The Nice knot as an improvement on current knot options: A mechanical analysis

P. Collin\textsuperscript{a}, E. Laubster\textsuperscript{a}, P.J. Denard\textsuperscript{b,c}, F.A. Aku\textsuperscript{a}, A. Lädermann\textsuperscript{d,e,f,*}

\textsuperscript{a} Saint-Grégoire Private Hospital Center, boulevard Bouteille 6, 35768 Saint-Grégoire cedex, France
\textsuperscript{b} Southern Oregon Orthopedics, Medford, Oregon, USA
\textsuperscript{c} Department of Orthopaedics and Rehabilitation, Oregon Health & Science University, Portland, Oregon, USA
\textsuperscript{d} Division of Orthopaedics and Trauma Surgery, La Tour Hospital, rue J.-D.-Maillard 3, 1217 Meyrin, Switzerland
\textsuperscript{e} Faculty of Medicine, University of Geneva, rue Michel-Serret 1, 1211 Geneva 4, Switzerland
\textsuperscript{f} Division of Orthopaedics and Trauma Surgery, Department of Surgery, Geneva University Hospitals, rue Gabrielle-Perret-Gentil 4, 1211 Geneva 14, Switzerland

A R T I C L E   I N F O

Article history:
Received 13 March 2015
Accepted 12 January 2016

Keywords:
Shoulder surgery
Rotator cuff repair
Nicky’s knot
Suture
Ethibond®
Ultrabraid
Mechanical testing
Biomechanical study
Arthroscopy

A B S T R A C T

Purpose: There is currently a wide range of suture knots used in rotator cuff repair. The purpose of this study was to compare a new type of self-locking sliding knot called the Nice knot to the self-locking and sliding Nicky’s knot.

Methods: Nice knots and Nicky’s knots were tied and subjected to mechanical testing including a pure traction stress and a series of dynamic stresses. Both knots were tied using standard braided suture and reinforced braided suture. The responses to these stresses were measured in the amount of elongation of the knot, maximum effort needed for failure, stiffness of construct and dynamic stiffness.

Results: With both knots the standard suture had a lower amount of elongation during the dynamic tests than the reinforced braided suture. The reinforced braided suture showed superior results during maximal effort in the pure traction tests. An increased failure rate occurred due to elongation when a dynamic stress was applied to the reinforced suture in both knot types. During dynamic testing the Nice knot showed a decrease in the amount of elongation (P<0.0001).

Conclusions: The Nice knot provides a sliding locking knot option which can decrease the risk of elongation during dynamic stress.

Level of evidence: Basic Science Study, Biomechanical Study.

© 2016 Elsevier Masson SAS. All rights reserved.

1. Introduction

The resistance of a knot to fail depends on several criteria including the behavior of the knot itself\textsuperscript{[1,2]} and suture material\textsuperscript{[3]}. With the advent of high strength polyblend sutures, the weak link in knot biomechanics appears to the knot itself.

The purpose of this study was to test a new type of sliding and self-locking knot called the Nice knot\textsuperscript{[4]} by comparing it to the Nicky’s knot\textsuperscript{[5]}. We hypothesized that the Nice knot is mechanically superior knot to the Nicky’s knot in preventing knot slippage and, therefore, failure of knot construct.

2. Materials and methods

This was an in vitro mechanical study. Two types of sliding and self-locking knots were tested: (1) the Nicky’s knot\textsuperscript{[5]} (Fig. 1), and (2) the Nice knot\textsuperscript{[4]} (Figs. 2 and 3). The Nice knot consists of two loops; therefore, to allow a reliable comparison, it was compared to a set of two stacked Nicky’s knots. All knots were performed by the same surgeon (PC) on a 30 mm diameter cylinder without the use of a knot pusher or a cannula, to avoid any friction and subsequent risk of deterioration. Both knots were tied with a so-called standard braided suture (U² Ethibond\textsuperscript{®} from Ethicon, Somerville, NJ), and a high strength polyblend suture (Ultrabraid\textsuperscript{®} from Smith and Nephew, Memphis, TN). All knots were cut to leave a 3– to 5-mm tag. Each knot and suture type test combination was conducted ten times with two types of experiments: a pure static traction and a dynamic study. In the former, the following parameters were recorded with a machine (Lloyd LR 30K, Segensworth, Frameham, England) as results for this manipulation.
2.1. Preload

A 5-N preload was selected to remove slack from the system at a load well below those seen clinically in the shoulder.

2.2. Load to failure

Elongation was defined as stretching that occurred during knot testing. Previous studies have indicated that 3 mm is the point where tissue apposition is lost [6–10]. Any traction curvature consists of a non-linear charging period for weak loads, followed by a linear part representing the purely elastic domain of the suture/knot combination being tested. Elongation was measured beginning at the end of the non-linear period in order to evaluate the elastic period. The maximum value of movement in mm was recorded at maximum effort. Second, the maximum effort before failure was defined as highest value on the vertical axis before rupture or slippage occurred. Third, stiffness, defined by the force divided by the amount of elongation in mm of the construct was studied. Stiffness calculations of the construct do not accurately reflect changes in the knot construct during its entire loading period. We, therefore, calculated a dynamic stiffness by integrating the curve force, defined as the force squared in Newton divided by the displacement in mm. This was achieved by squaring the ratio of the curve force and dividing it by the amount of elongation.

