Surg Radiol Anat (1996) 18 : 281-288

Surgical and Radiologic Anatomy
Journal of Clinical Anatomy
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The abdominal linea alba: an anatomo-radiologic and biomechanical study

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Summary: Traditionally, the linea alba represents the principal route of approach in abdominal surgery and in consequence it is the commonest site of incisional hernia. The aim of this study was to review its morphology and to study its mechanical parameters of resistance, deformation and elasticity in order to compare these with the prosthetic materials most often used in the treatment of incisional hernia. Forty fresh cadavers were dissected and tests with a dynamometer and "bursting strength tester" were performed on samples taken from the linea alba at three leveels: supra-umbilical, subumbilical and umbilical. Forty abdomino-pelvic scans were analysed. The morphologic results allowed definition of diastasis of the rectus mm. in terms of subject age: below 45 years of age diastasis was considered as a separation of the two rectus mm. exceeding 10 mm above the umbilicus, 27 mm at the umbilical ring and 9 mm below the umbilicus; above 45 years of age the corresponding values were 15 mm, 27 mm and 14 mm respectively. In the biomechanical study the subumbilical region exhibited a coefficient of elasticity greater than that of the supra-umbilical portion, but no significant difference in resistance was found between the different parts studied. The biomechanical results are compared with the corresponding data for prosthetic materials.

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La ligne blanche abdominale : étude anatomo-radiologique et bio-mécanique

Résumé : La ligne blanche représente la principale voie d'abord en chirurgie abdominale traditionnelle et, par conséquent, le siège le plus fréquent des éventrations abdominales. Le but de ce travail était de réviser sa morphologie et d'étudier ses paramètres mécaniques de résistance, de déformation et d'élasticité, afin de les comparer à ceux des matériaux prothétiques les plus souvent utilisés dans les cures d'éventration. Quarante cadavres frais ont été disséqués, et des tests au dynamomètre et à l'éclatomètre ont été pratiqués sur des échantillons prélevés dans la ligne blanche à trois niveaux: supra-ombilical, infra-ombilical et au niveau de l'ombilic. Quarante scanners abdomino-pelviens ont été analysés. Les résultats morphologiques permettent de définir le diastasis des muscles droits en fonction de l'âge des sujets : en-dessous de 45 ans sera considéré diastatique un écart entre les deux muscles droits supérieur à 10 mm en supra-ombilical, 27 mm au niveau de l'anneau ombilical et 9 mm en infra-ombilical; au-delà de 45 ans les valeurs seront de 15 mm, 27 mm et 14 mm respectivement. Quant à l'étude bio-mécanique, la région infra-ombilicale présente un coefficient d'élasticité supérieur à celui de la portion supra-ombilicale, mais aucune différence significative de résistance n'a été retrouvée entre les différentes portions étudiées. Les résultats bio-mécaniques sont comparés aux données correspondantes aux matériaux prothétiques.

Key words: Linea alba — Diastasis — Incisional hernia

The performance of repair of diastasis of the rectus abdominis mm. by abdominal surgery on the one hand and the technical problems posed by the repair of median incisional hernia on the other led us to make this anatomo-radiologic study of the linea alba. This repre-sents the ventral site of attachment of the muscles of the abdominal sling and the route of approach most often used for surgery of the abdominal cavity; consequently, it is also the commonest site of incisional hernia. The importance attached to this structure led us to study its mechanical characteristics of resistance and deformability, as well as to review its morphologic aspects. Apart from the classical anatomic treatises, we have not found any recent studies dealing with this subject.

The results of biomechanical tests undertaken in this study were compared with the data of an experimental study dealing with the prosthetic materials most commonly used for the cure of dehiscence [6].

Material and methods

1. Cadaver study

Forty fresh cadavers (20 women and 20 men), with an average age of 83.02 years (range 62-99) were allocated to four groups of 10. Their morphotypic distribution was as follows: 12 lean subjects, 17 of normal build and 11 fat. All were dissected in order to measure all the fasciae of the anterolateral wall of the abdomen (Fig.1).

In group 1, only dissection was made. There were 5 men and 5 women in this group, of which one was thin, 7 of average build and 2 fat. Biomechanical tests were made in the three other groups.

In group 2, composed of 4 men and 6 women, whose morphotypes were 5 lean, 3 medium and 2 fat, dynamometric tests were made, allowing calculation of the force of linear traction required for rupture of a strip of tissue 1 cm wide and 3 cm long removed in the direction of intersection of the fibers, ie perpendicular to the long axis of the linea alba. The samples were taken at two levels: halfway between the umbilical ring and the xiphoid process for the supra-umbilical linea alba, and halfway between the umbilical ring and the pubic symphysis for the subumbilical linea alba. This strip was attached to the jaws of the apparatus by the interposition of a rectangle of emery paper in order to prevent slipping of the sample. This test also provided information as to the deformability and elasticity of the tissues (Fig. 2).

