# Primary stability of shoulder arthrodesis using cannulated cancellous screws

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*There are no biomechanical studies available concerned with the primary stability of shoulder arthrodesis. The aim of our biomechanical investigations was to ascertain a minimal material combination with high primary stability for shoulder arthrodesis. For that purpose, the primary stability of 6 different forms of screw arthrodesis was investigated under the stress of abduction, adduction, anteversion, and retroversion. The mean values of the screw arthrodeses were compared with those of a 16–hole plate arthrodesis. All tests were carried out on 24 human specimens without destruction by use of a materials testing machine. The most stable form of screw arthrodesis for the load directions of abduction, adduction, anteversion, and retroversion results from a specific configuration of screws comprising 3 horizontal humeroglenoid screws and 3 vertical acromiohumeral screws (318.5 ± 99.0 N). For three forms of arthrodesis, each with 3 humerus–glenoid screws (299.9 ± 95.4 N), no significant difference (P = .530) was found compared with a 16–hole plate arthrodesis (293.4 ± 89.3 N). The plate arthrodeses only achieved higher power values on abduction and adduction stress in comparison with screw arthrodesis with 3 humerus–glenoid screws. The difference was insignificant. Because arthrodesis with 3 humerus–glenoid screws was significantly more stable on stress of anteversion and retroversion, this particular screw arthrodesis is considered superior to plate arthrodeses. The use of the most stable form of screw arthrodesis may reduce nonunion. (J Shoulder Elbow Surg 2005;14:51-59.)*

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Complications after shoulder arthrodesis are frequent. Cofield and Briggs[7] reported on the largest number of cases of shoulder arthrodesis. They stated that a total of 25 reoperations (35.2%) were required after 71 cases of shoulder fusion. The questions raised and the objectives aimed for in the present study concern the high complication rate of shoulder arthrodesis.*

A review of the literature (reports with ≥10 arthrodeses since 1970; 111 screw arthrodeses and 213 plate arthrodeses) shows that postoperative infection (1%-3%), fractures of the humerus (1%-3%), and removal of material because of persistent pain (9%-20%) are more frequent complications in plate arthrodeses[1,8,12,14,16,22-27,29] whereas the rate of nonunion is higher after screw arthrodeses (7%-13%).[3,9,25,28,31]

In comparison with plate arthrodesis, screw arthrodesis is superior in that only a small exposed area is required for surgery, thus reducing any soft–tissue damage. This, in turn, could be the reason for the lower rate of infection than with plate arthrodesis. Fractures in plate arthrodesis usually occur just below the plate. This can be avoided by using screws for fixation.

The technical procedure used for shoulder arthrodesis is extremely varied and depends solely on the experience and theoretic speculations of the respective surgeon. Methods described are glenohumeral (intraarticular)[2,6,9,30] and acromiohumeral (extraarticular)[11] shoulder arthrodeses as well as a combination of both methods.[1,3,7,15,22,24-29,31] The choice of fixation for osteosynthesis is extremely varied. Plate and screw arthrodeses are the most common.† Some authors also use an external fixator.[4,10,19,21]

When the developmental mechanism of nonunion is under consideration, factors such as excessive mobility (instability), absence of fragment contact, and impairment to the periosteal blood flow may be positively influenced by the method of surgical intervention by use of rigid fixation and a limited amount of osteosynthesis material. The rate of infection is likely

*References 1-5, 7, 9, 10, 12-16, 19, 20, 23-29, 31.

†References 1, 7, 8, 12, 15, 16, 18-26, 29-31.

to be minimized by shortening the time required for operation and reducing soft–tissue and bone necrosis arising through surgical intervention.

The literature reveals no biomechanical investigations of the best fixation method for shoulder arthrodesis. Therefore, several types of screw arthrodesis were tested biomechanically for their primary stability and compared with plate arthrodesis. The aim of this study was to find a material combination offering a high degree of primary stability. The clinical application of such an osteosynthesis could lead to a decrease in the high complication rate in shoulder arthrodesis.

## MATERIALS AND METHODS

We used 24 fresh cadaveric shoulder specimens (14 right and 10 left; 13 male and 11 female; mean age, 66 years [range, 42-90 years]). Macroscopically, radiologically, and computed tomographically, all specimens showed anatomically normal characteristics of the shoulder joint with different degrees of arthritic changes. A computed tomography investigation (Somatom–Plus–4 apparatus; Siemens AG, Munich, Germany) served to define the bone density.

The specimens were prepared as follows: the spine of the scapula and the humerus form an angle of 90° to each other, the humerus is seen to extend from the spine of the scapula, and the bicipital sulcus is positioned opposite the anterior acromial corner (Figure 1). This position of arthrodesis corresponds to the desired clinical operative position of the humerus, namely, 20° abduction, 30° anteversion, and 40° internal rotation in relation to the thorax. After osteotomy of the head of the humerus parallel to the glenoid surface, the cortex of the acromial undersurface and the cranial part of the head of the humerus were removed and adjusted for compatibility. Temporary fixation was carried out by use of K–wires.

