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# Hand Surgery and Rehabilitation

## Biomechanical evaluation of the ST-knot: a new suture for flexor tendon repair

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<b>Abstract:</b>	<p><b>Purpose</b></p> <p>Although tendon lacerations are common injuries for the hand surgeon, there is currently no consensus regarding the choice of one suture over another. Easy and fast sutures that impart enough strength to allow mobilization are needed. This study compares the ex vivo biomechanical strength (force required to create a 2 mm tendon gap) of a new suture (ST-knot) with that of a conventional suture (double Kessler).</p> <p><b>Materials and methods</b></p> <p>Forty fresh deep flexor tendons from porcine forelimbs were used. Both repaired tendon ends were mounted on standard traction jaws of an axial traction machine at an initial distance of 40 mm for all tendons. A high-definition camera was used to determine the force forming a 2 mm gap. Ten tendons from group 1 (ST-knot) and ten tendons from group 2 (double Kessler) were prepared with PDS 4.0 (single thread for Kessler but double for ST-knot). Tendons in group 3 (ST-knot) and 4 (double Kessler) were repaired with PDS 1.0 using the same principle.</p> <p><b>Results</b></p> <p>There was no significant difference in the force required to form a 2 mm tendon gap between groups 1 and 2 and this trend was identical when using a stronger thread in groups 3 and 4. The maximum force before rupture, mode of repair failure, stress, and stiffness were also comparable, with no significant differences between groups 1 and 2, or between groups 3 and 4.</p> <p><b>Conclusions</b></p> <p>The ST-knot shows comparable results to the double-Kessler, regardless of the thread used. Because it involves fewer steps than conventional techniques, and it is easy to perform, the ST-knot may offer a therapeutic solution, particularly in complex traumas with multiple tendon injuries.</p>

**Title: Biomechanical evaluation of the ST-knot: a new suture for flexor tendon repair**

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## 1 **Abstract**

2 **Purpose:** Although tendon lacerations are common injuries for the hand surgeon, there is currently no  
3  
4 3 consensus regarding the choice of one suture over another. Easy and fast sutures that impart enough  
5  
6 4 strength to allow mobilization are needed. This study compares the *ex vivo* biomechanical strength (force  
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8 5 required to create a 2 mm tendon gap) of a new suture (ST-knot) with that of a conventional suture  
9  
10 6 (double Kessler).

11 7 **Materials and methods:** Forty fresh deep flexor tendons from porcine forelimbs were used. Both  
12  
13 8 repaired tendon ends were mounted on standard traction jaws of an axial traction machine at an initial  
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15 9 distance of 40 mm for all tendons. A high-definition camera was used to determine the force forming a  
16  
17 10 2 mm gap. Ten tendons from group 1 (ST-knot) and ten tendons from group 2 (double Kessler) were  
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19 11 prepared with PDS 4.0 (single thread for Kessler but double for ST-knot). Tendons in group 3 (ST-knot)  
20  
21 12 and 4 (double Kessler) were repaired with PDS 1.0 using the same principle.

22 13 **Results:** There was no significant difference in the force required to form a 2 mm tendon gap between  
23  
24 14 groups 1 and 2 and this trend was identical when using a stronger thread in groups 3 and 4. The  
25  
26 15 maximum force before rupture, mode of repair failure, stress, and stiffness were also comparable, with  
27  
28 16 no significant differences between groups 1 and 2, or between groups 3 and 4.

29 17 **Conclusions:** The ST-knot shows comparable results to the double-Kessler, regardless of the thread  
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31 18 used. Because it involves fewer steps than conventional techniques, and it is easy to perform, the ST-  
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33 19 knot may offer a therapeutic solution, particularly in complex traumas with multiple tendon injuries.

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42 20  
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44 21 **Keywords:** biomechanical study; *ex vivo*; suture; tendon  
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## 22 **Résumé**

23 **Objectif :** Bien que les sections tendineuses soient des blessures courantes pour le chirurgien de la  
24 main, il n'existe actuellement aucun consensus concernant le choix d'une suture par rapport à une  
25 autre. Des sutures simples et rapides, offrant une résistance suffisante pour permettre la mobilisation,  
26 sont nécessaires. Cette étude compare la force biomécanique ex vivo (force nécessaire pour créer un  
27 espace de 2 mm entre les deux extrémités suturées du tendon) d'une nouvelle suture (nœud ST) à celle  
28 d'une suture conventionnelle (double Kessler).