Group 3 consisted of 5 men and 5 women, of whom 2 were lean, 3 medium and 5 fat. Group 4 consisted of 7 men and 3 women: 4 lean, 4 medium and 2 fat. Bursting strength tests were made in groups 3 and 4. This apparatus served to measure the pressure per unit of surface required to produce rupture of a tissue. The mechanism exerted by the apparatus is similar to the action of the intra-abdominal pressure on the abdominal wall, since the force is exerted from the depth towards the surface, the deep aspect of the sample being placed on the membrane beneath which the hydraulic pressure is increased. The specimen was

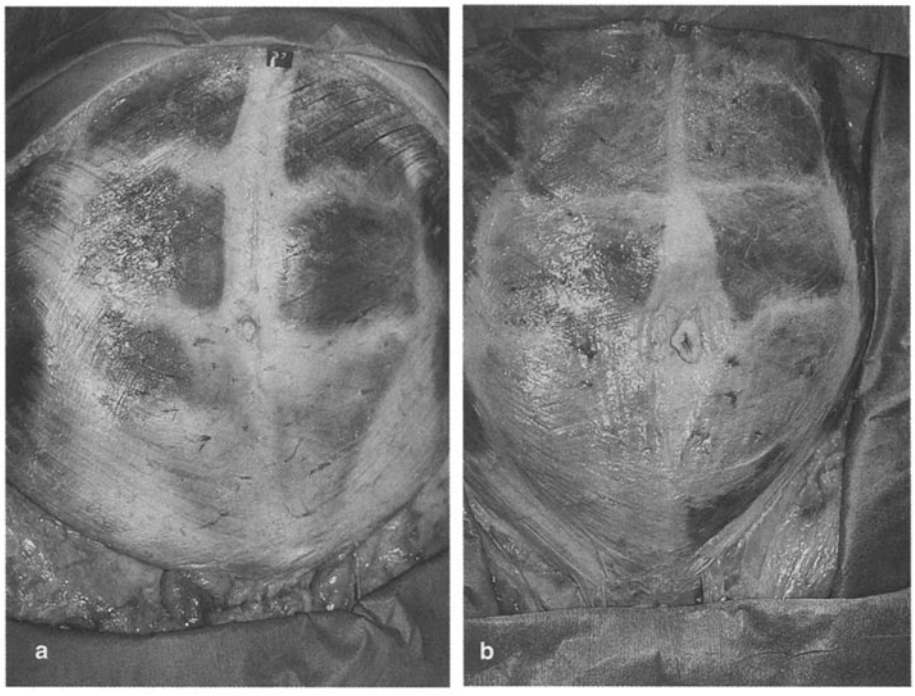


Fig.1a, b
Cadaveric study: dissection of abdominal wall. **a** Linea alba, male. **b** Linea alba, female

Étude cadavérique : dissection de la paroi abdominale. **a** Ligne blanche chez un homme. **b** Ligne blanche chez une femme

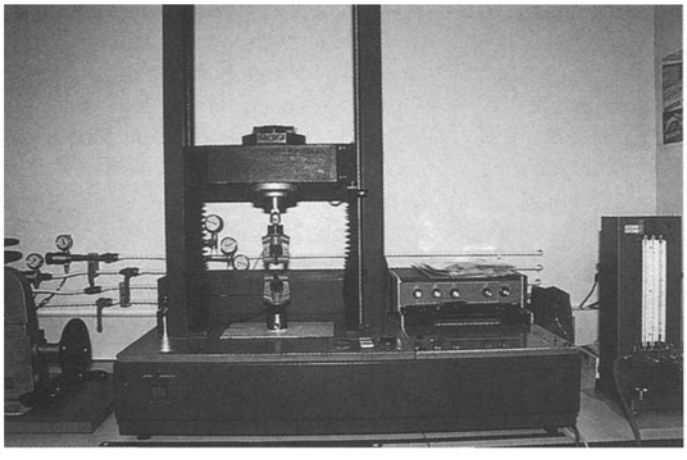


Fig. 2
Dynamometer

Le dynamomètre

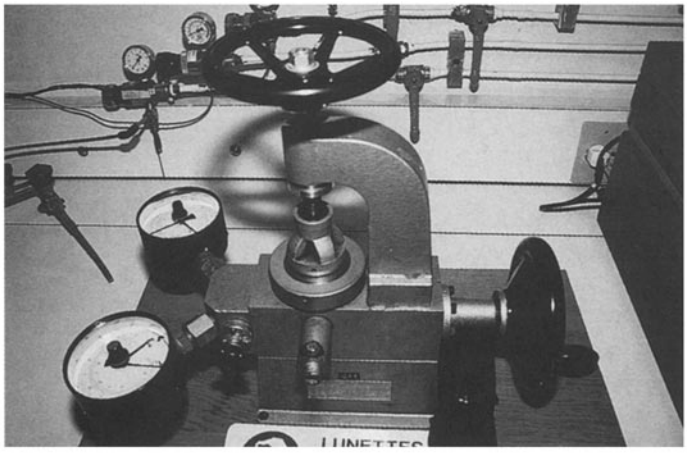


Fig. 3
Burstometer

Bursting strength tester

held in place by means of the system of fixation of the apparatus. The size of the samples was 5 x 5 cm and this did not allow for them all to be collected from the same subject. They were removed from the supra- and subumbilical linea alba in group 3 and from the umbilical region in group 4 (Fig. 3).