A constant basic position of 4 screws was always chosen and left unchanged (glenoid–humerus–acromion) for screw arthrodesis; 2 screws were inserted from lateral through the head of the humerus into the glenoid (HG), exiting through a ventral outlet (HGp and HGz), and 2 screws from cranial through the acromion into the head of the humerus, exiting dorsally (AHdl and AHdm). Additional screws were alternately applied; a third screw was inserted from lateral through the humerus into the glenoid, exiting ventrally (HGd), and 2 screws from cranial through the acromion, exiting caudally from the head of the humerus, with one coursing laterally (AHl) and the other coursing ventrally (AHv) (Figure 1). Cannulated cancellous bone screws were used with 7–mm–diameter/32–mm thread (DePuy Orthopaedics Co, Sulzbach, Germany) of varying lengths (50-95 mm) with supporting washers. All screws were tightened with a torsiometer (Stahlwille torsiometer No. 760; Eduard Wille GmbH & Co, Wuppertal, Germany) to achieve firm fixation and the values recorded. The screw position was recorded radiologically before each respective investigation (Figures 2 and 3).

Screw arthrodeses were compared with plate arthrodesis. Testing of the plate arthrodesis was carried out subsequent to screw arthrodesis. Sixteen–hole reconstruction plates (4.5 mm/6.5 mm; DePuy Orthopaedics Co) were fixed to ensure that 7 holes of the plate were fitted securely to the humerus/head of the humerus and acromion/spine of the scapula and 2 holes were left exposed in the region of plate bending. Compression was applied to the fusion area as with screw arthrodesis by use of cannulated cancellous bone screws (2 screws from lateral through the plate and the head of the humerus into the glenoid and from cranial through the plate, acromion, and head of the humerus, respectively). The remaining 5 plate holes were fixed to the spine of the scapula and humerus with cortical screws (diameter, 4.5 mm; DePuy Orthopaedics Co, Sulzbach, Germany) of varying lengths (20-40 mm). The outcome was radiologically recorded (Figure 4).

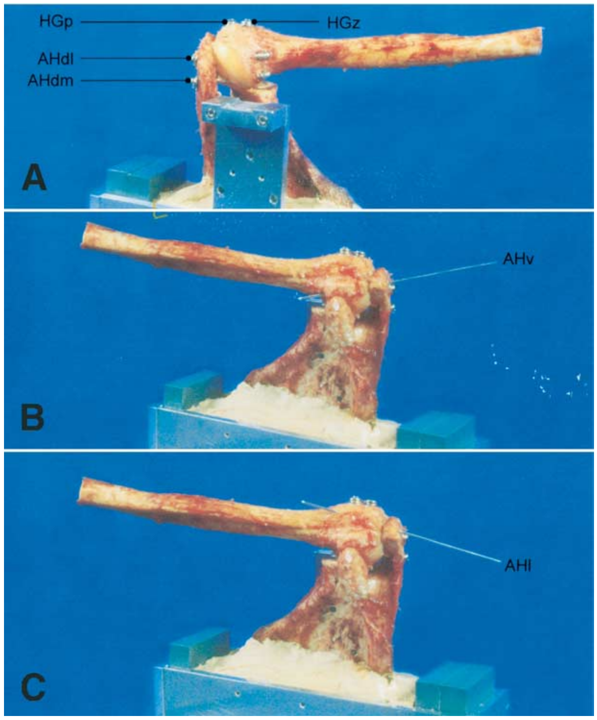


**Figure 1** Technique of screw placement. **A**, View from posterior (basic position, 2HG–2AH). **B**, View from anterior; a K–wire marks the position of the AHv screw. **C**, View from anterior; a K–wire marks the position of the AHl screw.

The tests were performed with a universal testing machine (type 1445; Zwick Roell AG, Ulm, Germany). The pickup unit used for measurement of force (type Z6; Hottinger–Baldwin Measuring Technique GmbH, Darmstadt, Germany) provides a measuring range of ±200 N with a resolution of 0.001 N. Recording of deflection of the humerus in relation to the scapula was carried out with a measurement device developed especially for this purpose. This entailed 4 potentiometric miniature recording devices (series MM; Megatron Electronic AG, Putzbrunn/Munich, Germany) (resolution, <0.01 mm) positioned at an angle of 90° with a distance of 200 mm (Figure 5).

For testing of stability, a constant advancement of 5 mm/min was enforced as long as load was applied to the

