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ORIGINAL PAPER

Comparative biomechanical study of five systems for fixation of the coracoid transfer during the Latarjet procedure for treatment of anterior recurrent shoulder instability

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Abstract

Purpose This work compares the biomechanical resistance of five modes of fixation coracoid bone-block fixation during Latarjet open-air or arthroscopic procedures. The hypothesis is that these systems are equivalent.

Methods Latarjet procedures were performed on cadavers, then the samples were subjected to an increasing tension until the fixation failed. Five systems were tested: two malleolar screws, one screw with washer, two 3.5-mm self-compressive screws, one 4-mm self-compressive screw associated with one 3-mm self-compressive screw, and endobutton. The main judgment criterion was the strength necessary for the failure of the fixation. The secondary criterion was the stiffness of the assembly.

Results The single malleolar screw fixing has a lower breaking threshold than other fixings. There is no difference in strength concerning the other systems. The average strength is greater than the stresses of a shoulder during daily life activities. There is no difference regarding the secondary criterion.

Conclusion The use of a single screw is insufficient, but the other systems seems reliable. The use of small diameter self-compressive cannulated screws can provide a better result. This biomechanical work must be validated in clinical studies.

Keywords Latarjet procedure · Coracoid bone-block · Glenohumeral instability · Glenohumeral stabilization · Fixation system · Graft healing

Introduction

Glenohumeral stabilization by coracoid bone-block was described in 1954 by Latarjet [1].

The procedure consists, by a delto-pectoral approach, in transposing the horizontal portion of the coracoid process to the lying position at the anterior-inferior edge of the glenoid, through an incision in the tendon of the subscapular.

Stabilization is obtained by a stop effect related to the increase of the inferior-internal rim of the glenoid, associated with a sling effect of the coraco-biceps tendon when placing the upper limb in anterior elevation. Patte [2] and Walch [3] proposed improvements to the original technique, doing a capsuloplasty on the coracoacromial ligament. Coracoid bone grafting can restore the glenoid rim defect [4], and this triple locking technique remains the gold standard for the treatment of anterior glenohumeral instability [5, 6].

The results are effective with a recurrence in 1 to 7% of cases and a low number of complications [7].

Bone-block fixation is essential because poor bone contact is responsible for non-union [8] (Fig. 1). In the Latarjet-Patte-Walch procedure, the coracoid process is fixed by two 4.5-mm partial threaded cancellous AO malleolar screws.

Failure and re-intervention can occur in case of non-union, lysis of the bone-block, or secondary displacement [9, 10], and the length of the screws can cause neurological damage [11].

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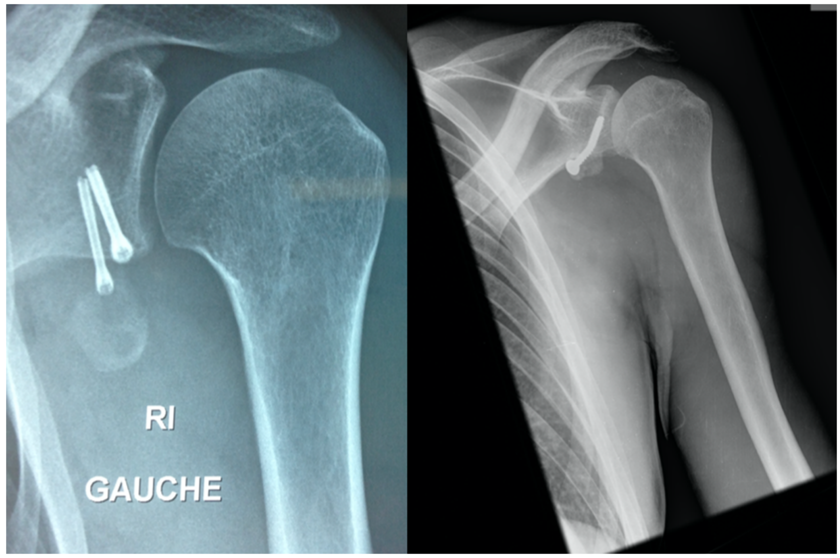

Fig. 1 Examples of Latarjet procedures failure

Other fixing methods were later described to overcome these pitfalls: use of a single screw, optimization of the screw support using a washer or miniplate, use of screws with a smaller diameter, full threaded, or cannulated screw as Saragaglia's mini-invasive technique [12].