To restore the hydration of the dead tissues and thus their elasticity, we used the method of Yamada [9], which consists of removing specimens from the cadavers within 72 hours of death and preserving them in a saline bath at 4°C for 24 hours. This yields a state of mechanical stability (SMS). Yamada compared the resistance and deformation of the tissues of animals in SMS with those measured just after death and concluded that the resistance was slightly underestimated in SMS, whereas the deformation was almost identical. In our series, the time interval after death for the groups tested was 43.2 hrs (23-72).

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

Table 1. Age distribution of scanned patients
Distribution des patients scannérisés par intervalles d'âge

Age group (years)	Number of cases
10-20	2
21-30	5
31-40	7
41-50	6
51-60	4
61-70	11
≥71	5

2. In vivo study

Forty abdominopelvic scans made in a series of patients with an average age of 51.5 years +/- 19.61 years were analysed. These scans were made for diagnostic purposes in patients with suspected intra-abdominal disease, or for monitoring such disease, and none was made just for the purposes of this study. Naturally, the patients had no parietal pathology and had not undergone abdominal surgery. There were 16 women (40%) and 24 men (60%). The distribution by age groups is shown in Table 1. Measurements were made on three sections at the same levels as in the cadaveric study at the middle of the pointer of the scan computer.

Results

a. Morphologic data in the cadaver

The mean length of the linea alba in the 40 dissected subjects was 29.11 cm (20-40). Its mean width was 1.72 cm above the umbilicus (0.5-3.5), 2.25 cm at the level of the umbilicus (0.5-5) and 0.66 cm below the umbilicus (0.1-2). No significant difference was found in relation to age, sex or morphotype in this series.

b. Biomechanical tests

No statistically significant relation was found between age, sex or morphotype and the bio-mechanical parameters within each of the groups.

b.1. Dynamometer tests

The constraint , or force exerted per unit of section, is a measure of the resistance of the tissues to linear traction. It is expressed in kgf/mm^2 or in MPa. The results are given in Table 2. For the supra-umbilical linea alba, the mean constraint was 0.367 kgf/mm^2 (0.109-0.698). The subumbilical portion proved slightly more resistant, with a mean constraint of 0.447 kgf/mm^2 (0.134-0.896)) but this difference was not statistically significant.

The deformation expresses the percentage of elongation of the specimen at the moment of rupture and is obtained by the following formula: LR - IL/IL x 100 (LR = length at rupture, IL = initial length). The linea alba is slightly more deformable above than below the umbilicus (45.57% and 31.55% respectively, difference not significant) (Table 3).

The curves drawn by the dynamometer allow calculation of the elasticity of the tissues (Fig. 4). Several stages can be distinguished in the design of these curves. Initially there appears an almost linear segment called the "elastic deformation", where the fascia stretches when force is applied but can return to its initial length if this force is stopped. If the pull is increased we reach the second stage of the curve, the so-called "plastic deformation", where the degree of deformation increases and the fascia remains stretched if the traction force is discontinued. This immediately precedes rupture for materials that are brittle, like those studied in this report. Based on the constraint (force/section) and the deformation (final length minus initial length/initial length) calculated for several points in the period of elastic deformation, it is possible to calculate Young's modulus, ie the modulus of elasticity (E= constraint/deformation). The greater E is, the more the mate-

Table 2. Dynamometer test: constraint
Tests au dynamometre: contrainte

	kgf/mm^2	Mpa	Statistics SD	Descriptives C Var
LA sup	0.368	3.610	0.208	0.56
LA sub	0.447	4.385	0.27	0.60

LA: linea alba; *sup*: supraumbilical; *sub*: subumbilical; kgf/mm^2: kilogram-force per square mm.; *MPa*: megapascal. The statistics relate to the first column

LA: ligne blanche ; *sup*: supra-ombilical ; *sub*:infra-ombilical ; kgf/mm^2: kilogramme-force par milimètre carré ; *MPa*: mégaPascal. Les statistiques portent sur la première colonne

Table 3. Dynamometer test: deformation
Test au dynamomètre déformation

	% elongation	Statistics SD	Descriptives C. Var
LA sup	45.579	16.604	0.36
LA sub	31.554	16.116	0.51

LA: linea alba; *sup*: supraumbilical; *sub*: subumbilical

LA: ligne blanche ; *sup*: supra-ombilical ; *sub*: infra-ombilical

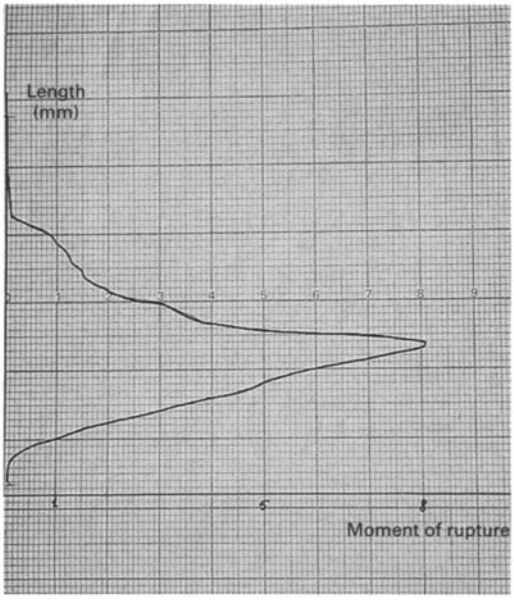


Fig. 4
Dynamometer test. *X-axis*: linear traction, in kgf/mm^2 or in MPa, *y-axis*: length of the studied strip

