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Treatment of femur pseudoarthrosis using wave plate: Evaluation of consolidation and its relationship with graft type

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ABSTRACT

Introduction: In the pathogenesis of femoral pseudoarthrosis, the arched shape of the bone is important when determining traction force on the anterolateral face and posteromedial compression. In plate osteosynthesis, flexion forces affect the implant and can determine its breakdown and osteosynthesis failure. The wave plate seeks to solve the problem by transferring the support to the cortical under the plate or creating the resistance of a leaf spring. Objectives: To evaluate the bone healing pattern of femoral pseudoarthrosis treated with wave plate and its effectiveness in consolidation. Materials and methods: We retrospectively evaluated 18 patients with femoral pseudoarthrosis treated with wave plate. Results: Three months after surgery, one patient presented healing of pseudoarthrosis, six months after surgery, 16 patients presented healing of pseudoarthrosis and at 12 months, all patients had complete bone healing. Regarding the viability of pseudoarthrosis, nine patients had avascular and nine vascular pseudoarthrosis. Fifteen patients had medial cortical failure and three, lateral cortical failure. In all cases, consolidation started where there was bone failure, be it medial or lateral. Discussion: The wave plate technique is well indicated for the existence of cortical bone failure, both in fractures and in pseudoarthrosis. Objective is to stabilize the fragments by transferring and allowing contact between them. The formation of the bone callus occurred in our sample from the region of the bone defect to the region of bone contact, using either a tricortical or cancellous bone graft. The elastic force of the wave and the eccentric distribution of loads in the femur favored the formation of a callus where it was distracted (bone failure) and the location with concentration of movement (proximity between the fragments) was the end of bone healing.

Conclusion: The wave plate technique was effective in bone healing of femoral pseudoarthrosis, promoting consolidation from the cortical failure to the bone contact zone.

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Introduction

Plates have a prominent place among the implants used for treating fractures and their complications. Restoration of anatomical relationships should be sought, using careful technique for preserving vascularization of soft tissue and bone. The principles of fracture stabilization must consider the fracture's characteristics, the limb's injury severity, and the patients' profile, allowing early and safe rehabilitation of the orthopedic injury and the patient [1].

Surgical techniques of osteosynthesis are based on two principles: relative stability and absolute stability. The relative stability involves maintaining the length, axes, and neighboring joints in correct spatial position, allowing controlled mobility sufficient for secondary bone healing (formation of periostal callus) [1].

Conversely, absolute stability results in primary consolidation (without periostal callus formation) as a consequence of anatomical reduction and interfragmentary compression in a good vascularization environment [1].

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The search for absolute stability requires a direct surgical approach as it requires anatomical reduction, which may cause greater damage to vascularization—local biology—thus contributing to eventual devascularization of bone and soft tissues leading to delay or failure in consolidation, refracture, or infection. Perren explains the importance of balance between stability and biology, stating that more flexible fixations with relative stability encourage bone callus formation at the expense of micromovements in the fracture focus, and suggests that indirect reduction is also desirable as it leads to minor tissue damage during surgery [2]. The surgical tactic applying these principles is described by Perren as "biological osteosynthesis." These micromovements are a result of applied load and muscle contraction; on the contrary, the amount of movement between the fractured fragments is inversely proportional to the rigidity of the fixation [3].

The techniques for achieving absolute stability using plates and screws are as follows: lag screws (with or without protection plate), axial compression by plate, support plate, and tension/rod band on a bone with eccentric load [1].

The relative stability technique performed with the plate is known as "bridge" plate, which enables alignment between the main fragments, preserving vascularization of the focus of the fracture to the fullest by maintaining indirect reduction without its violation [1].

Wave plate has principle relative stability, regardless of compression between the main fragments, as anatomical reduction is not performed (this compression is usually performed using an articulated tension device). It can also be used by the abovementioned "bridge" technique, as it avoids manipulation of the focus of the fracture and reduces periosteal injury caused by contact between the plate and the bone away of focus by wave molding [4].

