

**Mechanical response of animal abdominal walls in vitro:  
Evaluation of the influence of a hernia defect and a  
repair with a mesh implanted intraperitoneally**

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1 Mechanical response of animal abdominal walls *in vitro*:  
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21  
22  
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24 ABSTRACT  
25

26 Better mechanical knowledge of the abdominal wall is requested to further develop and  
27 validate numerical models. The aim of this study was to characterize the passive behaviour of  
28 the abdominal wall under three configurations: intact, after creating a defect simulating an  
29 incisional hernia, and after a repair with a mesh implanted intraperitoneally. For each  
30 configuration, controlled boundary conditions were applied (air pressure and then contact  
31 loading) to the abdominal wall. 3D Local strain fields were determined by digital image  
32 correlation. Local strains measured on the internal and external surfaces of the intact  
33 abdominal wall showed different patterns. The air pressure and the force applied to the  
34 abdominal wall during contact loading were measured and used to determine stiffness. The  
35 presence of a defect resulted in a significant decrease of the global stiffness compared to the  
36 intact abdominal wall (about 25%). In addition, the presence of the mesh enabled to restore  
37 the stiffness to values that were not significantly different from those of the intact wall. These  
38 results suggest that intraperitoneal mesh seems to restore the global biomechanics of the  
39 abdomen.

40

41 *Keywords:* Biomechanics, mesh repair, digital image correlation, pressure, contact loading.

42

43

## 44 **1. Introduction**

45 Treatment of incisional hernias is a common surgical procedure (Cobb et al., 2003). The  
46 laparoscopic repair with mesh implantation improves the treatment of incisional hernia by  
47 reducing the rate of recurrence and risk of wound complication (Cobb et al., 2005a). The use  
48 of composite mesh, that limits adhesions with abdominal organs, makes the laparoscopic  
49 repair easier by putting the mesh in the intraperitoneal location (Cobb et al., 2003). However,  
50 problems of recurrence can still happen. Problems of restriction of the abdominal wall  
51 mobility or pains may also occur to patients (McLanahan et al., 1997; Müller et al., 1998).  
52 Studies on the interaction of mesh with the abdominal wall have been performed. Factors  
53 identified as possible causes of recurrence include the size of the implanted mesh compared to  
54 the size of the defect (the overlap), and the method of mesh fixation (Binnebösel et al., 2007;  
55 Schwab et al., 2008). It has also been suggested that the mesh structure should be improved in  
56 order to have similar biomechanical behaviour to the abdominal wall to reduce discomforts  
57 (Konerding et al., 2011a; Hernández et al., 2011).

58 Numerical models could be useful to assess the influence of a mesh on the behaviour of the  
59 abdominal wall. In particular, such models could be used to evaluate the possible effects of  
60 mesh design changes or implantation procedures very early in the design process. However,  
61 experimental data on the mechanical response of the abdominal wall are a prerequisite to  
62 develop models. Hernández et al. (2011) conducted uniaxial tensile tests on the flat abdominal  
63 muscles of rabbits in order to characterize the passive behaviour of the abdominal wall and  
64 develop a numerical model of a healthy and a partially herniated repaired abdominal wall of  
65 rabbit (Hernández-Gascón et al., 2011). Förstemann et al. (2011) performed uniaxial tensile  
66 tests on the linea alba to develop an analytical model of the abdominal wall. While these  
67 studies can provide useful data to help in building a model, they cannot be used to evaluate or  
68 validate the performance of a whole abdominal wall model subjected to mechanical load.

69 Thus, Konerding et al. (2011a) performed a human cadaver study to validate the model  
70 proposed by Förstemann et al. (2011).

71 Song et al. (2006) and Szymczak et al. (2012) studied the complete human abdominal wall  
72 response respectively to pressure during a laparoscopic surgery and during different physical  
73 exercises. While such studies provide a useful starting point for the validation of model, it  
74 only included data on the response of the external surface of the intact human abdominal wall  
75 . This is an important limitation for the validation of a model, whose purpose is to study the  
76 interaction of the mesh with the wall when implanted on the internal surface. No study  
77 comparing the behaviour of the external wall (skin side) and the internal wall (peritoneal side)  
78 could be found in the literature.

79 Furthermore, many studies provide experimental results on the mechanical properties of the  
80 complete abdominal wall (Song et al., 2006; Konerding et al., 2011a; Junge et al., 2001) and  
81 its components (Hernández et al., 2011; Förstemann et al., 2011; Rath et al., 1996, Hollinsky  
82 et al., 2007), or on the characterization of meshes only (Junge et al., 2001; Hernández-Gascón  
83 et al., 2011). However, only a few studies were found regarding the mechanical response of  
84 the abdominal wall with an implanted mesh, and how it may differ from the response of a  
85 healthy wall. Müller et al. (1998) studied the difference of abdominal wall mobility between a  
86 healthy control group and a group of patients with incisional hernia, who was treated by mesh  
87 implantation. Hernández-Gascón et al. (2011) observed the mechanical response of intact  
88 abdominal wall and abdominal wall that was repaired using different meshes on rabbits. This  
89 study was performed on small animals and only the lateral part of the abdominal wall was  
90 considered. Also, samples were characterized by uniaxial test that do not reproduce the  
91 physiological loading conditions of the abdominal wall. To the authors' knowledge, no  
92 studies compared the behaviour of a same intact abdominal wall, and then implanted with a  
93 mesh.

