THE WAVE PLATE METHOD IN NON UNION FEMORAL SHAFT FRACTURES TREATMENT

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SUMMARY

Twenty-five patients with non union femoral diaphyseal fractures treated with the wave plate method were retrospectively studied. Union was achieved in 24 patients (96%) in an average time of 5.32 months, ranging from three to seven months. We observed excellent and good results in 21 patients (84%) in the endpoint evaluation. This treatment approach didn't cause leg-length discrepancy. No rotational deviations were seen. The range of motion of hips and knees was not affected, although in four patients (16%) knee flexion restraint was found, but previously to the wave plate treatment. Two patients (8%) presented a deep infection during the treatment with the wave plate, recurrent to previous infectious process. Loosing plate occurred in the ninth post-operative in one patient (4%), although bone union has occurred. In another patient (4%) the wave plate has broken within 14 months postoperatively, leading to the replacement of the first wave plate to a new one with subsequent union. Nevertheless, method failure was considered. The wave plate is a treatment option for non-united femoral fractures due to its biomechanical properties favoring bone union, providing stability without jeopardizing blood intake, with biological synthesis characteristics.

Keywords: Pseudoarthrosis; Bone Plates; Femoral fractures.

INTRODUCTION

Many surgical techniques are used for treating femoral diaphyseal fractures in adults and they present some complications, one of which is the pseudoarthrosis, rare in literature, which challenges the orthopaedic doctor.

Blatter G et al.[1] described, in 1990, a biomechanical study of the wave plate and its use for the treatment of failures of synthesis materials, delayed union and pseudoarthrosis on femoral diaphyseal fractures, targeting bone union. The method proposed constitutes a new treatment option, being easily available, low-cost, ratifying biological and mechanical advantages of the wave plate when compared to traditional straight plate.

This paper is aimed to evaluate the use of the wave plate in 25 femurs (25 patients) with non-united diaphyseal fractures of the femur and to demonstrate the efficiency of the method.

MATERIALS AND METHODS

Within the period of July 1991 to October 1998, at Hospital São Paulo and in two other institutions, 25 patients with pseudoarthrosis have been treated by the wave plate method, where large, with big fragments DCP (Dynamic Compression Plate) and LCDCP (Low Contact Dynamic Compression Plate) and bicortical iliac bone graft were used, and were prospectively followed up.

A protocol was developed in which patients had to be followed up until the end of the study.

Fractures were considered as diaphyseal when located below minor trochanter up to adductors tuberculum or condyles protuberance[2].

The AO-ASIF Classification was adopted - (Arbeitsgemeinschaft für Osteosynthesefragen – Association for the Study of Internal Fixation)[3] for categorizing fractures (Figure 1) and, for pseudoarthroses, the classification recommended by Weber[4] was employed (Figure 2).

Inclusion criteria:

Patients experiencing femoral diaphyseal fractures treated with compression plates and evolving with delayed union, pseudoarthrosis or failure of synthesis material (rupture or loosening) were included. The wave plate was prescribed when X-ray signs of instability at fracture core were found: identification of avascular bone, persistent core movement forming irritative callus, bone absorption or failure of synthesis material, such as rupture, loosening or plastic deformity.

Exclusion criteria:

Patients presenting with infection and those treated with intramedullary nails have been excluded from study.

Data were collected for the patients, according to a numeric order, name's initials, original hospital, age, gender, affected side, anatomical site, AO classification, date of wave plate implantation, indication of the wave plate and union disorders (Table 1).

Study conducted at Paulista Medical School – Federal University of São Paulo – DOT.EPM/UNIFESP.

