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How to Tie Dangerous Surgical Knots and avoid this with Robotics and Automation in Surgery?

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Description

We recently submitted an article “How to tie dangerous surgical knots-easily: Can we avoid this” [1]. Though the title sounded somewhat dramatic, we believe it reflects an uncomfortable truth. Inherently, surgeons tend to believe that the knots they form during surgical procedures are secure, whether tied by hand, instrument, or with robotic assistance, and we might assume that this should be relatively simple to achieve. However, access to some body cavities, and location where a suture or ligature is laid, may make it difficult to form a flat reef knot, or other knot, to secure the intended anastomosis or control of a blood vessel.

Our initial study demonstrated that it was disturbingly easy to form an insecure knot with the types of suture material in common use today. All knots formed when our participants failed to cross their hands appropriately, and all knots formed by participants mimicking a situation of tying a knot at depth in a body cavity, holding the suture material under tension whilst forming each layer, slipped on subsequent testing, and slipped significantly. Our test bed required each participant to tie two metal rings together securely, with each of four suture materials, 2/0 polyglactin 910 (vicryl), 3/0 Polydioxanone (PDS), 4/0 poliglecaprone 25 (monocryl) and 1 nylon (Ethilon), and the security of each knot was tested by distracting the rings apart [2]. Three outcomes were observed; knots could break without any slippage, they could slip to some degree and then break, or they could slip completely without fracture of the suture material. The degree of slippage, if any, was assessed by measuring how much extra suture material would appear within the loop holding the two metal rings. Three knot techniques were used, a flat reef knot technique, and the two techniques above. The mean amount of slippage observed with knots tied when the operator deliberately failed to cross their hands appropriately, was 113% (95% CI 94.3%-131.0%), that observed with knots tied under continual tension was 312% (95%CI 280.0%-344.0%). In contrast, only 20% of knots tied with a flat reef knot technique, forming each layer of the knot with equal amounts of both suture ends, and without undue tension on one end, slipped to any degree, and the mean degree of slip was 6.3% (95% CI 2.2-10.4%) (Table 1).

The mean lengths of suture material incorporated into knots, the length of material in the loop tied around the hooks, held by the knot, were measured for each knot type. The average lengths of suture material included in the loop for knots tied under tension (TK mean 17.0 mm 95% CI 16.3 mm-17.7 mm) and those tied without the operator crossing their hands (NHCK mean 16.3 mm 95%CI 15.9 mm -16.7 mm) were significantly lower than that for Flat Reef Knots (FRK mean 25.1 mm 95% CI 24.2 mm-26.0 mm). This would suggest that that the first two types of knot may tighten more than anticipated, once they are initially formed, in comparison to flat reef knots, and this further tightening may potentially produce undue tissue tension, which may affect tissue viability and healing (Table 2).

Method of formation of square reef knot	Total number of knots formed	Mean length of suture material incorporated into loop held by knot mm	95% lower CI of mean	95% upper CI of mean
Flat Reef knot (FRK)	120	25.1	24.2	26
No Hand Crossing Knot (NCHK)	120	16.3	15.9	16.7
Knot tied under tension (TK)	120	17	16.3	17.7

Table 2. Mean lengths of suture material incorporated into loop holding hooks in test bed, for each type of knot method.

We would suggest the failures observed with two of the knot tying methods in our initial study were due to the techniques employed. We observed no significant difference in the proportion of knots that slipped between the four materials used in the study, braided and monofilament sutures. Once knots did slip, the stronger suture material, 1 nylon, did

Method of formation of square reef knot	Number of knots tied	Number, and proportion (%) of knots that slipped on testing	Mean length of slippage, mm, and proportional degree of slippage, (%), recorded for knot method	95% Lower CI, mm (%)	95% Upper CI, mm (%)	Median length of slippage mm
Flat Reef Knot (FRK)	120	24 (20)	1.2 (6.3)	0.5 (2.2)	2.0 (10.4)	0
No Hand Crossing Knot (NHCK)	120	120 (100)	18.5 (113.0)	15.5 (94.3)	21.5 (131.0)	11.9
Knot tied under tension (TK)	120	120 (100)	50.6 (312.0)	45.9 (280.0)	55.4 (344.0)	51.5

Table 1. Number of knots tied with each method, and proportion of knots tied with each method, that slipped on testing, mean length of slippage mm, and proportional increase in amount of suture material held within knot post slippage, for each method and 95% confidence intervals.