94 Therefore, the current study focused on the anterolateral abdominal wall, where incisional  
95 hernias may occur. The objective of this work was to study the response of a same abdominal  
96 wall under three different states: intact, with a hernia defect, and repaired. Particular attention  
97 was paid to study simultaneously the internal and external surfaces. Boundary and loading  
98 conditions were defined to ensure reproducibility and control.

99

## 100 **2. Materials and methods**

### 101 *2.1 Specimen & preparation*

102 Anterolateral abdominal walls of six female pigs, aged 4 to 5 months and weighing about 45  
103 kg, were used for the current study. The abdominal walls were removed from the animals less  
104 than 30 minutes after euthanasia at the VetAgro Sup, Veterinary Campus of Lyon (Marcy  
105 l'Etoile, France), and then kept frozen at -20°C until testing. The abdominal walls were cut  
106 along the xiphoid process and the costal margins and along the pubic bones and the iliac  
107 crests. The lateral incisions were done between the iliac spines and the lower part of the rib  
108 cage. Thus the abdominal wall had a triangular shape (Fig. 1). All the layers were preserved:  
109 muscles, aponeuroses, adipose tissue, skin and peritoneum. The abdominal walls were thawed  
110 at room temperature 16 hours before the test. Just before testing, the external surface of the  
111 abdominal wall was shaved. The thickness of each abdominal wall was also measured (Fig. 1)  
112 and their average thickness is reported in Table 1. The specimens were sprayed with saline  
113 solution to enable their hydration.

114

### 115 *2.2 Experimental setup*

116 First, the abdominal wall was placed on a hemispherical support (diameter of 9 cm) in order  
117 to induce a curvature. Then, it was put on an aluminum plate with a triangular hole exposing  
118 the anterolateral abdominal wall. A rubber sheet with the same hole was added to cover the

119 section of the abdominal wall outside the hole. This sheet was clamped using custom designed  
120 clamps positioned all around the hole (Fig.2a). As the abdominal wall thickness was not  
121 constant over its circumference, the clamps were adjusted to provide adequate tightening in  
122 over the whole circumference and prevent local sliding during loading. The abdominal wall  
123 was not removed from this fixture until the very end of the experiment.

124 Then, the abdominal wall was positioned on a custom designed aluminium table mounted on a  
125 testing machine (INSTRON 8802, High Wycombe, England) (Fig. 2b). The external face of  
126 the wall was directed downwards, leading to a natural curvature due to gravity.

127 Physiologically, the abdominal wall can be loaded by contact of the hollow organs or by  
128 pressure in case of laparoscopic surgery. So, during the experiment, the abdominal wall was  
129 submitted to two mechanical loading cases: contact and air pressure.

130 First, the air pressure was applied on the internal surface (Fig. 3a). A Plexiglas plate was  
131 mounted on the top of the aluminium plate in order to create a closed cavity. The Plexiglas  
132 plate was transparent, allowing to observe the internal abdominal wall. Compressed air and a  
133 manual valve were used to control the pressure in the cavity. At a laparoscopic pressure of 12  
134 mmHg, a smaller displacement of the abdominal wall than the one measured by Song et al.  
135 (2006) was observed due to strong boundary conditions. So, the pressure was increased until  
136 it reaches 50 mmHg, which is in the physiological range of intra-abdominal pressure (Cobb et  
137 al., 2005b). Then, it was let to return to atmospheric pressure by opening the valve. The  
138 pressure loading cycle was repeated six times. The first 5 cycles enabled to precondition the  
139 wall in order to reach a steady state, limiting variability to assess various conditions. Only the  
140 sixth cycle of pressurization was used for the data analysis.

141 Then, a contact loading was applied to the internal side using a rigid sphere, to better control  
142 the loading conditions for further numerical model (Fig. 3b). After the pressurization test, the  
143 Plexiglas plate was removed and the abdominal wall was loaded directly by the rigid

144 Plexiglas sphere (12 cm in diameter) fixed to the actuator of the testing machine. First, the  
145 sphere was moved to get in contact with the abdominal wall. Then, the specimen was  
146 preconditioned with 5 cycles of 20 mm amplitude at a frequency of 0.5 Hz, close to the  
147 respiratory frequency. A displacement of 35 mm, which is in the range of physiological  
148 displacement of the abdominal wall (Klinge et al., 1998), was finally applied at a velocity of  
149 80 mm per minute. The velocity was slow enough to characterize the quasi-static response  
150 and also led to a short duration of test that limit the quite long duration of all the protocol.