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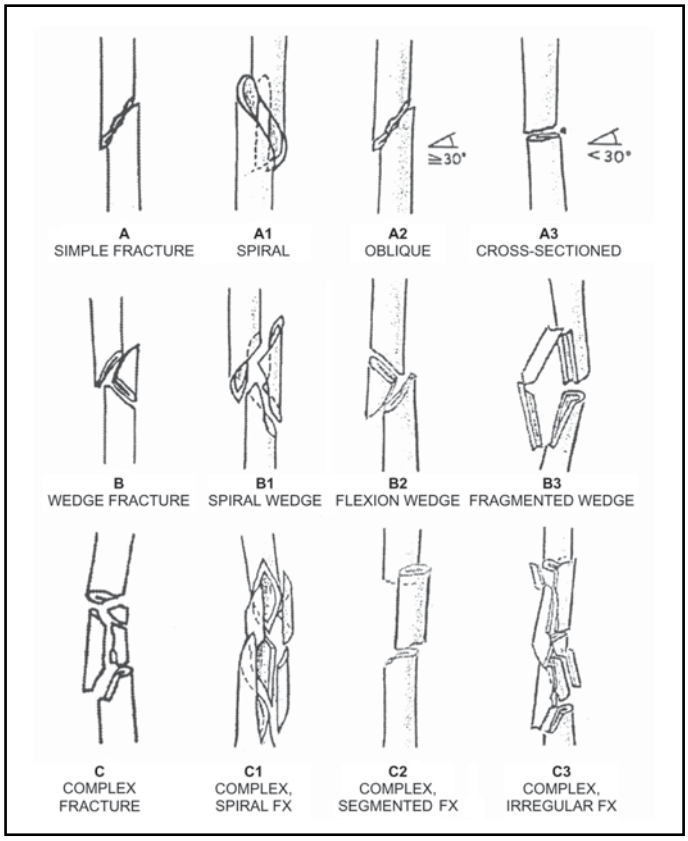
From the 25 patients submitted to surgery, 14 had their right side affected (56%) and 11 the left side (44%); 21 were closed (84%) and four open (16%) at the acute phase. Patients' ages ranged from 16 to 53 years old, with an average of 26.68 years, being 19 males (76%) and six females (24%).

Regarding fracture site, one patient (4%) presented with a fracture on the proximal third, 22 (88%) on the medial third, and two (8%) at the distal third of the affected femur.

Fractures were categorized according to AO Classification, with four being A2-type (16%), two A3-type (8%), 12 B1-type (48%), one B2-type (4%), two B3-type (8%) and four C1-type (16%).

Lack of support was observed at the medial cortical in femoral diaphyseal fractures in 23 patients (92%).

Spongy bone graft was used in the first surgery for fracture stabilization with plate and screws in 12 patients (48%).



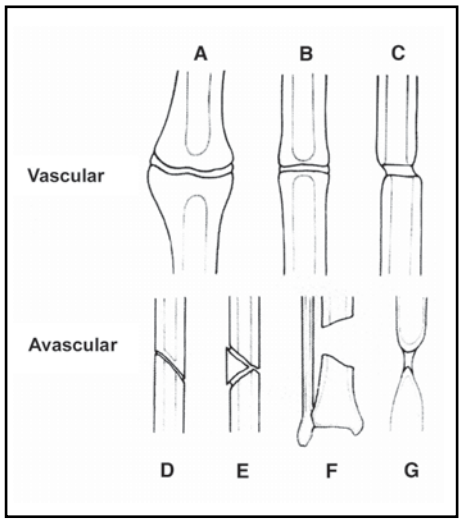
A=simple fracture: A1=spiral, A2=oblique, A3=cross-sectiones. B=wedge fracture: B1= spiral wedge, B2= flexion wedge, B3=fragmented wedge. C= complex fracture: C1=complex spiral FX, C2=complex segmented FX, C3=complex irregular FX.

Figure 1- *AO Classification of femoral diaphyseal fractures.*

Three patients (12%) had been submitted to two surgeries before wave plate was indicated, and the other 22 (88%), only a prior surgery. All initial surgeries employed DCP straight plates and in patients with two previous surgical interventions, the straight plate was replaced by another straight plate. One patient was treated with the DCP plate, but with biological synthesis (bridge plate) and the second surgery was performed for placing a bone graft; still, the failure of synthesis material occurred.

Plate replacement was chosen in 16 patients due to synthesis rupture (64%), three due to non union (12%), and six due to material loosening (24%).

