone fragments to glide towards each other during screw tightening. External tensioning devices, which had been temporarily attached to the bone plate, fell out of favour due to the large surgical exposure they required. Plate pre-bending at the site of the fracture (concave bending with the plate lifting off at the site of the fracture) brings the far cortex under compression. During loading the near cortex tends to close, creating further compression at the fracture gap [19]. Self-compressing plates, such as the dynamic compression plate (DCP), convert the screw torque into a shearing force between the plate and bone. The screw head slides down an inclined plane within the plate’s screw hole, converting the descending movement of the screw into gliding of the plate at right angle. The resulting shear force compresses the fracture, thereby increasing the stability of fracture fixation.