BIOMECHANICAL EVALUATION OF HACKETHAL'S INTRAMEDULLARY BUNDLE PIN FIXATION OF HUMERAL NECK FRACTURES

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Humeral neck fractures can be stabilized using a bundle of intramedullary pins as described by Hackethal. In order to decrease the risk of pin migration, packing of the medullary cavity with as many pins as possible is sometimes recommended, but others believe that stability can be decreased by destruction of cancellous bone in the humeral head by a large bundle of pins.

A surgical neck fracture was created with a saw in 30 frozen cadaveric humeri. Bone quality was evaluated by radiography and densitometry. Fractures were stabilized using Hackethal's technique of retrograde intramedullary pinning with varying numbers of 2.5-mm diameter pins ; increasing torsion or bending moments of force were then applied to the bones studied. Stability was found to improve with an increasing number of pins and with higher humeral head density. Based upon these findings, the use of a large number of pins is recommended to reduce the risk of pin migration. Up to eight pins, the risk of destruction of cancellous bone in the humeral head appears very low.

Keywords : humerus ; fracture ; pins ; biomechanics.

Mots-clés : humérus ; fracture ; broches ; biomécanique.

INTRODUCTION

Hackethal's fascicular pinning (4) is very popular in Europe for the treatment of displaced humeral neck fractures. This technique provides satisfactory fracture fixation that allows early mobilization of the shoulder.

Nevertheless, clinical studies have reported some mechanical complications. The most frequent has been axial migration of pins. This could be avoided by introducing the largest number of pins possible to achieve diaphyseal locking (5, 8). Under these conditions, however, some authors believe that numerous pins can destroy the cancellous bone of the humeral head with subsequent loss of anchorage of the pins in the humeral head (1, 9, 3, 6). The only biomechanical studies on such techniques have been related to Ender nailing of the femur (7). To understand the modes of failure and to allow safe early mobilization of the shoulder, the mechanical stability of humeral neck fractures treated using various modalities of Hackethal's fascicular pinning was studied on cadaveric bones.

MATERIAL AND METHODS

Thirty-five frozen embalmed humeri were obtained from 35 cadavers of unknown sex. Each bone was radiographed in order to detect structural or anatomical abnormalities resulting for example from previous fracture. Thirty humeri were suitable for the study. The mineral content of the humeral head bone was measured by xray densitometry (QDR 1000, Hologic, Waltham MA, USA). A surgical neck fracture was made with a saw. The diaphysis was held vertically in a container filled with plaster. A metal ring was fixed around the humeral head with four screws (fig. 1). Hackethal's pins, 2.5 mm

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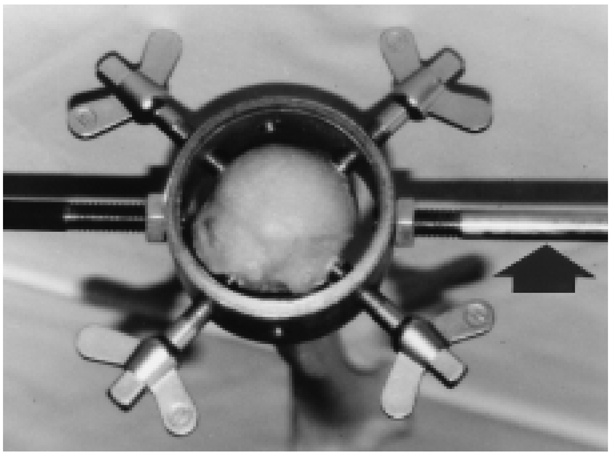

Fig. 1. — Metal ring used to fix the humeral head and rod fixed on the ring (arrow) to apply the force.

Fig. 2. — Specimen loaded in torsion with cable in horizontal position by the adjunction of a pulley. The plastic container is attached to the cable and is progressively filled with water in order to produce the moment of force. The humeral diaphysis is replaced by a metal tube (arrow). Under these conditions, stability of the pins in the humeral head is selectively measured (see text).

in diameter, were angulated 30° at 2.5 cm from their proximal extremity. Four, six or eight pins were introduced through the osteotomy surface into the humeral head. They were then carefully glided into the diaphysis until the humeral head was in the anatomical position. A metal rod was fixed on the ring (fig. 1, arrow). In order to produce a moment of force, a cable was attached to the end of the rod. Traction on the cable was made by a plastic container progressively filled with water and submitted to gravity. Knowing the mass of water and the length of the lever arm allowed us to calculate the moment of force applied on the head through the metal ring. The specimens were loaded in bending with the cable simply in vertical position and in torsion with the cable in horizontal position by adjunction of a pulley (fig. 2). The relative displacement between the humeral head and the diaphysis was measured by reflexion of a laser spot on a mirror fixed to the metal ring (fig. 3). In order to measure selectively the stability of the pins in the humeral head when torsion moments were applied,