Twelve patients have been identified with non united fracture of the femur (48%) and delayed union in 13 patients (52%), and, according to the classification[30] of pseudoarthrosis, 10 patients (77%) with hypertrophic pseudoarthrosis and three (23%) with atrophic pseudoarthrosis.



Vascular: A = hypertrophic (elephant foot), B = normotrophic (horse foot), C= hypotrophic. Avascular: D = torsion wedge, E = multifragmented, F = bone gap, G= atrophic.

Figure 2 - *Weber's Classification of pseudoarthrosis.*

An incision is performed on the lateral surface of the thigh, having major trochanter and lateral femoral condyle as parameters, trying to follow the same incision used in the first surgery. Fascia lata is addressed through a parallel incision performed at skin level, and muscle access is performed according to previous surgery (trans- or retro-vastus lateralis). Reaching to bone plane, adherences are detached and eventual periosteal reactions are osteotomized to allow for the removal of initial synthesis material positioned laterally to the bone.

After the identification of the pseudoarthrosis core, eventual deviations are corrected and dispersiostization is performed as minimum as possible.

Plate modeling to a wave form is done in its medium portion, where the extension varies according to pseudoarthrosis dimension, however, as shortest as possible (Figure 3). A bicortical graft is removed from iliac bone, contralaterally to operated side, with the previously molded wave thickness (one centimeter, in average). If this region had been addressed in a previous surgery, a new graft was removed from the side ipsilaterally to the affected femur.

Fixation of the DCP or LCDCP plate molded to the bone is done through big-fragment screws proximally and distally (eight to 10 proximal and distal corticals), changing plate positioning in order to not to match the holes of previous screws.

When graft area is considered very large or unstable, it can be fixed to the femoral diaphysis with screws, transfixing it across the plate, without the need of thread reaching medial cortical.

After plate and graft are fixed, surgical wound wash is performed with approximately five liters of saline solution for removing clots and devitalized tissues. Then, suture is performed by planes, leaving two aspiration drains. Those must be removed within 24 – 48 hours after surgery, depending on the drainage volume.

Patients are kept with occlusive patch and flexed knee at 90º for three days. Active movements are encouraged since the first post-

SURGICAL TECHNIQUE DESCRIPTION:

The patient is positioned in dorsal decubitus in an ordinary surgical table with hips slightly upwards at the side to be operated (cushion).

operative period. Physical therapy is more intense, with isometric and active assisted exercises after drain is removed.

Initial load on the operated limb was 20% of body weight. Total discharge is allowed when X-ray signs evidence bone union.

Bone non union within up to six months after initial surgery with straight plate was considered as delayed union, and non united fractures in more than six months were considered as pseudoarthrosis.