151 An incision was made in the middle of the linea alba over a length of 5 cm, which is the size  
152 of a medium incisional hernia. The skin was kept intact. The incision was filled with Vaseline  
153 and covered with a latex film to avoid air leaks below the skin during pressure loading. The  
154 incised abdominal wall was re-loaded. Then a surgical repair was performed using a 10\*15  
155 cm<sup>2</sup> Parietex<sup>®</sup> Composite mesh, centred on the defect and fixed on the wall with 20 tackers  
156 (AbsorbaTack<sup>®</sup>). The tackers were located at one centimetre of the border of the implant and  
157 spaced apart 2 cm. A plastic film (15\*20 cm<sup>2</sup>, thickness 10µm) was put on the mesh to avoid  
158 air infiltrations between the implant and the peritoneum. Finally the repaired abdominal wall  
159 was loaded in the same conditions.

160

161 In summary, the abdominal walls were loaded consecutively by pressure and contact in the  
162 three following states:

- 163 - intact abdominal wall,
- 164 - incised abdominal wall (after creating a defect simulating an incisional hernia),
- 165 - repaired abdominal wall (finally after surgical repair by mesh implantation).

166

167 *2.3 Testing duration influence on an intact abdominal wall behaviour*



168 Beforehand, a healthy abdominal wall was tested to assess the effect of time and of the  
169 loading sequence on the abdominal wall response. An abdominal wall was subjected to the  
170 protocol twice within 4 hours, by switching the different loading cases (pressure, contact and  
171 pressure loading again). Between the two series of tests, the specimen was covered with moist  
172 gauzes.

173

174

#### 175 *2.4 Measurements*

176 The pressure and the force applied by the sphere to the abdominal wall were measured by a  
177 7 bar ENTRAN EPX-N02 pressure sensor and a 1000 N INSTRON force sensor (accuracy  
178 0.5%), respectively.

179 Four synchronized SA3 PHOTRON black and white video cameras (Tokyo, Japan) were used  
180 to record videos of the abdominal wall during the deformation. Two cameras equipped with  
181 35 mm Zeiss lenses (Oberkochen, Germany) were set on the internal surface, and the two  
182 others (equipped with 24-70mm Sigma lenses (Tokyo, Japan) in 24 mm position) were set on  
183 the external surface. The resolution of the cameras was 1024 by 1024 pixels, which led to  
184 approximately 3 pixels per mm in the area of interest. The acquisition frequency was 10  
185 frames per second.

186 Before testing, the two faces of the abdominal wall were covered with white make-up to make  
187 the background uniform. Then a random speckle pattern was applied with a black paint spray .  
188 The speckle enabled to determine 3D local displacement and 3D strain fields by digital image  
189 correlation using the VIC3D<sup>®</sup> stereo-correlation software (Correlated Solution, South  
190 Carolina, USA).

191

#### 192 *2.5 Data analysis*

193 For the contact loading case, the force versus displacement curves were plotted for the last  
194 (6<sup>th</sup>) loading cycle, and a stiffness in N/mm was worked on. This stiffness was calculated as  
195 the slope of the curve determined by linear regression between 26 and 30 mm of displacement  
196 (Fig. 4). This interval of displacement defined a common quasi linear area for all the tested  
197 abdominal walls. The relative differences of stiffness were calculated between two states,

198 
$$\Delta_{state_1-state_2} = \frac{S_{state_2} - S_{state_1}}{S_{state_1}} \times 100$$
, where S is the stiffness.

199 The displacement and strain fields were obtained by stereo correlation for all configurations  
200 and for both loading cases on the external wall surface. The strain fields could only be  
201 computed on the intact internal wall surface for pressure loading because the Plexiglas sphere  
202 hid the internal wall surface during the test. An average strain value was calculated in the  
203 central area of the abdominal wall (~ 70mm\*105mm between the nipples) from the Lagrange  
204 strain values computed by Vic 3D in first principal direction (E1) (Fig. 5). Average strains  
205 along longitudinal (linea alba) and transverse lines of the external abdominal wall surface  
206 were also calculated for the pressure loading case.

207

## 208 2.6 Statistical analysis

209 A statistical analysis was performed in order to assess the influence of the state (intact,  
210 incised, and repaired) of the abdominal wall on its mechanical response. A Wilcoxon non-  
211 parametric test (Wilcoxon, 1945) for paired samples was used. A value of  $p < 0.05$  was  
212 selected to indicate statistical significance. Parameters studied are the stiffness and the  
213 average strain. Statistical analysis was performed using Unistat® software (London,  
214 England).

215

## 216 3. Results

217 *3.1 Testing duration influence on an intact abdominal wall behaviour*

218 For both mechanical loading, the mechanical response of the abdominal wall was found to be  
219 non-linear, with a toe zone followed by a more linear zone . The unloading curve did not  
220 overlap with the loading curve. As an example, the force-displacement curves for contact  
221 loading are given Fig. 4. A similar mechanical response was obtained whatever the time of  
222 test for the pressure and the contact loading, with respectively difference of stiffness of about  
223 5% and 10%.

