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Two load sharing plates fixation in mandibular condylar fractures: Biomechanical basis

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SUMMARY. **Mandibular condylar fractures have a high incidence but there is no consensus regarding the best choice of osteosynthesis. From a review of the literature, it is evident that the technique used most frequently for fixation is the positioning of a single plate despite complications concerning plate fracture or screw loosening have been reported by various authors. Different studies have highlighted that the stability of osteosynthesis is correlated with the mechanical strains occurring in the condylar region, generated by the muscles of mastication. The aim of our study was, through a mandibular finite element model (FEM), to confirm this correlation and to analyse the behaviour of single and double elements of union in the fixation of mandibular subcondylar fractures. We concluded that the use of two plates provides greater stability compared with the single plate, reducing the possibility of displacement of the condylar fragment. Therefore we recommend that this technique should be adopted whenever possible.** **© 2009 European Association for Cranio-Maxillo-Facial Surgery**

Keywords: **mandibular condylar fractures, compressive stress patterns, tensile stress patterns, fixation with two plates**

INTRODUCTION

Between 17.5% and 52% of all mandibular fractures are in the condylar region (*Zachariades* et al., 2006). Even if the are despite being very common, their treatment remains controversial (*Cascone* et al., 2008). In contrast to the non-surgical approach to condylar fractures in children, for which there is a good consensus of opinion, the treatment of condylar fractures in adults is still a much debated topic (*Ellis* and *Dean*, 1993). Although there is still controversy about the therapy for condylar fractures in adult patients, many surgeons favour open treatment of displaced condylar fractures, because such reduction and rigid fixation allows good anatomical repositioning and immediate function (*Choi* et al., 2001). Different types of rigid internal fixation are available for the reduction and fixation of condylar fractures (*Tominaga* et al., 2006). Such techniques are the result of technical progress which has led to the development of numerous osteosynthesis methods in clinical routine (*Seemann* et al., 2007). However, there is no consensus regarding the choice of the best type of osteosynthesis (*Tominaga* et al., 2006). From data in the literature, it is evident that the technique used most frequently is the positioning of a single plate, despite complications concerning plate fracture or screw loosening having been reported by various authors (*Gysi*, 1921; *Lindahl*, 1977; *Kubein* and *Jähnig*, 1983; *Hart* et al., 1988; *Iizuka* et al., 1991; *Paydar* et al., 1991; *Sargent* and *Green*, 1992; *Ellis* and *Dean*, 1993; *Meijer* et al., 1993; *Krenkel*, 1994; *Throckmorton* and *Dechow*, 1994; *Hammer* et al., 1997; *Choi* et al., 1999, 2001; *Meyer* et al., 2002, 2006; *Rallis* et al., 2003; *Tominaga* et al., 2006; *Seemann* et al., 2007). On the other hand, favourable data have demonstrated the greater stability of the double plate compared with the use of the single plate in the fixation of mandibular condylar fractures (*Gysi*, 1921; *Lindahl*, 1977; *Kubein* and *Jähnig*, 1983; *Hart* et al., 1988; *Iizuka* et al., 1991; *Paydar* et al., 1991; *Ellis* and *Dean*, 1993; *Meijer* et al., 1993; *Krenkel*, 1994; *Hammer* et al., 1997; *Choi* et al., 1999, 2001; *Meyer* et al., 2002, 2006; *Rallis* et al., 2003; *Tominaga* et al., 2006), but at the cost of an additional plate and longer operation times (*Rallis* et al., 2003). Despite this, there are no clinical studies that have proved the usefulness of a 2-miniplate system (*Choi* et al., 2001). Different studies (*Paydar* et al., 1991; *Sargent* and *Green*, 1992; *Meijer* et al., 1993; *Throckmorton* and *Dechow*, 1994; *Meyer* et al., 2002, 2006; *Rallis* et al., 2003; *Seemann* et al., 2007) have highlighted that the concept of the stability of osteosynthesis is correlated with the mechanical strains that occur in the condylar region, generated by the masticatory muscles. The goal of this study is to analyse the biomechanical stability of two elements of union compared with a single element of union in the treatment of mandibular condylar fractures, through the use of a mandibular finite element model (FEM).

