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1 **Experimental investigation of pressure applied on the lower leg by**
2 **elastic compression bandage**

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11 **Abstract**

12 Compression therapy with stockings or bandage is the most common treatment for
13 venous or lymphatic disorders.

14 The objective of this study was to investigate the influence of bandage mechanical
15 properties, application technique and subject morphology on the interface pressure,
16 which is the key of this treatment.

17 Bandage stretch and interface pressure measurements (between the bandage and the leg)
18 were performed on 30 healthy subjects (15 men and 15 women) at two different heights
19 on the lower leg and in two positions (supine and standing). Two bandages were applied
20 with two application techniques by a single operator.

21 The statistical analysis of the results revealed: no significant difference in pressure
22 between men and women, except for the pressure variation between supine and standing
23 position; a very strong correlation between pressure and bandage mechanical properties
24 ($p < 0.00001$) and between pressure and bandage overlapping ($p < 0.00001$); a significant
25 pressure increase from supine to standing positions ($p < 0.0001$). Also, it showed that
26 pressure tended to decrease when leg circumference increased.

27 Overall, pressure applied by elastic compression bandages varies with subject
28 morphology, bandage mechanical properties and application technique. A better
29 knowledge of the impact of these parameters on the applied pressure may lead to a more
30 effective treatment.

31

32 **Keywords:** compression bandage, pressure measurements, pressure variation, bandage
33 application technique, bandage mechanical properties, subject morphology, venous and
34 lymphatic disorders

35 **1 Introduction**

36 Compression bandage is a common treatment for venous or lymphatic pathologies such
37 as venous ulcers or lymphedema. In such diseases, bandages are preferred in the first
38 step of the treatment by compression, instead of stockings. Indeed, during the first days
39 of the treatment, the patients' leg shape changes a lot and the same compression
40 bandage can be applied on the leg with different geometries, whereas a new stocking
41 size would be needed to accommodate these changes. Once the leg shape is stable, the
42 treatment by compression is usually performed with socks or stockings. Bandages are
43 also used when the patient's pathology prevents the use of any other treatment (for
44 example after a knee arthroplasty). Moreover, it is easier for a caregiver to apply
45 bandages than stockings on patients' legs, especially with patients with impaired
46 mobility. Consequently, compression bandage and stockings are complementary.

47 The bandage, tight on the limb, applies a pressure on the external surface of the limb
48 which is then transmitted to the internal tissues and to the veins ^{1,2}. Numerous studies
49 have proven the effect of compression therapy on venous and lymphatic system ³⁻⁵,
50 whether compression is performed with bandage or stockings ⁶.

51 The efficacy of the treatment mainly depends on the level of pressure which is applied
52 on the limb ^{7,8}. This level of pressure depends on several parameters such as:

- 53 - The bandage mechanical properties
- 54 - The bandage components (padding layer, cohesive bandage, ...)
- 55 - The bandage stretch
- 56 - The local curvature of the limb on which the bandage is applied
- 57 - The application technique (spiral or figure of eight)
- 58 - Other parameters such as friction between the different layers, mechanical
59 properties of the limb soft tissues, ...

60 Better understanding how these parameters impact the level of applied pressure would
61 lead to an improved treatment with compression bandage.

62 A well-known theoretical relationship between the tension, T , of the bandage (force
63 needed to stretch the bandage, which is given by the bandage mechanical properties and
64 the applied stretch), the local curvature, r_c , of the limb and the locally applied pressure,
65 P , is given by the Laplace's Law:

$$P = T/r_c$$

66 However, it has been shown that this law is not sufficient to explain the pressure
67 distribution over a limb^{9,10}, hence the need for an experimental investigation of the
68 pressure applied by compression bandage on the lower leg.

69 Several measurements of the pressure applied by bandages were carried out, with
70 various types of bandages, at different measurement points and on a wide range of
71 subjects in different body positions¹¹⁻¹³. In order to standardize the way to perform
72 pressure measurements, recommendations have been published to proceed to interface
73 pressure measurements⁸. Measurement points have been identified on the lower leg⁸
74 such as (Figure 1):

- 75 - Measurement point B1: corresponding to the height where the Achilles' tendon
76 turns into the gastrocnemius muscle.
- 77 - Measurement point C: corresponding to the height where the calf circumference
78 is the largest.

79 The pressure sensors used for the measurements should meet some requirements: for
80 example to be thin and flexible⁸. Different types of sensors exist but some have proven
81 to be more reliable than others¹⁴ (Kikuhime[®] and Picopress[®] for example).

82 Most of the measurement campaigns which were performed on men and women did not
83 take the gender difference into account^{13,15}. However the leg morphology has an

84 influence on the applied pressure. Indeed, the leg morphology varies from a subject to
85 another and maybe even more especially from a female subject to a male subject¹⁶.
86 Other groups investigated the impact of the application technique on the interface
87 pressure¹⁷ and they also measured the stretch of the applied bandage. However, as the
88 aim of this previous study was to compare the pressure applied by different application
89 techniques, it was carried out for a single bandage type. Other studies were focused on
90 the influence of bandage mechanical properties and position (supine, standing, sitting)
91 on the interface pressure^{12,18-20}, but as far as we know, none of them measured the
92 stretch of the applied bandage, though it is one of the main parameters which controls
93 the interface pressure.

94 This shows the need of performing other pressure measurements in order to
95 simultaneously evaluate the influence of all following parameters on the interface
96 pressure: bandage mechanical properties, application technique, subjects' gender and
97 morphology and position (supine or standing).

98 Within this context, the objective of the present study is to perform a complete
99 campaign including bandage stretch and pressure measurements in order to test the
100 following hypotheses:

- 101 - The applied pressure is proportional to the bandage elastic modulus (or the force
102 needed to stretch the bandage)
- 103 - The applied pressure is proportional to the bandage overlapping (50% or 66%
104 overlapping means that respectively 2 or 3 bandage layers cover the leg)
- 105 - The interface pressure significantly decreases when the subjects' leg
106 circumference increases.