29 **Matériels et méthodes :** Quarante tendons fléchisseurs profonds frais issus de membres antérieurs de  
30 porcs ont été utilisés. Les deux extrémités du tendon réparé ont été fixées sur des mors de traction  
31 standard d'une machine à traction axiale à une distance initiale de 40 mm pour tous les tendons. Une  
32 caméra haute définition a été utilisée pour déterminer la force nécessaire à la formation d'un espace de  
33 2 mm entre les deux extrémités suturées. Dix tendons du groupe 1 (nœud ST) et dix tendons du groupe  
34 2 (double Kessler) ont été préparés avec du PDS 4.0 (simple pour le Kessler mais boucle pour le nœud  
35 ST). Les tendons des groupes 3 (nœud ST) et 4 (double Kessler) ont été réparés avec du PDS 1.0 selon  
36 le même principe.

37 **Résultats :** Aucune différence significative n'a été observée dans la force nécessaire pour former un  
38 espace de 2 mm dans le tendon entre les groupes 1 et 2, et cette tendance était identique lors de  
39 l'utilisation d'un fil plus résistant dans les groupes 3 et 4. La force maximale avant rupture, le mode de  
40 rupture, la contrainte et la rigidité étaient également comparables, sans différence significative entre  
41 les groupes 1 et 2, ni entre les groupes 3 et 4.

42 **Conclusion :** Le nœud ST montre des résultats biomécaniques comparables au double Kessler,  
43 indépendamment du fil utilisé. Étant donné qu'il nécessite moins d'étapes que les techniques  
44 conventionnelles et qu'il est facile à réaliser, le nœud ST pourrait offrir une solution thérapeutique,  
45 notamment dans les traumatismes complexes avec de multiples lésions tendineuses.

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47 **Mots clefs :** Étude biomécanique, ex-vivo, suture, tendon

48 **Introduction**

1  
2 49 Tendon lacerations represent a common therapeutic challenge for hand surgeons [1]. Good outcomes  
3  
4 50 do not only depend on surgery, but also on early mobilization and physiotherapy [2–4]. To facilitate  
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6 51 early and optimal post-operative physiotherapy, the tendon suture must possess the capacity to endure  
7  
8 52 the stresses of mobilization. At present, a definitive consensus regarding the optimal selection of sutures  
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10 53 for employment in multi-strand repair techniques is lacking, and surgeon preferences frequently rely on  
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12 54 individual experience rather than robust scientific evidence [5]. It is currently understood that numerous  
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14 55 factors have a positive impact on repair strength. These include the quantity of strands traversing the  
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16 56 repair, slight crowding at the repair site, employment of a larger suture gauge, and configuring the  
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18 57 peripheral sutures appropriately [6,7]. In an *ex vivo* study, Savage et al. reported that six-strand repair  
19  
20 58 appears to be three times more potent than conventional two-strand repair (Kessler, Kleinert, Beckert,  
21  
22 59 Bunnel) [3]. Other more recent *ex vivo* studies however, seem to invalidate this theory [8]. Tang et al.  
23  
24 60 subsequently advocated for the adoption of loop sutures, which allows for the creation of two strands  
25  
26 61 per pass. This approach reduces tendon edge damage by minimizing the number of needle passes while  
27  
28 62 maintaining comparable strength to that of conventional sutures [7,9–11].  
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33 63         Nonetheless, no study has conclusively demonstrated the superiority of one 4-strand suture over  
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35 64 another. Some sutures present cumbersome configurations and involve multiple trans-tendinous  
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37 65 passages [12]. In order to aid the hand surgeon in the treatment of tendon injuries, it appears imperative  
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39 66 to employ a suture that is straightforward, swift, employs a single thread, and imparts sufficient strength  
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41 67 to facilitate mobilization. Moreover, in the various comparative studies of new sutures, the Kessler  
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43 68 suture seems to be the most widely used reference suture, with results equal to or better than those of  
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45 69 the new suture knots tested [3,12–17].  
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49 70         The aim of this study was to compare the mechanical properties of two suture techniques: the  
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51 71 four-strand double Kessler and the ST-Knot (which creates an S and a T pattern on the tendon upon  
52  
53 72 completion), a new suture technique. The primary objective was to evaluate the 2 mm gap-forming force  
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55 73 (N). The secondary objectives were to evaluate the maximum force before rupture (N<sub>max</sub>), the mode of  
56  
57 74 repair failure (knot rupture, suture rupture, and suture pull-out), stress (ultimate tensile strength divided  
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59 75 by tendon cross-sectional area, in N/mm<sup>2</sup>), and stiffness (N/mm).  
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76 **Materials and methods**