Test au dynamomètre. *En absisse* : force de traction en kgf/mm^2 ou MPa, *en ordonnée* : longueur du segment étudié

most resistant to pressure exerted from below at its surface: a mean of 6.715 kg/cm^2 (2.7-10.2). The resistances were approximately similar for the port-ions of the linea alba above and below the umbilicus (5.868 and 6.01 kg/cm^2 respectively). There was no statistical difference between the three levels.

c. Radiologic findings (Figs. 5-7)

The results obtained from analysis of the scans were as follows. The mean width of the linea alba above the umbilicus was 8.3 mm +/- 5.63 (as against 17 mm in the cadaveric study), 21.2 mm +/- 8.07 at the level of the umbilical ring (as against 22.4 mm), and 9.3 mm +/- 6.74 below the umbilicus (more than in the cadaveric study which showed a mean of 6.6 mm); it appeared therefore that there was a major difference between the two studies at the supra-umbilical level.

Study of the frequency distribution of the width of the supra-umbilical linea alba showed two peaks: the first between 5 and 6 mm and the second between 12 and 14 mm (Fig. 8); analysis of the histogram by age groups shows that the first peak corresponds to subjects below 50 years of age and the second to those over 50 (Fig. 9). Thus, the width of the linea alba increases significantly with age (p=0.005).

As regards the umbilical level, the peak of frequency lay between 17 and 19 mm, the majority of the readings being between 13 and 23 mm (Fig. 10). As the histogram shows, at this level there was no significant increase in width with age (Fig. 11). These results coincided with those obtained from dis-

rial can sustain a force without deformation (1).

The mean coefficient of elasticity of the linea alba is slightly higher below than above the umbilicus: 2.429 kgf/mm^2 and 1.151 kgf/mm^2 respectively (p=0.05). This fact can be explained by taking account of Laplace's law, according to which, for constant radii of curvature, the pressure and elasticity of the wall of a sphere vary proportionally. In practice, there is a gradient of intra-abdominal pressure which decreases towards the upper level of the abdomen, as follows from Pascal's principle, according to which the pressure of a fluid at constant viscosity and coefficient of gravity at a given level of a fluid column is equal to the height of the column above this level [2]; the mean intra-abdominal pressure varies from 6 to 8 cm H2O. Thus the elasticity increases proportionally to the pressure below the umbilicus (Table 4).

b.2. Bursting strength tests

The bursting pressure estimates the resistance to the pressure exerted on a tissue surface calculated at the moment of its rupture when the hydraulic pressure under the membrane of the apparatus is increased. The apparatus stops automatically as soon as this rupture occurs. The resistance to pressure depends on the architecture of the fibers, which determines the manner in which the forces are distributed. It is expressed in kg/cm^2 or in PSI. The results are given in Table 5.

The umbilical region seemed the

Table 4. Dynamometer test: coefficient of elasticity

Test au dynamomètre coefficient d'élasticité

	Young's modulus (kgf/mm^2)	Statistics SD	Descriptives C Var
LA sup	1.151	0.797	0.69
LA sub	2.429	1.405	0.57

LA: linea alba; *sup*: supraumbilical; *sub*: subumbilical; kgf/mm^2: kilogram-force per square mm.

LA: ligne blanche ; *sup*: supra-ombilicale ; *sub*: infra-ombilicale. kgf/mm^2: kilogramme-force par milimètre carré

Table 5. Burstometer test: bursting pressures

Tests à l'éclatomètre pressions d'éclatement

	kg/cm^2	PSI	Statistics SD	Descriptives C Var
LA sup	5.869	86.812	2.359	0.40
LA umb	6.715	97.125	2.523	0.37
LA sub	6.010	88.400	1.518	0.25

umb: umbilical level; *PSI*: pounds/square inch. The statistics relate to the first column

umb: anneau ombilical ; *PSI*: pound/square inch. Les statistiques portent sur la première colonne

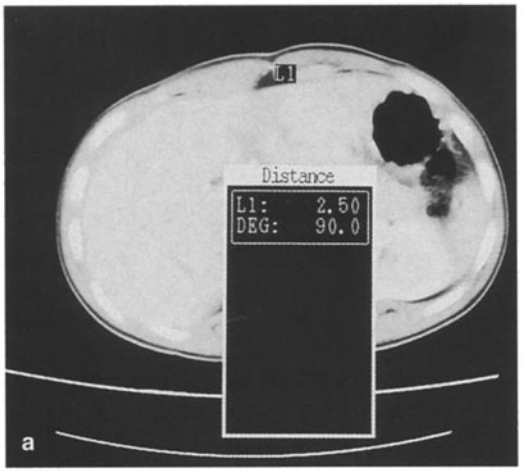
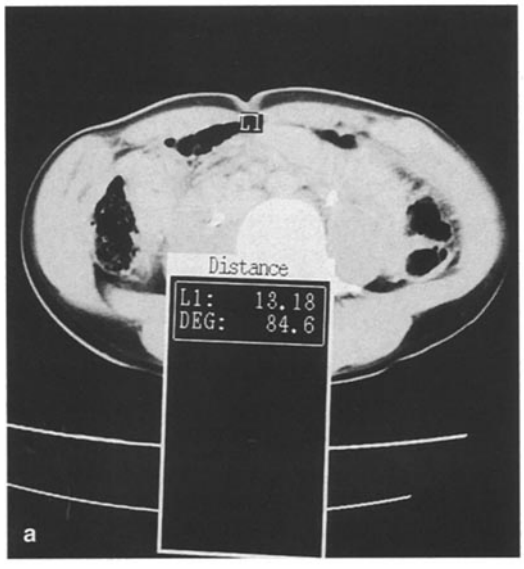