107 Moreover, these measurements result to a quantitative evaluation of the pressure
108 differences among female and male subjects and of the pressure increase between the

109 supine and the standing position.

110 **2 Methods**

111 Briefly, stretch and pressure measurements were performed on healthy male and female
112 subjects in order to estimate the gender influence. Subjects were chosen in order to have
113 a wide range of morphologies. Two different elastic bandages, with different
114 mechanical properties, were applied on the subject's leg with two application
115 techniques with the aim of evaluating the influence of mechanical properties,
116 application technique and position (supine or standing) on the interface pressure.

117 **2.1 Bandages**

118 Two commercially available elastic bandages, which differ in their mechanical
119 properties, were applied on the subjects' leg by the same experienced operator: the
120 Biflex[®] 16 (B16) and the Biflex[®] 17 (B17) (Thuasne, Levallois-Perret, France) which is
121 stiffer (Table 1). Bandage elastic modulus (K), in N/mm, is defined as follows:

$$K = \frac{\text{Force to stretch the bandage}}{\text{bandage width} * (L - L_0)/L_0}$$

122 where L is the length of the stretched bandage and L_0 its initial length (Figure 2). Both
123 bandages were 10 cm wide. They were applied on the leg with a target stretch of 1.3, in
124 accordance with the manufacturer's recommendations and visual calibration marker
125 (Figure 2). This visual calibration marker is a rectangle which turns into a square when
126 the bandage stretch is equal to 1.3. It gives a visual indication to the bandager that the
127 stretch is in accordance with the manufacturer's recommendations. The stretch is
128 defined as the ratio between the length of the stretched bandage and its initial length
129 ($stretch = L/L_0$). Bandage can be applied in the form of a spiral with a 50% or a 66%
130 overlap, which means that at each turn, the bandage layer on top covers the bandage

131 layer below respectively by 50% or 66% (Figure 2 and Figure 3). For a 50% or 66 %
132 overlapping technique, the leg is covered by respectively 2 or 3 bandage layers. The
133 value of the overlap is usually prescribed by medical doctors. Lines were drawn on the
134 bandage to help the bandager to apply the bandage with the correct overlap: one at 50%
135 and one at 33% of the bandage width, for respectively a 50% and a 66% overlapping
136 technique (Figure 2).

137 **2.2 Pressure sensors**

138 The interface pressure was measured with pneumatic pressure sensors Picopress®
139 (MicroLab Elettronica, Ponte S. Nicolo, Italy). This pressure sensor is a convenient
140 device which was used in several previous pressure measurements studies^{11,21,22}.

141 As a preliminary study, the accuracy, the linearity and the hysteresis of the sensors were
142 tested. To achieve this, the sensor was placed at the bottom of a water column. First, the
143 column was filled with water and a measure was taken every 10 mmHg (13.6 cmH₂O)
144 from 0 to 147 mmHg (199.9 cmH₂O). Then the column was emptied and a measure was
145 taken every 10 mmHg. This allowed characterizing the hysteresis of the sensor, which is
146 given by the following equation:

$$E_h = \text{mean}_{x_i} \left(\frac{|y_+(x_i) - y_-(x_i)|}{x_i} * 100 \right)$$

147 where, $y_+(x_i)$ and $y_-(x_i)$ are the measured pressure value for a theoretical applied
148 pressure equal to x_i , respectively during the loading and the unloading phases. The
149 second test consisted in applying 20 different pressure values, which were randomly
150 determined and allowed characterizing the sensor linearity. The coefficient of
151 determination R^2 was used as the indicator of the linear dependence between the
152 theoretical and the measured pressure. The closer to 1 the coefficient R^2 was, the more
153 linear the sensor was.

154 These tests were performed for the Picopress[®] device and the two sensors which were
155 used in the study (respectively at measurement points B1 and C).
156 The tests showed that R^2 was almost equal to 1 for both sensors ($R^2 = 0.9999$) and that
157 the hysteresis was slightly higher for the sensor located at measurement point B1 (1.0%)
158 than for the other sensor located at measurement point C (0.0%).
159 The tests performed on the sensors showed that these sensors were very reliable and,
160 hence, suitable for the present work, which was in accordance with the tests conducted
161 by Partsch et al. ¹⁴.

162 **2.3 *Experimental protocol***

163 *Subject selection*

164 Pressure measurements were carried out on 30 healthy subjects, 15 women and 15 men,
165 following informed consent (Table 2). This protocol was approved by the local ethics
166 committee.

167 The subjects' selection was made with regards to their circumference at measurement
168 point B1 (Figure 1) in order to be equally distributed in 3 groups of circumference at B1
169 height.

170 For this, a list of 205 women and one of 147 men were built and alphabetically ordered.

171 Six groups (three for women and three for men) were created, depending on the
172 subjects' circumference at measurement point B1:

- 173 - Circumference ≤ 29 cm
- 174 - Circumference > 29 cm & < 32 cm
- 175 - Circumference ≥ 32 cm.

176 Then 5 subjects were randomly selected in each group. The only criteria for subject
177 selection were their gender and their circumference at point B1.

178 Once the subjects were chosen, the order in which they would take part in the study was
179 randomly determined.

180 *Pressure measurements*

181 Two sensors were positioned on the medial side of the right leg at heights
182 corresponding to the measurement points B1 and C (Figure 3). Measurement point B1
183 was chosen following the recommendations of a consensus paper on interface pressure
184 measurements⁸ and measurement point C was chosen because it corresponds to a part
185 of the calf which is mainly composed of soft tissues. All bandages were applied by the
186 same trained operator. Four types of bandages were applied in the form of a spiral
187 (Figure 3):

- 188 - B16 with a 50% overlap (B16 – 2 layers)
- 189 - B16 with a 66% overlap (B16 – 3 layers)
- 190 - B17 with a 50% overlap (B17 – 2 layers)
- 191 - B17 with a 66% overlap (B17 – 3 layers).