77 *Surgical technique*

78 The ST-knot begins with the use of a 4/0 diameter looped suture. We prefer to use a polydioxanone  
79 (PDS, Ethicon, Somerville, NJ), suture with a 19 mm needle. The first step consists in docking the  
80 proximal tendon stump using Tsuge and Ikuta's stratagem [18] (**Figure 1A**). This allows the flexor  
81 tendon, which tends to retract naturally, to be held in place, thus bypassing the use of a transtendinous  
82 needle to reduce retraction forces. The suture continues by crossing intratendinously to reach the distal  
83 tendon stump, thus initiating a transverse pass within the tendon (**Figure 1B and 1C**). The same  
84 technique is used on the other side of the tendon. As the tendon is docked to the suture on the proximal  
85 stump, this double anchoring in the distal stump brings the two tendon parts together, thereby reducing  
86 the retraction forces on each tendon. As a result, the proximal stump is less likely to retract, and the two  
87 tendon stumps are closer together (**Figure 1D**). When using an undocked suture, the suture slides  
88 through the tendon, preventing the tendon from being approached. An intratendinous pass is then made  
89 at the proximal stump on the contralateral side, to adjust the tendon suture axially and prevent  
90 intratendinous torsion (**Figure 1E**). Note that this adjustment is simpler if the tendons are closer together  
91 than if they are further apart. A final pass between the two passages secures the suture, forming a knot  
92 without any retraction tension, thus eliminating the necessity for force to bring the two stumps into  
93 proximity (**Figure 1F**). By applying an appropriate tension, this final pass enables the degree of  
94 bunching up to be adjusted by 20 to 30%, as recommended by Tang JB et al. [7]. Following the method  
95 outlined by Tsuge et al. a tension-free knot is made (**Figure 1G**)[18]. This produces a 6-strand  
96 intratendinous suture resembles the M-Tang repair but employs a single thread, with an extra-tendinous  
97 knot. The Kessler knot is executed using a PDS 4/0, a 26 mm needle, two strands, a single extratendinous  
98 knot within the repair site, and four loops (**Figure 2**).

100 *Samples*

101 This study follows the concepts and sample sizes of other published biomechanical studies concerning  
102 *ex vivo* flexor tendon repair techniques [5,19]. Forty fresh deep flexor tendons from porcine forelimbs  
103 were used as experimental models. These tendons are similar in structure and size to the human flexor

104 digitorum profundus, and have been used in numerous studies [5,19–21]. The two deep flexor tendons  
105 from each forelimb were harvested between pulleys A2 and A4. With an average cross-sectional area  
106 of 21 mm<sup>2</sup> and a minimum length of 10 cm, these tendons were suitable for installation in the jaws of a  
107 traction machine. All tendons were measured in width, thickness, and length using a calliper, and cross-  
108 sectional area estimates were calculated using the following formula for the area of an ellipse [(small  
109 diameter (mm)/2)\*(large diameter (mm)/2)\* $\pi$ ]. The tendons were maintained in a frozen state at -20°C  
110 until 24 hours prior to testing. At that point, they were thawed and immersed in saline at -4°C.

### 112 *Repairs and equipment*

113 A 23 blade was used to make a clean cross-section through the middle of each tendon. The 40 tendons  
114 were randomly divided into four groups of 10, repaired, and then tested in axial traction. All tendons  
115 were repaired using PDS, which is a synthetic monofilament absorbable suture material commonly used  
116 for tendon repair. The entry and exit points of the central sutures were located 7 mm from the cut end  
117 of the tendon for all repairs with a 10% shortening to ensure the best tensile strength. This 7 mm distance  
118 was systematically measured using the same metal ruler. This distance was chosen because it has been  
119 shown that, although a distance of 4 mm or less results in significantly weaker repairs, increasing the  
120 suture distance from 7 mm to 10 mm or 12 mm does not increase repair strength [21]. The reference  
121 repair technique chosen for comparison in this study was the double Kessler technique or 4-strand locked  
122 cross repair [22] (**Figure 2**). Groups 1 (ST1) and 3 (ST2) tendons were repaired with an ST-knot, while  
123 groups 2 (K1) and 4 (K2) tendons were repaired using the double Kessler technique. For the central  
124 sutures in groups 1 (ST1) and 2 (K1), a PDS 4.0 was used, including a loop PDS in group 1. Tendons  
125 in groups 3 (ST2) and 4 (K2) were repaired with PDS 1.0. All tendon sutures were reinforced with a  
126 peripheral PDS 5.0 peritendinous suture 2 mm from the transection site. The tendons were repaired by  
127 two qualified surgeons.