In 1990 Blatter & Weber, in their study entitled "Wave plate osteosynthesis as a salvage procedure," demonstrated the first result of treatment with wave plate, proposing this method for the treatment of pseudoarthrosis [5].

In bones exposed to eccentric axial load, such as the femur, tension and compression forces act on the lateral cortical[1] and medial cortical, respectively. When there is a failure in the cortical *trans* and contact in the cortical *cis*, the conventional installed plate suffers cyclic force in flexion that may not resist until bone healing, suffering fatigue. The function of the wave-shaped plate, associated with bone graft under it, is transforming flexion force during bone failure in the cortical *trans* to compression force in the cortical *cis* where there is bone contact [6]. Thus, the main indication of wave-shaped plate is when there is failure in the cortical *trans* with or without the presence of devascularized bone segment [5–8]. The wave transfers the charges from the cortical *trans* to *cis* and from *cis* to the wave and graft when the latter is used.

Wave molding is performed by bending a straight and long plate at its central region using a molder. This molding on the plate causes its separation from the cortical bone *cis*, giving the osteosynthesis biological and mechanical advantages. From a biological point of view, the separation allows preservation of bone vascularization in the focus; additionally, the absence of plate contact with bone allows better irrigation of the cortical under the plate, avoiding ischemic changes arising from plate pressure against the cortical [5–6,9–10]. The original technique described includes placement of a cortico-cancellous graft below the wave, which further favors local biology [5]. This principle explains the use of wave plate in cases of cortical *cis* failure with placement of cancellous bone graft for structural repair in this region.

[1] In all cases, the plate was positioned to the lateral face of the femur. Thus the lateral cortical corresponds to the cortical cis of the plate and the medial cortical corresponds to the trans cortical of the plate.

In multifragmented fractures, there is greater tolerance to micromovements, as the tissue tension ("strain") is distributed among multiple spaces between the fracture's fragments. In simple line fractures, tension occurring in the single fractured trait between the two fragments is concentrated at that area. In such cases, when it is associated with excessive mobility between these fragments, as in a "bridged" plate, a lesion may occur on the forming bone tissue [11]. Bench test studies demonstrate mechanical advantages of wave molding in situations that simulate fractures with cortical contact, mainly associated with the addition of structured support at the interface between the plate wave and the cortical *cis* (usually tricortical bone graft). This assembly has a mechanical effect, similar to a "leaf spring" type shock absorber wherein wagged metal blades provide elasticity and support cyclic overload. On the contrary, the straight plate is superior in terms of maximum strength and stiffness in the absence of cortical support between the fragments. This can be attributed to decreased material strength due to plate's molding and increased bending forces in it due to further distance from the mechanical axis [6–8].

In the presence of relative stability with the use of wave plate, bone callus formation is stimulated in the fractured bone in addition to further secondary bone healing. However there is an indispensable prerequisite: reasonable vascularization of the main fragments in a mechanical environment with enough stability for cell proliferation. In multifragmented fractures, the wave plate allows movements within the limits of tension tolerated by granulation tissue originating from the fractured hematoma, enabling formation of a viable bone callus [11].

As presented earlier, wave plate is used in situations where there is one cortical with high strain contact and another with cortical failure and low strain. Based on these assumptions, we hypothesized that consolidation occurs initially from the segment with contact, toward segment without cortical support.

Objective

To evaluate, using radiographs, the evolution of bone healing in the treatment of femur diaphysis pseudoarthrosis with "wave plate", its effectiveness and the influence of plate position and type of autologous bone graft used.

Materials and methods

This was a retrospective and observational study involving analysis of medical records and image files.

We included patients who developed pseudoarthrosis of the femur, after surgical treatment using any osteosynthesis method in the acute phase, and underwent correction by wave plate. Patients of both sexes and who were skeletally adults were included (evaluated for the presence or absence of growth physis on radiographs). Patients with osteometabolic diseases, pathological bone fractures, active and/or persistent infections, active rheumatological diseases, nephropathies, and incomplete medical records were excluded.