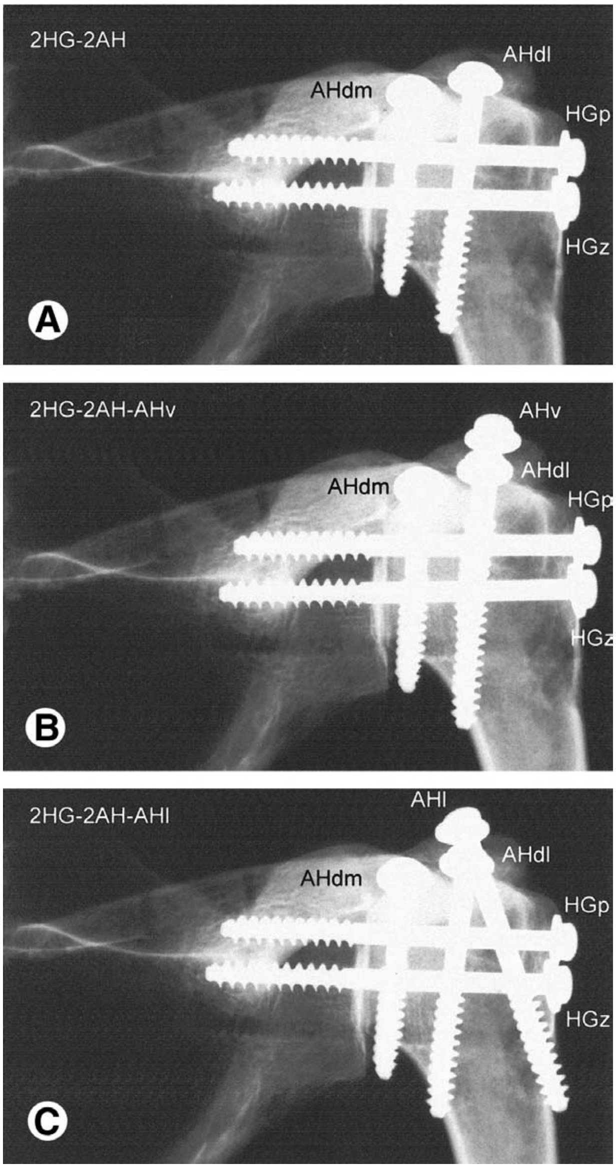


**Figure 2** Radiographs of screw arthrodeses with 2 humerus–glenoid screws: 2HG–2AH (basic position) (**A**), 2HG–2AH–AHv (**B**), and 2HG–2AH–AHl (**C**).

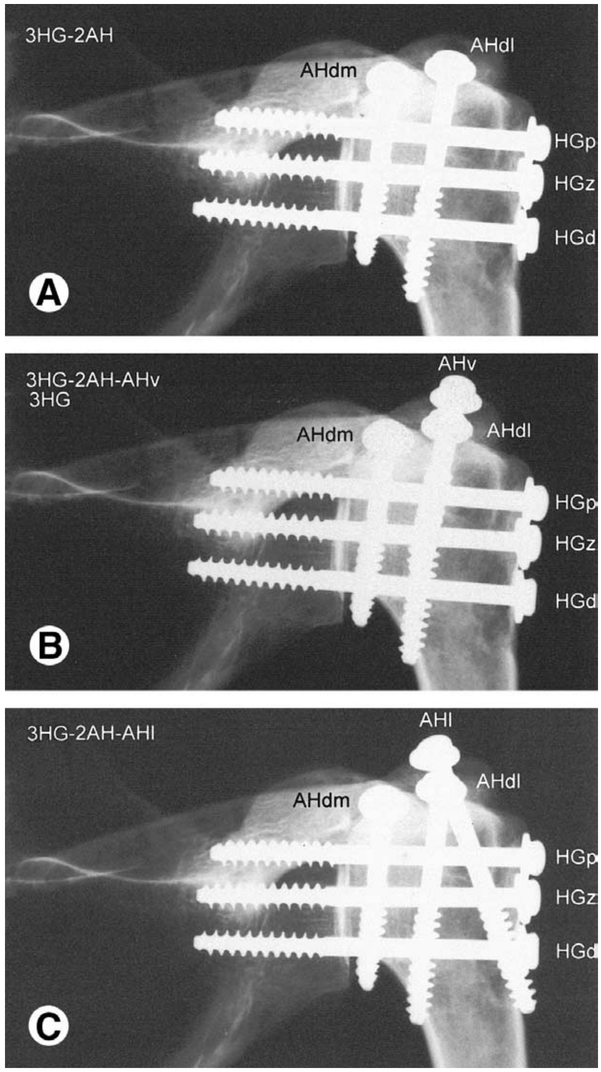


**Figure 3** Radiographs of screw arthrodeses with 3 humerus–glenoid screws: 3HG–2AH (**A**), 3HG–2AH–AHv (**B**), and 3HG–2AH–AHl (most stable form of tested arthrodeses) (**C**).

humerus. At the point when 1 of the 4 potentiometers achieved a maximum deflection of 2.0 mm, the test was discontinued.

The specimens with the aligned arthrodeses were connected to the measuring device (to the humerus, 125 mm caudal to the acromion undersurface). Installation of this complex, comprising clamping fixture, specimens, and measuring device, was carried out with the aid of an adjustable screw rod that was fixed with screw clamps to the traverse of the materials testing machine. By means of a transfer module connected to the materials testing machine, either traction (anteversion and abduction stress) or pressure (retroversion and adduction stress) was applied vertically to a defined point on the humerus at a 155–mm distance from the acromial undersurface (Figure 5). The direction of motion (abduction, adduction, anteversion, or retroversion) was recorded, and each individual recording of all motions was repeated 5 times. Before each reading with another composition of material, the torques of the screws were controlled with the torsiometer and, if necessary, restored to the initial values.