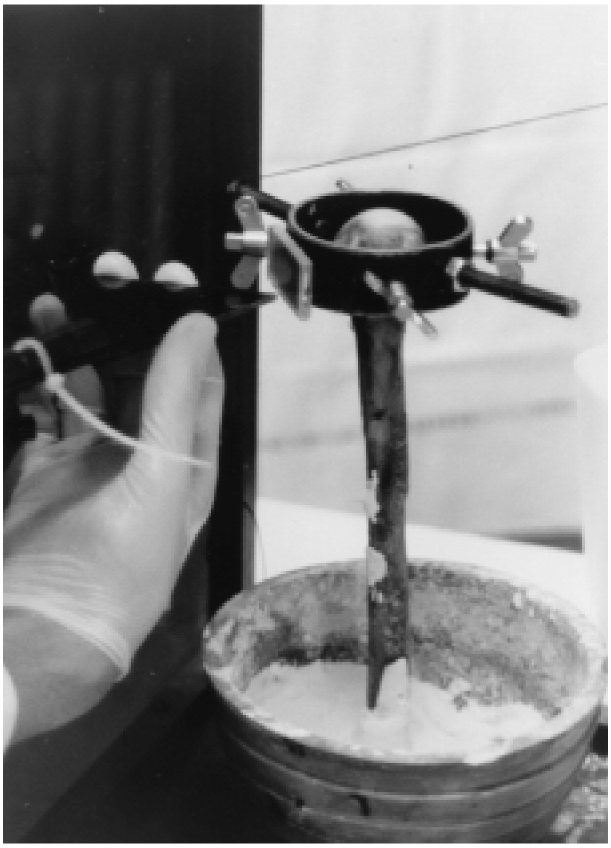

Fig. 3. — Calibration of the laser reflexion to measure relative displacement of the humeral head.

Table I

Humerus number	Humeral head density (g/cm²)	Humeral head diameter (mm)	Loading mode	Number of pins	Moment of force to failure (g. m)
1	577	56	Torsion with free pins in the humeral diaphysis	4	17
3	583	50		4	28
4	506	50		4	26
6	538	51		4	4
7	422	42		4	30
8	469	50		4	15
9	433	46		6	20
19	513	56	Torsion with pins locked distally in a metal tube	4	40
22	480	55		4	45
18	447	52		4	70
17	380	46		4	65
33	461	51		6	192
23	447	45		6	210
20	525	56		6	88
21	437	54		6	130
32	668	47		8	330
16	400	44		8	205
30	704	45		8	490
31	406	45		8	111
13	387	40	Bending	4	18
10	406	51		4	28
11	438	52		4	49
15	453	44		4	43
14	358	44		6	75
12	384	53		6	87
25	448	55		6	135
24	685	54		6	300
28	407	51		8	150
27	448	45		8	120
26	703	53		8	330

the humeral diaphysis was replaced by a metal tube in which the pins were firmly locked. (fig. 2, arrow).

Statistical analysis using Student's t-test and non-parametric Mann Whitney U-test was performed. Significant findings were accepted with $p < 0.05$.

RESULTS

The mean mineral content of the humeral heads was 484 g/cm² (range : 358 to 704 g/cm²). The diameter of the humeral heads averaged 49 mm (range : 40 to 56 mm). With increasing torsion moments of force, the osteotomy was progressively displaced. The slight rotation initially observed at the osteotomy site, was caused by twisting of the pins in the metaphysis. Subsequently, the osteosynthesis suddenly failed in the cancellous bone of the heads, or the bundle of pins rotated in the diaphysis. The displacement of the osteotomy was then very significant (fig. 4). The moment of force necessary to obtain this major displacement of the osteotomy was very low (mean = 20+/- 10 g . m) and was not dependent on the diameter or the mineral content of the humeral heads (table I).