### 129 *Biomechanical testing*

130 The tests were carried out using an Instron 5566A axial traction machine (Instron Corp; **Figure 3**). Both  
131 mended tendon ends were affixed to standard traction mounts, with the initial distance uniformly set at



132 40 mm for all tendons. Subsequently, the repaired tendons underwent a tensile strength assessment.  
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2 133 After applying a preload of 1 newton (N), the tendons were drawn at a uniform rate of 10 mm/min. Data  
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4 134 points were captured at a frequency of 10 Hertz. The Bluehill Universal software (Instron Corp) was  
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6 135 employed to generate a force-versus-displacement curve, from which the ultimate tensile strength  
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8 136 (identified as the peak of the curve) was ascertained (**Figure 4**). Stiffness was calculated as the slope of  
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10 137 the initial linear section of the curve. A ruler was attached to the upper clamp next to the tendon, and  
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12 138 the test was monitored using a high-definition camera to determine the force forming a 2 mm gap  
13  
14 139 (**Figure 3**). The 2 mm benchmark was considered to have been reached as soon as a 2 mm gap had  
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16 140 formed over part of the repair site. The mode of failure was determined by visual examination of the  
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18 141 tendons by the surgeon, during and after the test.  
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#### 24 143 *Statistical methods*

26 144 A Shapiro-Wilk test was used to ensure that tendon cross-sections were normally distributed. The non-  
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28 145 parametric Mann-Whitney test was used to compare numerical results (mechanical test results and cross-  
29  
30 146 sectional areas) between all groups.  
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#### 35 148 **Results**

37 149 Regarding the primary endpoint, there was no significant difference in the occurrence of a tendon gap  
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39 150 at 2 mm between groups 1 and 2 (23.7N [17.5; 29.8] vs 24.2N [17.45; 30.9]; 95% CI) and this trend was  
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41 151 identical with the use of a stronger thread (groups 3 and 4) (55N [30.2; 79.8] vs 45.6N [30.8; 60.4]; 95%  
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43 152 CI). Other results (maximum force before rupture, mode of repair failure, stress and stiffness) were  
44  
45 153 comparable between groups 1 and 2, and between groups 3 and 4 (**Tables 1, 2, and 3**).  
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49 154 Regarding the mode of repair failure, 7 suture ruptures, 2 knot ruptures, and 1 suture pull-out  
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51 155 were observed in group 1 (ST1) while 7 suture ruptures and 3 suture pull-outs were observed in group  
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53 156 3 (ST2). The mode of repair failure in group 2 (K1) and 4 (K2) were almost exclusively due to suture  
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55 157 rupture, except for 1 suture pull-out which occurred in group 4 (**Table 1**).  
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#### 60 159 **Discussion**

160 At present, although some recommendations were made over 30 years ago, there exists no unanimous  
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2 161 consensus regarding the treatment of flexor tendon injuries [23]. There appears to be a dispute  
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4 162 concerning the necessity of employing multiple intratendinous strands [3,8,10]. The present results  
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6 163 indicate that the number of passes does not appear to exert a notable influence on the maximum load or  
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8 164 the load required to induce a 2-mm gap. The findings herein are in line with previously published studies  
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10 demonstrating similar load levels [12,13,15,24,25]. Schädel-Höpfner et al. reported that the Kessler has  
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12 by far the best ultimate tensile strength when compared with 4 other sutures, likely explaining why this  
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14 knot is frequently found in comparative studies [13]. In 1999, McLarney demonstrated through a  
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16 biomechanical study that the cruciate four-strand flexor tendon repair exhibited a high failure load,  
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18 nearly double that of the Kessler knot [26]. However, no other biomechanical study of this knot without  
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20 a cross-lock was found in the literature. While forces up to 2.9N (2N [min; 0- max; 2.9]) might be  
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22 expected during unresisted active flexion of the wrist and up to 28.4N (18.6N [min; 1-max; 28.4]) during  
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24 unresisted active flexion of the long fingers, the ST-knot was consistent with these results showing a  
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26 mean resistance of 26N, a lower limit of 17.2N, and an upper limit of 34.9N when using PDS 4.0 [27].  
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28 The referenced study reported results in kilogram force (kgf), where 0.1 kgf corresponds to 1N. At  
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30 present, there is a wide disparity in the choice of suture between different centres and no single suture  
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32 appears to offer any real superiority [5,28,29]. In the management of flexor tendon injuries, it would  
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34 seem worthwhile to take a step back from the type of suture used and focus more on the practical and  
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36 technical use of these sutures. In the present study, the ST-knot yielded comparable results to the double-  
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38 Kessler technique, with no notable superiority observed for either method. The equivalence remains  
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40 unchanged with the use of a thicker suture.  
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46 181 According to various literature reviews and expert opinions, the key to successful tendon  
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48 suturing seems to be based not on the type of suture but on other multiple local factors such as pulley  
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50 preservation, adjusted tension between the two stumps, careful and limited soft tissue dissection  
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52 [6,28,29]. The ST-knot then takes its place as a practical addition to the suture. The tendon docking at  
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54 the very beginning of the suture enables the proximal stump to be mobilized solely by traction on the  
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56 suture thread as the M-Tang or Lim-Tsai suture when starting with the backwall of the running suture.  
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58 In addition, by bringing the two stumps together at an early stage and applying a slight tension at rest  
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188 between the two stumps, the use of tendon-damaging forceps is reduced, allowing intrinsic tendon  
189 structures to be protected as much as possible. This is not possible when using the Kessler suture, as the  
190 thread slips through the tendon if it is pulled along its axis. Moreover, the closing forces of the two  
191 stumps are applied during the locking of the knot in a Kessler-type suture. In this situation, there is a  
192 risk of suture rupture, due to the combination of the tension applied to lock the knot and the tension  
193 needed to bring the two tendon stumps together. However, when the ST-Knot is performed, the two  
194 tendon stumps are already brought together, reducing the shearing forces involved in locking the knot.  
195 In addition, a double Kessler suture requires 12 different intratendinous passages, compared with 7 for  
196 the ST-Knot. This is particularly important in the case of multiple tissue and tendon injuries, where  
197 tendon repair time is paramount. Moreover, compared to other 6-strand sutures, the ST-knot enables a  
198 6-strand suture to be produced using a single thread [11,30,31]. The strength of a suture must be  
199 considered not only in terms of continuous axial traction, but also in terms of cyclic loading. Whether  
200 the suture is 6- or 4-strand, previous studies showed that the transverse components of the suture are a  
201 detrimental factor in the development of a tendon gap, however this aspect was not found in our study,  
202 as the ST-knot has only one transverse component whereas the double Kessler has 4 transverse  
203 components [32,33]. In our opinion, the ST-knot is not a stronger suture than the classic double Kessler,  
204 but it does offer the surgeon greater comfort in suturing tendon injuries.