We reviewed medical records and radiographic files of 18 patients operated from 1990 to 2012 by the Orthopedic Trauma Group of the Department of Orthopedics and Traumatology of the Hospital Irmandade Santa Casa de Misericórdia de São Paulo. Data related to patients' sex and age, trauma origin, fracture classification, and time elapsed between the fracture and pseudoarthrosis treatment were collected. Regarding the implant, we determined plate size, wave length, and "working area" of the implant. Regarding the use of graft, we identified whether it was tricortical (10 cases), cancellous (5 cases), or tricortical and cancellous (3 cases) (Fig. 1). We also used radiographic images to evaluate the evolution of bone healing and determine whether it occurred from cor-

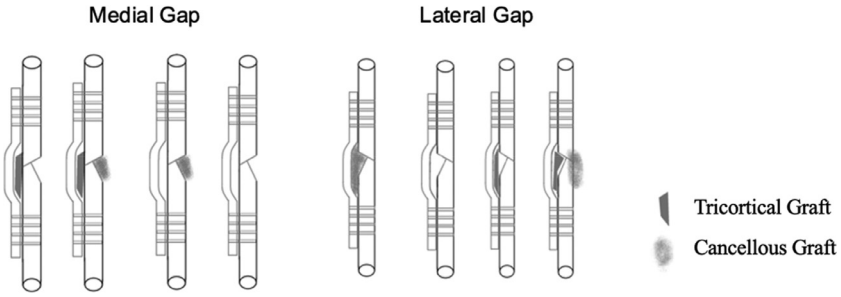

Fig. 1. Possible techniques used in medial and lateral failure
Legend: Schematic design representing the possible forms of osteosynthesis with wave plate in medial and lateral gaps and tricortical and/or cancellous graft.

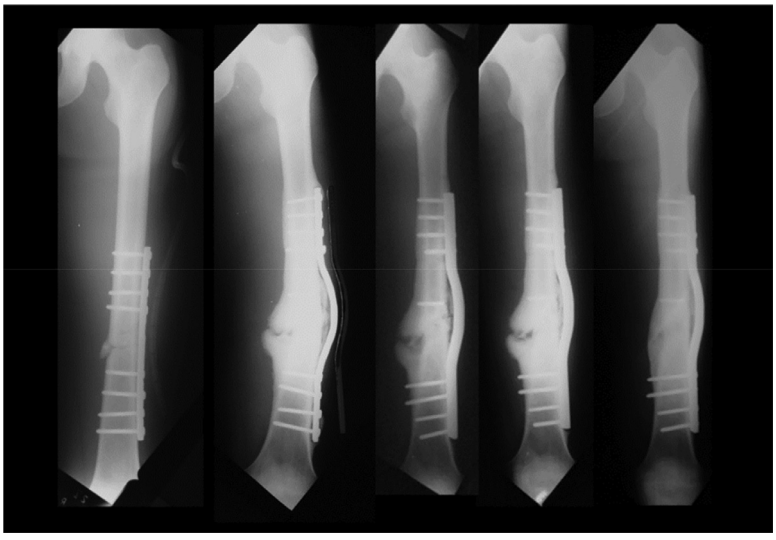

Fig. 2. Example of hypertrophic pseudoarthrosis treated with wave plate associated with placement of cancellous graft under the plate. Consolidation occurred from cortical *cis* to cortical *trans*.

tical *cis* or *trans* and the time elapsed between surgery and observation of consolidation in the four cortices.

The criteria used for technical choice of graft type to be affixed were as follows: cancellous bone when the gap was in the cortical *cis*, (3 cases) and tricortical structured when the failure was predominantly in the cortical *trans* (10 cases). Structured graft associated with cancellous bone was used in three cases of avascular pseudoarthrosis according to Weber and Chec's classification [12]. In two patients, cancellous bone graft was used for cortical *trans* failure because the lateral hypertrophic callus occupied radiographic bone gap under the plate, sometimes replacing the structured graft. For radiographic determination of bone healing, we analyzed two planes of orthogonal projections when, after the appearance of bone bridge and disappearance of fracture line, pseudoarthrosis was considered healed [13].