Numeric Order	Original Hospital	Initials	Age	Gender	Affected side	Fracture site	Classification of First Fracture (AO)	Date of wave plate	Indication	Union Disorder
1	HSP	RCJL	18	M	L	MEDIUM 1/3	B3	JUL/91	BREAKAGE	H PSEUDOARTHROSIS
2	HSP	AGO	21	F	L	MEDIUM 1/3	B1	JUL/91	BREAKAGE	DELAY
3	HSP	JTS	37	F	L	MEDIUM 1/3	B2	MAR/92	BREAKAGE	A PSEUDOARTHROSIS
4	HSP	GMA	53	M	R	MEDIUM 1/3	C1	SEP/92	BREAKAGE	DELAY
5	HSP	JRMP	28	M	R	MEDIUM 1/3	A2	NOV/92	NO CALLUS	DELAY
6	HSP	EFS	22	M	R	MEDIUM 1/3	B1	DEC/92	NO CALLUS	H PSEUDOARTHROSIS
7	HSP	OMF	29	M	R	MEDIUM 1/3	B3	APR/93	BREAKAGE	DELAY
8	HSP	JLS	27	M	R	MEDIUM 1/3	B1	AUG/94	BREAKAGE	DELAY
9	HSP	MMD	51	F	R	MEDIUM 1/3	A2	OCT/94	LOOSENING	DELAY
10	HSP	MASP	21	F	L	MEDIUM 1/3	A2	MAR/95	BREAKAGE	H PSEUDOARTHROSIS
11	HSP	OGO	25	M	R	MEDIUM 1/3	B1	APR/96	BREAKAGE	DELAY
12	HSP	JA	23	M	L	MEDIUM 1/3	B1	MAY/96	LOOSENING	DELAY
13	HSP	KCVB	20	M	R	PROXIMAL 1/3	B1	OCT/97	BREAKAGE	DELAY
14	HSP	MTL	29	M	R	DISTAL 1/3	B1	OCT/07	BREAKAGE	H PSEUDOARTHROSIS
15	HSP	RS	17	F	R	MEDIUM 1/3	B1	OCT/97	BREAKAGE	A PSEUDOARTHROSIS
16	HSP	AS	30	M	R	MEDIUM 1/3	C1	NOV/97	LOOSENING	H PSEUDOARTHROSIS
17	HSP	LJL	27	M	L	MEDIUM 1/3	A2	MAR/98	LOOSENING	DELAY
18	HSP	JNS	26	M	L	MEDIUM 1/3	B1	MAR/98	LOOSENING	H PSEUDOARTHROSIS
19	HSP	GCL	24	M	R	MEDIUM 1/3	B1	APR/98	LOOSENING	DELAY
20	HSP	MAS	16	F	R	MEDIUM 1/3	B1	MAY/98	BREAKAGE	H PSEUDOARTHROSIS
21	HSP	RTK	21	M	L	MEDIUM 1/3	A3	MAY/98	NO CALLUS	A PSEUDOARTHROSIS
22	HSP	JPM	16	M	R	MEDIUM 1/3	B1	JUL/98	QUEBRA	DELAY
23	HSP	FE	19	M	L	DISTAL 1/3	A3	JUL/98	QUEBRA	H PSEUDOARTHROSIS
24	Limeira	NF	46	M	L	MEDIUM 1/3	C1	SEP/98	BREAKAGE	H PSEUDOARTHROSIS
25	Diadema	RSAV	41	M	L	MEDIUM 1/3	C1	OCT/98	BREAKAGE	H PSEUDOARTHROSIS

Abbreviations: HSP=Hospital São Paulo; M=male; F=female; L=left; R=right; P=plate; H=hypertrophic; A=atrophic.
Source: Hospital São Paulo, Hospital de Limeira, and Hospital Estadual de Diadema

Table 1- *Data of the 25 patients with femoral diaphyseal fracture in non union treated with the wave plate method according to a numeric order, original hospital, name initials, age, gender, affected side, anatomical site, AO classification, date of wave plate implantation, indication of the wave plate, and union process change.*

Evaluation criteria:

Shortening: lower limbs equalization grade five, with pre-existent shortening to the use of wave plate were graded three, and those with a higher degree of shortening existing prior to surgery with wave plate were graded zero.

Angular deviations (varus and valgus): no deviation, grade five; with up to five degrees of deviation, grade three, between 5 and 10 degrees, grade one; and grade zero for those presenting deviations above 10 degrees.

Knee motion: normal range of motion, grade five; flexion up to 90 degrees, grade three; flexion below 90 degrees, grade zero.

From this population, outcomes for wave plate treatment were assessed. Patients were considered as EXCELLENT when achieved a 15 score, GOOD when they achieved a 14 – 10 score, FAIR when scores were between 9 – 7, and BAD when scores were below 7 (Table 2).

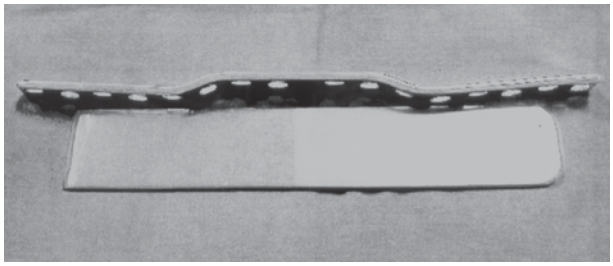


Figure 3 - *Plate molded with both ends lifted approximately 0.5 cm from a flat surface.*

