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Case Report

Twist Knot: A New Sliding Noose in Adjustable Suture Strabismus Surgery

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To permit noose movement without fraying the sutures following strabismus surgery, we designed a new sliding noose, the "twist knot" and investigated its advantages and disadvantages. We measured the tensile strength required to move the twist knot in a tightly tied state (134 ± 19 gf) and in a loosened state (21 ± 7 gf), and that required to move the conventional sliding noose in a tightly tied state (48 ± 14 gf), and used the Kruskal-Wallis test to compare them. A significant difference was observed among the three tensile strengths ($p < 0.001$). The twist knot technique allowed easy sliding without the multifilament braided suture becoming frayed and a knot to be firmly fixed without slipping. However, if the 2 strings of the pole sutures exit from the sclera at 2 widely separated positions, the sliding noose may become slack. Therefore, the distance between the pole sutures should be small. The simple twist knot technique was found to be an effective approach following adjustable surgery of strabismus.

Key words: adjustable suture, the new sliding noose method, tensile strength, strabismus surgery, esotropia

The adjustable suture strabismus technique permits the adjustment of sutures after strabismus surgery, thereby allowing fine-tuning of the eye position to the satisfaction of the patient. Numerous variations of the method were developed around a century ago [1-9]. The major approaches can be broadly divided into 2 types: the sliding noose techniques [10, 11] and the bow-tie techniques [11] (Fig. 1). The polyglactin 910 suture, an absorbable multifilament braided suture, is generally used for the sliding noose techniques. Compared to a nylon suture, which is a non-absorbable monofilament suture, the polyglactin 910 suture has the advantage of being less slippery, but in adjustable suture strabismus surgery, there is a drawback when the knot is tied too tightly. Unfortunately it is not easy to loosen the noose in such cases and the fibers may become frayed during adjustment. There is thus need of

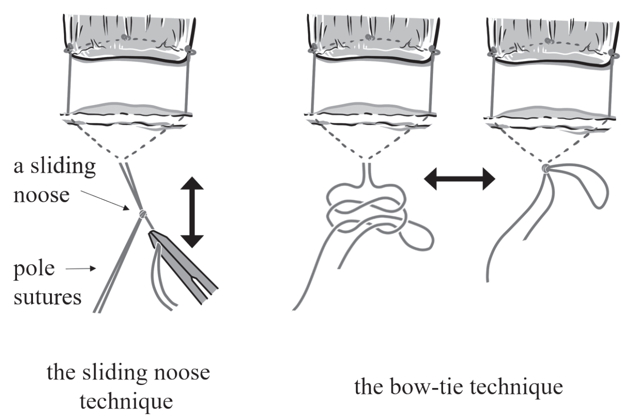

Fig. 1 Representative examples of the two major techniques. The sliding noose technique: a sliding noose is moved over the pole sutures to adjust the length of the pole sutures. The bow-tie technique: the sutures are tied together in a single-loop bow tie similar to a shoelace, retied again and adjusted.

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a new and more effective suturing method following strabismus surgery.

We devised a new suture method that allows easy sliding without the multifilament braided suture becoming frayed. The extraocular muscle is secured using double-armed 6-0 polyglactin 910 sutures that are detached and reinserted in the original positions using pole sutures. Then, the extraocular muscle is recessed to the length of the pole sutures. Next, the remaining 6-0 polyglactin 910 formed into a loop is placed underneath the pole sutures at the position where the pole sutures are secured after they exit from the sclera. The looped polyglactin 910 suture is wrapped around the pole sutures once. The 2 free ends of the polyglactin 910 suture are passed through the loop from the outer side of the loop in the opposite directions, and tied into a knot. This technique creates a new sliding noose (Fig. 2) that we call a "twist knot." Finally, we evaluated and compared the tensile strengths applied during movement using the new sliding noose and the conventional sliding noose technique.

Methods

To investigate the movability of the sliding noose in practice, 6-0 polyglactin 910 was used to make the pole sutures through a sheet of cardboard. Two strings of the pole sutures were made to exit from the cardboard in states as close to each other as possible. Using the twist knot, a sliding noose was made in a tightly tied state and another was made in a loosened state (Fig. 3). A video illustrating the formation of the twist knot is available on the YouTube website at https: //youtu.be/7Pu2iQO_dYQ. Finally, a third noose was made in a tightly tied state using the conventional sliding noose technique [10] (Fig. 2). All 3 nooses were made by a single investigator (I.H.).