As a constant starting point, the basic position with the 2 laterally applied humerus–glenoid screws (HGz and HGp) and the 2 cranially positioned acromion–humerus screws (AHdl and AHdm) was recorded (PRAE) (Figure 1, *A*, and 2, *A*). In addition, a recording was also made of the situation with the supplementary screws HGd, AHv, and AHl (Figures 1-3). Commencement of recording was then carried out on a random basis at base point. In conclusion, a reading of the basic position was taken once again

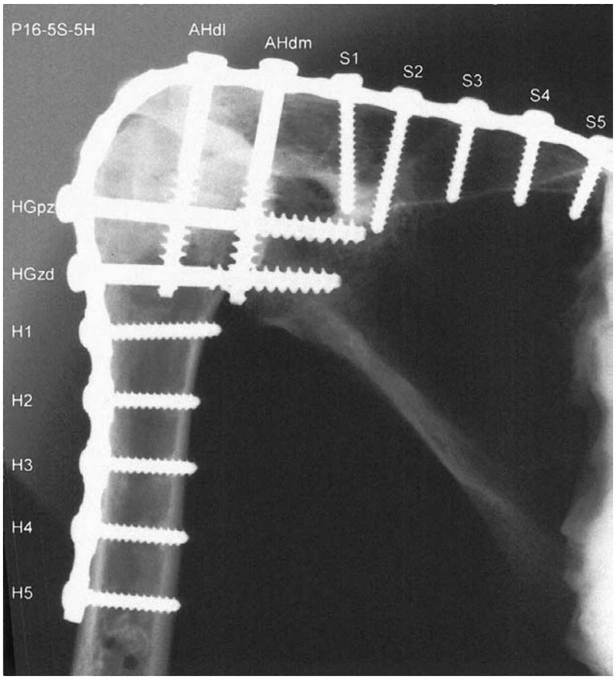


**Figure 4** Radiograph of plate arthrodesis with a 16–hole reconstruction plate (P16-5S–5H). Two compression screws: plate–humerus–glenoid (HGpz and HGzd) and plate–acromion–humerus (AHdl and AHdm). Five plate screws: plate–humerus (H1–H5) and plate–spine of the scapula (S1–S5).

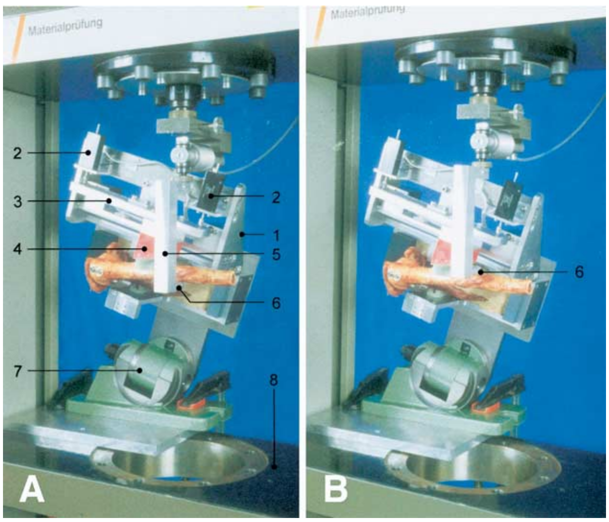


**Figure 5** Test setup, with installation in the universal testing machine. **A**, Load direction: anteversion (traction). **B**, Load direction: retroversion (pressure). *1*, Measurement device; *2*, potentiometric miniature recording devices (pickup unit for measurement of motion); *3*, transfer module; *4*, contact of humerus and transfer module; *5*, module for introduction of force (machine to specimen); *6*, point of contact for introduction of force (transfer module to specimen); *7*, variable adjustable screw rod; *8*, traverse of test machine.

**Table I** Overview of examinations/terms

| |
|---|
| Synopsis of Tests/examinations |
| 24 Specimens: 14 right and 10 left and 13 male and 11 female |
| 7 Configurations of material: 6 screw arthrodeses and 1 plate arthrodeses |
| 4 Load directions: abduction, adduction, anteversion, and retroversion |
| 5 Repetitions |
| Screw arthrodeses |
| 2HG-2AH: 2 humerus-glenoid screws and 2 acromion-humerus screws |
| 2HG-2AH-AHv: 2 humerus-glenoid screws and 3 acromion-humerus screws (1 exiting ventrally) |
| 2HG-2AH-AHl: 2 humerus-glenoid screws and 3 acromion-humerus screws (1 exiting laterally) |
| 3HG-2AH: 3 humerus-glenoid screws and 2 acromion-humerus screws |
| 3HG-2AH-AHv: 3 humerus-glenoid screws and 3 acromion-humerus screws (1 exiting ventrally) |
| 3HG-2AH-AHl: 3 humerus-glenoid screws and 3 acromion-humerus screws (1 exiting laterally) |
| Plate arthrodeses |
| P16-5S-5H: 16-hole reconstruction plate, 5 screws in spine of scapula, and 5 screws in humerus |

(POST). In addition, the tests were performed with plate arthrodeses (Table I).

The maximal values of force necessary for the given constant deflection of 2 mm were taken by use of the average valuation for assessment. The comparison of the PRAE and POST tests was used as a control. The assessments were prepared with the SPSS 10.0.7 program (SPSS Inc, Chicago, IL, USA). Significant findings were accepted at $P < .05$. For each direction of motion, all forms of arthrodesis were tested with the Friedman test for global differentiations. The post hoc pairwise comparison (Wilcoxon test) was used in the case of any significant results and made between the leading value and the ensuing values. The insignificant differing pairwise comparisons were interpreted as being equally satisfactory. The significant different pairwise comparisons were interpreted as being better or worse (greater or smaller initial value).

## RESULTS

The degree of force achieved for all load directions and their summation values revealed a significant difference in relation to the configurations of material ($P < .001$).