205 One criticism that can be made about the ST-knot is that the 6-strand tensions are neutralized  
206 by a single knot. A recent study however, showed that the presence of 1 or 2 knots has no impact on the  
207 functional outcome [34]. Furthermore, the presence of an extratendinous knot does not appear to have  
208 a negative biomechanical impact compared with that of an intratendinous knot [11,35]. Indeed, Chang  
209 et al. showed that the Lim/Tsai repair with extra-tendinous knot had a statistically significantly higher  
210 ultimate strength and load to 2 mm gap force, as compared with the repair with intra-tendinous knot  
211 [18,34,36]. However, suture knot location could affect glide especially in the digital canal. Noguchi et  
212 al. showed in a *in vivo* study that the Tajima repair, whose knot is internal, exhibits significantly lower  
213 gliding resistance than the modified Kessler which is identical except for an externally placed knot [37].  
214 The contrary argument is that knot placement between the cuts could reduce the tendon end contact  
215 surface area that is involved in healing [38].

216            Nonetheless, the present study is subject to several limitations, one of which is the exclusive  
1 performance of in-axis traction. Novel modes of suture failure have indeed been shown when using  
2 217  
3 cyclic load tests [32,33]. As the ST-Knot has a transverse component, it would be interesting to explore  
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5 this weakness. In addition, although a total of 40 sutures were performed, each group contained only 10  
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7 sutures. Although this sample size is found in many comparative studies it may nevertheless represent  
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9 a potential limitation [13,25,32,33]. The failure loads observed in our study are relatively low for both  
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11 repairs (around 25 N) when using a 4.0 suture. The authors propose that a slightly lower strength is  
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13 observed, which may be attributed to the use of frozen tendons and the associated protocol,  
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15 distinguishing it from clinical findings. Furthermore, we claim that the ST-Knot appears to be easier  
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17 than a double Kessler suture, but unfortunately, we did not measure suture completion time, which could  
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19 be an interesting indicative marker to assert this ease. The completion time for an ST-knot should be  
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21 assessed on a cadaver finger, considering that one of the key features of this knot is the docking system.  
22 227  
23 In any case, suturing two tendon stumps ex-vivo does not appear to be representative of a real-life tendon  
24 228  
25 suturing clinical context. Moreover, other references than the Kessler knot could have been used in this  
26 229  
27 study. On the one hand, our choice to use the Kessler knot as a reference aligns with its widespread  
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29 utilization in recent biomechanical literature [14,19,24,39]. On the other hand, a comparative analysis  
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31 between the ST-knot and the cruciate four-strand flexor tendon repair would be of significant interest.  
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#### 40 234 **Conclusion:**

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42 235    The ST-knot seems to be a viable and secure suture, with biomechanical capacities that are comparable  
43 236  
44 to conventional sutures. Due to its fewer procedural steps and ease of execution compared to  
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46 conventional techniques, the ST-knot could provide a therapeutic option, especially in intricate traumas  
47 238  
48 involving multiple tendon injuries. To validate these hypotheses, *in vivo* studies are needed.  
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#### 51 239 52 240 **Disclosure of interest**

53 241    The authors declare that they have no known competing financial or personal relationships that could  
54 242  
55 be viewed as influencing the work reported in this paper.  
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356 **Figures legends**