Fig. 5
Radiologic study: scan section of supra-umbilical linea alba

Étude radiologique. Coupe scannographique de la ligne blanche supra-ombilicale

section. At the subumbilical level, the first frequency peak was situated between 5 and 6 mm and there was a second peak between 10 and 11 mm (Fig. 12). There was a significant broadening with age ($p=0.003$), the first peak corresponding to subjects less than 40 years old and the second to those over 40 (Fig. 13). The sole significant difference in length related to sex occurred in the supra-umbilical level: the male subjects had a linea alba 4.2 mm wider on average than that of the females ($p=0.01$).



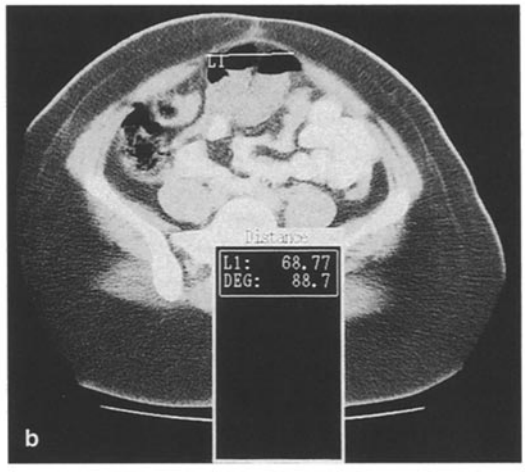
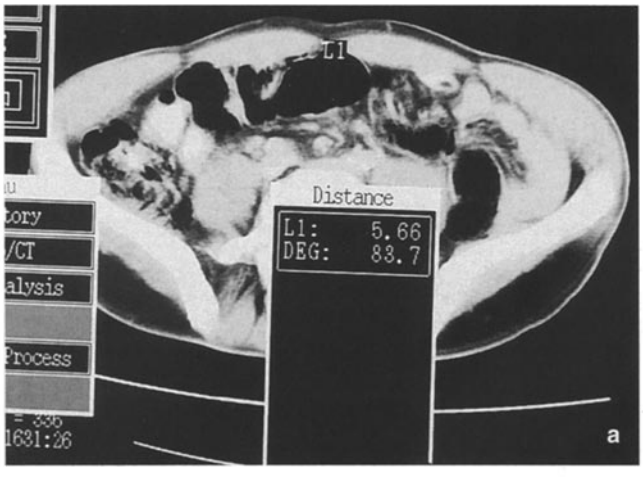


Fig. 6a, b
Radiologic study: CT scan of linea alba at level of umbilical ring. **a** Llinea alba of normal width. **b** Linea alba widened

Étude radiologique. Coupes scannographiques de la ligne blanche au niveau de l'anneau ombilical. **a** Largeur normale. **b** Ligne blanche élargie



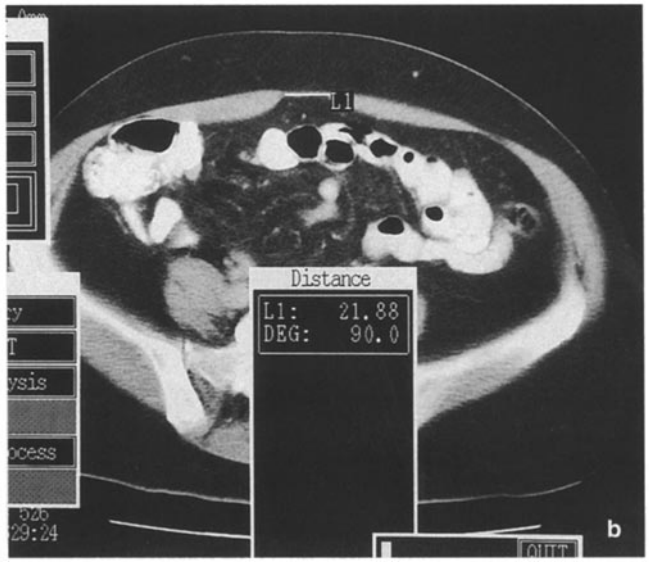


Fig. 7a, b
Radiologic study: CT sections of subumbilical linea alba. **a** Normal width, **b** widened

Étude radiologique. Coupes scannographiques de la ligne blanche infra-ombilicale. **a** Largeur normale, **b** ligne blanche élargie