To test the tensile strength required for movement, each noose was moved to a predetermined position on the cardboard. Each noose was then retied after one measurement, so that it matched the tightly tied state before measurement as much as possible. The direction of pulling was reversed on the oddly numbered measurements and again on the evenly numbered measure-

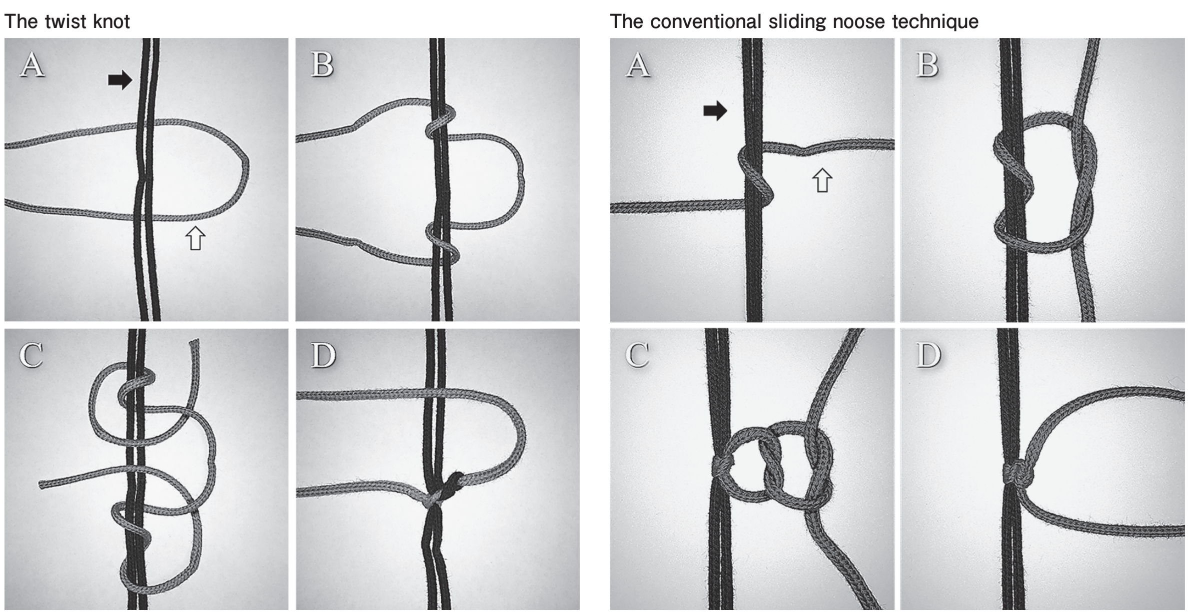

Fig. 2 Diagrammatic illustration of the twist knot and the conventional sliding noose technique.
Black arrow: pole sutures; white arrow: a string for sliding noose. The twist knot. A, A suture is made into a loop form and placed underneath the pole sutures; B, The loop is wrapped once around the pole sutures and again positioned underneath the pole sutures; C, Each of the two free ends of the suture is passed through the loop from the outer side of the loop, in opposite direction to each other; D, The two ends of the sliding noose are pulled tightly in opposite directions, and tied securely to form a twist knot.
The conventional sliding noose technique. A–B: The working end of the suture in wrapped twice around the pole suture. C–D: A single overhand knot is thrown. A square knot is tied. Resulting in a double wrap of suture on one side and a 1–1–1 knot on the other.

ments (Fig. 3). To mimic the real surgical situation, the sutures were moistened with saline. The tensile strength [gram-force (gf)] required to slide the noose was measured ten times using a Kanon TK 300 CN Tension Gauge (Nakamura Manufacturing, Tokyo). Finally, the tensile strengths for each of the different states of suture were compared using a Kruskal-Wallis test.

Results

Figure 4 shows the results of tensile strength measurement. Using the twist knot, the mean(±SD) tensile strengths were 134 (19) (range, 112-163) gf in a tightly tied state (A) and 21 (7) (range, 10-31) gf in a loosened state (B). Using the conventional sliding noose technique, the mean (±SD) tensile strength was 48 (14) (range, 31-71) gf in a tightly tied state (C). A significant difference was found among the 3 groups ($p < 0.001$), and also among each pairing of 2 groups: A versus B ($p < 0.001$), A versus C ($p < 0.05$), and B versus C ($p < 0.05$).

Case Report

A 48-year-old man who had been subjectively aware of diplopia for some twenty years requested surgery because he had started to drive. At far distance he had 30 prism diopters and at near distance he had 33 prism

Fig. 4 Tensile strength in various states of tying.