MATERIALS AND METHODS

We carried out our own investigations by means of a mandibular FEM.

The starting model is based on a real surface mock-up of the mandible, carried out through a triangulation of the same in Virtual Reality Modeling Language (VRML) (*Verna* et al., 1999) (Fig. 1).

The model created is three-dimensional and takes into account the anisotropic properties typical of the mandibular bone; this allows there to be a correspondence between the simulated and the real mandible. The mandible was divided according to stiffness: in the inner area, a softer spongy structure, and, in the outer area, a harder structure.

These areas are characterized by a variable and growing stiffness passing from the posterior to the anterior aspect of the mandibular body.

The mandible was subjected to six muscular forces active during mouth closure: anterior temporalis (AT); posterior temporalis (PT); superficial masseter (SM); deep masseter (DM); medial pterygoid (MP); and lateral pterygoid (LP).

Mastication is accomplished through the activity of these muscles. The values of these forces expressed in MegaPascal (MPa) were obtained from literature (*Paydar* et al., 1991) (Table 1).

In the model the intensity and the direction of the muscular action and the mastication pressure exerted were considered to be constant (this latter is not in fact rigorously constant because the occlusal forces increase by moving themselves from the incisor area to the first molar) and equal to the maximum values. The occlusal point considered was modelled with a knot tied in a direction normal to the occlusal plane. The boundary conditions (the conditions tied) used to simulate the temporo mandibular joint were carried out through some springs in direction normal to condylar surfaces, distributed on the anterior-superior side of the condyles, in order to make them work only in compression. The model proposed, and already quoted in literature (*Gysi*, 1921; *Barbenel*, 1972; *Champy* and *Lodde*, 1976; *Lindahl*, 1977; *Kubein* and *Jähnig*, 1983; *Faulkner* et al., 1987; *Hart* et al., 1988; *Iizuka* et al., 1991; *Ellis* and *Dean*, 1993; *Meijer* et al., 1993; *Krenkel*, 1994; *Hammer* et al., 1997; *Choi* et al., 1999, 2001; *Meyer* et al., 2002, 2006; *Tominaga* et al., 2006; *Cascone* et al., 2008), was created with boundary conditions in order to analyse the mechanical—structural behaviour of the mandible during the function of the masticatory muscular forces. In our mandibular model, a right subcondylar fracture was caused and repaired through the use of union elements, having two different methods of fixation. The union elements that we used were made of titanium American Society for Testing and Materials (ASTM) grade 5, corresponding to the alloy Ti6Al4V (Titanium, 6% Aluminium, 4% Vanadium), the one which is most frequently used. It is one of the alpha—beta alloys, containing both alpha stabilizing elements (6% aluminium) and beta stabilizing elements (4% vanadium) and presenting also certain mechanical and physical characteristics listed in Table 1. The first technique consisted in the positioning of one element of union (simulating a straight four hole plate) in the posterior border of the external surface of the condylar neck along its axis (Fig. 2). The second technique consisted in the use of two elements of union (simulating two straight four hole plates), the first positioned as in the previous case, the second positioned parallel to and below the sigmoid notch (Fig. 3). The mandibles, repaired with these two different techniques, were subjected to the forces of the six above mentioned muscles in order to analyse the mechanical—structural behaviour of the fracture line in function of the muscular forces applied on it during mastication.