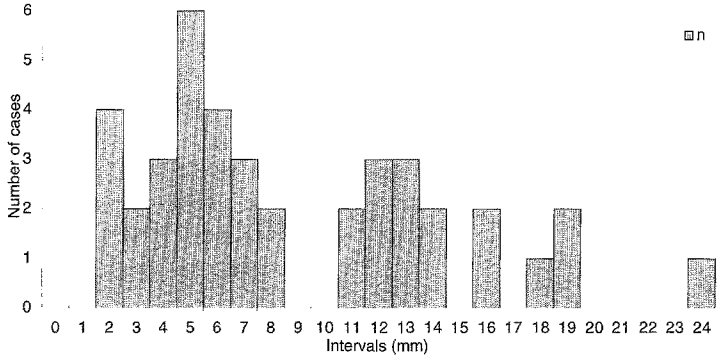


Fig. 8
Distribution of frequency, supra-umbilical linea alba. Number of cases intervals (mm)
Distribution de fréquence à l'étage supra-ombilicale

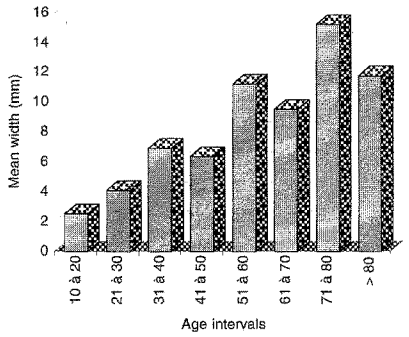


Fig. 9
Relation between age and supra-umbilical width of linea alba. Mean width (mm) age goups
Rapport largeur/âge à l'étage supra-ombilicale

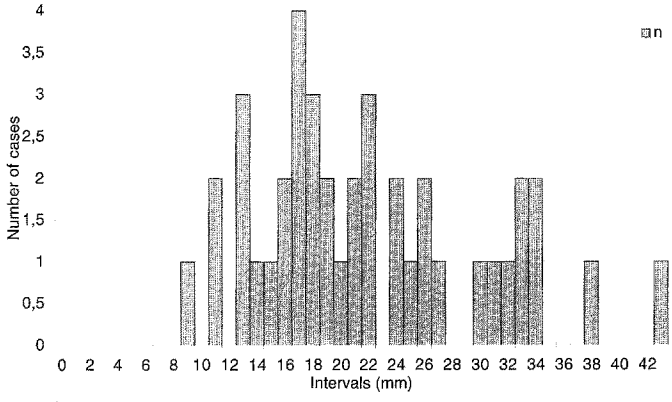


Fig. 10
Distribution of frequency at umbilical level. Number of cases intervals (mm)
Distribution de fréquence à l'étage ombilicale

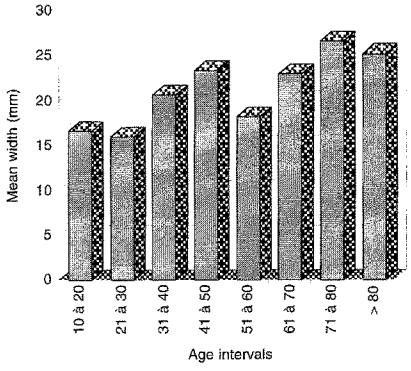


Fig. 11
Relation between age and umbilical width of linea alba. Mean width (mm) age groups
Rapport largeur/âge à l'étage ombilicale

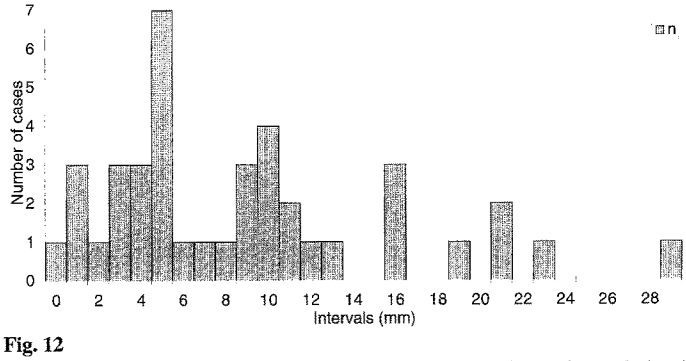


Fig. 12
Distribution of frequency, subumbilical linea aba. Number of cases intervals (mm)
Distribution de fréquence à l'étage infra-ombilicale