192 The order in which the bandages were applied was randomly determined for each
193 subject.

194 The bandage was applied in the supine position, after a rest time of 5 to 10 minutes
195 (time needed to set the sensors on the subject leg). Immediately after the bandage
196 application, the stretch of the bandage around the measurement points B1 and C was
197 measured thanks to a mark printed on the bandage every 100 mm (Figure 2). The
198 distance between three consecutive marks (initially equal to 200 mm) was measured
199 using a measuring tape once the bandage had been applied on the leg, around the
200 locations of measurement points B1 and C, providing the stretch of the bandage (for
201 example, if the distance was equal to 252 mm, the stretch of the bandage at this location
202 was $252 / 200 = 1.26$).

203 After bandage application, the subject waited for two minutes in the supine position
204 with the foot slightly raised in order to prevent any contact between the calf and the
205 examination bed. After this time, three successive measurements were acquired. The
206 mean value of the three measurements was considered as the pressure value.
207 Then the subject was asked to stand up and waited for 2 minutes before the measures
208 were taken again.

209 **2.4 Statistical analysis**

210 For all results, the values are given with their 95% confidence interval and all
211 histograms represent the mean value and the 95% confidence interval.

212 Parametric tests (analysis of variance (ANOVA)) were used to evaluate all difference
213 between two samples (whose size $n \geq 30$), except to analyse the effect of circumference
214 on the pressure (the samples were too small: $n < 30$).

215 For the small samples ($n < 30$), the Kruskal–Wallis one-way analysis of variance was
216 used and then the individual effects were tested with a Mann-Whitney U test ($\alpha =$
217 $\frac{0.05}{\text{number of tests}}$).

218 To evaluate the linear correlation between two samples, the coefficient of determination
219 R^2 was computed, which equals the square of the Pearson correlation coefficient
220 between the experimental data and the values from the linear regression. The variable t ,
221 which is approximately distributed as a Student's distribution with $n-2$ degrees of
222 freedom for a zero correlation, was used to test the significance of the coefficient of

223 determination R^2 : $t = \sqrt{R^2 * \frac{n-2}{1-R^2}}$.

224 The coefficient of determination was used to characterize the linear correlation between
225 the following parameters:

226 - the pressure applied by a B16 and the one applied by a B17

- 227 - the pressure applied by 2 layers and the one applied by 3 layers
- 228 - the pressure at measurement point B1 and the one at point C
- 229 - the pressure in the supine position and the one in the standing position.

230 Difference was considered as significant if $p < 0.05$.

231 **3 Results**

232 **3.1 Bandage Stretch**

233 Considering all bandages together, mean stretch was equal to 1.30 ± 0.007 , in
234 accordance with the manufacturer's recommendations (Figure 4 - a). However, the
235 results demonstrated that, irrespective of bandage type (B16 or B17), stretch at point B1
236 was significantly lower ($p < 0.0001$) than at point C. Mean stretch at point B1 was lower
237 than recommended (1.27 ± 0.009). Conversely, at point C, mean stretch was higher
238 than recommended (1.33 ± 0.008).

239 Also, B17 was applied with a significantly lower stretch than B16 ($p < 0.03$),
240 respectively 1.29 ± 0.009 and 1.31 ± 0.01 .

241 No significant difference in stretch was observed at point C between bandage applied
242 with 50% and 66% overlapping. Conversely, at point B1, bandages applied with 66%
243 overlapping exhibit higher stretch compared to bandages applied with 50% overlapping
244 ($p < 0.002$), respectively 1.29 ± 0.012 and 1.26 ± 0.012 .

245 **3.2 Pressure values for the different bandages**

246 Considering all bandage types, body positions and measurement points, interface
247 pressure increased significantly ($p < 0.0001$) with bandage overlapping. Interface
248 pressure applied by bandage with 66% overlap were higher than pressure applied by
249 bandage with 50% overlap (Figure 4 - b). Similarly, interface pressure increased

250 significantly ($p < 0.0001$) with bandage elastic modulus: pressures applied by B17 were
251 higher than pressures applied by B16 with the same application technique.

252 There was no significant difference ($p > 0.05$) between interface pressure measured with
253 B16 applied with 3 layers and B17 applied with 2 layers.

254 **3.3 Gender influence**

255 There was no overall significant difference between male and female in terms of
256 pressure values and pressure gradient ($p > 0.05$).

257 However, pressure variations between supine and standing positions were significantly
258 different between male and female ($p < 0.01$). These variations were higher for males
259 irrespective of bandage type and measurement point but the difference between sex
260 remained low: the pressure variations between the two positions were +11% for women
261 and +14% for men.

262 **3.4 Influence of bandage mechanical properties**

263 The correlations between the pressures exerted by the B16 and the B17 were significant
264 at all measurements points, in all positions and for both application techniques
265 ($p < 0.0001$) (Figure 5 - a). The pressure exerted by the B17 was about 1.5 times as high
266 as the pressure exerted by the B16 whereas the ratio of elastic moduli was 1.

267 **95. Influence of application technique**

268 The correlation between the pressures exerted by any bandage applied with 66%
269 overlap and the same bandage applied with 50% overlap was significant at all
270 measurement points and in all positions ($p < 0.01$) (Figure 5 - b).

271 **3.5 Influence of measurement point (degressivity)**

272 The results demonstrated that, irrespective of bandage type, application method and
273 body position, the elastic bandages followed the principle of pressure gradient along the
274 length of the limb (Figure 5 – c). The measured pressures decreased significantly
275 ($p < 0.0001$) from point B1 to point C, which means that bandages are degressive
276 (decreasing pressure from the ankle to the knee). Pressures measured at point B1 were
277 about 7% higher than pressures measured at point C.