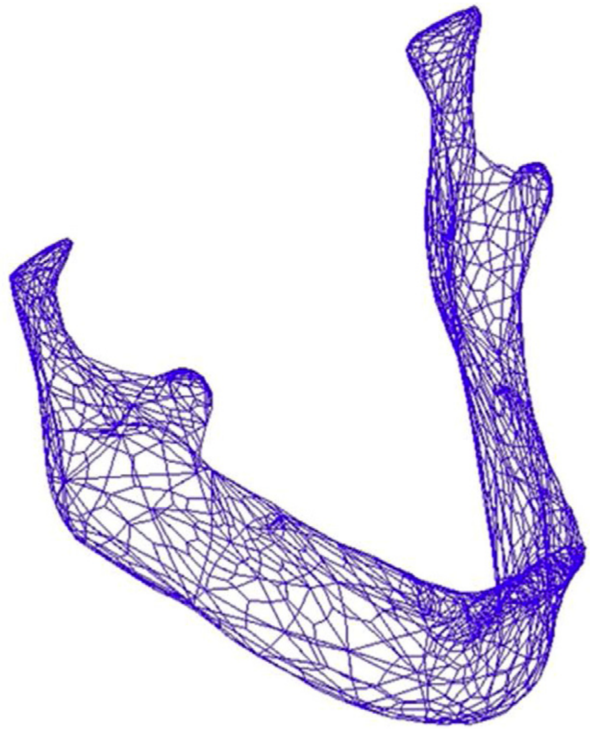

Fig. 1 — Superficial mesh generated in the boundary conditions code: 4560 quadrilateral elements at eight knots.

Table 1 — **Chemical composition** and **mechanical properties** and **physical properties** of the elements of union

Chemical composition
Titanium ASTM grade 5 (Ti6Al4V)
Mechanical properties
Traction breaking load: 950 MPa
Compression breaking load: 970 MPa
Yield point: 880 MPa
Young's Modulus: 113,800
Physical properties
Poisson coefficient: 0.34 MPa

RESULTS

In the first part of our study, we confirmed the presence of tensile and compressive mechanical isostatic strain lines in the condylar region during the physiological act of mastication. The main finding was that there were compressive isostatic strain patterns along the

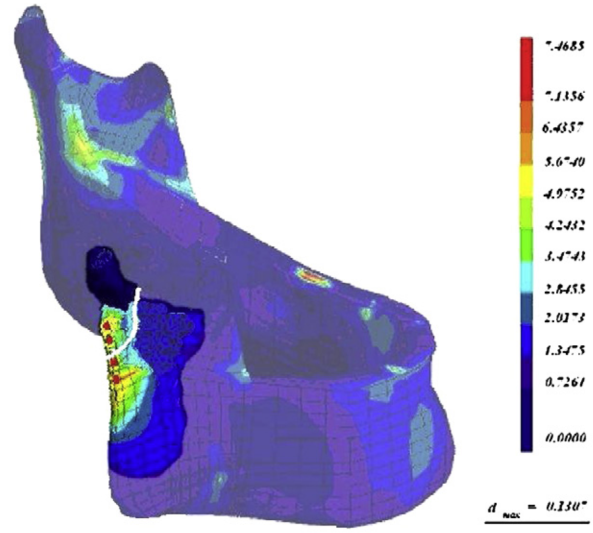

Fig. 2 — Stabilization of a right subcondylar fracture through a single element of union. Representation of the tension state (nMPa).

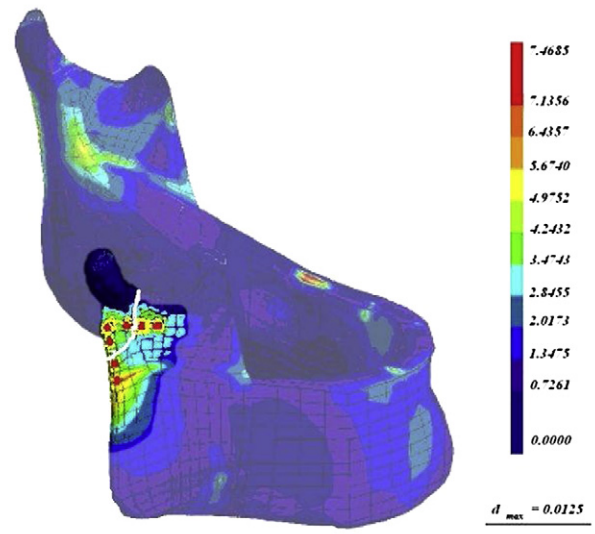

Fig. 3 — Stabilization of a right subcondylar fracture through two elements of union. Representation of the tension state (nMPa).

posterior border of the condylar region and tensile isostatic strain patterns running parallel to and below the sigmoid notch (Fig. 4 Table 2).