Recently, Lafosse [13] described arthroscopic procedure using two screws, while Boileau [14] described cortical button fixation. An arthroscopic procedure seems to be as reliable as open procedure regarding to the positioning of the graft [15], and Kordasiewicz showed a very high graft healing rate using two cannulated screws with washers [16].

Several studies have already compared the methods of fixing the block, whether on biomechanical models or on cadaveric models [17–19]. The resistance of endobuttons has also been studied compared with malleolar screws [14, 20, 21]. Previous works have shown that bicortical fastening systems are more resistant than the use of unicortical screws [18, 22].

The use of self-compressive screws such as Herbert seems to us be an interesting option to allow good contact between the bone-block and the glenoid and to promote bone union [23]. However, they have not been studied biomechanically in this application.

Given the diversity of fastening systems on the market, we wanted to compare their effectiveness under physiological conditions. The purpose of this study is to explore the strength of these systems, in order to choose the one that offers satisfactory strength, while allowing optimal contact between the bone surfaces, minimum drilling to avoid weakening the bone-block, and offering solutions for precise placement of the block. Null hypothesis was that all these fixation systems are bio-equivalent on resistance to tensile strength.

The main judgment criterion was the maximum strength developed to achieve system failure.

The secondary judgment criterion was the stiffness of the assembly, calculated from the force/displacement curve of each test.

Material and methods

Five fixation devices of coracoid bone-block were tested during a cadaveric biomechanical study: two 4.5- mm malleolar solid screws (Synthes, West Chester, USA), one 4.5-mm malleolar solid screw with washer (Synthes, West Chester, USA), one endobutton (Implanet, Martillac, France), one 4-mm self-compressive cannulated screw + one 3-mm self-compressive cannulated screw (Newclip Technics, Haute-Goulaine, France), and two 3.5-mm self-compressive cannulated screws (Newclip Technics, Haute-Goulaine, France) (Fig. 2).

For each of the five fixing modes, three laboratory tests were carried out. The shoulders were randomized, with a matched allocation so that two joints from the same cadaver would not be tested with the same device.

Cadaver with a surgical or shoulder trauma history were excluded.

For each shoulder, a Latarjet procedure was performed, then the scapula was included in a resin in a testing position allowing the force vector to simulate both the humeral head pressure and coraco-biceps traction, as described in previous work [17, 21] (Fig. 3).

All screws were bicortical. The tightening was done in real conditions: with two fingers, using the dedicated screwdriver, until a tension considered sufficient by the operator was reached. Traction was increasingly performed at a rate of 10 mm minute^{-1} with a traction machine equipped with a 1000 N sensor, with an accuracy of $\pm 5 \times 10^{-3}$ N (E5566A, Instron, Norwood, USA). The data