The highest mean value for all directions of motion was achieved by the arthrodesis form 3HG–2AH–AHl (318.5 ± 99.0 N), with the additional third HG screw (HGd) and acromiohumeral screw with lateral exit at the site of the humerus (AHl) (Figure 3, *C*). Taking into account each value obtained, for 21 of the 24 specimens, it was demonstrated that this particular combination resisted the highest degree of force of the four summated directions of motion. This was followed by the arthrodesis involving application of the AHv screw in

**Table II** Stability of different screw arthrodeses

| Rank | Configuration of screws | Abduction Mean (N) | Abduction SD (N) | Adduction Mean (N) | Adduction SD (N) | Anteversion Mean (N) | Anteversion SD (N) | Retroversion Mean (N) | Retroversion SD (N) | Sum of abduction, adduction, anteversion, and retroversion Mean (N) | Sum SD (N) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3HG–2AH–AHl | 97.1 | 31.0 | 102.0 | 33.1 | 60.5 | 21.9 | 58.9 | 19.5 | 318.5 | 99.0 |
| 2 | 3HG–2AH–AHv | 91.0 | 29.5 | 96.8 | 29.9 | 60.1 | 20.4 | 58.4 | 17.5 | 306.3 | 91.8 |
| 3 | 3HG–2AH | 80.1 | 32.5 | 86.1 | 33.6 | 55.5 | 21.1 | 53.1 | 21.1 | 274.8 | 104.4 |
| 4 | 2HG–2AH–AHl | 71.9 | 21.3 | 82.3 | 24.8 | 50.8 | 17.5 | 50.7 | 18.0 | 255.8 | 78.1 |
| 5 | 2HG–2AHPRAE | 67.2 | 20.0 | 75.4 | 25.1 | 49.6 | 17.6 | 47.2 | 16.9 | 239.5 | 75.6 |
| 6 | 2HG–2AH–AHv | 65.4 | 20.6 | 74.9 | 24.7 | 48.5 | 16.9 | 47.0 | 16.6 | 235.9 | 75.4 |
| 7 | 2HG–2AHPOST | 61.0 | 18.8 | 68.2 | 22.7 | 47.8 | 17.4 | 45.3 | 15.4 | 222.3 | 71.0 |
| Mean | | 76.3 | 27.0 | 83.7 | 29.8 | 53.3 | 19.3 | 51.5 | 18.3 | 264.7 | 91.0 |

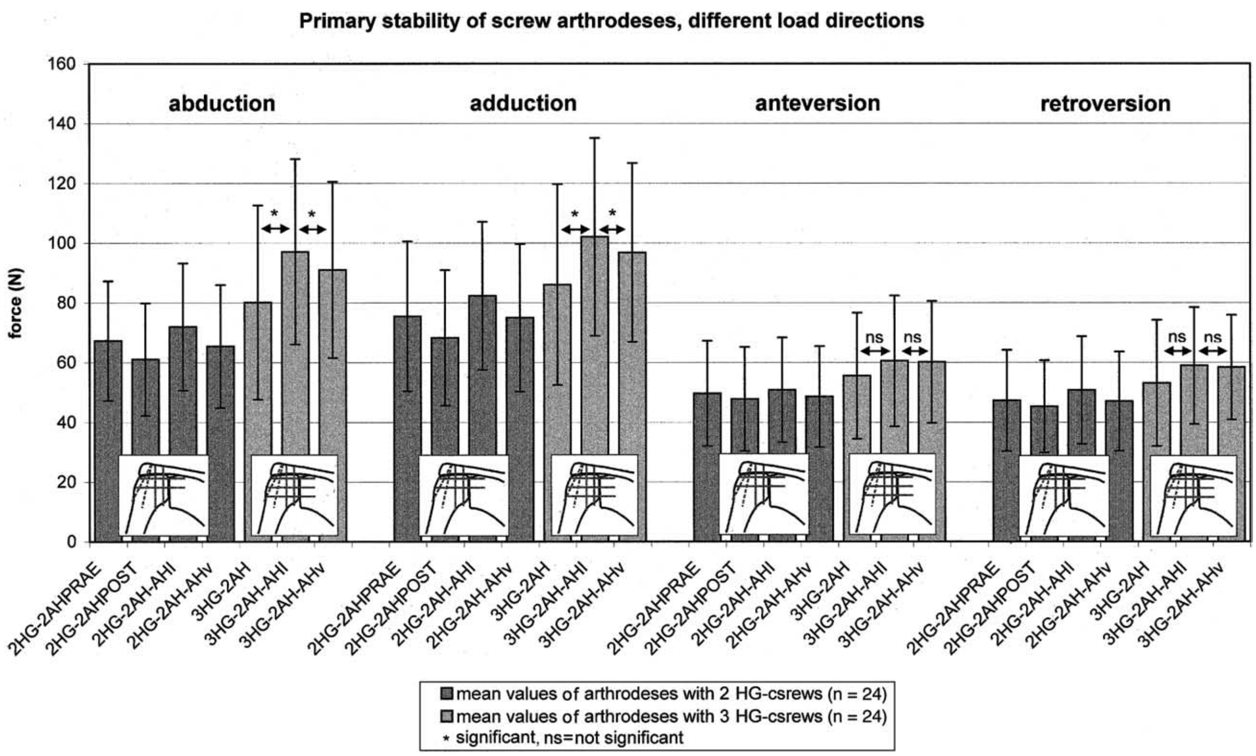


**Figure 6** Primary stability of screw arthrodeses with different load directions (mean values for different load directions of all 24 specimens for groups of arthrodeses with 2 HG screws and arthrodeses with 3 HG screws).

place of the AHl screw (306.3 ± 91.8 N) (Table II and Figures 3, *B*, and 6).