The analysis of the behaviour of the mandibular model repaired through the two techniques described and submitted to the masticatory load demonstrates the presence of a gap (d) inside the condylar fracture line in both cases.

But the significant result is that the value of the gap was considerably smaller in the case in which two elements of union were used for the fixation (Table 3).

DISCUSSION

Mandibular condylar fractures are one of the most frequent injuries of the facial skeleton. Although they are

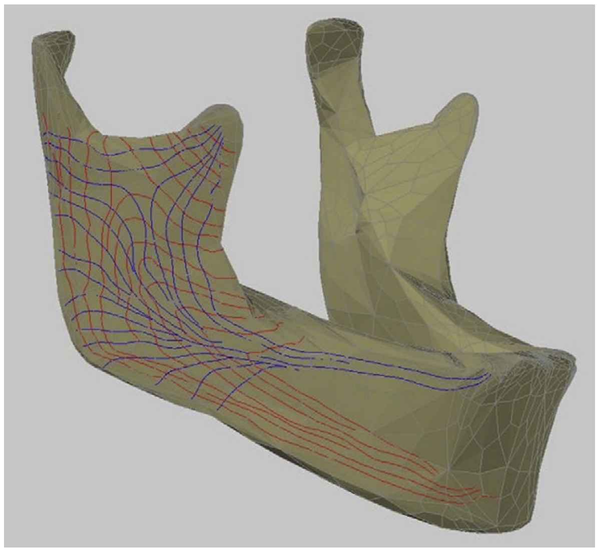

Fig. 4 — Compressive strain lines (red) and tensile strain lines (blue).

very common, their treatment in adults remains controversial (*Cascone* et al., 2008).

Recently, a consensus for the open reduction and rigid fixation of condylar fractures has been obtained (*Seemann* et al., 2007), but there is no consensus regarding the choice of the best type of osteosynthesis. From a review of the literature it is evident that the technique used most frequently for fixation is the positioning of a single plate, even if complications concerning plate fracture or screw loosening have been reported by various authors (*Gysi*, 1921; *Lindahl*, 1977; *Kubein* and *Jähnig*, 1983; *Hart* et al., 1988; *Iizuka* et al., 1991; *Paydar* et al., 1991; *Sargent* and *Green*, 1992; *Ellis* and *Dean*, 1993; *Meijer* et al., 1993; *Krenkel*, 1994; *Throckmorton* and *Dechow*, 1994; *Hammer* et al., 1997; *Choi* et al., 1999, 2001; *Meyer* et al., 2002, 2006; *Rallis* et al., 2003; *Tominaga* et al., 2006; *Seemann* et al., 2007).

Choi et al. (1999), comparing the biomechanical stability of four different plating techniques used to fix condylar neck fractures when submitted to a functional load, demonstrated that a double miniplate was more stable than a single plate.

The same authors in another clinical study reported on their experience with 40 condylar neck fractures in 37 patients who had been treated with a single minidynamic compression plate or with double plates. Complications concerning the plates (plate fractures or screw loosening) occurred exclusively in the groups that had been treated with a single plate, but not in those where two plates were used (*Choi* et al., 2001).

The use of double plates instead of a single plate is also recommended by *Rallis* et al. who in their retrospective study of 45 patients treated with single and double plates demonstrated that the use of 2.0 mm miniplates seems to produce better stability and fewer complications (*Rallis* et al., 2003).

In 2006 *Tominaga* et al., through the use of 18 synthetic mandibles in which they caused and then treated subcondylar fractures with different osteosynthesis techniques, demonstrated, by submitting the same mandibles to the masticatory load, that the mandibles repaired with double plates showed better stability (*Tominaga* et al., 2006).