2.3. Cyclic loading

According to dynamic study, two sets of monotonically increasing peak load levels [11], were performed depending on the number of loops. For constructs using a single loop, the plateaus consisted of 50 cycles at 50 Newton, followed by 50 cycles at 100 Newton, another 50 cycles at 150 Newton, 50 cycles at 200 Newton, 50 cycles at 250 Newton and then finally a 100 cycles at 300 Newton. For constructs with a double loop, the plateaus were doubled (Newton value). Stresses applied during this part of the study were intended to simulate the stresses that the knot construct will experience during the post-repair rehabilitation period. Only elongation and stiffness of the construct were recorded during these dynamic tests.

2.4. Statistical analysis

Continuous data were described by mean, standard deviation, and range. The data was collected from results generated by the testing unit. Analysis of the amount of elongation, force and stiffness was performed. Differences between these measurements were tested using two-way Anova model followed by Fisher’s test. Statistical analysis was performed using StatView® for MacOX (Informer Technologies Inc., Redwood City, CA, USA). Data was expressed as mean ± standard deviation. $P<0.05$ indicated a significant difference.

3. Results

3.1. Load to failure

The results in pure static traction are summarized in Tables 1 and 2. When tied with Ethibond® the Nice knot tied had
Table 1 Comparison of two knots in pure static traction with a standard braided suture (Ethibond®).

<table>
<thead>
<tr>
<th></th>
<th>Nice knot</th>
<th>Nicky’s knot</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elongation (mm ± SD)</td>
<td>6.86 ± 0.55</td>
<td>7.36 ± 0.73</td>
<td>0.1027</td>
</tr>
<tr>
<td>Max effort (mm ± SD)</td>
<td>335.75 ± 22.25</td>
<td>334.80 ± 20.02</td>
<td>0.9200</td>
</tr>
<tr>
<td>Stiffness (F/mm ± SD)</td>
<td>49.18 ± 4.34</td>
<td>45.05 ± 2.48</td>
<td>0.0334</td>
</tr>
<tr>
<td>Dynamic stiffness (F2/mm ± SD)</td>
<td>97.91 ± 11.1</td>
<td>87.58 ± 6.06</td>
<td>0.0182</td>
</tr>
</tbody>
</table>

Table 2 Comparison of two knots in pure static traction with a reinforced braided suture (Ultrabraid®).

<table>
<thead>
<tr>
<th></th>
<th>Nice knot</th>
<th>Nicky’s knot</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean elongation in mm ± SD</td>
<td>6.63 ± 0.65</td>
<td>7.82 ± 3.08</td>
<td>0.8240</td>
</tr>
<tr>
<td>Max effort in mm ± SD</td>
<td>527.01 ± 50.03</td>
<td>522.84 ± 46.07</td>
<td>0.8280</td>
</tr>
<tr>
<td>Stiffness in N/mm ± SD</td>
<td>77.38 ± 21.20</td>
<td>80.71 ± 15.66</td>
<td>0.4160</td>
</tr>
<tr>
<td>Dynamic stiffness in F2/mm ± SD</td>
<td>225.36 ± 49.12</td>
<td>191.02 ± 59.21</td>
<td>0.0783</td>
</tr>
</tbody>
</table>

Table 3 Comparison of two knots in dynamic tests with a standard braided suture (Ethibond®).

<table>
<thead>
<tr>
<th></th>
<th>Nice knot</th>
<th>Nicky’s knot</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elongation (mm ± SD)</td>
<td>6.57 ± 0.27</td>
<td>7.53 ± 0.52</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Stiffness (N/mm ± SD)</td>
<td>45.69 ± 1.92</td>
<td>39.88 ± 2.65</td>
<td>0.0468</td>
</tr>
</tbody>
</table>

significantly higher stiffness and the dynamic stiffness measurements. However, there was no significant difference between both knot types performed with Ultrabraid®.

3.2. Cyclic Loading

The results of the dynamic study are summarized in Tables 3 and 4. With both Ethibond® and Ultrabraid® sutures the

Table 4 Comparison of two knots in dynamic tests with a reinforced braided suture (Ultrabraid®).

<table>
<thead>
<tr>
<th></th>
<th>Nice knot</th>
<th>Nicky’s knot</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elongation (mm ± SD)</td>
<td>8.52 ± 0.88</td>
<td>12.32 ± 1.12</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Stiffness (N/mm ± SD)</td>
<td>72.33 ± 9.22</td>
<td>57.05 ± 7.57</td>
<td>&lt;0.005</td>
</tr>
</tbody>
</table>

Nicky’s knot was significantly stiffer and had less elongation than the Nicky’s knot.

