THE STRENGTH OF SURGICAL REPAIRS OF
THE ROTATOR CUFF

A BIOMECHANICAL STUDY ON CADAVERS

L. SWARD, J. S. HUGHES, A. AMIS, W. A. WALLACE

From the University Hospital, Nottingham

Using 26 cadaver shoulders, we produced a standard defect in the supraspinatus tendon and performed one of three types of repair. Their strength was found by testing in tension the force required to produce a gap of 3 mm, then 6 mm, and finally total disruption of the repair.

The use of a polyethylene patch to spread the forces over the lateral bone surface and of extra sutures to grasp the tendon end raised by 2.6 times the load at which a 3 mm gap in the repair occurred and by 1.7 times the load to failure.

Rotator cuff tears are very common. De Palma (1983) found an incidence of 37% for partial tears and 9% for full-thickness tears in patients with a mean age of 59 years. This increases with age but tears may also occur in young athletes. Their natural history varies, but large tears are often slowly progressive. Although Neer (1990) reported that there may be spontaneous healing of partial-thickness tears, this has rarely been observed in full-thickness lesions. The symptoms are very variable but usually include pain at rest or on movement, and a decreased range of motion resulting in considerable restriction of normal activities (Chakravarty and Webley 1990). Non-operative management is satisfactory in only 44% of patients (Takagishi 1978). There is, therefore, a strong case for surgical repair which relieves pain in approximately 85% of patients, but gives a good functional result in only 75% (Cofield 1985). Secondary rupture after repair is associated with very poor results and re-operation usually fails to improve function although it may relieve pain (DeOrio and Cofield 1984). The first operation has the best chance of relieving both pain and disability.

Wallace (1984) calculated that the supraspinatus tendon transmitted 300 N when the arm was abducted to 30°, and France et al (1989) showed that their strongest repair method failed at 200 N. Our aim was to compare some new methods of surgical repair with those in general use.

MATERIALS AND METHODS

We collected 26 (21 male, 5 female) cadaveric human shoulders within 12 hours of death. All subjects with previous shoulder surgery, a ruptured rotator cuff, or aged less than 40 years were excluded. The shoulders were divided into three groups: group 1, ten specimens; group 2, six specimens; group 3, ten specimens. The mean age in group 1 was significantly less than that in group 2 or group 3 (Table I).

We divided the deltoid muscle from the acromion and performed an osteotomy of the spine of the scapula and clavicle, reflecting the acromion medially and thus exposing the supraspinatus muscle-tendon unit. The deltoid was reflected distally and the humeral shaft divided proximally to the deltoid insertion. A 30 mm

Table I. Age and results of strength tests in three groups of rotator cuff repairs

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean age (year)</th>
<th>Force (N) (SD)</th>
<th>Failure (N)</th>
<th>Mode of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>65 (9)</td>
<td>164 (38)</td>
<td>224 (44)</td>
<td>273 (52)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 mm gap</td>
<td>6 mm gap</td>
<td>Failure</td>
</tr>
<tr>
<td>2</td>
<td>78 (13)</td>
<td>146 (28)</td>
<td>226 (49)</td>
<td>356 (136)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 mm gap</td>
<td>6 mm gap</td>
<td>Failure</td>
</tr>
<tr>
<td>3</td>
<td>74 (6)</td>
<td>429 (96)</td>
<td>510 (79)</td>
<td>605 (109)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 mm gap</td>
<td>6 mm gap</td>
<td>Failure</td>
</tr>
</tbody>
</table>

*avulsion of the greater tuberosity
wide attachment of the supraspinatus tendon and its muscle belly was preserved and the other soft tissues were removed from the humeral head. The supraspinatus tendon was divided 5 mm from the greater tuberosity and one of us (JSH) performed one of the surgical repairs described below. Each specimen was then wrapped in gauze soaked in Hartmann’s solution, sealed in a polyethylene bag and stored at $-20^\circ$C.

After thawing, the strength of each repair was measured by testing to failure in tension in an Instron 1122 machine (Instron Ltd, High Wycombe, England). The humeral head was fixed in a vice at 30° abduction. This angle was chosen because Wallace (1984) has shown that the tension in the supraspinatus, while abducting the arm, is greatest at 30°. The musculotendinous region of the supraspinatus was gripped in freezing jaws (Riemersa and Schamhardt 1982) and the specimens were elongated at a rate of 50 mm/min while a load versus displacement curve was recorded on an integral graph plotter. The site and mode of failure were recorded, as well as the force required to cause a gap of 3 mm, and then 6 mm, at the site of repair.

**Rotator cuff repair techniques.** Three methods of re-attaching the supraspinatus tendon to the humeral head were tested.

*Group 1.* A standard repair, as described by Matsen and Arntz (1990), was used as the control. A 30 mm bevelled bony trough was made just lateral to the articular surface of the humeral head, down to cancellous bone. Drill holes for sutures were made connecting the base of the trough to the lateral aspect of the greater tuberosity, sufficiently distal to avoid the sutures, knots or patches causing impingement when the shoulder was abducted. Three grabbing stitches (double-loop technique) were inserted in the tendon and then passed through four drill holes, using a No 2 Ethibond suture (braided polyester suture coated with polybutylate 5metric; Ethicon Ltd, Edinburgh, Scotland), and tied over the lateral cortex of the proximal humerus (Fig. 1).