By locking the pins in the proximal metaphyseal region, we could study selectively the failure in the cancellous bone of the humeral head. Under these conditions, there was no displacement of the

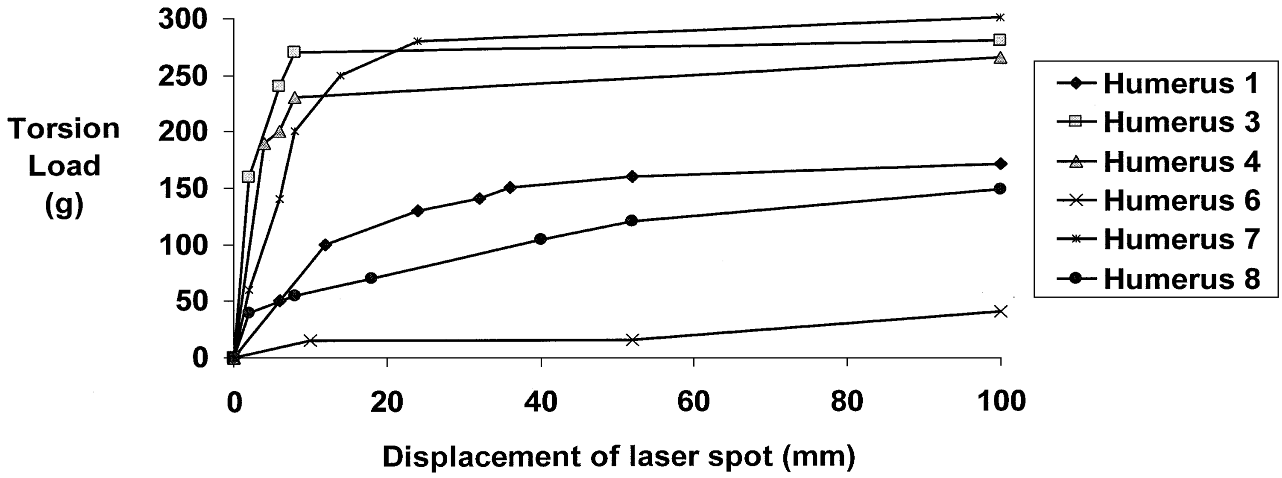

Fig. 4. — Displacement of reflected laser spot with increasing torsion load for different samples with free pins in the humeral diaphysis.

fracture until the anchorage of the pins failed in the humeral head. The failure of fixation with 4 pins occurred with a mean moment of force that was significantly higher (mean = 55 +/- 15 g. m ; p = 0.0019) than in the first experiment. The load to failure increased with the number of pins, although the humeral head mineral content was not different between groups with 4, 6 or 8 pins and despite the fact that the diameter of the humeral heads was significantly smaller in the group with 8 pins (mean : 45 +/- 1 mm) than in the groups with 6 pins (mean : 52 +/- 5 mm p = 0.0452) or 4 pins (mean : 52 +/- 5 mm ; p = 0.0241) (table I). Mann-Whitney U-test determined that the difference in torsion moments of force was significant between groups with 4 or 6 pins and groups with 4 or 8 pins (p = 0.0094) but not significant between groups with 6 or 8 pins (p = 0.1489). Whatever the number of pins, the intensity of the moment of force necessary to displace the fracture was correlated with the density of the humeral head (r = 0.73) with a p value less than 0.01 (fig. 5).

In the experiment in which the construct was submitted to bending, humeral head mineral content and diameter were not different between groups with 4, 6 or 8 pins. The moment of force necessary to displace the osteotomy increased with the number of pins (table I). The difference in bending moments of force was significant between groups with 4 or 6 pins (p = 0.0094) and groups with 4 or 8 pins (p = 0.0133) but not significant between groups with 6 or 8 pins (p = 0.1573). As in the second experiment moments of force were significantly correlated (p < 0.01) with the density of the humeral heads (r = 0.9029) (fig. 6).

DISCUSSION

The initial displacement of the osteotomy in rotation resulted in all cases from twisting of the pins in the metaphyseal region. It is probably the high elasticity of the pins that allows their twisting in the metaphysis where the mineral content is very low and the mechanical strength is very poor. The poor density of this region was clearly demonstrated by the xrays of the bones studied. This explains why neck fractures are often comminuted in the metaphysis. As the latter is the widest part of the humerus, it will never be possible to achieve firm fixation of any intramedullary device in this region. In our experimental conditions, the displacement of the osteotomy due to the weak anchorage of the pins in the metaphysis remained very slight. Such limited fracture mobility would probably not prevent callus development in in vivo situations. Nevertheless if the torsion forces increase, the displacement of the osteotomy