1 357 **Figure 1: Illustration of the various stages of an ST-Knot.**

2  
3 358 *A/ Docking of proximal tendon stump to PDS loop. B/ Intratendinous passage through proximal*  
4  
5 359 *stump, then lateral suture exit. C/ Transtendinous passage. D/ Intratendinous passage again. E/*  
6 360 *Passage back into the proximal tendon stump. F/ Extratendinous passage in the distal stump,*  
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8 361 *returning to the proximal stump via an intratendinous passage. G/ Knot lock*

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10 362  
11 363 **Figure 2: Illustration of the 4-strand Kessler repair used in this study.**

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15 365 **Figure 3: Installing the tendon in the Instron 5566A machine.**

16 366 *A/ Installation of tendon and camera*  
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18 367 *B/ Occurrence of peritendinous suture rupture after axial traction*

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20 368  
21 369 **Figure 4: Biomechanical test: displacement curve (mm) as a function of load (N).**

22  
23 370 *ST-knot load-displacement graph with 10mm/min traction generated by Bluehill Universal software. A*  
24  
25 371 *deviation of 2mm generally occurred before rupture of the peritendinous suture.*



372 **Table 1. Biomechanical results according to the 4 different suture groups**

	<b>ST1 (n=10)</b>	<b>K1 (n=10)</b>	<b>ST2 (n=10)</b>	<b>K2 (n=10)</b>
<b>Force (N)- 2mm gap, mean [95% CI]</b>	<b>23.7</b> [17.5 ; 29.8]	<b>24.2</b> [17.45 ; 30.9]	<b>55</b> [30.2 ; 79.8]	<b>45.6</b> [30.8 ; 60.4]
<b>Force (N) Max, mean [95% CI]</b>	<b>26</b> [17.2 ; 34.9]	<b>29.8</b> [19.7 ; 39.9]	<b>68</b> [35.6 ; 100.4]	<b>60.7</b> [40.5 ; 80.9]
<b>Stress (N/mm<sup>2</sup>), mean [95% CI]</b>	<b>1.3</b> [0.8 ; 1.8]	<b>1.5</b> [0.9 ; 2]	<b>2.9</b> [1.6 ; 4.2]	<b>3</b> [1.7 ; 4.3]
<b>Stiffness (N/mm), mean [95% CI]</b>	<b>4.2</b> [2.4 ; 6]	<b>3.8</b> [2.5 ; 5.2]	<b>4.8</b> [3.2 ; 6.5]	<b>5.1</b> [3.2 ; 7]
<b>Failure mode (n=40)</b>	<b>10</b>	<b>10</b>	<b>10</b>	<b>10</b>
<b>Suture rupture (n=33)</b>	<b>7</b>	<b>10</b>	<b>7</b>	<b>9</b>
<b>Knot rupture (n=2)</b>	<b>2</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Suture pull-out (n=5)</b>	<b>1</b>	<b>0</b>	<b>3</b>	<b>1</b>

374  
 375 *Abbreviations: CI, Confidence interval; Max: maximum; N, Newton*

376 **Table 2. Statistical analysis for the comparison of biomechanical results from sutured tendons in**  
 377 **groups 1 and 2.**

	<b>ST1 (n=10) (Group 1)</b>	<b>K1 (n=10) (Group 2)</b>	<b>p-value</b>
<b>Force (N)- 2mm gap, mean [95% CI]</b>	<b>23.7 [17.5 ; 29.8]</b>	<b>24.2 [17.5 ; 30.9]</b>	<b>0.94</b>
<b>Force (N) Max, mean [95% CI]</b>	<b>26 [17.2 ; 34.9]</b>	<b>29.8 [19.7 ; 39.9]</b>	<b>0.57</b>
<b>Stress (N/mm<sup>2</sup>), mean [95% CI]</b>	<b>1.3 [0.8 ; 1.8]</b>	<b>1.5 [0.9 ; 2]</b>	<b>0.97</b>
<b>Stiffness (N/mm), mean [95% CI]</b>	<b>4.2 [2.4 ; 6]</b>	<b>3.8 [2.5 ; 5.2]</b>	<b>0.73</b>

378

379 *Abbreviations: CI, Confidence interval; Max: maximum; N, Newton*

380 **Table 3. Statistical analysis for the comparison of biomechanical results from sutured tendons in**  
 381 **groups 3 and 4.**

	<b>ST2 (n=10) (Group 3)</b>	<b>K2 (n=10) (Group 4)</b>	<b>p-value</b>
<b>Force (N)- 2mm gap, mean [95% CI]</b>	55 [30.2 ; 79.8]	<b>45.6</b> [30.8 ; 60.4]	<b>0.76</b>
<b>Force (N) Max, mean [95% CI]</b>	<b>68</b> [35.6 ; 100.4]	<b>60.7</b> [40.5 ; 80.9]	<b>0.97</b>
<b>Stress (N/mm<sup>2</sup>), mean [95% CI]</b>	<b>2.9</b> [1.6 ; 4.2]	<b>3</b> [1.7 ; 4.3]	<b>0.97</b>
<b>Stiffness (N/mm), mean [95% CI]</b>	<b>4.8</b> [3.2 ; 6.5]	<b>5.1</b> [3.2 ; 7]	<b>0.68</b>