*Group 2.* The method was similar to the above but was augmented by a 1 mm thick (8 mm × 35 mm) ultra-high-molecular-weight-polyethylene (UHMWP) patch (Hoechst Chemicals, Frankfurt, Germany) with four holes to match the bone drill holes, which was placed between the sutures and the bone of the distal greater tuberosity (Fig. 2). Its purpose was to spread the forces at the bone–suture interface to prevent the sutures from cutting through the bone. UHMWP was chosen because it could be moulded to the curved surface of the humerus and was known to be biocompatible.

*Group 3.* The same technique was used as in group 2 but three horizontal mattress sutures were inserted in the tendon and passed through the four drill holes. In addition, four sutures were then passed through the four drill holes, applied as double-loop stitches to the cut edge of the tendon. They were brought over the top of the greater tuberosity and tied to themselves (Fig. 3). This increased the number of sutures crossing the repair site from six (in group 2) to 14.

Correlations between age, ‘gapping’ force, mode of failure and failure strength were examined for all three methods using unpaired Student’s $t$-tests.

**RESULTS**

Although the mechanism of failure differed for each type of repair the initial response was the same. As tension was applied, the sutures stretched and cut into the substance of the tendon, compressing the bone beneath. This resulted in ‘gapping’ of the tendon out of its trough, without true failure of the repair. The extent of this gapping was measured for the different types of repair.

In group 1, the commonest mechanism of failure was at the bone–suture interface; eight of the ten
specimens failed by the sutures cutting through the bone. The force required for gapping was only 50% of that predicted to occur during active abduction of the arm.

In group 2 the UHMWP patch appeared to protect the bone–suture interface, and failure occurred more often at the tendon–suture interface. Five of the six specimens failed at the tendon–suture interface and one had a combined failure of bone and tendon. The use of the patch, however, neither increased the force at which gapping occurred nor raised the failure load significantly (p = 0.103).

The method used in group 3 increased the strength of the repair and reduced gapping. There were significant increases in the gapping load (p < 0.0001) and the ultimate strength (p = 0.001) when compared with group 2. In 50% of specimens the loads generated during testing were such that the greater tuberosity was avulsed (Table I and Fig. 4).

**DISCUSSION**

The factors affecting rotator cuff repair have been analysed by various authors (Ellman, Hanker and Bayer 1986). Abduction splints have been used, but their benefit has not been demonstrated clinically (Watson 1985) although there is some biomechanical evidence that they can reduce the tension on the repair (Zuckerman et al 1991). In fact, the best results have been associated with early movement postoperatively (Cofield 1985) highlighting the potential value of a surgical repair strong enough to resist stretching or disruption before healing can take place. The strength of cuff repairs continues to improve for six to 12 months after surgery (Walker et al 1987).

The most common tendon in the rotator cuff to be repaired is the supraspinatus, and it is seldom possible to perform an end-to-end repair, because the tendon is more usually avulsed from bone or leaves a residual short stump of tendon attached to bone which will not retain sutures (Ellman, Hanker and Bayer 1986). Usually the tendon is re-attached into a bony trough in the humeral head (McLaughlin 1944; Matsen and Arntz 1990). Tests of the tensile strength of cadaveric tendons have shown wide variations between specimens. Even tendons with the same cross-sectional area may differ dramatically; values of 60 to 124 MPa (N per mm²) were reported by Cronkite (1936). Biomechanical studies of the shoulder suggest that the forces passing through the rotator cuff are greatest during abduction and may be of the order of 300 N, or approximately half the body-weight (Wallace 1984). Most repairs are undertaken in elderly patients and, in view of these high forces, the quality of the bone of the greater tuberosity is very important.

Although the high incidence of re-rupture is well recognised in patients who have been inadequately supervised or in whom active abduction exercises have been started too early, it has only been shown recently that these repairs are often tenuous. France et al (1989) were the first to study the initial strengths of cuff repairs in cadavers, and showed that the strongest repair was one augmented by patches on both the bone–suture and tendon–suture interfaces. The absolute strength, however, was still only about 200 N, but they obtained a 30% improvement over the standard repair. Our technique, using a UHMWP patch to spread the forces over the bone surface and extra sutures to grasp the tendon more securely, raises by 2.6 times the load at which a 3 mm gap occurred in the repair. We did not use a patch at the tendon–suture interface because it could have caused impingement. The force that produces a 3 mm gap may be of greater clinical significance than the ultimate tensile strength, since gap formation will prejudice healing, or cause lengthening of the healed tendon, even if complete disruption of the repair does not occur.

The ultimate tensile strength and the force which produced a 3 mm gap both decreased with increasing age of the specimen in all repairs, but in group 3 this decrease was highly significant only for the maximum load (r = −0.895; p = 0.001, Spearman correlation). Since the specimens in groups 2 and 3 were significantly older than those in group 1 (p = 0.02) the increases in strength produced by our new method over that of the standard Matsen repair may have been underestimated.

We conclude that the use of a polyethylene patch and a greater number of sutures crossing the repair gave a reconstruction which was capable of withstanding the loads encountered during the normal activity of an unloaded arm. This improvement may allow earlier rehabilitation without disruption and the method deserves to be evaluated clinically.
REFERENCES


Wallace WA. Evaluation of the forces, the ICR and the neutral point during abduction of the shoulder. Trans 30th Meeting of the Orthopaedic Research Society, Atlanta, 1984:5.