224

225 *3.2 Relation between internal and external surface strains in the intact abdominal wall*

226 The strain fields of the internal and the external abdominal wall surfaces exhibited different  
227 patterns as illustrated on Fig. 5. The location of the maximum strain on the internal surface  
228 did not match the location of the maximum strain on the external surface. On the internal  
229 surface, a region of greater strain near the long edge was observed. On the external surface,  
230 there was less strain near the edges and especially at the three corners of the triangle.

231 Table 1 displays the mean value and the standard deviation of the local strains in the central  
232 area for the internal and external surfaces for the pressure loading case at 50 mmHg. The  
233 average strain in the central area of the external surface (13.7 (2.1) %) was almost 2.6 higher  
234 than the mean strain of the internal surface (5.3 (0.7) %), with variation of 23.3%.

235

236 *3.3 Influence of a defect and of mesh repair on the behaviour of the abdominal wall*

237 The curves of the contact loading case for the three studied states are displayed on Fig. 6.  
238 Mean stiffness calculated for each state are presented in Fig. 7. The difference of stiffness  
239 between intact walls and incised walls was statistically significant ( $p = 0.03$ ). However, the  
240 stiffness obtained for intact and repaired states were similar ( $p = 0.43$ ). Relative differences  
241 between the abdominal walls states are summarized Table 2. The stiffness of the incised cases

242 was lower by about 25% than the stiffness of intact cases. There was a smaller relative  
243 difference of stiffness between intact and repaired walls; the stiffness of intact cases was 6%  
244 greater than the stiffness of repaired cases.

245 The mean strains values computed in the central area for the external surfaces of the  
246 abdominal wall for each configuration and loading case are displayed in Table 3. For both  
247 pressure and contact loading cases, the defect had a significant effect on the strain of the  
248 abdominal wall ( $p = 0.03$ ). The defect increased the average strain of about 74% and 35%  
249 respectively for the pressure and contact loading. For both loading cases, significant  
250 differences of strains were found between incised and repaired states ( $p = 0.03$ ). For the  
251 pressure loading case, significant differences of strains were found between intact and repaired  
252 states ( $p = 0.03$ ) whereas no significant differences were found for the contact loading case  
253 ( $p = 0.81$ ). More elongation was observed in the longitudinal direction than in the transverse  
254 direction for each state (e.g. for the repaired state: 15.9 (3.0) % and 15.3 (2.8) % respectively)  
255 The defect doubled the average strains along the two directions. No differences were found  
256 between incised and repaired states.

257

#### 258 **4. Discussion**

259 In this study, an experimental protocol was developed to characterize the mechanical response  
260 of animal passive abdominal wall in three states (intact, incised and repaired) and for two  
261 loading cases (increased air pressure similar to a laparoscopic procedure and contact loading).  
262 The test of an intact abdominal wall on a day showed that the evolution of the mechanical  
263 response of a wall is low (relative difference of 10% for the stiffness). Thus, the duration of  
264 the test on a same abdominal wall has limited influence on its behaviour. So, it is expected  
265 that differences observed for each configuration can be attributed to the change of state and  
266 not to the duration of the protocol.

267 This study was conducted on porcine abdominal walls. An animal model was used to develop  
268 the protocol since the anatomical samples were easier to access than those of human. Pig was  
269 chosen, because the dimensions of its abdominal wall are close to those of human. Swine are  
270 also often used in biomedical research since they have large anatomical and physiological  
271 similarities with humans (Swindle et al., 1998). In addition, the experiments on porcine  
272 abdominal walls allowed us to validate the repeatability of our protocol. For six specimens  
273 with small inter-individual variability (pigs of same weight, about 45kg, and of same age,  
274 between 4-5 months) and with very constrained testing boundary conditions, relatively small  
275 variability of the stiffness data was observed, with variations in the order of 12.3% for the  
276 intact state, 16.5% for the incised state, and 6 % for the repaired state.

277 This study also shows the influence of a defect and a mesh repair on the behaviour of the  
278 abdominal wall. The defect decreased the stiffness of the intact abdominal wall by 25% on  
279 average and increased the average strain of the abdominal wall by about 74% and 35%  
280 respectively for the pressure and contact loading cases. The presence of the mesh in  
281 immediate postoperative configuration on an incised abdominal wall enabled to restore the  
282 stiffness to values that were not significantly different from those of an intact wall. Other  
283 studies interested in the repaired abdominal wall, but when the mesh is integrated. Konerding  
284 et al. (2011b) compared the response of different types of meshes that are integrated to the  
285 abdominal wall without referring to intact abdominal wall behaviour. This is not the case for  
286 the study of Hernández-Gascón et al. (2012) that assessed the response of the repaired  
287 abdominal wall and compared it to the response of intact abdominal wall. However, the  
288 response was obtained by uniaxial test.

