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The sheath of the rectus abdominis muscle: an anatomical and biomechanical study

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Summary: The anterior layer of the sheath of the rectus muscles is often used in the repair of incisional hernias through the linea alba. This practice has led us to undertake an anatomical and biomechanical study of its structure. Thirty fresh cadavers were divided into three groups of ten. All were dissected and biomechanical tests were carried out on the latter two groups: in Group 2 a dynamometer was used to measure the resistance to linear traction and to deformation. In Group 3 a bursting strength tester was used in order to determine the resistance to pressure. Morphological studies included measurements of the mean dimensions of the sheath, and of its composition at different levels. The biomechanical results show that the anterior sheath is more resistant to traction below the arcuate line than above it, whereas the resistance to pressure shows an opposite pattern. The resistance to traction of the posterior sheath is similar in its aponeurotic portion both above and below the umbilicus, the resistance to pressure being slightly less in the region of the arcuate line. The figures for deformation are essentially the same at all levels. The implications of these results for the repair of abdominal wall defects are discussed.

Key words: Rectus sheath — Biomechanics — Mechanical properties

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The anterior rectus sheath is often used in the repair of midline incisional hernias for the construction of overlapping repairs or, less often, to fill in an area of loss of substance in the abdominal wall. This practice has led us to undertake an anatomical and biomechanical study of the rectus sheath.

Apart from the classical anatomical texts [Poirier 1912, Paturet 1951, Rouvière 1939, 1967, Neidhart 1994] very few workers have interested themselves in the anatomy of this structure. Askar (1984, 1994) undertook a detailed study of the complexity of the direction of the aponeurotic fibres of the sheath, but as regards biomechanical studies, there is only one which in recent years has compared the anterior sheath with the transversalis fascia [Pans 1997]. One other study of the resistance to traction of vertical or transverse suture lines in the rectus sheath has been carried out by Greenall and Pollock (1980).

Material and methods

Thirty fresh cadavers (16 female and 14 male), of mean age 83.24 (range 62-95) were divided into three groups of ten. Their morphological type was as follows: nine were obese, thirteen were

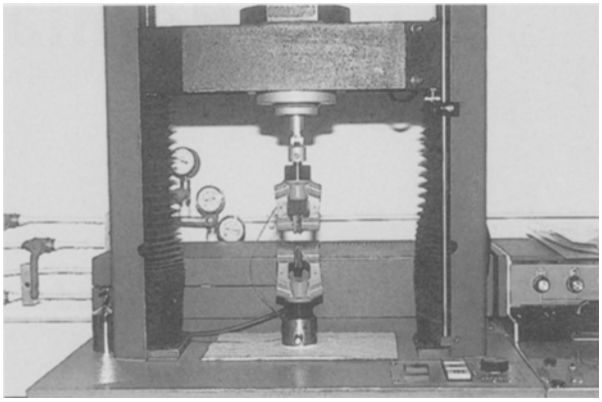

Fig. 1
The dynamometer. The strip of tissue is fixed between the two clamps which are progressively drawn apart, exerting traction. A deformation curve ending in rupture is described at the same time

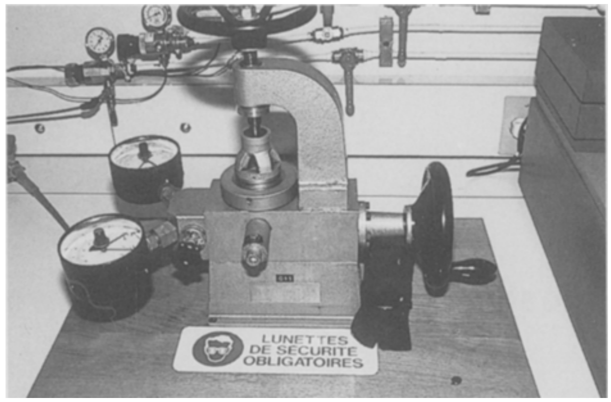

Fig. 2
The bursting strength tester. The specimen is fixed on to the rubber membrane by the guide wheel. The pressure on the membrane is increased by turning the handle. The apparatus switches itself off automatically as soon as the tissue ruptures

of average build and eight were thin. All bodies were dissected in order to measure all the musculo-aponeurotic structures of the anterolateral abdominal wall.

In Group 1, only a dissection was carried out.

Biomechanical tests were performed in the other two groups. In Group 2 a dynamometer (Fig. 1) was used in order to calculate the force of linear traction required to rupture a strip of tissue 1 cm wide and 3 cm long, removed vertically from the linea alba. This test also provided results on the deformability of the tissue.