The mean age of patient sample was 33 years, ranging from 21 to 60. Additionally, 1 patient was female and 17 were male (94%). Regarding the origin of trauma, 14 patients were victims of road accidents: motorcyclistic accidents (n = 9), automobile accidents (n = 3), and run over (n = 2). The other trauma mechanisms included gunshot injury (n = 2), sports trauma (n = 1), and fall from a height (n = 1) (Table 1).

All plates used in the study were straight dynamic compression plate (DCPs), wide for large fragments (4.5 mm with dynamic compression type holes), made of stainless steel. The average size of the plate used was 15 holes, ranging from 12 to 24. The average wave size extended by 6 holes, varying the length of the molding from 4 to 10. Autologous bone graft was used in all patients. Cancellous graft was used in the *trans* cortical for five patients, tricortical graft in cortical *cis* for ten patients, and tricortical graft in cortical *cis* associated with cancellous bone in the *trans* cortical for three other patients.

Table 1
Epidemiological profile of patients.

Pc	Age (years)	Sex	Mechanism of trauma	Conversion (months)
1	29	M	Gunshot injury	21
2	31	M	Sport	12
3	34	M	Auto	12
4	21	M	Motorcycle	2
5	27	M	Auto	12
6	21	M	Auto	13
7	26	M	Gunshot injury	24
8	48	M	Run over	10
9	24	M	Motorcycle	12
10	27	M	Fall from a height	4
11	30	M	Motorcycle	12
12	34	M	Motorcycle	12
13	60	M	Motorcycle	2
14	56	F	Run over	15
15	29	M	Motorcycle	13
16	30	M	Motorcycle	2
17	33	M	Motorcycle	24
18	39	M	Motorcycle	2

Source: Data obtained via survey of medical records and evaluation of patients' images.
Legend: **Pc**—patient; **Age**—in years; **Sex**—M: male, F: female; **Mechanism of trauma**—initial trauma that generated the fracture; **Conversion**—time from first osteosynthesis of fracture to reviewing with wave plate, in months.

Table 2
Number of patients and cortical healed according to time elapsed since the procedure, as evaluated using radiographs.

	1 month	3 months	6 months	12 months	24 months
None	14	5	0	0	0
1 cortical	4	1	0	0	0
2 cortical	0	11	2	0	0
3 cortical	0	0	3	0	0
4 cortical	0	1	13	18	18
No. Patients	18	18	18	18	18

Source: Medical records of the Central Hospital of the Santa Casa de Misericórdia de São Paulo

Table 3
Bone healing pattern related to the type of bone failure and technique employed.

Pc	Failure	Pseudoarthrosis	Graft	1st cort.	Time
1	Trans	Vascular	Tricortical	Trans	6 m
2	Trans	Avascular	Tri + Cancellous	Trans	6 m
3	Trans	Vascular	Tricortical	Trans	6 m
4	Cis	Vascular	Cancellous	Cis	6 m
5	Trans	Avascular	Tricortical	Trans	3 m
6	Trans	Vascular	Tricortical	Trans	6 m
7	Cis	Avascular	Cancellous	Cis	6 m
8	Trans	Vascular	Tricortical	Trans	6 m
9	Trans	Vascular	Cancellous	Trans	12 m
10	Trans	Vascular	Tricortical	Trans	6 m
11	Trans	Vascular	Tricortical	Trans	6 m
12	Trans	Avascular	Tricortical	Trans	12 m
13	Cis	Avascular	Cancellous	Cis	6 m
14	Trans	Avascular	Tricortical	Trans	6 m
15	Trans	Avascular	Tri + Cancellous	Trans	6 m
16	Trans	Avascular	Tri + Cancellous	Trans	6 m
17	Trans	Vascular	Tricortical	Trans	6 m
18	Trans	Avascular	Cancellous	Trans	6 m

Source: Data obtained via survey of medical records and evaluation of patients' images.
Legend: **Pc**—patient; **Failure**—cortical failure; Cis—lateral cortical; Trans—cortical medial; **Pseudoarthrosis**—type of pseudoarthrosis according to Weber and Chec; **Graft**—type of graft used; **1st cort.**—first cortical to heal; **Time**—time until healing of at least 3 cortices of pseudoarthrosis (in months).