289 For the first time, this study provides data on the strain fields of the abdominal wall for the  
290 internal and external surfaces. Szymczak et al. (2012) highlight the interest of studying the  
291 internal abdominal wall surface since it is where incisional hernias occur. However, as they

292 performed *in vivo* experiments, they only considered the external abdominal surface. The  
293 mean strains computed on the external surface of the abdominal wall were found to be 2.6  
294 times greater than those computed on the internal surface of the abdominal wall. For *in vivo*  
295 study, only the external surface of the abdominal wall can be measured. It is unclear if the  
296 mean ratio found between internal and external strains can be applied because of the  
297 difference of boundary conditions and of the muscular activity. Also, specimen to specimen  
298 variations on this ratio were relatively high (23.3 %). This suggests that relatively large  
299 uncertainties would be associated with the estimation of internal strains solely based on  
300 external strains.

301

302 .

303

304 Regarding the present study, some limitations can be mentioned. The effect of freezing was  
305 not considered however the literature is often contradictory on the effect of freezing of soft  
306 tissues (Van Ee et al., 2000; Clavert et al., 2001; Rubod et al., 2007). During harvesting, there  
307 was no opportunity to measure the curvature of the abdominal wall and the shortening of  
308 tissues. Thus, the initial curvature and tension could not be reproduced *in vitro*. The initial  
309 tension and boundary conditions were not representative of physiological conditions.  
310 Perspectives of this study are to approach the physiological conditions with *in vivo*  
311 experiments. The anisotropy of the strain was assessed in this study but the analysis is limited  
312 by the shape of the current device which is not symmetric. However, these findings  
313 correspond with the studies analysing the surface deformation of the *in vivo* human abdominal  
314 wall (Song et al., 2006 and Szymczak et al., 2012). Boundary conditions were well controlled  
315 in order to develop a numerical model. Due to the strong boundary conditions, the results of  
316 stereo-correlation showed artefact near the edges for the pressure loading case. So, the strains

317 patterns analysis was restricted to the central part of the abdominal wall limited by the  
318 nipples.

319

320 The main results of this study regarding the stiffness variations between states are currently  
321 used to test the validity of numerical models of a porcine abdominal wall. In the future, the  
322 same methodology will be used to characterize the passive response of human abdominal  
323 walls.

324

325

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328

### 329 **Conflict of interest statement**

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332

333

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402 Figure legends:

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404 **Fig. 1.** Part of the abdominal wall removed from pigs for the tests: (a) The incisions were  
405 made along the dotted line. (b) The thickness of the abdominal wall was measured in several  
406 points (A to H).

407 **Fig. 2.** Experimental device: (a) Tightening of the abdominal wall between an aluminium  
408 plate and a rubber sheet with clamps screwed in the plate. (b) Positioning of the abdominal  
409 wall on the table of the testing machine and arrangement of the cameras.

410 **Fig. 3.** Loading mechanisms: (a) Pressure loading, (b) Contact loading

411 **Fig. 4.** Calculation of the stiffness (N/mm) for the contact loading case. The stiffness was  
412 computed in the linear region of the curve between 26 and 30 mm of displacement.

413 **Fig. 5.** Lagrange first principal strain fields of the internal (a) and external (b) surfaces of an  
414 abdominal wall (sternum side at the top of the figure) subjected to a 50mmHg air pressure.  
415 Average strains were calculated in the central area inside the dotted lines.

416 **Fig. 6.** Displacement- Force curves for the contact loading for the three states. Error bars:  
417 Standard deviation

418 **Fig. 7.** Mean stiffness calculated for the contact loading case for each abdominal wall state:  
419 intact, incised and repaired (n=6). Error-bars: standard deviation.

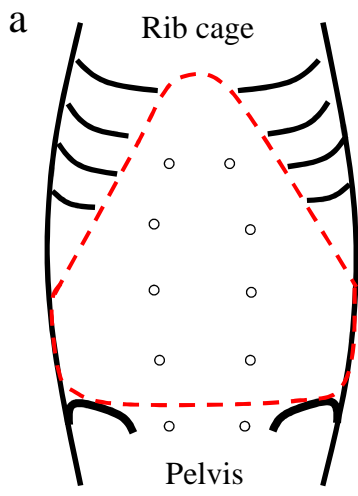
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421 **Table 1.** Mean Lagrange first principal strains E1 in % calculated for the internal and external  
422 surfaces of each abdominal wall for the pressure loading case at 50 mmHg.

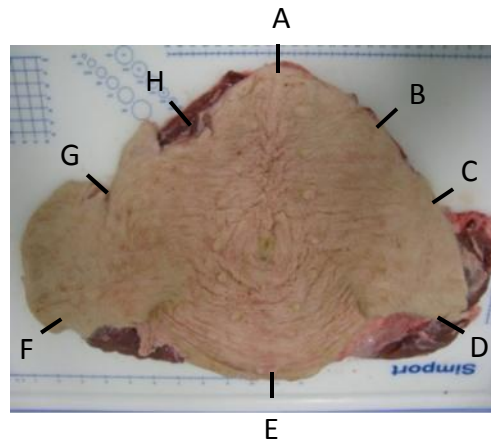
423 **Table 2.** Relative difference of stiffness between the abdominal wall states for the contact  
424 loading case.