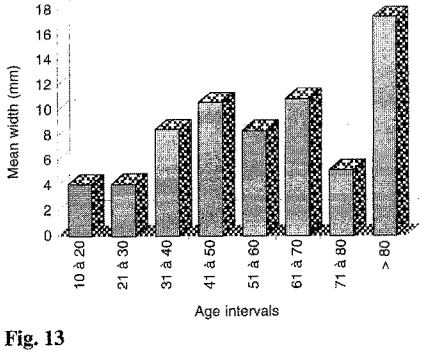
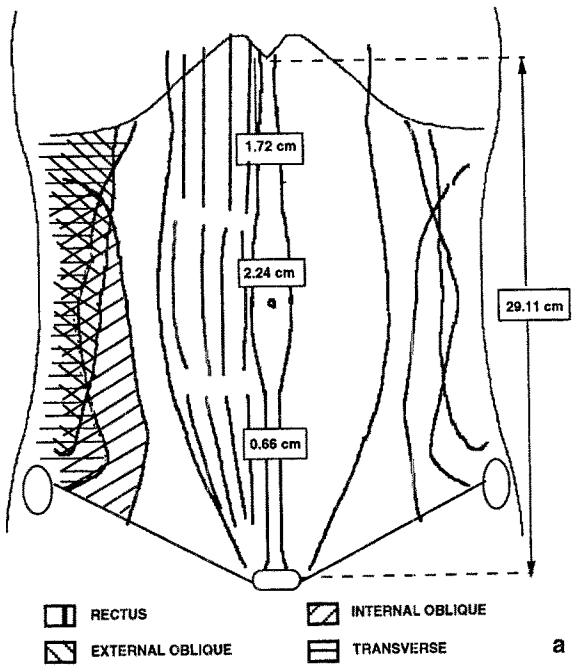
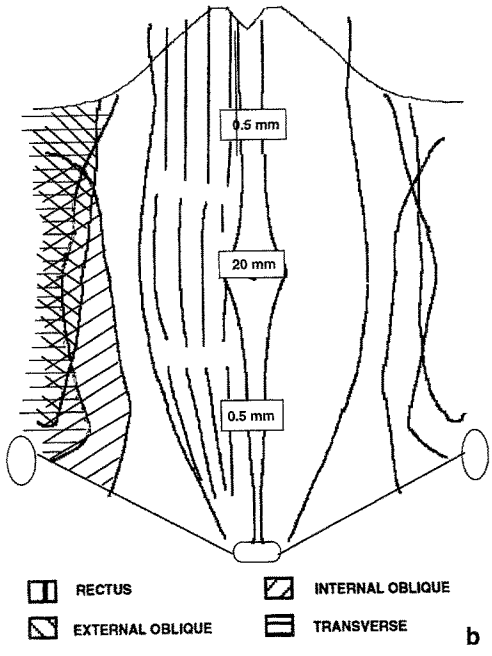


Fig. 13
Relation between age and subumbilical width of linea alba. Mean width (mm) age groups
Rapport largeur/âge à l'étage infra-ombilicale

Discussion

The aim of the morphologic study was to attempt to specify the dimensions and especially the width of the linea alba at the three different levels, as a basis on which to define the term "diastasis". The measurements obtained from the cadaveric study were slightly greater than those in the classical anatomic treatises [3, 5, 8]; thus for Poirier the width of the linea alba is 0.6-0.8 cm above the umbilicus, 1.5-2.5 cm at umbilical level and 0.3 cm below [5]. Further, the results found in the cadaveric study did not always correspond to those of the *in vivo* radiologic study, which can be explained by the mean age of the cadavers dissected.





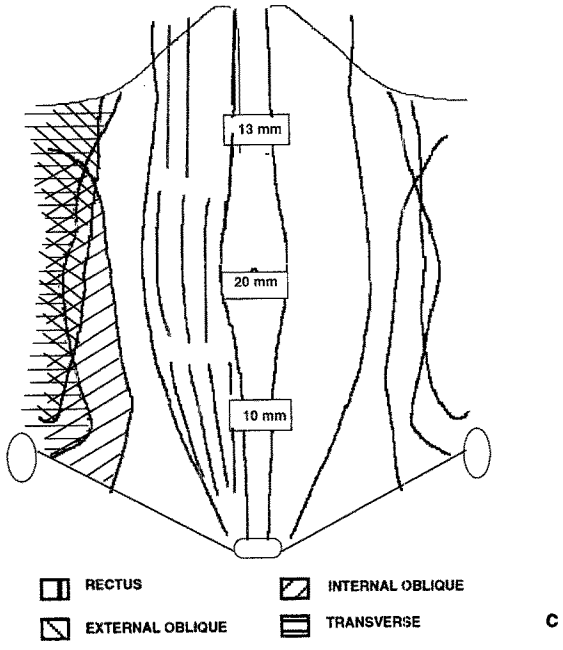


Fig. 14a-c
Diagram of mean dimensions of linea alba. **a** Cadaveric study (scale 1:50). **b** Radiologic study, patients less than 45 years of age (scale 1:50). **c** Radiologic study, patients over 45 years of age (scale 1:50)

Schéma des dimensions moyennes de la ligne blanche. **a** Étude cadavérique, échelle 1:50. **b** Étude radiologique. Patients de moins de 45 ans, échelle 1:50. **c** Étude radiologique. Patients de plus de 45 ans, échelle 1:50

Actually, the *in vivo* study showed that there are differences related to patient age on the one hand and their sex on the other. Analysis of the scan sections showed that the supra-umbilical linea alba is 4 mm wider in men than in women.

As regards age, there is a marked change at around the age of 45; the width of the linea alba then increases significantly especially above and below the umbilicus. The values to be considered as normal for the width of the linea alba are as follows:

- supra-umbilical: before the age of 45, 1 5-6 mm; after 45, 12-14 mm;
- at the level of the umbilical ring: 19-23 mm;
- below the umbilicus: before 45, 5-6 mm; after 45, 9-11 mm (Fig. 14).

A knowledge of the biomechanical parameters of the normal linea alba allows us to establish objective bases for evaluating the different prosthetic materials most often used in the treatment of incisional hernia.