278 **3.6 Influence of position**

279 The interface pressure increased significantly ($p < 0.0001$) from the supine position to the
280 standing position, at point B1 and at point C, irrespective of bandage type and
281 application method (Figure 5 - d). On average, interface pressures in standing position
282 were 12% higher than in supine position.

283 **3.7 Pressure and circumference**

284 Irrespectively of bandage type, application method and body position, interface
285 pressures tended to decrease when circumference at measurement point B1 increased
286 (Figure 6). Differences were always significant ($p < 0.05$) between circumferences at B1
287 below 29 cm and over 32 cm.

288 **4 Discussion**

289 The main strength of the study is to provide a unified investigation of the influence of
290 several parameters on the applied pressure. It quantifies the influence of parameters
291 which were usually not taken into account. Among the most significant results, it was
292 shown with our measurements that the bandage stretch is the key to a better control of
293 the treatment. This data should be provided and considered in every future study on

294 compression bandages. It was also shown that the relationship between applied pressure
295 and elastic modulus of the bandage is not linear, which disputes once again Laplace's
296 law in the context of compression bandages.

297 The objective of the present study was to perform a complete campaign of stretch and
298 interface pressure measurements carried on 30 subjects in order to test the following
299 hypotheses:

- 300 - Hypothesis 1: the applied pressure is proportional to the bandage elastic
301 modulus
- 302 - Hypothesis 2: the applied pressure is proportional to the bandage overlapping
- 303 - Hypothesis 3: the interface pressure significantly decreases when the subjects'
304 leg circumference increases.

305 All bandages were applied by the same trained operator and the stretch of the applied
306 bandage was close to the manufacturer's recommendations. It was noticed, however,
307 that the actual stretch was not constant over the leg and was influenced by the bandage
308 mechanical properties. It was shown that the interface pressure proportionally increased
309 with the elastic modulus (Hypothesis 1) and the overlapping (Hypothesis 2) of the
310 bandage and that it tended to decrease when the leg circumference increased
311 (Hypothesis 3). Moreover, no significant difference was observed between men and
312 women except for the pressure increase between the supine and standing position,
313 which was larger for men. These results lead to a more detailed analysis of the
314 quantified respective influence of the different parameters on the interface pressure,
315 hence an improved understanding of the treatment. The following discussion is
316 structured around three topics: the bandage itself, the subject and its position.

317

318 Even though the bandage stretch greatly impacts the level of interface pressure, it was
319 noticed in previous studies^{23,24} that the bandage tension varied a lot with the bandager,
320 even for experienced bandager. However each bandager seemed to be constant and
321 repeatable in applying bandages^{25,26}. In this study, all bandages were applied by one
322 trained bandager. This is why the observed trends only reflect one bandager's
323 application technique and cannot be generalized straightaway.

324 Nevertheless, the maximum, minimum and mean stretches (respectively 1.45, 1.18 and
325 1.30) measured in the present study were in the vicinity of the target value of 1.3. This
326 showed that the calibration marker (a rectangle which turns into a square when the
327 stretch is equal to 1.3 (Figure 2) was effective in having a bandage stretch close to 1.3
328²⁷. However, the stretch was not constant over the leg, with larger stretch at point C than
329 at point B1, suggesting an influence of the leg's diameter on the bandager application
330 technique. Moreover, the stretch was larger for the B16 than for the B17, which could
331 be explained by the fact that the B16 was less stiff, so was easier to stretch, thus
332 providing a different feedback to the operator. Measuring the stretch has shown that its
333 control during bandage application can still be improved.

334

335 The results revealed a very strong correlation between the pressure and the bandage
336 mechanical properties ($p < 0.00001$). The ratio between the pressure exerted by the B17
337 and that exerted by the B16 was about 1.5. This result raised an important question.
338 Indeed, the ratio between the forces necessary for a 1.3 stretch was equal to 1.95 (force
339 for the B16 = 0.069 N.mm^{-1} ; force for the B17 = 0.0135 N.mm^{-1}), which should induce
340 a ratio of 1.95 in pressure according to Laplace's Law as the pressure is supposed to be
341 directly proportional to the force needed to stretch the bandage. Even though the
342 measured stretch was lower for the B17 than for the B16, the relative difference in the

343 stretch (1.3 ± 0.9 % of the stretch) is not sufficient to explain the difference between
344 the experimental ratio (1.48, $p < 0.00001$) and the expected ratio (1.95), as this ratio is
345 equal to 1.93 considering the slight difference in stretch. It is hypothesized that this
346 difference is due to friction between the bandages and/or the application gesture.
347 However, these are complex phenomena and need to be further investigated.
348 This study highlighted a strong correlation between the interface pressure and the
349 bandage overlapping ($p < 0.00001$). The impact of the application technique on the
350 pressure seemed to be in accordance with what was expected. Indeed, the ratio between
351 the pressure applied by a 3-layer bandage and the one applied by a 2-layer bandage
352 should be equal to $3/2 = 1.5$. The experimental ratio was about 1.5 ($p < 0.00001$), which
353 is in accordance with the theory.

354

355 The second group of parameters which impacts the interface pressure is directly related
356 to the subjects: their gender and morphology. In this study, pressure measurements were
357 performed on both men and women subjects and the only significant difference between
358 these two populations was for the pressure increase between the supine and the standing
359 position. However the results were not treated separately for men and for women
360 because it has been considered that the difference (3% of the pressure values) was small
361 enough to merge the results. Nonetheless, it may be hypothesized that this small
362 difference is due to the difference in musculature between men and women, which leads
363 to a difference in the geometry variation between the supine and the standing position.