4. Discussion

The quality and resilience of a rotator cuff tendon repair depends on (1) bone quality [12,13], (2) tendon quality [14], (3) contact surface [15,16], (4) anchor [17], (5) suture type [3,18], and (6) knot type [3]. The failure of any of these elements can be a limiting factor in the overall construct. Two of the five elements (suture type and knot type) interact strongly together [3]. Lo et al. have shown that the resistance of a knot varies as a function of the type of suture (standard or reinforced) used [3]. Their study pointed to the absolute necessity of using three half-hitches after tying a sliding self-locking knot, and that utilizing a braided suture increased the risk of sliding. As a result, they concluded that it is necessary to increase the performance of the knot. Literature has suggested that it is imperative to add three half-hitches when utilizing a sliding knot [3,19]. The authors of the present study, therefore, became interested in testing a new self-locking knot, called the Nicky knot.

The stiffer a suture is, the less it will tend to move at the same loading level. Stiffness alone, however, appeared to be insufficient to adequately compare the knot constructs. We found that stiffness was very similar during the initial stages of testing. This phenomenon was due to the fact that average stiffness in between the starting point and the point where the two curves (A, high strength and B, standard) intersect each other were the same. The gradient of the A and B curves were, however, completely different. The A curve showed a strong initial stiffness but sliding occurred at high force values, whereas the B curve showed mild stiffness at a low load but the stiffness increased significantly as the load increased. Because of the relative similarities in average stiffness values, but with significant differences at the initial stages of the test, we decided to introduce the concept of dynamic stiffness. We also believe that the values from this calculation describe the knot’s response during the initial stages of stress loading more accurately.

Our results are similar to that of Lo et al. [3] for standard braided sutures (such as Ethibond®), which concluded that the total length of the loop becomes elongated without modification of the knot until the point of rupture [3,6,20]. Lo et al. consider failure to be above 3 mm per suture (6 mm total) [3]. We believe that the total length of the loop is much smaller in vivo, and that the value threshold to determine failure should be reconsidered.

During the static study the Nicky knot yielded better results for stiffness and dynamic stiffness compared to Nicky’s knot when Ethibond® was used. However, current data supports the use of high strength polyblend sutures [21]. We agree with this data as we also calculated significantly better results for all criteria, except elongation. This applied for both knot types. The dynamic study, however, introduced a new sliding phenomenon that did not occur in the static study. The combination of Ultrabraid® and the Nicky’s knot showed an increased failure rate due to elongation of the construct. This, however, did not occur when standard suture was used. This confirms the postulate that one cannot use the resistance of the suture as a sole criterion, and that it is the global resistance of the knot constructs that is of importance in knot security. This sliding phenomenon does not disappear simply by using a Nicky knot, but it can be decreased as indicated in the results. There was no dynamic component to the study by Lo et al. [3]. It seemed of interest to us to utilize repetitive cycles with higher and higher resistance plateaus in order to obtain measurements that would more closely mimic the post-operative reality. Indeed, the traction exercised on a tendon is not linear, but rather a succession of repetitive stresses during passive mobilization post-operatively.
The present study has shown that there is a “setting in” phenomenon during which all construct types lose their efficiency. While not escaping this phenomenon, the use of a Nice knot does limit the amount of elongation during the initial stages of stress.

The clinical outcome is highly dependent on a number of factors, among them the knot construct and its response to load stresses. In open surgery the gold standard remains the modified knot of Mason and Allen [22]. However, more and more rotator cuff repairs are currently performed arthroscopically [23–27]. The Nice knot, used in open or arthroscopic surgery [with an anchor (Fig. 2), during side-to-side (Fig. 3) or transosseous repair with an Arthrotunnel® (Tornier, Montbonnot, France)] could decrease the amount of knot elongation during dynamic stresses and therefore improve knot security during the rehabilitation period and tendon healing.

4.1. Strengths and limitations

To the best of our knowledge, this is the first study that compares the Nice knot to the Nicky's knot. Moreover, the concept of dynamic stiffness has never been used in a study of this nature. There is an increased rate of construct failure due to elongation when using reinforced braided sutures especially during the dynamic testing, which corresponds to the rehabilitation period. We believe that the values from this calculation describe the knot's response during the initial stages of stress loading more accurately.

Several important limitations of the current study should be recognized. We only compared the Nice knot to one sliding locking know. However, a previous study compared sliding locking knots including the Weston, Duncan, and Nicky's knot and found no significant differences [28]. Moreover, in vitro realization of the knots cannot accurately indicate the knot construct's response to biomechanical load stresses. In vivo loads are applied to constructs that include bone, anchor, suture, knot, and soft tissue. As a result, failure may occur at any of these locations. Isolating the suture and the knots offers an explanation for failure but may not be the reason for failure in physiologic repairs. In addition, although the Nice knot may improve the responds to dynamic stresses by in fact increasing its stiffness and therefore improving its knot security, the present study did not evaluate the clinical utility or outcome using this technique.

5. Conclusions

The Nice knot provides a new knotting option as it can decrease the risk of elongation during dynamic stress.

Disclosure of interest

One author of this study (PC) is a paid consultant from Tornier and Smith and Nephew and received royalties from Tornier, Storz and Advanced Medical Application. Dr P.J. Denard is a paid consultant for Arthrex. There were no outside funding or grants received that assisted in this study.

References