The tests in Group 3 used a bursting strength tester (Fig. 2), an apparatus which measures the pressure required to rupture a piece of tissue 5 x 5 cm through a mechanism similar to that which intra-abdominal pressure exerts on the abdominal wall.

Four specimens were removed for study of the rectus sheath: two on the anterior layer, one above and one below the arcuate line, bearing in mind the structural differences between these two sites. Additionally, specimens were retrieved from the posterior sheath, one above the umbilicus and the other below it but from above the arcuate line.

In order to re-establish the hydration of the dead tissue (and thus its elasticity) we used the method described by Hiroshi Yamada (1970) which consists in removing specimens from the body within 72 h of death and preserving them in saline at 4° C for 24 h. By this means one attains a state of mechanical stability (SMS). Yamada compared the resistance and deformability of animal tissues at SMS with those obtained immediately after death, and found that resistance is slightly underestimated at SMS but deformability is almost identical. In our series, the mean interval between death and assessment was 41 h 45 min (22-72).

The statistical tests used were those of Spearman, Mann-Whitney and Anova.

Results

Morphological studies

The mean length of the infra-xiphoid portion of the rectus abdominis muscles was 29.11 cm.

Their breadth was measured at three levels: supra umbilical, at the umbilicus and sub umbilical. It was on average 7.24 cm (3-10.6), 6.88 cm (3-12.8) and 5.62 cm (2.5-8.8) respectively.

As is known, the rectus sheath has a different composition above and below the arcuate line of Douglas. Above the line, in effect, the anterior layer is formed by the aponeurosis of the external oblique and the anterior part of the doubled aponeurosis of the internal oblique muscle. The posterior layer is formed by the union of the posterior leaf of the internal oblique aponeurosis with the aponeurosis of transversus abdominis. Below the arcuate line all of the aponeuroses of the flat muscles pass in front of the rectus, their posterior aspects being covered only by transversalis fascia. We observed that the arcuate line is a single structure in almost half the cases (16 out of 30) and a more or less clearly defined double arcade in the remaining 14. In effect, the posterior leaf of the internal oblique aponeurosis is the first to pass in front of the rectus, the transversus aponeurosis crossing a little further down, thus constituting a double arcade. When it is single, the arcuate line lies on an average 4.46 cm (2-10) below the umbilicus, an when double the upper arch lies at 4.39 (1.5-12) and the lower at 7.25 (3-13) cm below the umbilicus.

Biomechanical studies

Dynamometric tests

The breaking strain, or force exerted per unit, is a measure of the resistance of the tissues to linear traction. It is expressed as kgf/mm^2 or in MPa. The results are shown in Table 1.

Table 1. Dynamometric tests. Breaking strain

	kgf/mm^2 (SD)	MPa
ASS	0.503 (0.174)	4.943
AIS	0.771 (0.843)	7.566
PSS	0.618 (0.392)	6.064
PIS	0.657 (0.477)	6.452

ASS, anterior supra-arcuate line sheath; *AIS*, anterior infra-arcuate line sheath; *PSS*, posterior supra-umbilical sheath; PIS, posterior infra-umbilical sheath

Table 2. Dynamometric tests. Deformability

	% Elongation (SD)
ASS	26.088 (11.778)
AIS	36.621 (21.211)
PSS	35.041 (14.535)
PIS	30.770 (13.384)

ASS, anterior supra-arcuate line sheath; *AIS*, anterior infra-arcuate line sheath; *PSS*, posterior supra-umbilical sheath; PIS, posterior infra-umbilical sheath

Table 3. Bursting strength test. Bursting pressures

	kgf/mm^2 (SD)	PSI
ASS	5.895 (1.411)	83.05
AIS	3.632 (1.114)	51.93
PSS	3.710 (1.340)	52.71
PIS	2.484 (1.527)	35.25

ASS, anterior supra-arcuate line sheath; *AIS*, anterior infra-arcuate line sheath; *PSS*, posterior supra-umbilical sheath; PIS, posterior infra-umbilical sheath

The anterior layer of the rectrus sheath is less resistant above than below the arcuate line (0.503 kgf/mm^2 vs. 0.771 kgf/mm^2 respectively). However, this increased resistance does not reach statistical significance. As regards the posterior layer, resistance to traction is virtually uniform over both areas, 0.617 kgf/mm^2 above and 0.657 kgf/mm^2 below the umbilicus, on average.

Deformability represents the percentage elongation of the specimen at the moment of rupture and is expressed by the formula LR - IL/IL x 100 where IL is the initial length and LR the length at the moment of rupture. The values are reasonably constant at all levels of the rectus sheath. For the anterior layer deformability was on average 26.08% above and 36.62% below the arcuate line. For the posterior layer it was 36.44% above the umbilicus and 30.76% between the umbilicus and the arcuate line. The differences between the two figures are not significant (Table 2).