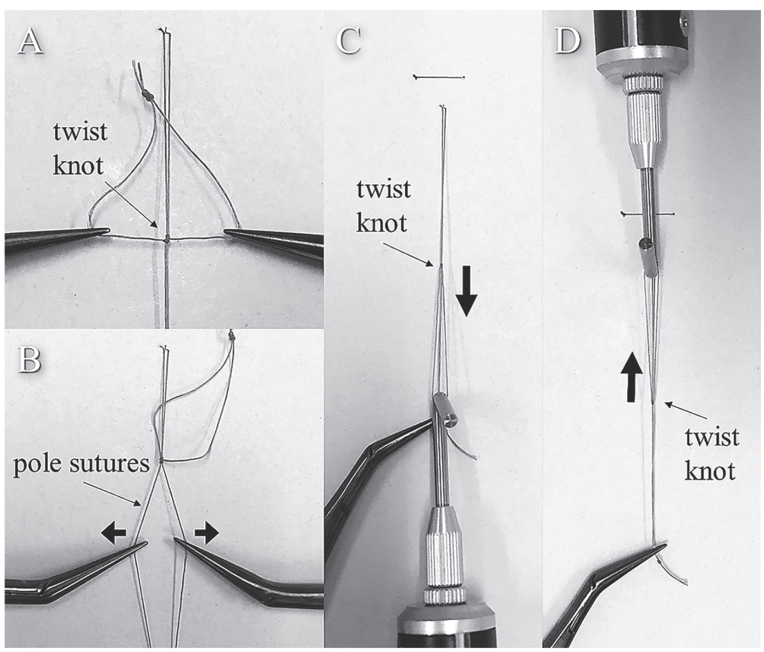

Fig. 3 States of the twist knot and the direction of pulling of measurement.
A, A tightly tied state: the two ends of the sliding noose are tied tightly as possible; **B**, A loosened state: the two strings of the pole sutures were pulled outward away from each other, the knot was loosened; **C**, The direction of pulling at odd number times of measurement; **D**, The direction at even number times.

diopters of esotropia in the primary position. The Bagolini striated glasses test showed diplopia at far distance and binocular single vision at near distance. To get as close to the desired correction as possible, adjustable suture strabismus surgery was selected. Sub-Tenon's anesthesia was used. After instilling 4% lidocaine, sub-Tenon's anesthesia with 2% lidocaine was administered without adrenaline (epinephrine). Combined medial rectus muscle recession of 5.5 mm with lateral rectus muscle resection of 5.0 mm in the right eye was planned. For the medial rectus muscle recession, adjustment was performed using the twist knot (Fig. 5). Since the muscle tone was relaxed due to the influence of anesthesia, adjustment was conducted in the evening after the muscle tone had recovered based on the consideration that the action time of lidocaine is 1.5 to 2 h, and the muscle tone of extraocular muscles should recover adequately 6 h after surgery [12]. Adjustment was performed with only instillation of 0.4% oxybuprocaine hydrochloride. The length of the suture was adjusted while consulting with the patient to obtain eye positions both at far and near distance that the patient found satisfactory. When either of the strings of the pole suture was pulled outward away from the other, the knot was loosened and slid easily. When the suture was on slack, the 2 sutures of the noose were pulled together and tied loosely. When a stronger tie was desired, the 2 sutures of the noose were pulled in the opposite directions, resulting in a twist knot. Eventually a recession of 5.0 mm was achieved. The pole sutures were secured by the following procedure: one string of each pole suture was tied with one string of each suture of the sliding noose, and eventually all of the strings of the pole sutures were tied together. At one month after surgery, the eye positions at far distance were orthophoric and exophoric of 3 prism diopters at near distance. At four months after surgery, the eye position was stabilized.

Discussion

Although the tensile strength of each muscle is different, the mean tensile strength of the medial rectus muscle is 75 gf with a maximum of 103 gf, while the mean tensile strength of the lateral rectus muscle is 59 gf with a maximum of 92 gf [13]. In the present study, even the lowest tensile strength measured for the twist knot method exceeded these values. In the conventional sliding noose technique used as a control in the present study, the tensile strength was lower than