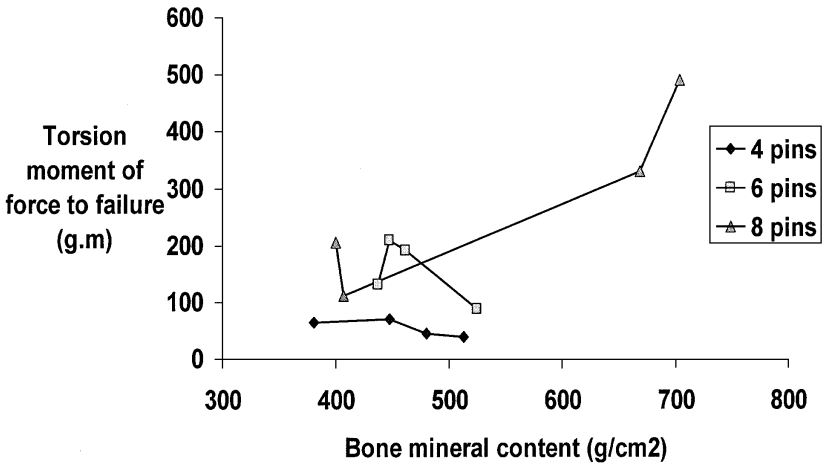

Fig. 5. — Bone mineral content of samples with locked pins and moments of force to failure in torsion

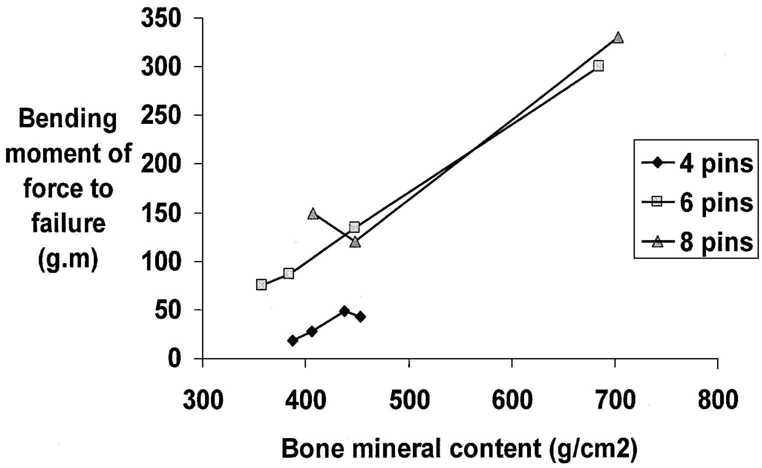

Fig. 6. — Bone mineral content and moments of force to failure in bending

becomes much greater. The resultant loss of fixation of the pins, either in the humeral head or in the diaphysis is unacceptable.

To selectively measure the resistance of the pin anchorage in the humeral head against torsion forces, it was necessary to lock them in the metaphyseal region. The moment of force producing failure of osteosynthesis with four pins was then significantly higher than in the first experiment. This could be explained by the fact that this second experiment investigated only the failure in the humeral head, whereas in the first one, the failure was located either in the humeral head or in the diaphysis. The load to failure increased with the number of pins and was correlated with the density of the humeral head. Even in cases with eight pins where the humeral head diameters were significantly smaller than in cases with four pins, there was no instance of fixation failure caused by iatrogenic destruction of the humeral head cancellous bone, as feared by some surgeons. We were however able in these experimental conditions to place these pins in divergent positions in the humeral head, which is not always possible in in vivo situations.

Bending of the fracture could also be better prevented by using six or eight rather than four pins. The bending moments of force in flexion were also significantly correlated with the density of the humeral heads whatever the number of pins.

CONCLUSIONS

To fix humeral neck fractures by a bundle of intramedullary pins, the use of the largest number of pins can be recommended in order to obtain locking in the diaphysis and to reduce the risk of migration. Destruction of the cancellous bone in the humeral head by this large bundle may theoretically render the fixation unstable. This complication was never observed even with eight pins of 2.5 mm diameter. It is however advisable to remain cautious, particularly with small osteoporotic humeral heads in which a bundle of eight pins could probably destroy the cancellous bone and reduce the anchorage strength. Moreover the pins should be placed in divergent positions in the humeral head. The forces necessary to displace the fracture in rotation as well as in flexion remain very low. Vigorous postoperative rehabilitation during the first three weeks is therefore not advisable.