364

365 Considering both populations altogether, it was showed that the pressure tended to
366 decrease when the leg circumference increased, which is in general agreement with the
367 Laplace's law, as the pressure is supposed to be inversely proportional to the radius of

368 curvature. Also, the circumference at point C was larger than the circumference at point
369 B1, hence the fact that the bandage was degressive (the pressure at point B1 is higher
370 than the pressure at point C). However, in the Laplace's law, only the local radius of
371 curvature has an influence of the pressure. A larger circumference is only the sign of a
372 global radius estimate but it does not consider local radius values. In that sense, our
373 results showed that the level of pressure can vary significantly from a subject to another
374 and that it depends on their leg geometry.

375

376 Eventually, the impact of the subject position was investigated: the pressure increased
377 when moving from the supine to the standing position. Due to gravity, the leg geometry
378 changes from the supine to the standing position (Figure 7). The bandage is applied in
379 the supine position. After bandage application, when the subject stands up, the leg
380 circumference tends to increase²⁸, which leads to an increase in the bandage stretch and
381 induces a pressure increase. This change in geometry from the supine to standing
382 positions may be a consequence of the muscle group tendency to fall down (because of
383 gravity) and of the increase of hydrostatic blood pressure. The observed pressure
384 difference can be used to characterize the stiffness of the bandage as described in the
385 literature²⁹. In this study, for which elastic bandages were used, the pressure increase is
386 equal to $6.10 \pm 0.54 \text{ mmHg}$. This is in accordance with the previous classification
387 given by Partsch et al.³⁰, where elastic bandages should display an increase below 10
388 mmHg.

389 ***Limitations***

390 The subjects in this study were all healthy subjects whose mean age was lower than the
391 mean age of pathologic patients using compression bandage. An interesting perspective
392 will be to carry out the same measurements on pathologic subjects. Moreover, the

393 pressure measurements were performed almost right after the bandage application,
394 therefore neglecting the behavior of compression bandage over time (slipping of the
395 bandage, pressure loss, ...). Also, all measurements were static measurements.

396 All the tests that have been performed on the sensors were performed on a flat surface
397 whereas they were used on a curved surface. This type of sensor was already tested on
398 curved surface and showed some imprecisions: they tend to slightly overestimate
399 pressure values ³¹. However, the largest radius of curvature used in this study was 55
400 mm whereas the approximated radius of curvature of the limbs in this study went from
401 40 to 70 mm (for measurement points B1 and C). The influence of curvature on the
402 pressure measured by Picopress, in the range of limb curvature, should be further
403 investigated.

404 Moreover, an on-going work aims to study the modification in the radius of curvature
405 due to the sensor. Indeed, even though its thickness is very small, its 2 mL volume may
406 induce a local variation in the radius of curvature, which may affect the local value of
407 interface pressure.

408 All bandages were applied by the same person in order to prevent large variations in the
409 bandage application. However, it would have been interesting to evaluate the variation
410 in the application between different bandagers.

411 **5 Conclusion**

412 This study aimed at an objective evaluation of the influence of bandage mechanical
413 properties, application technique and subject morphology on the interface pressure
414 applied on the lower leg by elastic compression bandages and the influence of these
415 parameters on the stretch actually applied by the bandager. It has revealed a very strong
416 correlation between the applied pressure and the bandage mechanical properties but also
417 between the pressure and the application technique. In a previous study ²⁹, H. Partsch

418 has raised the question of the control of the application technique and our study
419 corroborates this claim. A better control of the stretch and the application technique will
420 lead to a better control of the pressure applied by compression bandages. This study also
421 shows the limit of the Laplace's law in explaining the level of interface pressure and
422 raises some questions about parameters which have not been taken into account yet,
423 such as the friction between the bandage layers. An interesting future direction will
424 address dynamic measurements of the pressure applied by a single compression
425 bandage or the superimposition of 2 compression bandages. These measurements could
426 be performed on pathologic subjects.

427 **Conflict of interest**

428 Thuasne is a compression bandage manufacturer.

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511 bandage pressure: Implications for clinical practice. *J Wound Care*.
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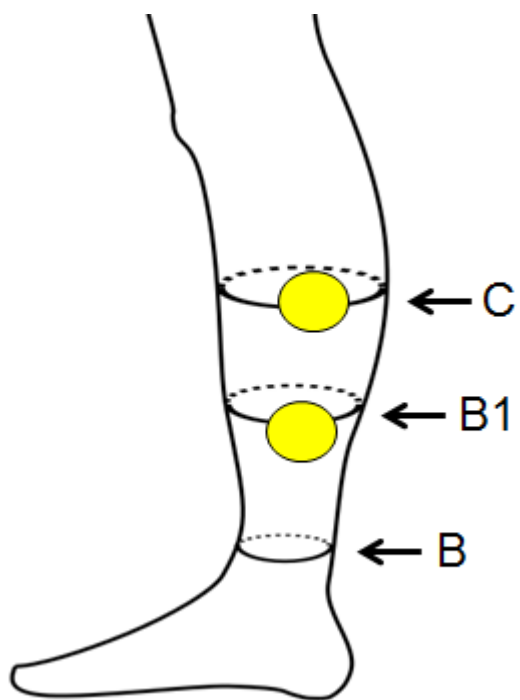
537 Table 1

	Longitudinal elastic modulus [N.mm⁻¹]	Force at stretch = 1.3 [N.mm⁻¹]
Biflex [®] 16 (B16)	0.23	0.070
Biflex [®] 17 (B17)	0.44	0.13