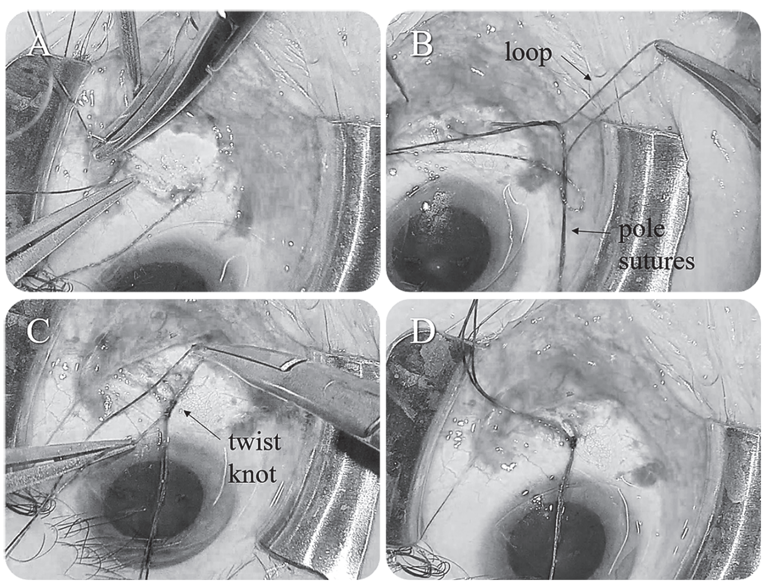

Fig. 5 Intraoperative photographs of strabismus surgery using the new sliding noose.
A, The sutures from the pole sutures are inserted slightly posterior to the edge of the muscle insertion site and passed under the sclera for a distance. The sutures on both sides are passed through the sclera to exit near the center of the muscle insertion site, as close to each other as possible; B, The loop of the sliding noose is passed round the pole sutures once; C, Each of the two ends of the sliding noose is passed through the loop from the outer side of the loop, and then tightly tied; D, The procedure is complete.

the tensile strengths of the medial and lateral rectus muscles. A possible explanation is that the static friction force of the suture passing through the sclera may cause changes in tensile strength [14,15]. However, as long as the static frictional resistance of the sclera is sufficient, there should not be any problem. In addition, tensile strength is affected by blood and aqueous solutions in the surrounding region, the type of suture, and the presence or absence of viscoelastic substances used for cornea protection [16,17]. Miller *et al.* [10] reported that the tensile strength of a sliding noose [7] like that used in the present study (150 gf) was stronger than the tensile strengths of the square knot and cinch knot [6]. In Miller's study [10], however, increased separation of the pole sutures as they approached the edge and the dryness of the sutures probably altered the static friction resistance and affected the tensile strength [10].

In the bow-tie technique, it is necessary to untie the knot and then tie the sutures again after adjustment. Using this method, the suture may be tied too tightly or too loosely, and it is difficult to finely adjust the suture. Moreover, an assistant is required to secure the pole sutures, and the assistant must have various specialized skills, such as proficiency with the tying method itself [4,5]. Miller *et al.* [10] evaluated 3 sliding noose techniques used in adjustable suture strabismus surgery (the sliding noose knot, cinch knot, and square knot methods) and reported that the 1-1 ties were difficult to untie, and the tensile strength decreased as the knots were moved repeatedly along the suture, even though the knots were retied each time after moving.

In our new sliding noose suture, the sliding noose and the pole sutures intertwine to form a twist knot, as shown in Fig. 2D and the video, rendering it difficult to move. However, when the 2 ends of the pole sutures are pulled outwards in opposite directions, the knot is loosened by the nature of this knot. If the 2 strings of the pole sutures exit from the sclera at 2 widely separated positions, the sliding noose may become slack. Therefore, the distance between the pole sutures should be small.

In several reports investigating the postoperative results of adjustable suture and nonadjustable suture strabismus surgeries, the reoperation rates of adjustable suture strabismus surgery ranged from 5.8% to 10% and were significantly lower than the rates of nonadjustable suture strabismus surgery (range: 7.8% to 30%), despite variations among studies [18-20]. When adjustable and nonadjustable suture surgeries were compared in patients with horizontal strabismus, some studies showed that while the success rates appeared to be higher in adjustable suture strabismus surgery, there were no significant differences [21-23]. In eyes with exotropia, exotropic drift occurs after surgery, which may be one reason for the observation that achieving an orthophoric eye position immediately after surgery is not necessarily ideal [24]. On the other hand, in reoperation cases, the success rate of adjustable suture surgery is significantly higher compared to that of nonadjustable suture surgery, and the difference has been reported to be marked in young patients [25]. Therefore, adjustable suture is indicated for cases of reoperation, strabismus cases such as thyroid-associated ophthalmopathy in which general strabismus surgical dose tables cannot be used, and patients who desire to avoid diplopia as much as possible after surgery. In our case, the patient wished to return to work early, and selected the option of adjustable suture after consultation. Hasebe *et al.* [26] reported that 76% of the patients who underwent adjustable strabismus surgery required re-adjustment after surgery. In our case also, the eye was over-corrected after surgery compared to the surgical dose, and readjustment using the sliding noose proceeded smoothly. The postoperative eye position was stable, and the patient was satisfied with the outcome.

A major limitation of this study is that only one patient was tested. In the future, an investigation using a larger number of cases will be needed to consider the clinical utility of our twist knot technique. The other limitation concerns the condition of the sutures moistened with saline. In an actual surgical setting, the tensile strength would be affected by blood and aqueous solutions in the surrounding tissues. The tensile strength of the sutures in this study might thus be different from that in an actual surgical setting.

The new sliding noose suture method proposed in this study, the twist knot method, allows easy loosening of the suture, and uses a secure tying technique that provides better tying strength compared to the conventional method. The twist knot technique is thus an effective method involving a simple maneuver.

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