382  
 383 *Abbreviations: CI, Confidence interval; Max, maximum; N, Newton*

POINT BY POINT RESPONSE TO REVIEWERS:

Dear Dr Dreant,

Thank you very much for sending us the reviewers' comments on the manuscript entitled "**Biomechanical evaluation of the ST-knot: a new suture for flexor tendon repair**". We would like to thank you for your interest in our work and for your contribution as experts in improving the quality of this submission.

We believe we have followed your advice and guidelines and addressed all comments the editor-in-chief had with our revised manuscript. The manuscript has been corrected in the text. We hope that you will judge the manuscript suitably revised for publication in *Hand Surgery and Rehabilitation* and remain at your disposal if necessary.

Submission:

Journal: *Hand Surgery and Rehabilitation*

Manuscript : HANSUR-D-23-00396

Type: Original article

## **Reviewer 1**

1) Chers auteurs,

merci pour les corrections apportées à votre manuscrit.

Il reste encore quelques points avant de publier votre article.

Tout d'abord pourquoi ST knot? Le lecteur sera curieux de savoir à quoi correspondent ces deux lettres. Merci de le préciser dès la première apparition de ce terme dans votre manuscrit (pas dans le résumé ni dans le titre)

*Auteurs : Le fil forme un S et un T sur le tendon lors de la réalisation du ST-knot, c'est pour cela que nous l'avons appelé de la sorte. Nous rajoutons la phrase suivante en accord avec votre commentaire page 3, ligne 71: (which creates an S and a T pattern on the tendon upon completion)*

2) Merci d'écrire "et al." normalement, et non en italique.

*Auteurs: La mise en forme de « et al. » a été corrigée dans l'ensemble du manuscrit.*

3) La référence [1] fait allusion aux propriétés mécaniques du ligament scapho-lunaire. La référence [2] est par contre appropriée. Merci de supprimer la ref [1] qui vient mal à propos, surtout au tout début d'un article sur les tendons.

*Auteurs : La référence [1] erronée a été supprimée.*

4) Veuillez ré-écrire la bibliographie en faisant bien attention aux noms des revues.

Par exemple, dans la référence [2] le nom de la revue n'est pas "The journal of hand surgery" mais "J Hand Surg Am" comme il est écrit dans la base pubmed.

*Auteurs : Nous avons vérifié et modifié l'ensemble des références erronées selon leur référencement pubmed.*

5) Enfin, renvoyez seulement le manuscrit propre, sans corrections visibles.

*Auteurs : Nous vous renvoyons uniquement le manuscrit corrigé.*

Camille Brenac, MD

Service de Chirurgie Plastique, Esthétique et Réparatrice

Hospices Civils Lyon, Hôpital Croix Rousse

E-mail : [camille.brenac@chu-lyon.fr](mailto:camille.brenac@chu-lyon.fr)

Dear Sir Dreant,

Editor-in-Chief

We would like to submit our manuscript entitled “Biomechanical evaluation of the ST-knot: a new suture for flexor tendon repair” for publication as an original article in *The Journal of Hand Surgery and Rehabilitation*

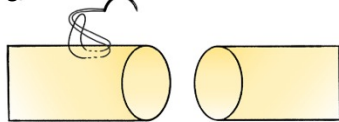
We believe that the teaching point of this article would be of great interest to the readers of *Journal of Hand Surgery and Rehabilitation*, as, in aiding the hand surgeon in the treatment of tendon lacerations, it appears imperative to employ a suture that is straightforward, swift, employs a single strand, and imparts sufficient strength to facilitate mobilization. In this biomechanical study, we demonstrate that ST-knots yield similar results in terms of resistance strength to double-Kessler sutures, irrespective of the thread size employed. Consequently, it emerges as a viable alternative for tendon repair.

All the authors have read the paper and agree with the content. No authors have conflicting interests. Neither the work nor any part of its essential substance, tables or figures have been, or will be, published or submitted to another scientific journal or are being considered for publication elsewhere. We are looking forward to reading your comments. Please feel free to contact me for any further questions.