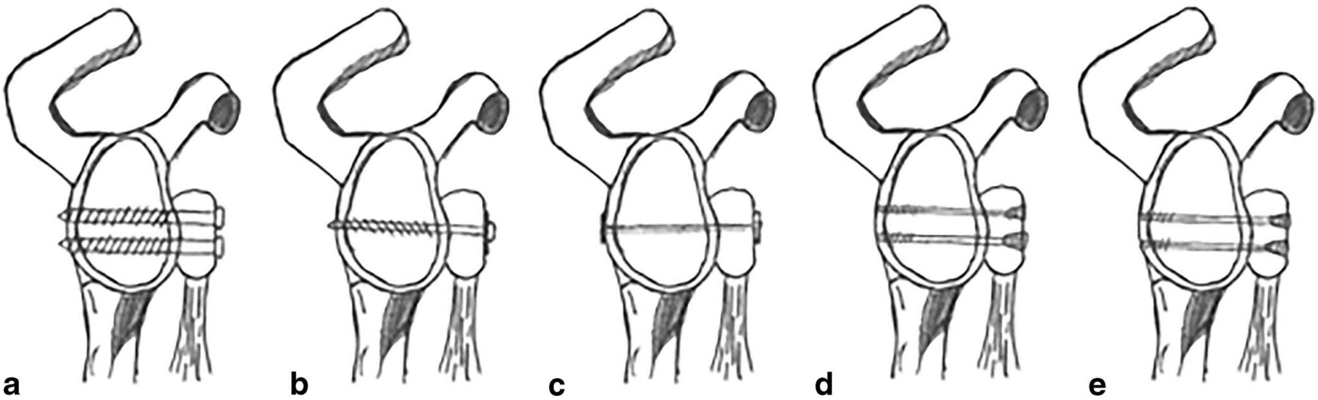

Fig. 2 Lateral view of right scapula after coracoid bone-block fixation. Fixation devices: **a** 2 malleolar screws, **b** malleolar screw with washer, **c** endobutton, **d** 3 mm + 4 mm self-compressive screws, **e** 2 × 3.5 mm self-compressive screws

obtained were processed using BlueHill 3 software (ITW, Norwood, USA).

A failure of the assembly was noted in the event of bone-block fracture, fixing material failure, bone-block displacement by more than 3 mm from its initial position (Fig. 4).

For each fixing method, mean strength and stiffness values of the three tests were compared with the mean of all other fixing modes using Mann-Whitney tests. Statistical tests were carried out using *P* value and graphical interface of R software (The R Foundation, Vienna, Austria).

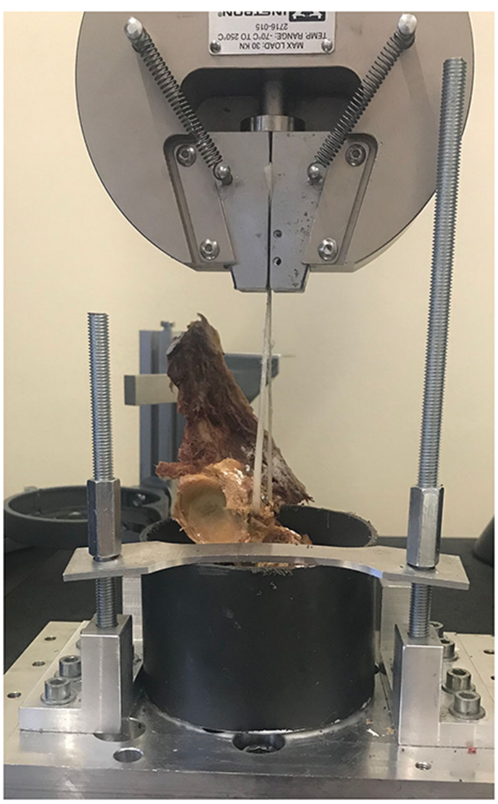

Fig. 3 Positioning of the model before increasing tension test

Results

A strength/displacement curve was obtained from each test (Fig. 5), and derivated function at the failure point was used to calculate stiffness.

Failure mode was different according to the type of fixing: single screw generally induced a displacement of the block around the screw then a tear-off, while fixing with large diameter screws (4.5 mm) induces a block's fracture or a cut-out of the screw.

For all the tests performed, the mean failure threshold was 193 N (SD 112 N).

The strength of failure for each fixing method using two screws or one endobutton is equivalent, without any significative difference. At the opposite, testing using one malleolar screw and washer showed a significative weaker fixation