538 Table 2

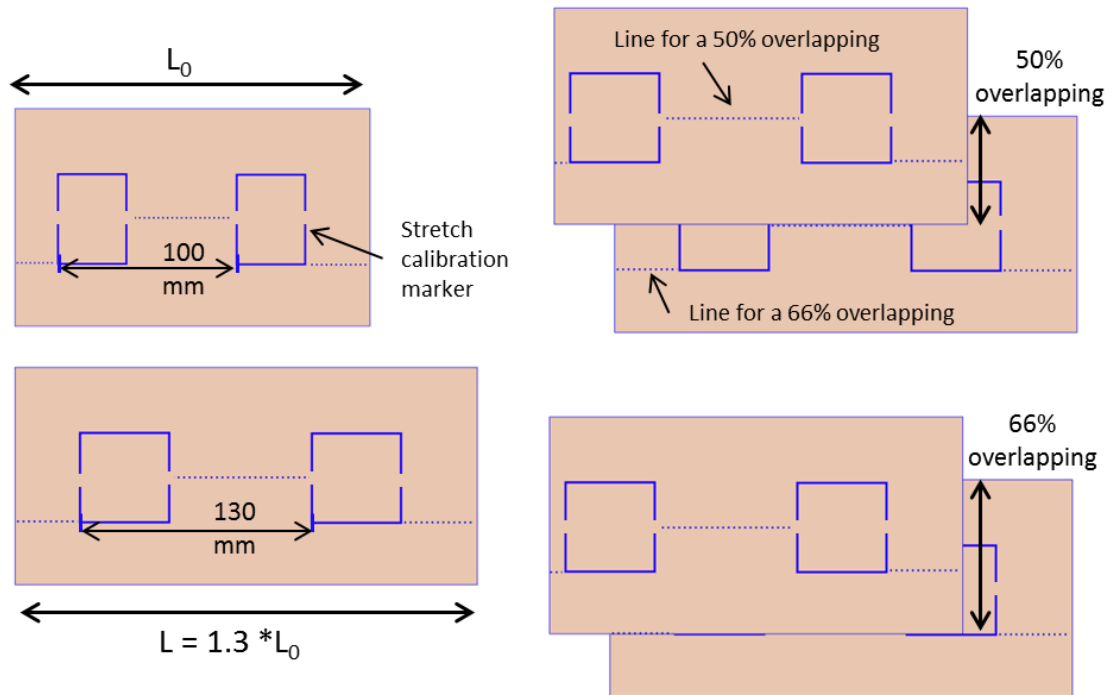
	Age	Circumference at B1 [cm]	Circumference at C [cm]
Women	41.6 ± 1.31	31.4 ± 1.3	36.2 ± 1.6
Men	43.6 ± 1.12	30.4 ± 1.2	36.9 ± 1.4

539 Figure 8: Location of measurement points B1 (where the Achilles' tendon turns into the
540 gastrocnemius muscle) and C (where the calf circumference is the largest)



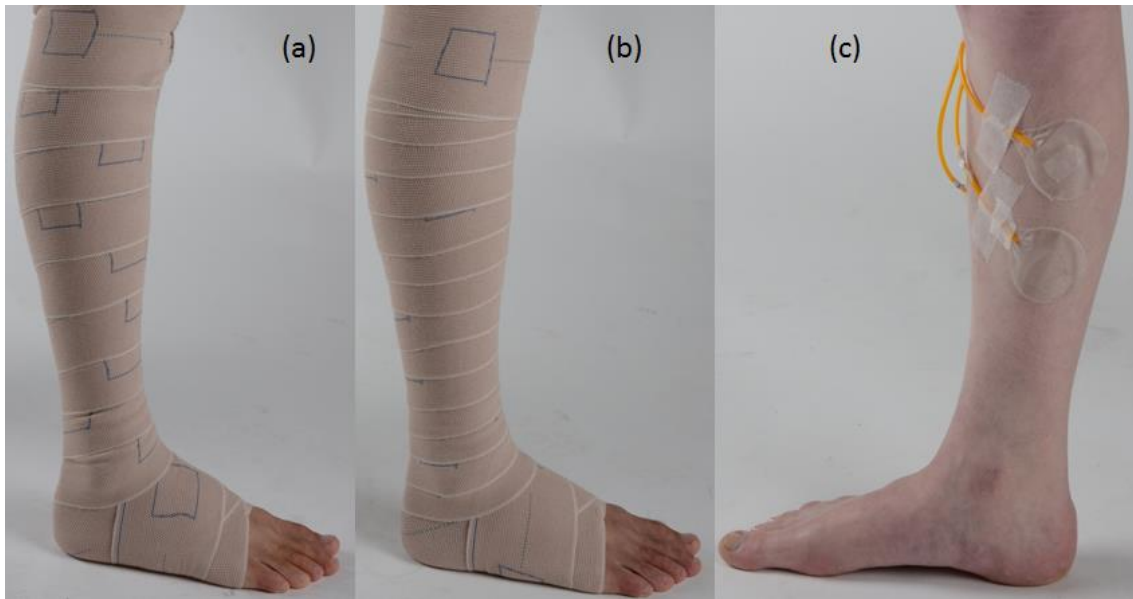
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542 Figure 9 : Bandage stretch and application technique in the form of a spiral;
543 marker (a rectangle which turns into a square when the bandage stretch is about 1.3)
544 helps to apply the bandage with the correct stretch; Lines are drawn to help to apply the
545 bandage with the correct overlap