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appear to slip to a greater length than other materials; it was more resistant to subsequent fracture than the others (Table 3).

Suture material	Number of knots tied with suture material	Number and proportion of knots that slipped n (%)	Mean length of slippage of knots tied with each suture material mm, and proportional increase in length of suture material held within knot post slip (%)	Lower 95% CI of mean length and mean proportion of slippage mm (%)	Upper 95% CI of mean length and mean proportion of slippage mm (%)	Median slippage mm
2/0 polyglactin (Vicryl)	90	71 (78.9%)	24.2 (136.0)	18.6 (104.0)	29.8 (167.0)	14
4/0 poliglecaprone 25 (Monocryl)	90	60 (66.7%)	15.5 (108.0)	10.9 (73.8)	20.2 (142.0)	4
3/0 polydioxanone (PDS)	90	63 (70.0%)	19.1 (119.0)	13.6 (83.0)	24.5 (154.0)	8.6
1 nylon (Ethilon)	90	70 (77.8%)	34.9 (213.0)	28.6 (173.0)	41.2 (252.0)	27.7

Table 3. Number of knots tied with each suture material, proportion of each that slipped on testing, mean degree of slippage in mm and proportional increase in amount of suture material held within each knot after slippage (%), for each suture material and 95% CI.

A knot relies on adequate friction between the strands of material laid against each other and a reef knot relies on equal amounts of both suture ends placed in each layer of the knot [3-6]. If formed with an appropriate technique, the flat reef knot technique in this case, adequate friction can be achieved; 80% did not slip, and those that did only slipped to a small degree.

Video recording of formation of these knots revealed that in some, twists of the suture material developed just as some layers were laid down, producing unequal amounts of suture in each layer. This would reduce friction and may account for some of these knots slipping on testing.

The technique of knot formation, rather than suture material, has been considered to be important in knot security historically, even in the 1930s with older materials such as catgut [7]. Concern that surgical knot technique may adversely influence its security is not new; Herakles wrote regarding technique in ancient Greek surgical texts [8].

Conclusion

Success of surgical treatment requires careful and skilful dissection and craft, whether delivered by open, laparoscopic, or robotically assisted methods. We still need to rely on simple techniques, including suturing and ligation of vessels, requiring secure knots to achieve these. Our initial study has demonstrated that less than meticulous techniques can produce reliably insecure knots, rather than the secure knots we would hope for. The increasing use of technology in surgery, and advances in this technology, have facilitated many complex procedures, and contributed to surgical safety and patient outcomes. However, this is achieved by using this technology to deliver safe and secure technique. Even the most complex surgical procedure could be considered to be a set of simple manoeuvres and steps, but many in number. Success relies on each one being performed meticulously. Robotics and automation could help surgeons deliver these simple steps meticulously. We can ensure that as simple a technique as forming a secure knot can be done reliably each and every time by ensuring our equipment and software guide our surgeons to lay equal and opposite amounts of material, in each layer of the knot, to ensure maximum friction between the layers of the knot, and apply the appropriate number of layers for the suture material employed . Meticulous technique of knot tying is essential for secure knots, appropriate tissue tension, and the security of anastomoses and haemostasis effected. The principles and intentions of safe knots, outlined as far back as the first and second centuries AD, can be applied in the 21st century using our modern robotics and automated technology, to achieve the same result-safer surgery and good patient outcomes.

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