425 **Table 3.** Mean Lagrange first principal strains E1 in % calculated for the external surface of  
426 each abdominal wall for the pressure at 50mmHg and for the contact at 165N.

**Fig. 1.**



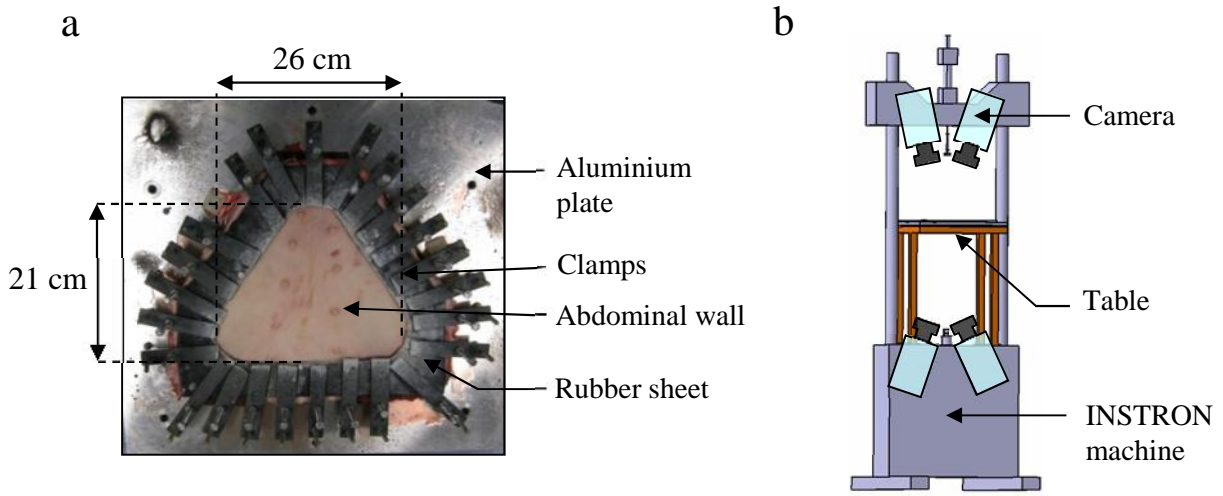
b



Cranial

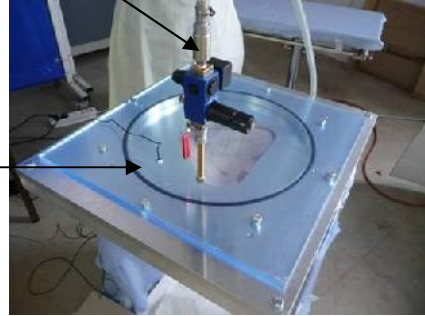
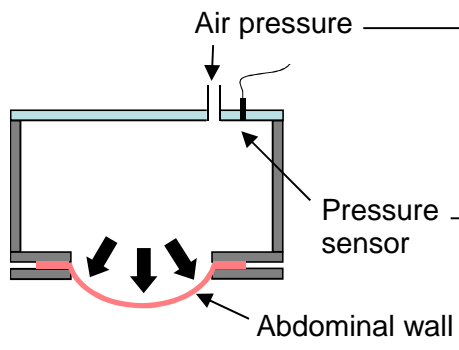
Caudal