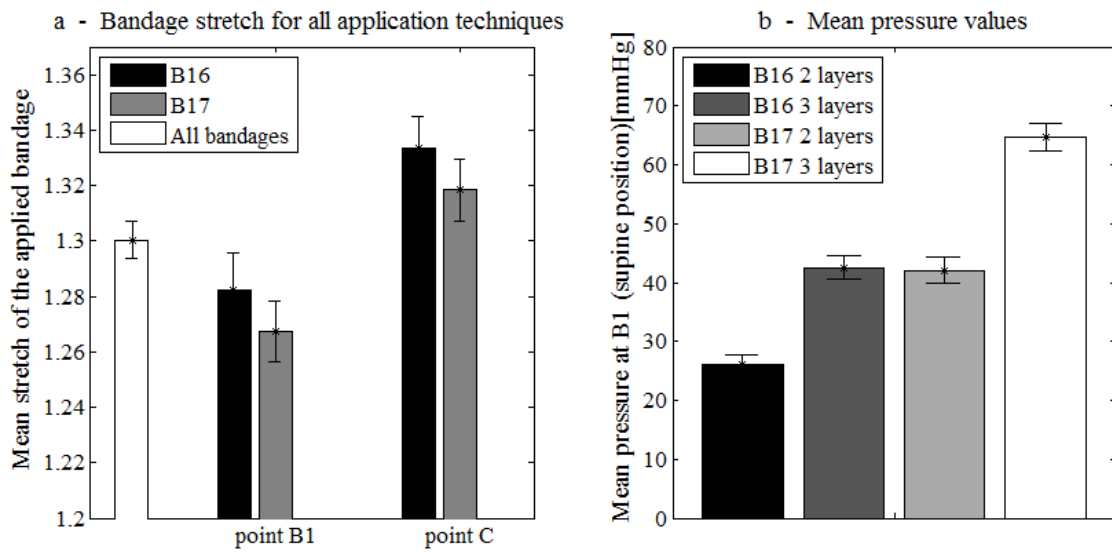
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547 Figure 10: Bandage applied in the form of a spiral with a 50% (a) or 66 % (b)
548 overlapping technique and locations of the sensors (c)



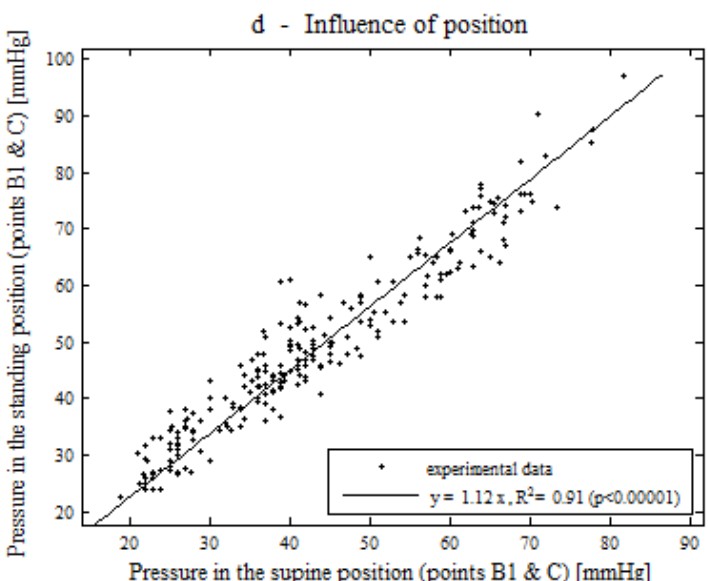
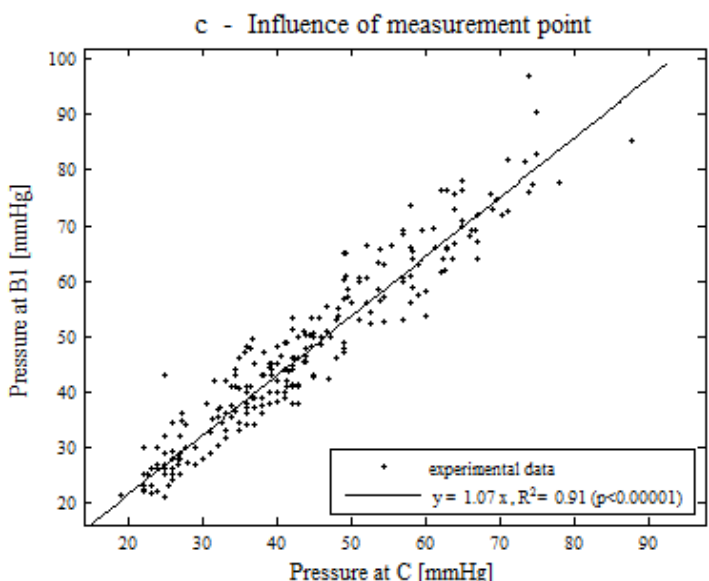
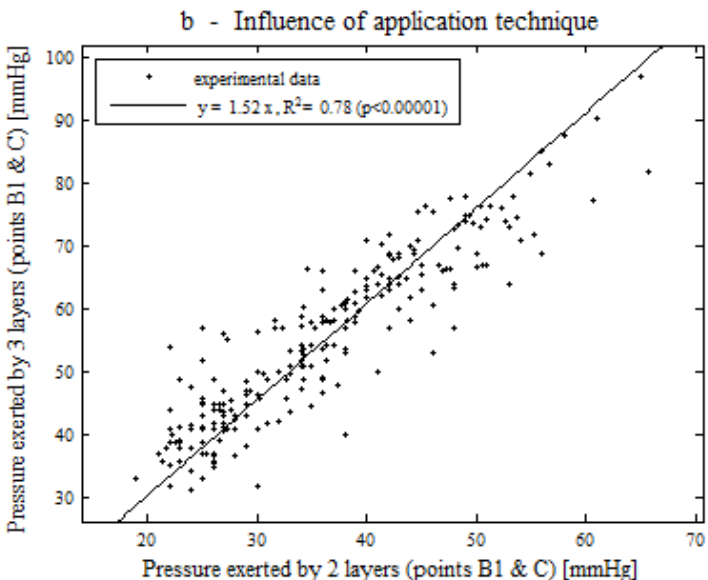
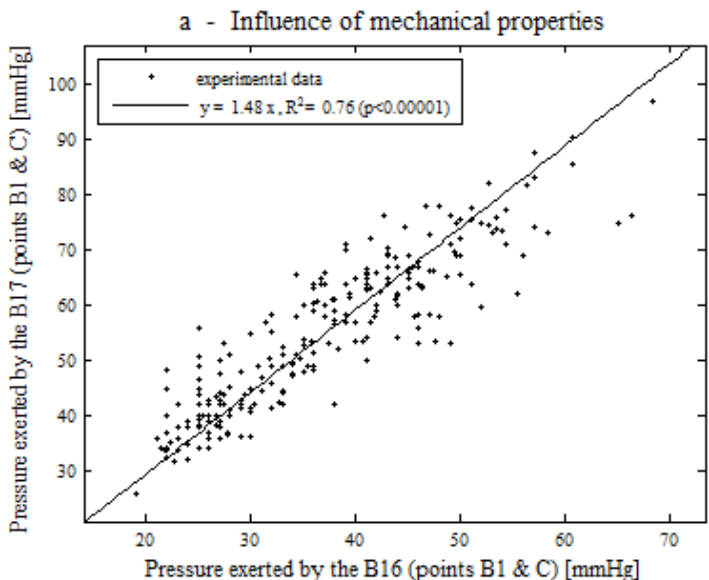
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550 Figure 11: Stretch of the applied bandages (a) and mean pressure values (in the supine
551 position) at measurement point B1 for the different bandages (b)