Bursting strength tests

The bursting pressure measures the resistance to pressure exerted on the tissue surface and corresponds to the moment when it tears in response to increasing hydraulic pressure beneath the membrane of the apparatus. The apparatus switches itself off automatically as soon as a tear occurs. The manner in which the forces are distributed depends on the architecture of the fibres. It is expressed in kg/cm^2. or in PSI. The results are shown in Table 3. In our series the most resistant area of the rectus sheath was the supra-arcuate part of the anterior layer: 5.895 kg/cm^2 on average, as against 3.632 kg/cm^2 for the infra-arcuate area ($p = 0.002$). For the posterior layer the results were: 3.71 kg/cm^2 above and 2.484 kg/cm^2 below the umbilicus. We see that resistance falls as one approaches the area of the arcuate line, but this is not statistically significant. In contrast, the supra-arcuate portion of the anterior layer is more resistant than the posterior layer at all levels ($p < 0.01$).

We found no significant correlation between the mechanical parameters measured in our study and the age, sex or body build of the subjects.

Discussion

The use of the anterior layer of the rectus sheath for the construction of a flap in order to reconstitute the linea alba in the repair of midline incisional hernias is justified by the better results obtained, as compared with simple suture [Chevrel 1990]. Additionally, in the repair of midline sub-xiphoid hernias, the nearby muscular insertions into the ribs sometimes make the reconstruction of the linea alba impossible. The defect in the wall may be filled in with a reversed flap of anterior rectus sheath, as we have done in one of our patients, at the same time reinforcing the repair by means of a prosthesis.

The better results obtained by use of the anterior rectus sheath are explained by comparing the resistance of this structure with that of the linea alba. In another anatomical and biomechanical study of the linea alba [Rath and Chevrel 1996] we obtained the following results: the resistance to linear traction of the linea alba is from 0.37 kgf/mm^2 above the umbilicus and 0.45 kgf/mm^2 below it, values which are less than those of the anterior rectus sheath, although not significantly so (0.50 and 0.77 kgf/mm^2 respectively). As regards tests of resistance to pressure, the anterior sheath gives values statistically similar to those of the supra-umbilical linea alba, which are 6.29 kg/cm^2 on average. However, it is less resistant below the umbilicus (3.63 as against 6 kg/cm^2 for the linea alba, $p < 0.05$).

Knowledge of the resistance to pressure of the posterior sheath is also important in the surgery of midline defects, as this constitutes the aponeurotic layer which underlies the prosthesis, when the latter is placed behind the muscles. The posterior sheath then becomes the layer which separates the prosthesis from the peritoneum and the viscera, and the first to sustain the action of the intra-abdominal pressure. It is significantly less resistant than is the normal linea alba, especially at and below the level of the umbilicus ($p < 0.01$). It is also important to compare its resistance with that of the non-absorbable prostheses currently in use for this technique. These are described in an experimental study of resistance of prostheses *in vivo* [Rath and Chevrel 1996] and *in vitro*. Dacron has a resistance to pressure *in vitro* of 3.9 kg/cm^2 but this value rises to by 55%

at the end of the first postoperative month. As for polypropylene, its resistance is 17 kg/cm^2 *in vitro*, rising by at least 210% at the end of 30 days after the operation. The resistance figures for the posterior rectus sheath lie between 2.48 and 3.63 kg/cm^2, this layer is thus weaker than the underlying prosthesis and will give way under an increase in intra-abdominal pressure, risking exposing the viscera to the prosthesis. This seems to us an argument in favour of caution in locating prostheses in this position in the treatment of incisional hernias.

Conclusion

Knowledge of the resistance values of the aponeurotic structures of the anterolateral abdominal wall is of undeniable importance in planning repair of incisional hernias.

The results of this work show that it is not justifiable to reconstruct the linea alba by simple suture in the repair of a midline defect, when a flap of the anterior rectus sheath is available for use. They suggest caution in the use of the retromuscular prefascial site for placement of a non-absorbable prosthesis. It seems preferable to insert a premuscular prosthesis fixed in position with fibrin glue, as the glue prevents the rectus muscle from separating and thus renders repair of the linea alba more sound.

It is accepted that the strength of the abdominal wall depends on multiple factors, such as the state of the muscular and aponeurotic structures following multiple previous surgery, and the resistance of the suture material during the immediate postoperative period, factors which could form the basis of further biomechanical studies.

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