Results

Regarding bone healing, consolidation of only one cortical was observed in four patients during the first month. At 3 months, we observed consolidation in at least 2 cortices in 12 patients, 1 cortical in 1 patient, and no signs of consolidation in 5 patients. At 6 months, 16 patients had at least 3 consolidated cortices and 2 had 2 consolidated cortices. After 12 months, they also presented consolidation of the 4 cortices (Table 2).

In the 15 patients with bone failure in the cortical *trans*, we observed that bone healing began in this cortical regardless of the type of affixed graft used. Similarly, the 3 patients with pseudoarthrosis and bone failure in the cortical *cis* began consolidation by the same cortical where the cancellous type graft had been placed (Table 3).

Discussion

The design and use of wave plate for treating pseudoarthrosis, as described by Blatter and Weber [5], has been established in several studies [9,10,14–16]. Its promising results and biomechanical advantages stimulated the study for acute fractures in cases of unavailability of intramedullary rods [4].

Regarding the length of plate and wave, there was no difference between the lesions healing from cortical *cis* to *trans* or vis-a-vis in the study sample. Kojima et al stated that there is no significant biomechanical difference in assemblies with short, long, high, or low waves [6], which is consistent with our findings.

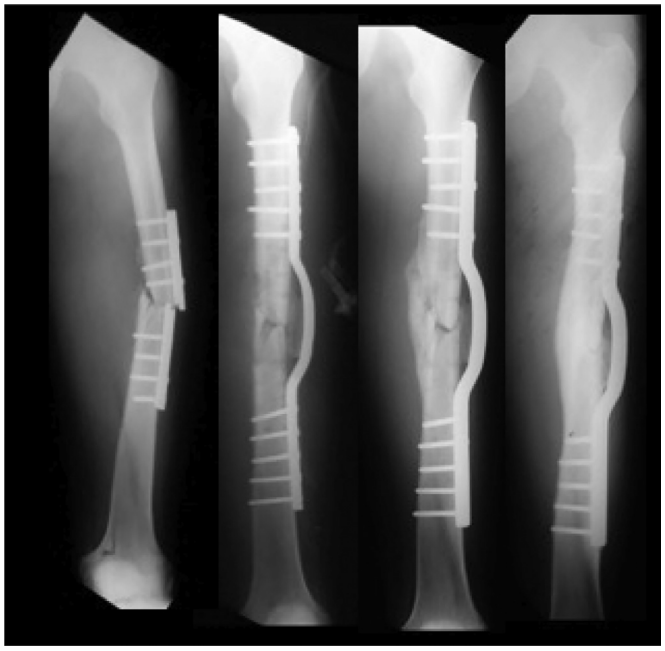

Fig. 3. Evolution of oligotrophic pseudoarthrosis treated with wave plate and tricortical graft. Initial consolidation from the cortical *trans*, even without affixing cancellous graft.

At a 12-month follow-up, femoral pseudoarthrosis was healed in all patients fixed with wave plate. At 3 months, 12 patients (66%) showed signs of bone healing in at least 2 of the 4 cortices and at 6 months, 16 (88%) had radiographic signs of consolidation in at least 3 cortices. These data are similar to the results reported by Ring et al [10] and Kojima et al [14], wherein the mean healing time ranged from 5 to 7 months [5,9,10,14–16].