For the humerus–glenoid screws, the three highest mean values of force in all directions of motion and their total (299.9 ± 95.4 N) was found with the three different forms of arthrodeses, each with three screws (HGp, HGz, and HGd). The mean values for these arthrodeses (3HG–2AH–AHv, 3HG–2AH–AHl, and 3HG–2AH) (Figure 3) were revealed to be constantly higher than those values with only two HG screws (2HG–2AH, 2HG–2AH–AHl, and 2HG–2AH–AHv) (236.9 ± 74.1 N) (Tables II and III and Figures 2 and 6).

For the acromion–humerus screws in both subgroups (3HG and 2HG), the highest primary stability was achieved for all directions of stress with the AHl screw inserted (3HG–2AH–AHl and 2HG–2AH–AHl) (Figures 2, *C*, and 3, *C*). The influence of this third

**Table III** Primary stability of screw and plate arthrodeses

| | Arthrodeses | | | | | |
|---|---|---|---|---|---|---|
| | 2 HG screws | | 3 HG screws | | 16-hole plate | |
| **Load direction** | **Mean (N)** | **SD (N)** | **Mean (N)** | **SD (N)** | **Mean (N)** | **SD (N)** |
| Abduction | 65.9 | 19.6 | 89.4 | 29.7 | 97.1 | 31.4 |
| Adduction | 74.6 | 23.8 | 95.0 | 31.0 | 102.5 | 32.1 |
| Anteversion | 49.1 | 17.2 | 58.7 | 20.4 | 47.4 | 16.5 |
| Retroversion | 47.3 | 16.4 | 56.8 | 18.9 | 46.4 | 17.1 |
| Sum (abduction, adduction, anteversion, and retroversion) | 236.9 | 74.1 | 299.9 | 95.4 | 293.4 | 89.3 |

acromion–humerus screw on the stability of arthrodesis was demonstrated by the results of the subgroup with 2 HG screws. With the AHl screw in place (2HG–2AH–AHl), significantly ($P < .001$) higher values resulted than without this screw (2HG–2AH) or with the AHv screw (2HG–2AH–AHv). On the other hand, the subgroup with 3 HG screws showed higher mean values of force with the additional AHv screw (3HG–2AH–AHv) compared with the basic situation (3HG–2AH) (Figures 2, 3, and 6).

The mean maximal force achieved for all individual tests was revealed as markedly greater for abduction (76.3 ± 27.0 N) and adduction (83.7 ± 29.8 N) than for anteversion (53.3 ± 19.3 N) and retroversion (51.5 ± 18.3 N). The values of 2 HG arthrodeses were significantly lower than those of 3 HG arthrodeses for abduction (65.9 ± 19.6 N vs 89.4 ± 29.7 N), adduction (74.6 ± 23.8 N vs 95.0 ± 31.0 N), anteversion (49.1 ± 17.2 N vs 58.7 ± 20.4 N), and retroversion (47.3 ± 16.4 vs 56.8 ± 18.9 N) ($P < .001$) (Tables II and III and Figure 6).

The mean values of the screws' torque were, in general, higher for the 3 horizontal glenohumeral screws (GHp, HGz, and HGd) than for the 4 vertical acromiohumeral screws (AHdm, AHdl, AHl, and AHv). In addition, the mean screw torque of the 3 humerus–glenoid screws (HGp + HGz + HGd), at 232 ± 71 Ncm, was greater (31% and 35%, respectively) than that of the acromion–humerus screws (160 ± 41 Ncm for AHdm + AHdl + AHl and 151 ± 40 Ncm for AHdm + AHdl + AHv).

The greatest mean torque was recorded for the HGd screw, at 268 ± 80 Ncm. In all specimens, one of the HG screws always showed the highest torque value (HGd 18×).

Greater torques resulted for the acromiohumeral screws AHdm, AHdl, and AHl (170 ± 55 Ncm, 150 ± 41 Ncm, and 165 ± 48 Ncm, respectively) compared with the AHv screw (136 ± 45 Ncm). The AHl screw (165 ± 48 Ncm) demonstrated higher mean torque values than the AHv screw (136 ± 45 Ncm) (Table IV and Figures 1-3).

**Table IV** Screw torque

| Rank | Screws | Mean (Ncm) | SD (Ncm) |
|---|---|---|---|
| Humerus-glenoid screws | | | |
| 1 | HGd | 268 | 80 |
| 2 | HGp + HGz + HGd | 232 | 71 |
| 3 | HGp | 223 | 93 |
| 4 | HGz | 206 | 65 |
| Acromion-humerus screws | | | |
| 5 | AHdm | 170 | 55 |
| 6 | AHl | 165 | 48 |
| 7 | AHdm + AHdl + AHl | 160 | 41 |
| 8 | AHdm + AHdl + AHv | 151 | 40 |
| 9 | AHdl | 150 | 41 |
| 10 | AHv | 136 | 45 |

The mean values for the 16–hole plate arthrodeses (P16-5S–5H) were compared with those for each of the three screw arthrodeses fixed with 3 or 2 humerus–glenoid screws. Comparison within these three groups showed a globally significant difference for all directions of load and their summation ($P < .001$).