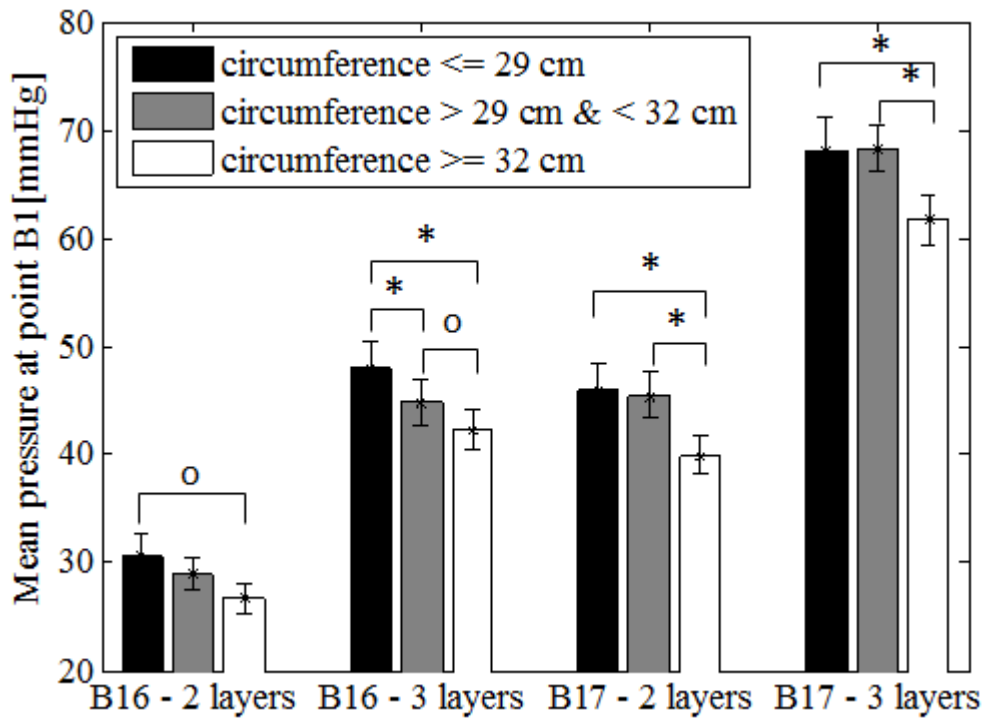


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553 Figure 12: Evaluation of the influence on the applied pressure of the bandage mechanical properties (a), application technique (b), and position (d)
554 considering both measurement points; Evaluation of the pressure difference between measurement points B1 and C (c)

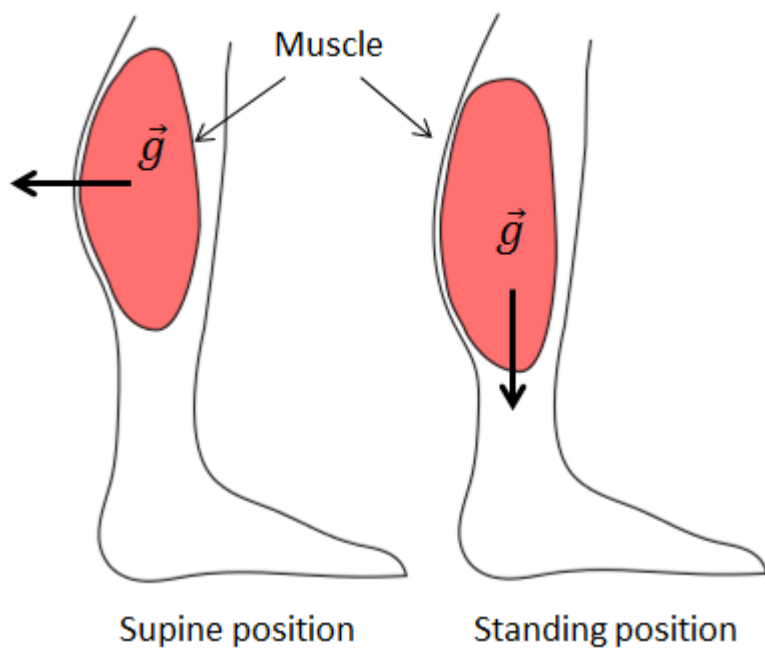


556 Figure 13: Influence of the leg circumference on the interface pressure at point B1 (o : $p < 0.05$, * : $p <$
557 0.02) – 3 groups of subjects were created regarding their leg circumference at measurement point B1



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559 Figure 14: Difference in leg geometry between supine and standing position



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