Table 2 – Directions and areas of insertion of the 6 muscular fascia and numerical values of the muscular forces

Muscles	Cosine values of the muscle force directions			Area of muscular intersection (mm^2)	Value of muscular forces (N)	Superficial traction (N/mm^2)		
	x	y	z			tx	ty	tz
LPT	0.10	0.76	0.64	363	11.0	3.0E−03	2.3E−02	1.9E−02
LAT	0.07	−0.34	0.94	363	27.9	5.4E−03	−2.6E−02	7.2E−02
LDM	−0.27	0.18	0.94	470	27.3	−1.6E−02	1.0E−02	5.5E−02
LSM	−0.27	−0.15	0.95	1098	20.2	−5.0E−03	−2.8E−03	1.7E−02
LMP	−0.32	−0.03	0.94	1199	17.1	−4.6E−03	−4.3E−04	1.3E−02
LLP	0.25	0.94	−0.25	123	7.4	1.5E−02	5.7E−02	−1.5E−02
RPT	−0.10	0.76	0.64	363	20.2	−5.0E−03	4.2E−02	3.6E−02
RAT	−0.07	0.34	0.94	363	21.9	−4.2E−03	2.0E−02	5.7E−02
RDM	0.27	0.18	0.94	470	13.5	7.8E−03	5.2E−02	2.7E−02
RSM	0.27	−0.15	0.95	1098	9.8	2.4E−03	−1.3E−03	8.5E−03
RMP	0.32	−0.03	0.94	1199	16.1	4.3E−03	−4.0E−04	1.3E−02
RLP	−0.25	0.94	−0.25	123	7.4	−1.5E−02	5.7E−02	−1.5E−02

Table 3 – Numerical values of the gaps

Union element	Gap value (mm)
Single union element	0.125
Double union element	1.307

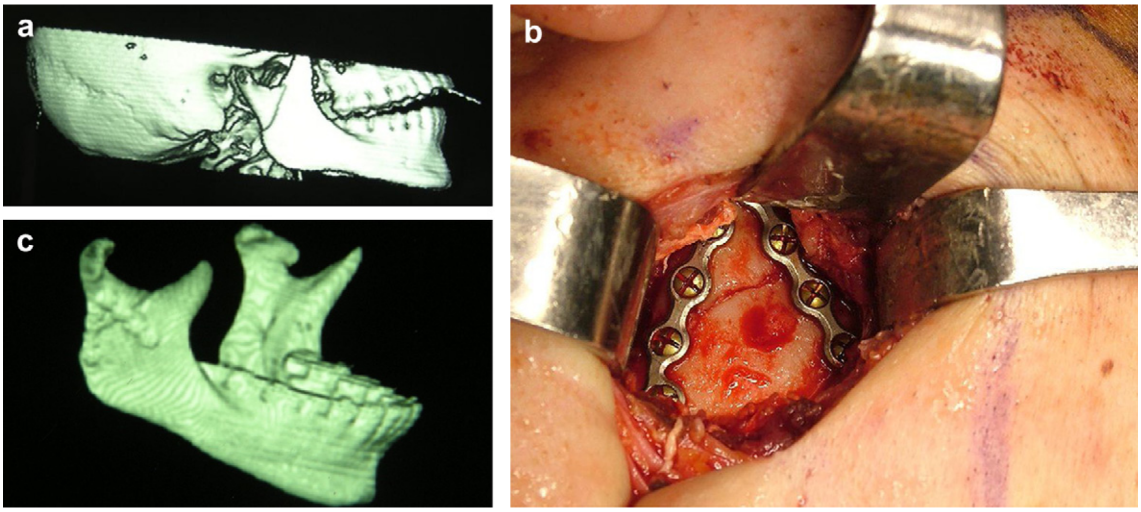

Fig. 5 – Right subcondylar mandibular fracture: a) pre-operative Computed Tomographic (CT), b) open reduction and internal fixation with two plates, c) post-operative CT.

In our surgical experience, in accordance with the authors above mentioned, we use, whenever possible, a double plate in the treatment of condylar fractures. In accordance with *Meyer* (*Meyer* et al., 2006), the principal goal of our treatment, in addition to achieving an anatomical reduction, is to maintain this reduction by means of stable osteosynthesis.