Acknowledgements

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REFERENCES

1. Apprill G., Boll P. Le traitement des fractures du col de l’humérus par embrochage centro-médullaire sans ouverture du foyer de fracture. Rev. Chir. Orthop., 1968, 54, 657-665.
2. Bombart M., Moulin A., Danan J. P., Alperovitch R. Traitement par embrochage à foyer fermé des fractures de l’extrémité supérieure de l’humérus. Rev. Chir. Orthop., 1978, 64, 221-229.
3. Destrée C., Safary A. Le traitement des fractures humérales, col et diaphyse, par l’enclouage fasciculé de Hackethal. Acta Orthop. Belg. 1979, 45, 666-677.
4. Hackethal K. H. Die Bündel-Nagelung. Springer-Verlag, Berlin, 1961, pp. 134-145.
5. Kempf F., Briot B., Jaeger H., Calderoli H., Copin G. L’enclouage selon Ender. Etude biomécanique et résultats à propos de 120 cas. Rev. Chir. Orthop., 1976, 62, 595-612.
6. Nottebaert M., Bertrand P., Amiri-Lamraski M. H., Delince Ph. L’embrochage multifasciculé selon Hackethal dans les fractures cervico-diaphysaires complexes de l’humérus chez le patient âgé. Acta Orthop. Belg., 1986, 52, 743-752.
7. Olerud S., Strack A., Gillström P. Malrotation following Ender nailing. Clin. Orthop., 1980, 147, 139-142.
8. Putz Ph., Arias Ch., Bremen J., Delvaux D., Simons M. Le traitement des fractures de l’épiphyse proximale de l’humérus par embrochage fasciculé selon Hackethal. A propos de 136 cas. Acta Orthop. Belg., 1987, 53, 80-87.
9. van der Ghinst M., De Geeter L. Fracture de la tête et de la diaphyse humérale : du plâtre pendant à l’embrochage fasciculé selon Hackethal. Etude critique. Acta Orthop. Belg., 1978, 44, 357-365.

SAMENVATTING

P.-Y. DESCAMPS, L. FABECK, P. KRALLIS, D. HARDY, PH. DELINCE. Biomechanische evaluatie van de techniek van Hackethal met meerdere intramodullaire pennen in humerushalsfrakturen.

Humerushalsfrakturen kunnen gestabiliseerd worden met behulp van meerdere intramedullaire pennen volgens de techniek van Hackethal. Teneinde het risico op migratie van de pennen te vermijden wordt door sommigen aanbevolen om zoveel mogelijk pennen centromedullair aan te brengen. Anderen menen dat hierdoor de stabiliteit verminderd wordt door vernietiging van het spongieus bot in de humeruskop. Een chirurgische fraktuur van de humerushals werd gecreëerd bij 30 kadaver humeri. De botkwaliteit werd zowel radiografisch als botdensitometrisch geëvalueerd.
De frakturen werden gestabiliseerd met variabele aantallen intramedullaire pennen volgens de techniek van Hackethal. De diameters van de pennen bedroegen 2,5 mm. Hierop werden toenemende momentums van buig- en torsiekrachten uitgeoefend op de constructies. Een meer stabiele constructie werd bekomen bij gebruik van een groter aantal pennen en bij hogere humeruskopdensiteit. Aan de hand van deze bevindingen raden wij aan om een groter aantal pennen te gebruiken ten einde het risico op migratie van de pennen te beperken. Bij gebruik van 8 pennen lijkt het risico op spongieuze destructie van de humeruskop laag.

RÉSUMÉ

P.-Y. DESCAMPS, L. FABECK, P. KRALLIS, D. HARDY, PH. DELINCE. Étude biomécanique de l’embrochage intra-médullaire fasciculé de Hackethal.

Les fractures du col de l’humérus peuvent être traitées par embrochage intra-médullaire fasciculé selon Hackethal. Afin de limiter le risque de migration, certains auteurs ont recommandé l’introduction du plus

grand nombre possible de broches dans le canal médullaire. Cependant, d'autres craignent qu'un trop gros faisceau de broches, en fragilisant le tissu osseux spongieux de la tête humérale, n'entraîne une perte de stabilité de l'ostéosynthèse.

Une fracture du col chirurgical a été créée à la scie sur 30 humérus congelés. La qualité de l'os a été évaluée par radiographie et densitométrie. Les fractures ont été stabilisées selon la technique de Hackethal par embrochage intra-médullaire rétrograde, en utilisant un nombre variable de broches de 2,5 mm de diamètre. Des moments de force de torsion et de flexion, d'intensité croissante, ont été appliqués sur le montage. Sa stabilité s'est améliorée par l'augmentation du nombre de broches et de la densité osseuse. Selon ces résultats, l'usage d'un nombre élevé de broches serait donc recommandé pour en réduire la fréquence de migration. Jusqu'à 8 broches, le risque de destruction de l'os spongieux dans la tête humérale semble faible.