In 2001, Angelini et al [17] used a bench test to comparatively evaluate the mechanical behavior of bridge DCP and wave plate fixed to wooden rods, simulating several types of long bone diaphysis fractures. The straight plate showed greater stiffness than the wave plate when there was diastasis between the rods (equivalent to a multifragmented fracture). Comparing the rigidity of the two assemblies, it was observed that the wave plate's stiffness was almost twice as that of the straight plate for cases of contact between the rods. Mechanically evaluating several wave plate assemblies on laboratory bench, Kojima et al concluded that placement of a structured block under the wave plate significantly increases rigidity and maximum resistance to deformation, thus being more stable in the presence of medial cortical failure [6]. These findings justify the use of wave plate for increasing the strength of the assembly, hence allowing favorable biological conditions for consolidation before fatigue and avoiding implant failure.

Evaluating the type of graft used, cancellous type graft was predominantly used in lateral cortical failures and bone healing started with this same cortical (three patients) (Fig. 2). In cases of failures in the *trans* cortical, wherein tricortical structured grafts were used with or without cancellous type graft, consolidation started from the medial cortical (Figs. 3 and 4). To the best of our knowledge, this specific finding was not found in the existing literature.

This pattern found in cases with medial failure and lateral structural graft placement was especially interesting, as our initial expectation was that consolidation would occur from a place where there was contact and compression between the fragments to a place where there was bone failure, mainly in the bone with the absence of medial cancellous graft.

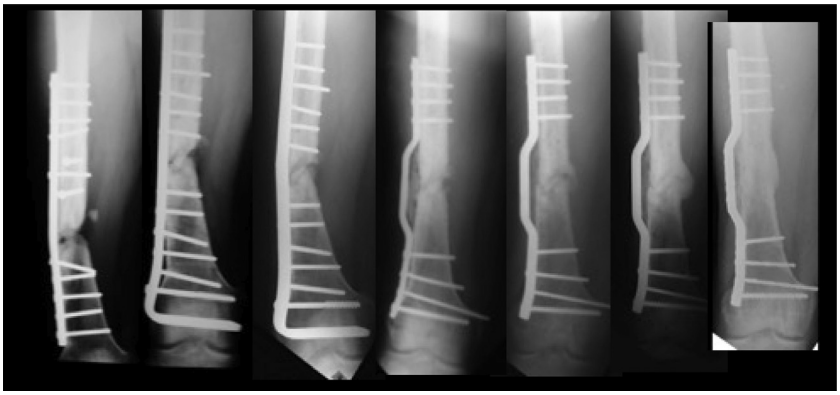

Fig. 4. Example of reoperated avascular pseudoarthrosis with wave plate and placement of tricortical graft and cancellous graft. We observed that consolidation had initiated and the callus was more exuberant in the cortical *trans*.

The wave plate (with or without associated structured graft) follows the principles of relative stability, allowing micromovements in the fracture focus. According to Perren's theory of tension ("Strain"), the presence of micromovements stimulates the formation of periosteal bone callus [2]. Still, following his theory, simple fracture traits tolerate little movement, having their consolidation delayed in a structure such as that of the wave plate. Hence, the lateral cortical with high strain healed more slowly than the medial with lower strain;

Similar to Perren's theory [2], Ilizarov's technique for stretching and bone transports states that tension (distraction) of the cartilaginous or fibrous callus stimulates bone tissue formation [18,19]. The placement of wave plate with discrete valgus molding and the placement of structured graft underneath results in the mechanical effect of the "leaf spring" causing a tension (distraction) in the callus, predominantly in the cortical *trans*.

The findings of cases where cancellous graft was placed in lateral cortical failure are simpler to interpret. They are more stable assemblies because they are supported by medial cortical while the osteoconductive and osteoinductive properties of the cancellous graft favor osteoblastic proliferation in the place where it was affixed. (Figs. 2,3, and 4).

Conclusions

The use of wave plate for treating diaphysial pseudoarthrosis of the femur was efficient in the studied sample.

The orientation of the direction of consolidation is influenced by the position and type of autologous bone graft used. Bone healing begins in the *trans* cortical when the structured graft is placed between the wave and cortical *cis* whereas healing begins in *cis* cortical when cancellous graft is used in the cortical *cis*.

Declaration of Competing Interest

The authors have no conflicts of interest to declare.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.injury.2021.01.045.

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