SCORES	SHORTENING	ANGLE DEVIATIONS (VARUS AND VALGUS)	JOINT RANGE OF MOTION
0	Greater than previous surgery with the wave plate	> 10º	Flexion < 90º
1	-	05 - 10º	-
3	Existing previously to the wave plate	< 05º	Flexion up to 90º
5	Lower limbs equalization	No deviation	Normal

Source: Hospital São Paulo, Hospital de Limeira and Hospital Estadual de Diadema

Table 2 - *Scores assessing shortening, angle deviations and joint range of motion.*

RESULTS

The outcomes of 25 patients treated with wave plate have been assessed during the post-operative period. Dada according to a numeric order, date of endpoint review, time to union, complications during treatment, discrepancy of lower limbs, angle deviations and knee joint range of motion after union are found on Table 3.

Bone union occurred in 96% of patients, in an average time of 5.32 months, ranging from three to seven months. Follow-up time ranged from five months to two years and nine months.

There were no changes in the final length of lower limbs in 18 patients (72%).

In 20 patients (80%) no angle deviations were seen at the end of treatment. Four (16%) achieved femoral union with a varus deviation and one (4%) achieved union with a valgus deviation. No rotational deviations were seen.

The range of motion of the hip joint did not change in any case. Knee joint was not restricted in 84% of the cases (21 patients). There was flexion restraint in 12% of the cases.

One patient (4%) presented with a stiff knee before wave plate implant. During surgery, after manipulation, a range of motion of 5 to 20º was achieved.

Complications were as follows: one patient with fracture, one patient with loose plate, one with broken plate and two infections.

Clinical evaluation of the 25 patients is shown on Table 4.

DISCUSSION

Fractures union process involves bone contact among fragments, stability and adequate blood supply for not becoming jeopardized[5-17].

The interruption of the bone union process causes the delayed union or pseudoarthrosis. Some authors rely on the evolution time and consider as a delayed union the one not showing union in up to six months, ranging from four to six months, and as pseudoarthrosis when union does not happen before six months [3,18-22]

Other authors believe that the threshold between delayed union and pseudoarthrosis are inaccurate, and they consider as pseudoarthrosis any deviation on union process, because this would be a natural development of a delayed union, provided no medical intervention occurs[4-6,12,23,24].

Pseudoarthrosis causes are related to: a) severity of fracture involving soft parts injuries, location, comminution, infection, associated arterial and nervous injuries; b) instability of the fixation method; c) inappropriate fixation; d) absence of bone contact[6-8,10,12,16].

The method selected in this study recommends the use of cortical-spongy bone graft in all patients, regardless of the kind of pseudoarthrosis involved, which is believed to be the determinant biological factor in union process.

Fibrous tissue between bone fragments in the 25 patients treated with the wave plate was not removed in order to preserve vascularization, being also associated to the cortical-spongy bone graft, assuring this tissue's feasibility.

The wave plate was chosen for the treatment of non union femoral diaphyseal fractures, due to the use of a DCP plate initially, which should be removed, even though it was already causing an injury of the periosteal flow due to bone contact beneath the plate. Thus, we tried to avoid producing another vascular injury, this time a medullary one, by switching the initial technique, which would occur if an intramedullary nail was to be used.

Femur arching determines a traction force on lateral cortical and a compression on medial cortical, which may lead to synthesis failure (fatigue fracture) as a result of the lack of medial support (Figure 4).

The wave plate changes this distribution due to its mechanical properties. It is known by basic mechanics that when an area is submitted to an eccentric load, tension is generated determining the arching force, and, if the area is doubled, this force will be reduced to one third (Figure 5).

The wave plate used in femoral diaphyseal fractures with no medial support increases the load area, which then ranges from the medial contact region to the wave plate, thus better distributing the arching force, reducing the compression force at the medial cortical and displacing traction force to the plate. In this case, the neutral fiber, a line away from forces action at the threshold between compression and traction regions, is displaced to the space between the bone and the plate (Figure 6).

With medial support, the wave plate causes a displacement of the neutral fiber, towards the plate, so that the fracture remains upon a distribution of forces following the same biomechanical principles described above by the increased load area, keeping compression over the fracture core (Figure 7).