Two types of forces act on the linea alba: the intra-abdominal pressure, which acts on the deep aspect of the abdominal wall, and the linear traction exerted by the flank muscles. It is these forces of linear traction which determine the tissue elasticity and deformation. The bursting strength test reproduces the action of the intra-abdominal pressure on the wall, whereas the dynamometer test provides information as to the phenomena of elastic and plastic defor-mation as well as the point of rupture provoked by linear traction.

If we compare the figures for resistance of the linea alba to traction, which vary beween 0.37 and 0.45 kgf/mm^2, to those of prostheses *in vitro*, it is found that composite dacron-polyglactin prostheses offer an almost identical resistance (0.39 and 042 kgf/mm^2 respectively). On the other hand, polypropylene exhibits figures markedly superior to those of the linea alba: 0.72 kgf/mm^2. Polyglactin 910 is also more resistant (0.61 kgf/mm^2) but this is an absorbable mesh.

We have conducted an experimental surgical study designed to discover the mechanical parameters of prostheses incorporated in the abdominal wall in vivo; this study was the subject of an

Table 6. Comparative results of resistance in anatomic study and in experimental surgery [1]

Résultats comparatifs des résistances de l'étude anatomique et de chirurgie expérimentale [1]

Dynamometer test (kgf/mm^2)		
Linea alba, human (mean):	0.407	
Linea alba, rabbit (control group):	0.068	
Prostheses	*in vitro*	*in vivo*
Dacron	0.39	+ 26.5% ns
Polypropylene	0.72	+ 235%, $p \leq 0.01$
Polyglactin	0.61	- 29.496 ns
Composite	0.42	+ 75% $p < 0.05$

ns: not statistically significant

Table 7. Comparative results of resistance in anatomic study and in experimental surgery [2]

Résultats comparatifs des résistances de l'étude anatomique et de chirurgie expérimentale [2]

Bursting strength test (kg/cm^2) Tests à l'éclatomètre (kg/cm cm^2)		
Linea alba, human (mean):	6.197	
Linea alba, rabbit (control group):	5.485	
Prostheses	*in vitro*	*in vivo*
Dacron	3.9	8.728: +59%, p<0.01
Polypropylene	17	>17* >210%
Polyglactin	6.9	6.388: +16%, ns
Composite	6.3	7.383: +35%, p<0.05

* Resistance in excess of maximal capacity of apparatus

*Résistance supérieure à la capacité maximale de l'appareil

earlier communication [6]. It was made in rabbits, which were sacrificed at 30,60 and 90 days after the operation.

Resistance to traction. Although resistance to traction of the abdominal wall in man is not comparable to that in the rabbit, an increase in resistance of the abdominal wall when reinforced by polypropylene of 205% compared with controls was found at the first postoperative month. Conversely, no increased resistance was demonstrable with dacron, whether simple or compound, both of which exhibited normal parameters. The abdominal walls reinforced by polyglactin were slightly weaker than the walls of control rabbits (Table 6).

Resistance to pressure. The figures for resistance of the linea alba to pressure lie between 5.87 and 6.715 kg/cm^2. Polyglactin 910 as well as the composite dacron-poylglactin mesh exhibited similar resistances *in vitro* (6.9 and 6.3 kg/cm^2 respectively). Dacron was markedly less resistant (3.9 kg/cm^2) whereas polypropylene had a bursting pressure of 17 kg/cm^2 *in vitro*.

The abdominal wall of the control rabbits showed a resistance to pressure which was only slightly less than that of the human linea alba (mean 5.48 kg/cm^2). In our series the walls reinforced by polypropylene could not be tested with the burstometer, as they offered a resistance which exceeded the limit of power of the apparatus. It is possible to say, then, that the gain in resistance at the first postoperative month was at least 210%. With dacron, resistance to pressure was increased by 56% at the 30th day and remained stable thereafter. Polyglactin offered no significant increase in resistance and the composite mesh showed figures slightly inferior to those of dacron. These results seem to be capable of extrapolation to man (Table 7).

Conclusion

A knowledge of the morphology of the linea alba allows us to define diastasis of the rectus abdominis mm. in relation to age. Below the age of 45, diastasis can be defined as a separation between the two rectus mm. in excess of 10 mm above the umbilicus, 27 mm at the level of the umbilical ring and 9 mm below the umbilicus. After the age of 45, the corresponding values are 15, 27 and 14 mm.

A knowledge of the normal values for resistance of the linea alba allows us to establish an objective basis for comparison with the suture and prosthetic materials used in surgery of the abdominal wall. The results of such comparisons indicate that nonabsorbable materials are preferable to absorbable, which offer no advantages in terms of resistance. The material which offers a wider margin of safety in patients who exhibit risk factors for recurrence of dehiscence is polypropylene. Dacron, with a 56% increase in resistance to pressure, remains a good material for patients who do not require major parietal reinforcement.

Further, the study of the elasticity and deformability of the linea alba is a factor of great importance for an understanding of the physiology of the abdominal wall, and may be related to the volumetric and pressure parameters of the abdominal cavity, so as to provide a better interpretation of the dynamic role of the abdominal wall in the physiology of the abdomen.

Acknowledgments. The authors wish to thank Monsieur J Dumont for making it possible for them to use the dynamometer and bursting strength tester of the Research Department of Laboratoires Ethicon France.

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Received July 28, 1996 / Accepted in final form September 6, 1996