Different studies (*Paydar* et al., 1991; *Sargent* and *Green*, 1992; *Meijer* et al., 1993; *Throckmorton* and *Dechow*, 1994; *Meyer* et al., 2002, 2006; *Rallis* et al., 2003; *Seemann* et al., 2007) have highlighted that the concept of stable osteosynthesis is correlated to the mechanical strains arising in the condylar region during mastication due to the action of the muscles acting on the mandible.

Throckmorton (*Throckmorton* and *Dechow*, 1994), in 1994, through an experiment in vitro on human mandibles, identified the presence of tensile strains occurring on the anterior and lateral surfaces of the condylar process and of compressive strains on the posterior surface. But it was *Meyer* (*Meyer* et al., 2002), in 2002, who for the first time developed a masticatory load device, capable of reproducing with accuracy the forces applied on the mandible during mastication. Using mandibles of cadavers put under a masticatory load, he highlighted and confirmed, through a photoelastic analysis, the presence of compressive strains running along the posterior border of the ramus and tensile strains positioned parallel to and below the sigmoid notch (*Meyer* et al., 2002). In light of *Throckmorton*'s (*Throckmorton* and *Dechow*, 1994) and *Meyer*'s experiments (*Meyer* et al., 2002) we have confirmed by means of our mandibular FEM the presence of tensile and compressive isostatic strain lines in the condylar region during mastication. Therefore all these studies suggest new concepts need to be considered in the positioning of osteosynthesis plates along the tensile strains lines. The tensile strains lines are mainly responsible for the complications concerning plate fracture or

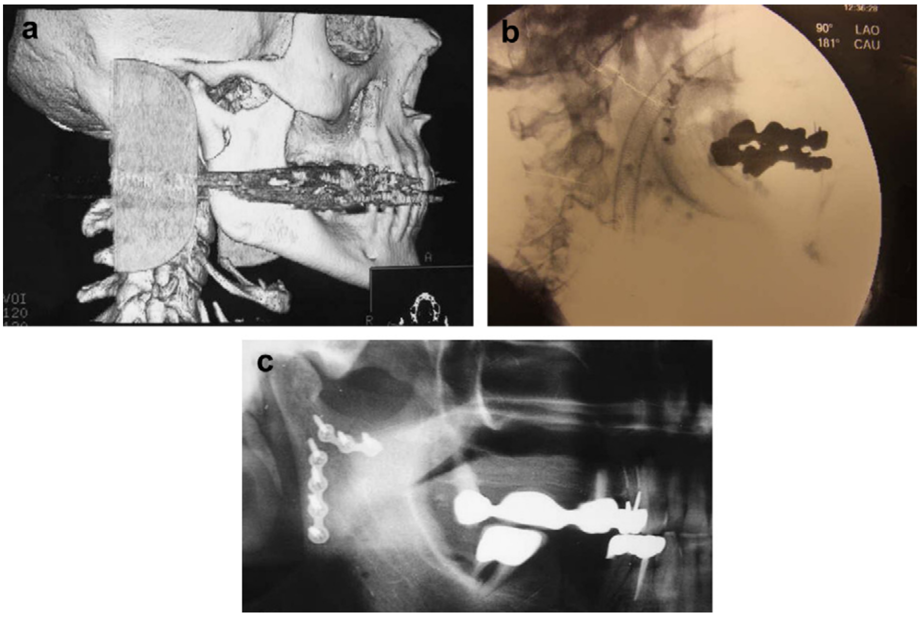

Fig. 6 — Right subcondylar mandibular fracture: a) pre-operative CT, b) intraoperative radiography with brilliance amplifier c) post-operative orthopantomogram.