NUMERIC ORDER	ENDPOINT REVIEW	UNION TIME	COMPLICATIONS	SHORTENING	ANGLE DEVIATIONS	JOINT R. OF MOTION	FINAL OUTCOME
1	FEB/92	7	NONE	NO	NO	NORMAL	EXCELLENT
2	NOV/91	5	NONE	NO	NO	NORMAL	EXCELLENT
3	APR/95	6	NONE	NO	NO	NORMAL	EXCELLENT
4	APR/93	6	NONE	NO	VARUS = 11°	NORMAL	GOOD
5	MAR/94	6	NONE	NO	NO	NORMAL	EXCELLENT
6	FEB/94	3	NONE	NO	NO	NORMAL	EXCELLENT
7	FEB/95	7	FEMORAL SUPRACOND. FRACT.	05 CM	VARUS = 10°	FLEXION = 90°	FAIR
8	JUN/96	5	NONE	NO	NO	NORMAL	EXCELLENT
9	JUL/97	6	NONE	NO	VARUS = 18°	NORMAL	GOOD
10	OCT/95	5	NONE	NO	VALGUS = 03°	NORMAL	GOOD
11	OCT/96	5	NONE	NO	NO	NORMAL	EXCELLENT
12	MAR/97	4	NONE	02 CM	VARUS = 18°	NORMAL	FAIR
13	MAY/99	6	BROKEN WAVE PLATE	NO	NO	NORMAL	BAD
14	SEP/ 98	7	NONE	NO	NO	NORMAL	EXCELLENT
15	JUL/98	4	NONE	2.5 CM	NO	FLEXION = 110°	GOOD
16	MAR/99	7	INFECTION RELAPSE	02 CM	NO	FLEXION = 20°	FAIR
17	JAN/99	6	NONE	NO	NO	NORMAL	EXCELLENT
18	JAN/99	5	NONE	NO	NO	NORMAL	EXCELLENT
19	JAN/99	3	NONE	NO	NO	NORMAL	EXCELLENT
20	APR/99	6	INFECTION RELAPSE	NO	NO	NORMAL	EXCELLENT
21	MAY/99	7	LOOSE WAVE PLATE	02 CM	NO	FLEXION = 120°	GOOD
22	FEB/99	5	NONE	NO	NO	NORMAL	EXCELLENT
23	APR/99	4	NONE	NO	NO	NORMAL	EXCELLENT
24	APR/99	5	NONE	02 CM	NO	NORMAL	GOOD
25	APR/99	3	NONE	02 CM	NO	NORMAL	GOOD

Source: Hospital São Paulo, Hospital de Limeira and Hospital Estadual de Diadema

Table 3 - *Final outcomes of 25 patients treated for femoral diaphyseal fractures, in non union, with wave plate, according to endpoint review date, union time, complications, shortenings, angle deviations and knee joint range of motion.*

NUMERIC ORDER	SHORTENING	ANGLE DEVIATIONS	JOINT R. OF MOTION	TOTAL SCORE
1	5	5	5	15
2	5	5	5	15
3	5	5	5	15
4	5	0	5	10
5	5	5	5	15
6	5	5	5	15
7	3	1	3	7
8	5	5	5	15
9	5	0	5	10
10	5	3	5	13
11	5	5	5	15
12	3	0	5	8
13	0	0	0	0
14	5	5	5	15
15	3	5	3	13
16	3	5	0	8
17	5	5	5	15
18	5	5	5	15
19	5	5	5	15
20	5	5	5	15
21	3	5	3	13
22	5	5	5	15
23	5	5	5	15
24	3	5	5	13
25	3	5	5	13

Source: Hospital São Paulo, Hospital de Limeira, and Hospital Estadual de Diadema

Table 4 - *Clinical evaluation of the 25 patients with femoral diaphyseal fractures, in non union, treated with wave plate, according to numeric order, shortening, angle deviations, joint range of motion, and scores sum.*

Union time for femoral diaphyseal fractures treated with the wave plate occurred in average within 5.32 months, ranging from three to seven months, which is considered a good outcome when compared to associated literature[19,20,25-31].