Fig. 4 One example of fixation failure: screws cut-out

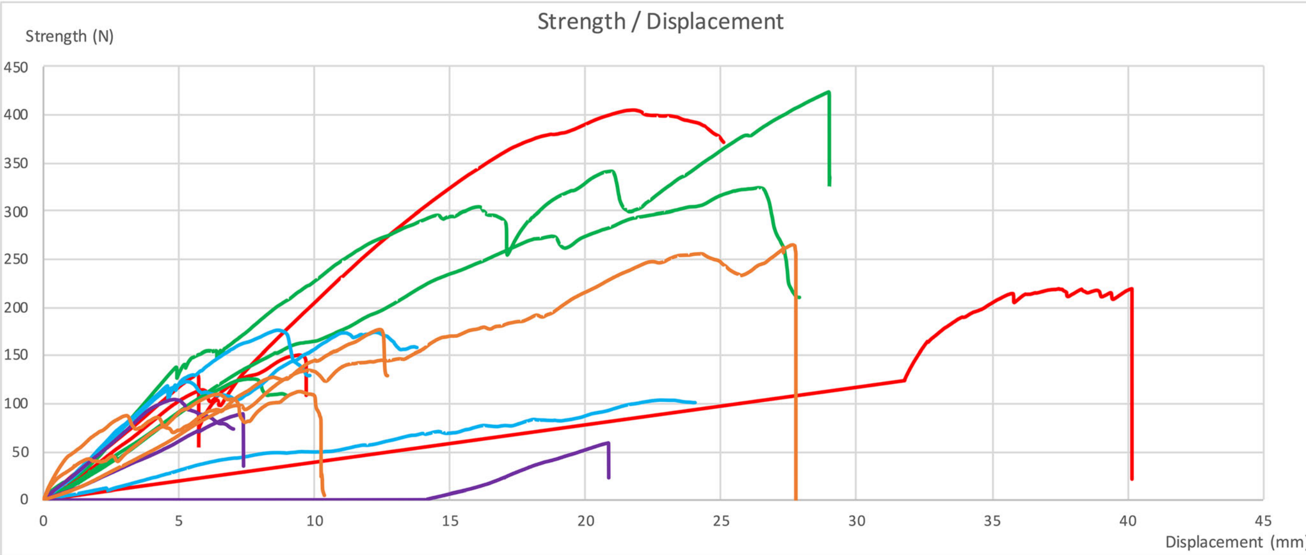

Fig. 5 Strength/displacement curves. Red, 2* 4.5-mm malleolar screws; purple, 4.5-mm malleolar screw + washer; blue, 2* 3.5 self-compressive cannulated screws; green, 4 mm + 3 mm self-c; orange, endobutton

strength, with a mean strength of 86 N (SD 27.1 N, $P < 0.01$) (Table 1).

Mean stiffness of all systems was 14.6 N mm^{-1} (SD 4.77 N mm^{-1}). Stiffness of the "endobutton group" was lower 11.6 N mm^{-1} (SD 1.44 N mm^{-1}), in a non-significant way. There was no difference on the secondary judgment criterion according to the others types of fixation (Table 1).

Discussion

Latarjet-Patte-Walch's procedure has become common because of its good clinical results [7]. Over successive developments and in particular since arthroscopic improvement, several fixing methods have been described and tested [14, 17, 21, 24, 25].

In order to optimize the clinical result, the positioning of the block is essential [26]. However, complications during fixation are frequent: according to Willemot, graft non-union is responsible of most revision cases [9]. The parameters influencing bone consolidation are numerous [27] but one of the most important is the contact between the two bone pieces. Claes showed less healing when the gap between the two bone pieces is greater than 2 mm [28], that is why a 3-mm displacement was considered as a failure.

Several types of screws have been marketed to solve these issues, by offering k-wires sighting instruments and self-compressive screws.

Table 1 Tests results and statistical analysis

	Main judgment criterion (strength, in *N*)					
	N	Mean (SD)	Median (Q25–75)	Min	Max	P*
All samples	15	193 (112)	170 (108; 242)	55.0	424	*N/A*
Endobutton	3	184 (± 76.8)	176 (144–220)	112	265	0.73
Single screw + washer	3	86.0 (± 27.1)	98.0 (76.5–102)	55.0	105	*< 0.01*
3 mm screw + 4 mm screw	3	288 (± 151)	314 (220–369)	125	424	0.18
2* 3.5 mm screws	3	148 (± 39.3)	170 (136–171)	103	172	0.63
2* malleolar screws	3	257 (± 129)	220 (185–310)	150	400	0.29
	Secondary judgment criterion (stiffness, in *N* mm–^{1})					
	N	Mean (SD)	Median (Q25–75)	Min	Max	P*
All samples	15	14.6 (4.77)	16.2 (11.9; 17.8)	4.24	22.6	*N/A*
Endobutton	3	11.6 (± 1.44)	11.6 (10.9–12.3)	10.1	13.0	0.18
Single screw + washer	3	14.9 (± 6.94)	12.8 (11.0–17.7)	9.23	22.6	0.95
3 mm screw +4 mm screw	3	15.9 (± 3.22)	17.4 (14.8–17.7)	12.2	18.1	0.73
2* 3.5 mm screws	3	12.7 (± 7.36)	16.4 (10.3–17.0)	4.24	17.5	0.73
2* malleolar screws	3	18.2 (± 1.99)	18.3 (17.2–19.2)	16.2	20.1	0.14

**Compared with other sample mean (Mann-Whitney's test)*

The aim of this study was to test the biomechanical resistance of these systems and compare them to the gold standard of open-air and arthroscopic Latarjet.