The sum of force values was highest at 299.9 ± 95.4 N for all directions of stress with the arthrodeses with 3 HG screws. No significant difference ($P = .530$) was revealed compared with plate arthrodesis (293.4 ± 89.3 N). The arthrodesis with 2 HG screws, on the other hand, showed a significant difference, at 236.9 ± 74.1 N ($P < .001$) (Table III and Figure 7).

The highest values were achieved with plate arthrodeses for abduction and adduction (97.1 ± 31.4 N and 102.5 ± 32.1 N, respectively). These values showed no significant difference from the force values for the screw arthrodesis with 3 HG screws (89.4 ± 29.7 N and 95.0 ± 31.0 N, respectively) ($P = .290$ and $P = .253$, respectively). The arthrodeses with 2 HG screws, at 65.9 ± 19.6 N and 74.6 ± 23.8 N,

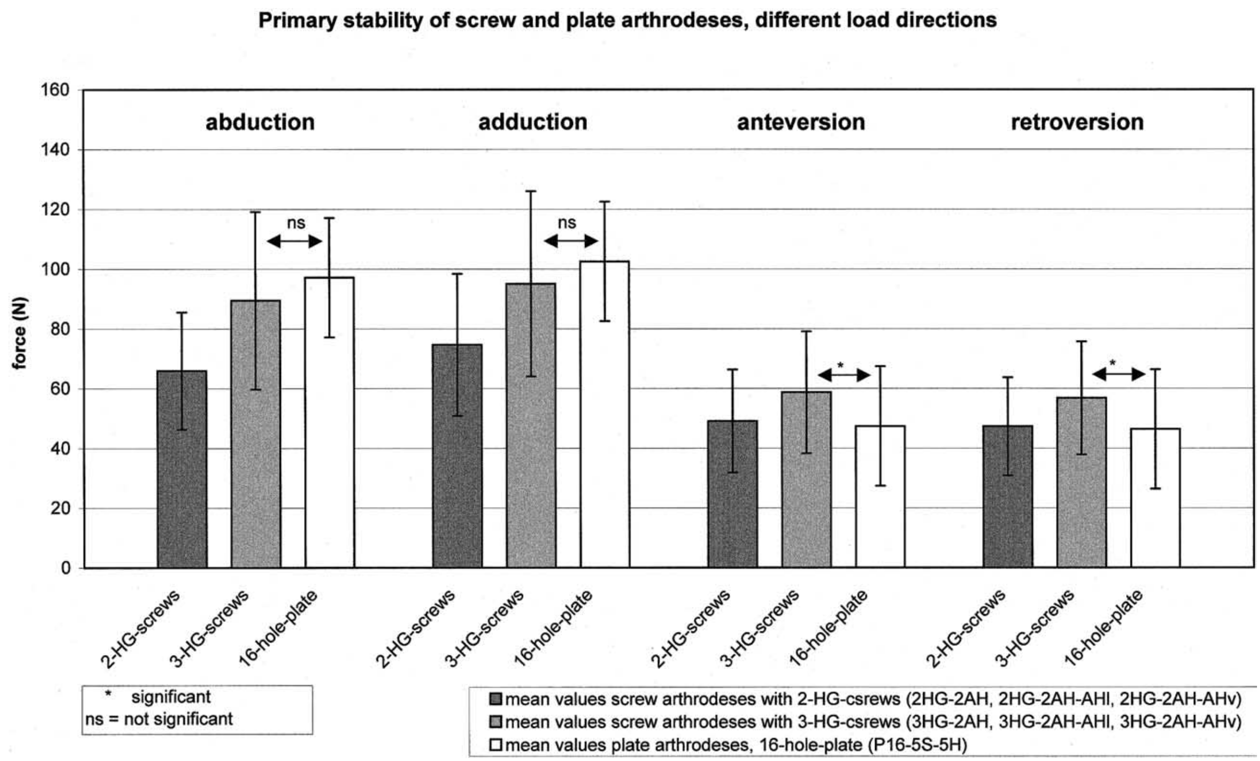


**Figure 7** Primary stability of screw arthrodeses with different load directions (mean values of four different load directions of all 24 specimens for groups of arthrodeses with 2 HG screws, arthrodeses with 3 HG screws, and plate arthrodeses).

respectively, were significantly lower for abduction and adduction ($P < .001$).

The highest values for anteversion and retroversion were achieved with the arthrodeses with 3 HG screws, at 58.7 ± 20.4 N and 56.8 ± 18.9 N, respectively. The stability of this form of arthrodesis was significantly greater ($P < .001$) than with plate arthrodesis (47.4 ± 16.5 N and 46.4 ± 17.1 N, respectively).

A marked difference between the arthrodesis with 2 HG screws and plate arthrodesis was not demonstrated for the stress directions anteversion and retroversion.

In summary, the 16–hole plate arthrodeses (P16-5S–5H) achieved higher force values than those with the screw arthrodesis with 3 HG screws only with abduction and adduction stress, but no significant difference was demonstrated here. Stress in anteversion and retroversion revealed that the arthrodesis with 3 HG screws was significantly more stable than the plate arthrodeses. In addition, the summation of all load directions showed the arthrodeses with 3 HG screws to be superior; however, the significance level could not be determined (Table III and Figure 7).