**Fig. 2.**

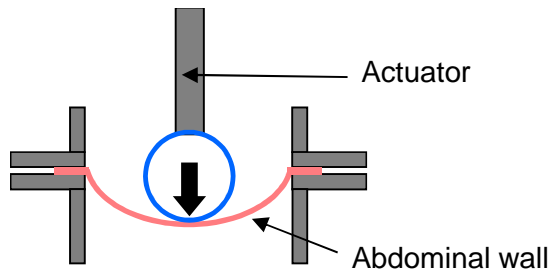


**Fig. 3.**

**a**



**b**



**Fig. 4.**

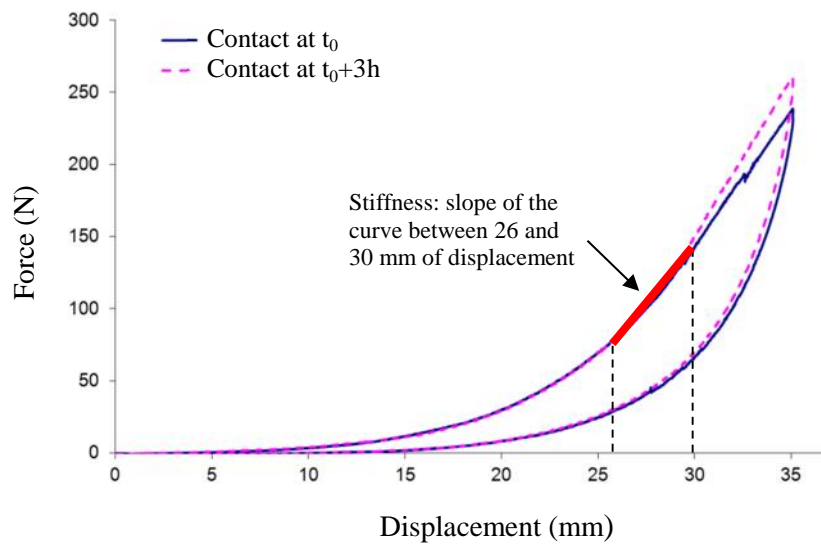
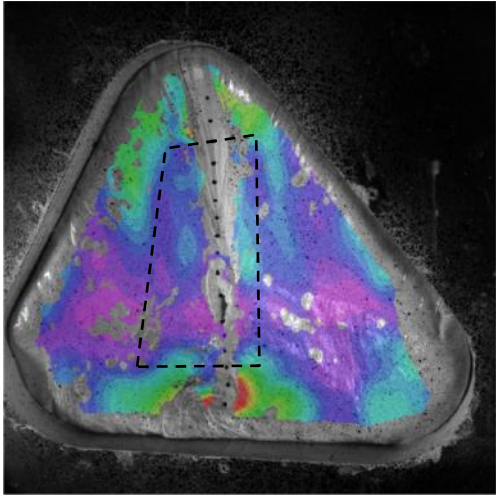
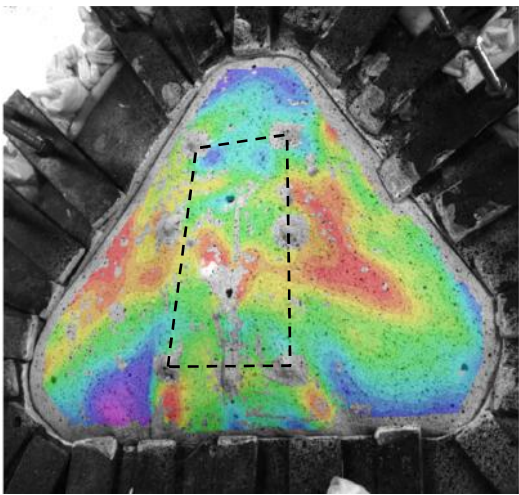


Fig. 5.