Wu and Shi[22] employed four treatment methods for pseudoarthrosis. The intramedullary nail showed the shortest union time – three months – and the straight plate, four months.

Any method selected for treating pseudoarthrosis imposes complications: shortenings, angular and rotational deviations, and joint stiffness as the most common sequels[18,22,32].

By assessing the length of affected limb one may say that the selected method does not cause shortening, because all patients presenting limbs dysmetria (28%) presented this change previously to the wave plate implantation. Furthermore, by preserving interfragment fibrous tissue and with the absence of bone resection, in no way could the method cause or contribute to the discrepancy between the limbs.

Hip joint presented a normal range of motion in all patients and the knee was not affected by the method, because patients presenting union with restrained range of motion also presented with previous changes.

Literature has not described synthesis material breakage or plate loosening[30] due to wave plate's property of distributing the cyclical force to the large area of the wave, instead of focusing a limited region, as occurs with the straight plate. Biomechanical tests, however, show that the wave plate tends to break at the screw hole distal to the curve.

Bone union occurs beneath the plate due to the bone graft, which stimulates regenerative process, allowing blood vessels to penetrate, and due to the excellent mechanical system [1] that changes the distribution of forces, allowing for the union to happen without submitting synthesis material to overload.

Although synthesis failure occurred in one of the patients, and a loose plate in one patient else, the outcomes were good and excellent in 84% of the cases, ratifying the wave plate as an excellent treatment option for patients with femoral fracture initially and unsuccessfully treated with the DCP plate.

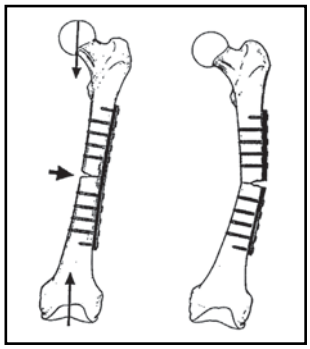


Figure 4 - *Lack of medial support with synthesis failure due to fracture by material overload.*

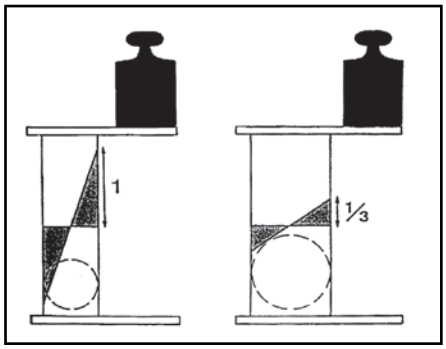


Figure 5 - *The increased surface (2 times) bearing an eccentric load makes generated force to be reduced to 1/3 of the original one.*

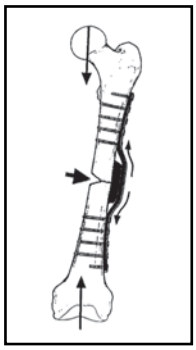


Figure 6 - *Lateral cortical is submitted to traction force and medial cortical is submitted to compression force.*

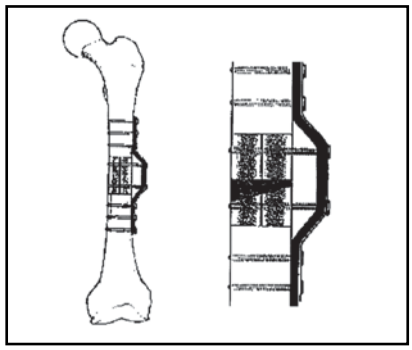


Figure 7 - *Location of the neutral fiber when using the wave plate, and plate region submitted to overload, smaller affected area.*

CONCLUSIONS

1.The treatment of non union in femoral diaphyseal fractures with the wave plate provides good and excellent outcomes, with a high union rate (96%) widening treatment options.

2.Final clinical evaluation of the patients showed 84% of good and excellent results, evidencing the efficiency of the treatment method.

3.The material used for wave plate therapy is cheap, being available at the majority of services in our field.

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