This study has several limitations: because it is a cadaveric work, the constraints applied to the model may differ from reality. Nevertheless, we tried to reproduce both the coraco-biceps' traction force and the humeral head's pressure force. Bone quality can be changing: most of anatomical subjects used come from elderly patients, and conservation care can alter bone quality. The shoulders were randomized in the study groups to avoid a bias related to very porotic bone, but Latarjet procedure is indicated in young people: it is likely that bone quality supposed to be better, so failure thresholds in real conditions may be higher.

This work is original since it compares five different bone-block fixation, using a standardized model. The gold standard is compared with commonly used and recently developed fasteners. The coraco-biceps' tensile force is taken into account, which is generally neglected in this type of study [17, 22], despite its stabilizing role [29].

The methods of attaching the coracoid bone-block, using two bicortical screws or an endobutton, therefore seem equivalent. While failures way vary, means are comparable which shows a homogeneity of testing. Standard deviations are relatively large, due to a low number of samples per group and likely sampling fluctuations, which are common in cadaveric studies. However, there is quite a homogeneity in order of magnitude, which are comparable with those described in the literature.

On the other hand, fixing with a single screw shows a lower failure threshold. It seems insufficient, even with bicortical screwing and distributing stresses along a washer [25]. The stiffness of the assemblies is also similar: these fixing methods suffer little distortion and failure mostly result as a tearing off of the bone/screw complex, or a bone-block's fracture on the screw holes.

The mean strength values of groups using endobutton or two screws are higher than the strength applied to a shoulder in daily life activities [30]. Concerning the "screw + washer" group, the rupture may occur too early, especially since the coraco-biceps tension has not been measured in vivo in the literature and remains unknown to date.

The use of a single screw is intended to reduce the risk of a small block fracture. Nevertheless, due to its reduced stability, the choice of this system seems to us to be abandoned. It may be more appropriate to turn to smaller diameter screws than to a single one.

The use of self-compressive Herbert-type screws ensures a good biomechanical resistance. As these screws are cannulated, they also provide precise positioning through use of k-wires. Alvi also showed biomechanical equivalence between cannulated and solid screws [17].

We have shown here a biomechanical equivalence in strength and stiffness between solid screws with a 4.5 diameter and cannulated screws with 3.5 diameter. This allow the drilling of holes with a smaller diameter, which favors holding in the cancellous bone [31].

Finally, as Gender previously noted, endobuttons seem to fully meet the requirements for this procedure and make it possible to safely replace use of screws [20]. The stiffness is slightly less, in a non-significant way, than the other groups. This shows the relative elasticity of this kind of assembly, as opposed to solid metal screws that support few distortion, and even if single-point fixations have a tendency to rotate around this pivot, it does not seem to impact the strength of failure.

This work should be completed by clinical studies, as radiological failures such non-unions or bone-block lyses have not always led to recurrence of instability or surgical recovery [10].

Conclusion

The methods of coracoid bone-block fixation tested in this study appear to be biomechanically comparable, except the use of a single screw that shows a lower failure threshold. Systems based on two bicortical screws or an endobutton accept higher stresses than those to which the joint is usually subjected. We can consider them to be reliable, as tensile tests are reproductible. Their stiffness is comparable, which implies that these devices may not deform under the effect of the stresses they undergo.

The use of a single screw should be abandoned at the risk of insufficient fixation including secondary displacement or increased pseudarthrosis.

The use of small-diameter screws can reduce the risk of fracture, and the use of cannulated self-compressive screws can increase the contact with the glenoid edge to maximize healing, while allowing accurate placement of the bone-block using specific instruments. Herbert 3.5-mm screws can solve all these problems. However, it is essential to clinically assess our biomechanical observations and further studies must be performed.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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