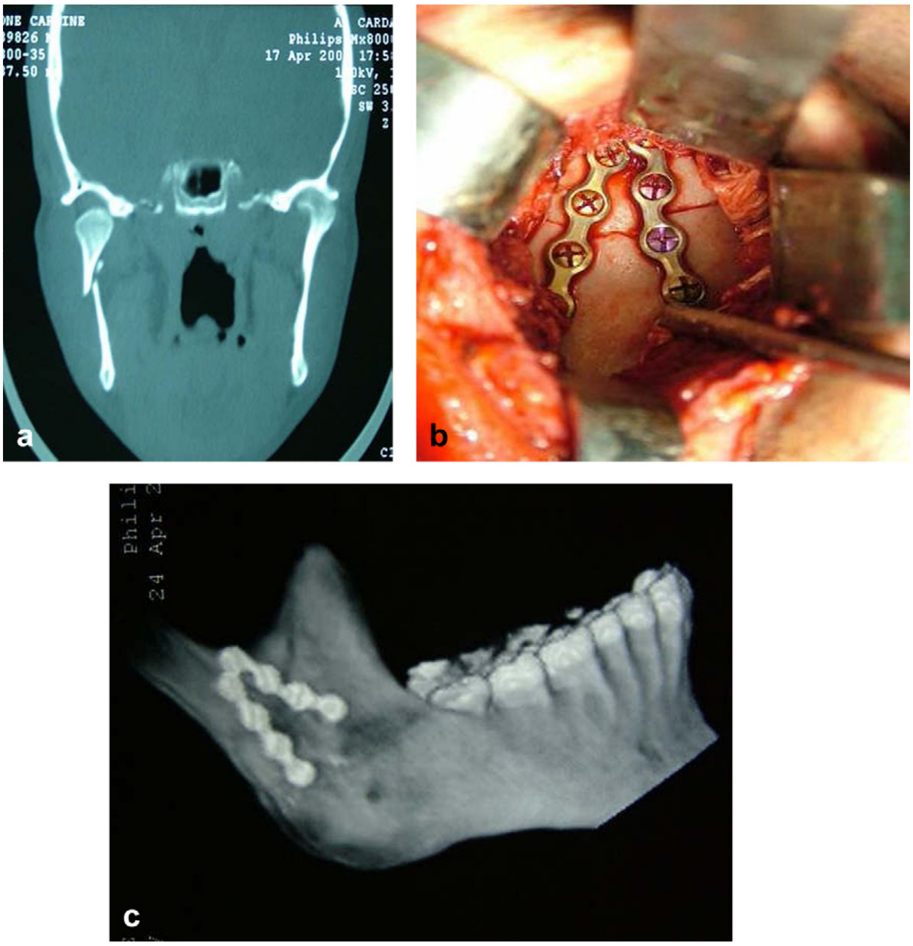

Fig. 7 — Right subcondylar mandibular fracture: a) pre-operative CT, b) open reduction and internal fixation with two plates, c) post-operative CT.

screw loosening that lead to the displacement of the reduced condylar fragment with the consequent presence of a gap in the fracture line. For this reason, our surgical experience, supported by the results obtained from our study, suggests that the use of two plates in the fixation of condylar neck and subcondylar fractures (*Lindahl*, 1977), whenever possible, leads to significantly greater primary stability, compared with the use of a single plate. The first plate, fixed by four screws (two on each side of the fracture), is positioned parallel to the condylar neck axis, respecting the compressive strain lines in this region. This first plate helps to obtain ''intermediary stability'', so permitting the restoration of the height of the ramus. But this same plate is not capable of resisting the biomechanical strains that occur in the condylar region during mastication, and more precisely the sagittal tension correlated to the tensile strain lines that lead to the displacement of the condylar fragment with the consequent appearance of the gap. This is the reason why it is necessary to position a second plate in an oblique direction along the tensile strain lines that run below and parallel to the sigmoid notch, in agreement with Champy's concept of stable osteosynthesis functionality (*Champy* and *Lodde*, 1976), with *Meyer*'s (*Meyer* et al., 2002) biomechanical studies and with the results that we obtained. This second plate should be fixed with at least one screw on each side of the fracture (Figs. 5–7). In agreement with *Krenkel* (1994) and more recently *Choi* (*Choi* et al., 1999), the second plate protects the first plate from damaging mechanical strains that could cause its fracture and a secondary displacement of the mandibular condylar fragment reduced.

CONCLUSION

From our results it is evident that the use of two plates, correctly positioned for the fixation of condylar neck and subcondylar fractures (*Lindahl*, 1977), represents the best solution to obtain a stable osteosynthesis, when load sharing plates are used.

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