a



b



E1

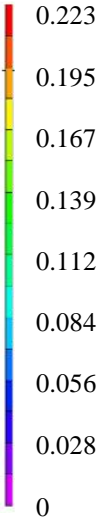
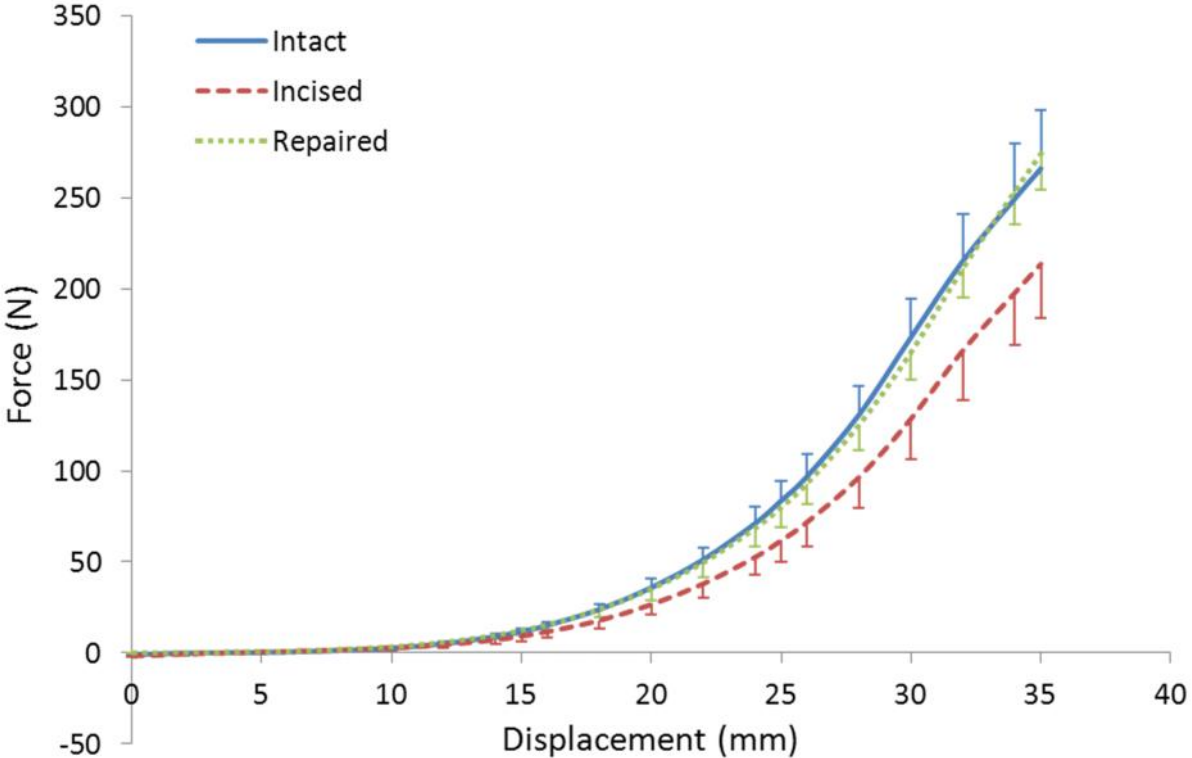
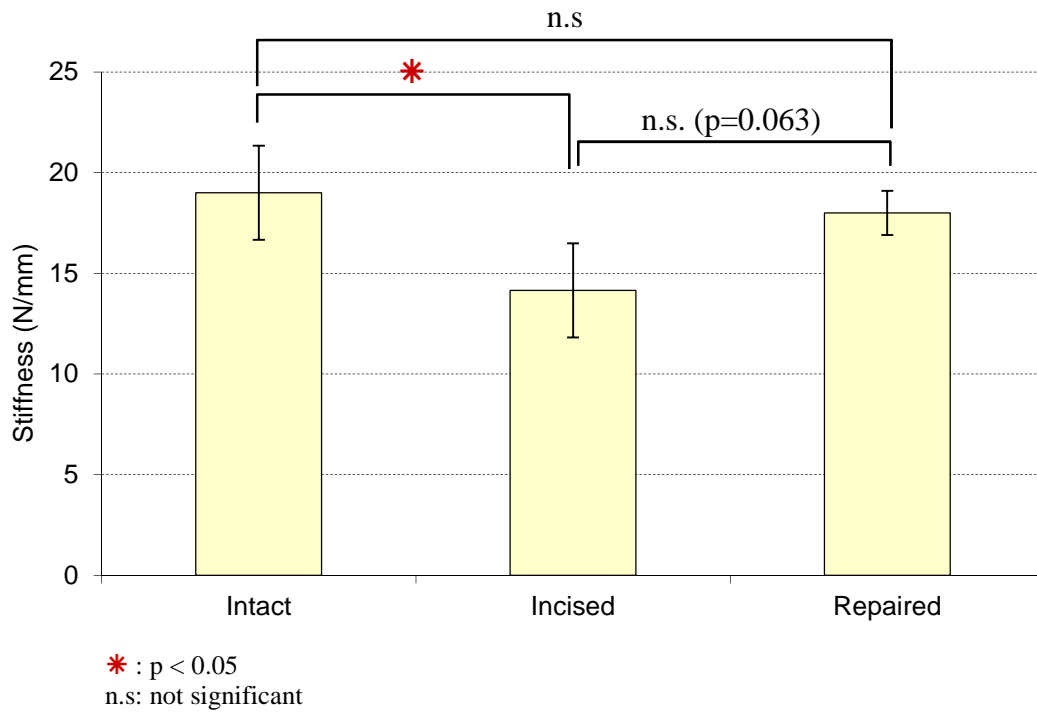




Fig. 6.



**Fig. 7.**



**Table 1**

	Thickness (mm)	E1 (%) Internal surface	E1 (%) External surface	Ratio E1 Ext. / E1 Int.
Wall 1	28	4.4	13.7	3.1
Wall 2	25	4.5	17.3	3.8
Wall 3	29	5.6	13.4	2.4
Wall 4	27	5.0	10.8	2.1
Wall 5	30	6.6	14.9	2.3
Wall 6	30	5.5	12.0	2.2
<i>Mean</i>	28	5.3	13.7	2.6
<i>SD</i>	1.7	0.7	2.1	0.6

**Table 2**

	Intact-Incised (%)	Intact-Repaired (%)	Incised-Repaired (%)
Wall 1	-32	-4	42
Wall 2	-26	3	39
Wall 3	-17	-24	-9
Wall 4	-10	23	37
Wall 5	-43	-12	55
Wall 6	-21	-7	18
<i>Mean</i>	-25	-4	30

**Table 3**

	Mean strain E1 (%) Pressure (P=50 mmHg) – External surface			Mean strain E1 (%) Contact (F=165N) – External surface		
	Intact	Incised	Repaired	Intact	Incised	Repaired
Wall 1	13.7	25.9	20.7	11.0	14.4	13.2
Wall 2	17.3	22.4	20.2	23.0	26.9	19.8
Wall 3	13.4	18.3	17.7	15.5	19.2	15.3
Wall 4	10.8	24.6	15.3	12.5	19.1	14.4
Wall 5	14.9	23.3	22.2	15.2	21.1	15.0
Wall 6	12.0	28.7	21.6	9.8	17.1	12.6
<i>Mean</i>	<i>13.7</i>	<i>23.9</i>	<i>19.6</i>	<i>14.5</i>	<i>19.6</i>	<i>15.0</i>
<i>SD</i>	<i>2.1</i>	<i>3.2</i>	<i>2.4</i>	<i>4.3</i>	<i>3.9</i>	<i>2.3</i>