When the parameters that might influence the quality of the specimens are taken into account, no constant relationship to the stability values could be found corresponding to age, sex, or bone density. The results varied. Age and sex did not correlate consistently with bone density. No specific relationship was shown with regard to the respective comparison of age and bone density with the results attained for the screw torques and arthrodesis stability.

## DISCUSSION

To our knowledge, the study with the highest number of published arthrodeses reported a follow–up of 71 cases carried out by different surgeons within a period of 24 years.[7] Because there are no comparable biomechanical studies, it was not possible to form a direct comparison of our results with those in the literature in order to demonstrate achievement of primary stability with arthrodesis by use of different material configurations.

Publications on clinical studies concerning screw arthrodeses reveal the nonunion rate to be exceptionally high, at 13% (14/111 arthrodeses).[3,9,25,28,31] This indicates that primary stability is difficult to achieve with screws only. There is no recognized standard form of screw arthrodesis mentioned in the literature, and the techniques appear to vary greatly. Few details are given about the screws used and their position.[1,7,15,17-19,21,30,31] Various cancellous bone screws and/or cortical screws are used in a number of different positions. The number of humerus–glenoid screws used and the total number of screws vary from 0 to 4, and the number of acromion–humerus screws varies from 0 to 2.[‡] Fixation by screws was undertaken 62 times in the 71 shoulder arthrodesis cases followed up by Cofield and Briggs.[7] Two humerus–glenoid screws and one acromion–humerus screw were used in most cases.

The only more detailed assessment of screw position was published by Ducloyer et al.[9] Two, three, or four humerus–glenoid screws were used for 23 cases of screw arthrodesis. The course of the screws was convergent in 11 cases, divergent in 10, and parallel in 2.

Horizontal or vertical screws can be used for compression when an arthrodesis is performed between the humerus and the glenoid as well as between the acromial undersurface and the humerus. For the horizontal humerus–glenoid screws, our tests have shown that 3 such screws (HGp, HGz, and HGd) achieve a more stable primary status than 2 screws (HGp and HGz). An additional third vertical acromion–humerus screw (AHl/AHv) also resulted in more stability, although it was shown that the arthrodesis form 3HG–2AH–AHl demonstrated the greatest primary stability. This result was confirmed by the intraindividual assessment of values for each preparation and indirectly by the torque of each screw. The most stable form of arthrodesis was that in which the 2 additional screws with the highest torques were used. A higher stability could also be shown for both of the additionally used HGd and AHl screws. In view of the load direction, screw arthrodeses demonstrated greater primary stability for abduction and adduction than for anteversion and retroversion.

The use of cannulated cancellous bone screws is advantageous because the screw position is marked by K–wires, thus allowing more exact positioning. Should inaccurate positioning occur, the K–wires may be removed and repositioned without incurring any bony damage (Figure 1, *B* and *C*).

In a comparison of screw and plate arthrodeses, a more stable fixation with the use of plates would have been expected, considering the rates of nonunion described in the literature. Our biomechanical investigations have shown that the mean power value of the summation of tested screw arthrodeses with 3 HG screws (299.9 ± 95.4 N) is higher than the corresponding value for plate arthrodesis (293.4 ± 89.3 N). The plate arthrodesis (P16-5S–5H) only achieved higher power values on abduction and adduction stress in comparison with screw arthrodesis with 3 HG screws. The difference was insignificant. The arthrodesis with 3 HG screws was significantly more stable on stress of anteversion and retroversion. When all of the investigated aspects are taken into account, the arthrodesis with 3 HG screws with its power values is considered superior to plate arthrodesis. The significance level could not be determined.

Surprisingly, the traction belt effect when plates were used did not result in any distinctive improvement in stability for abduction and adduction. The AHl screw plays an equally important role together with the third HG screw. By coursing from the acromion, through the head of the humerus with a lateral exit, resistance to abduction and adduction movements, as well as stability, is ensured.

In general, a comparative investigation is only possible when the tests allow an intraindividual assessment of the various conditions, such as shown here with the material composition. This necessitates a series of tests with the use of the same specimens. If several stability recordings are performed on one specific specimen, deterioration of this specimen is unavoidable. Only a limited number of specimens from human cadavers are made available for investigation purposes. We performed as many tests as possible on the available specimens and attempted to reduce the deterioration of quality during the course of the investigations. Careful testing with small movement amplitudes is essential to prevent any damage to the specimens. A constant sequence for insertion and removal of screws was determined for both screw and plate arthrodeses to reduce the process to a minimum. The same starting point was registered each time and checked again at the end of each respective series of investigations. After registration of the starting point, a randomized allocation ensued as to which form of arthrodeses was to be recorded next. The determined sequence was deduced, with minimalization of screw change being taken into account. The direction of motion to be recorded first was taken from a randomized allocation so that all directions of motion were investigated with respective frequency at the first, second, third, or fourth position. The deterioration of quality during the procedure lay at 8%.

The consistent results achieved in relation to the most stable forms of arthrodesis and their confirmation in view of the intraindividual results connected with the torques of the screws constituted the criteria of the specimens to be investigated. They demonstrated the success of the measures taken to reduce the deterioration of quality of the specimens together with the qualitative, equally satisfactory demonstra-

‡References 2, 3, 6, 7, 9, 11, 15, 25, 28, 30, 31.

tion of the respective forms of arthrodeses used for the 24 specimens.

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