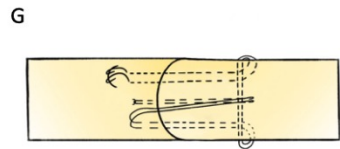
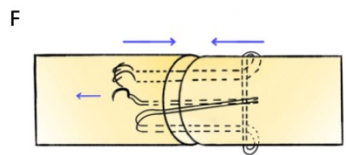
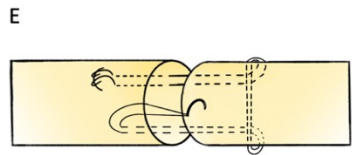
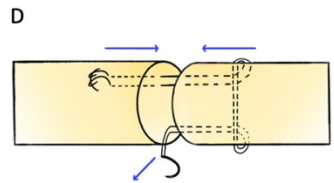
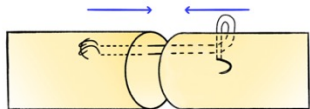
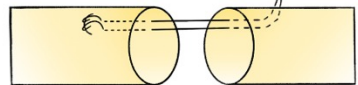
Yours sincerely,

Camille Brenac on behalf of all authors

Figure 1 PDF



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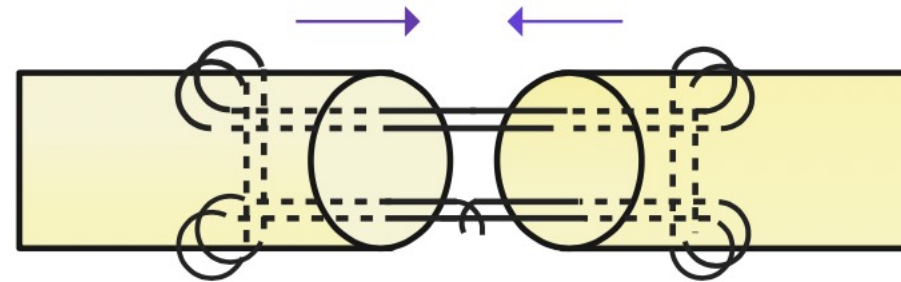


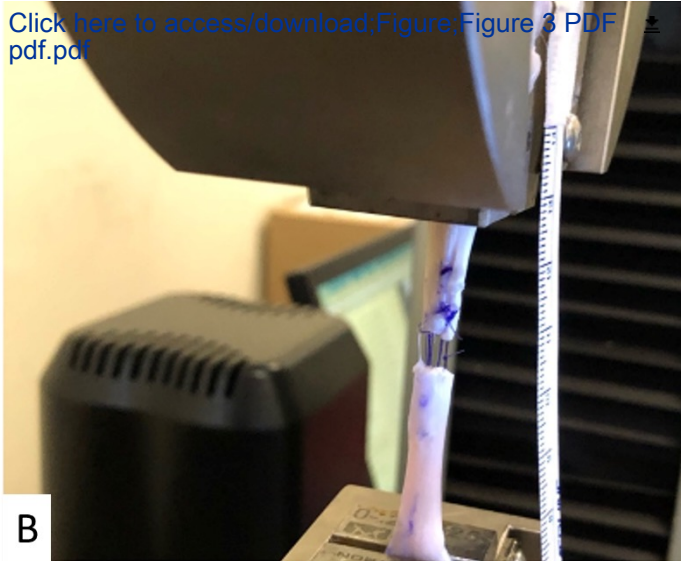


Figure 3



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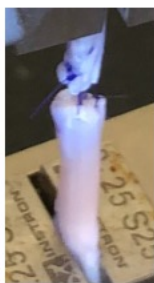
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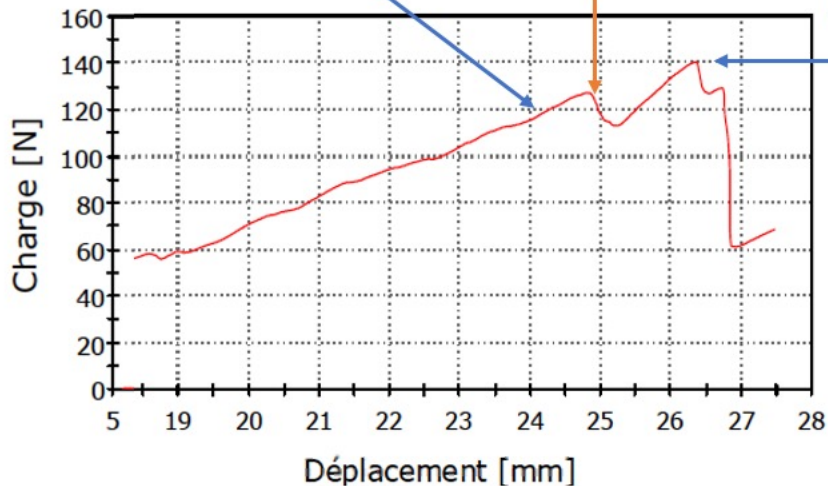
Figure 4

2 mm gap



Rupture of the peripheral suture

Suture breakage



## Author responsibilities, integrity, ethics



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