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ORIGINAL STUDY

The behaviour of knots and sutures during the first 12 hours following a Bankart repair

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It has been reported that the effectiveness of arthroscopic procedures in terms of preventing recurrent dislocation has not matched that from open techniques. Also little is known about how these knots behave when exposed to physiological loading following repair. This study presents the development of a practical tool to allow surgeons to test the quality of their arthroscopic knots and allow them to make choices with regard to knot configuration and suture material.

This study uses an apparatus to model the repair of a Bankart lesion. Ten examples of the Duncan loop and SMC knots were tied using PDS, Ethibond, Panacryl and Fibrewire. An arthroscopic knotting technique was used. Reverse slippage occurring during the tying process was recorded. Each knot was then left for 12 hours under loads equivalent to a Bankart repair and the subsequent reverse slippage was recorded.

After initial passing of the Duncan loop and after passing of locking hitches the sutures were ranked inversely to size of suture loop (resistance to slippage). Only Fibrewire showed a significant difference (5.7 ± 1.03 mm to 5.66 ± 0.5 mm ; $p < 0.05$). After 12 hrs, some evidence of reverse slippage was noted, especially with Fibrewire (5.66 ± 0.5 mm – ***significant*** $p < 0.05$**). The SMC knot showed generally inferior results.**

In this study using arthroscopic techniques, Fibrewire performed less well than other materials.

Keywords : shoulder ; Bankart repair ; arthroscopic knot tying.

INTRODUCTION

Historically it has been reported that the effectiveness of arthroscopic procedures in terms of preventing recurrent dislocation has not matched that from open techniques (2). This lower efficacy is generally thought in part to be due to the technical difficulties experienced while tying arthroscopic slip-knots (6). Also little or nothing is known about how these knots behave when exposed to physiological loading following repair. Several slipknots are commonly used in arthroscopic repairs. The Duncan Loop (7) is one of the most commonly used pure slipknots. The Snyder or Tennessee slider is a

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flip-knot recommended for use with monofilament sutures (*12*). A further modification of this knot is the Samsung Medical Centre (SMC) knot, which has been recommended for use with braided sutures. These two knots can be regarded as flip-knots because tension applied to the running post with the knot in its required position causes the knot to flip configuration to a locked form.

Many factors influence slipknot tying. These include the experience of the operator (*1*), the knot-configuration (*1,6-11*), suture material (*7,9*) and knot-pusher design (*1*). In a recent study the investigators found wide inter-operator variability with regards to slipknot tying (*3*). This study presents the development of a practical tool to allow surgeons to test the quality of their arthroscopic knots and allow them to make choices with regard to knot configuration and suture material.

MATERIALS AND METHODS

An apparatus has been developed to model the repair of a Bankart lesion using a slipknot (fig 1). Two freely rotating aluminium discs, suspended within a framework, provide attachment for a Mitek anchor and a low friction pulley-wheel (capsule analogue) respectively. The normal elastic recoil present in the capsule is modelled using a spring link between the two discs. These discs are also connected to each other via a rotary transducer. A suture is passed through the anchor and around the pulley. The suture ends are then passed out through a hole in the frame, which represents a portal. Arthroscopic knots can then be tied outside the frame and then slid in using a knot pusher. Differential movements of the capsule analogue and anchor can be recorded as relative movements of the discs via the rotary transducer. After calibration with a hand-held micrometer, loop security and reverse slippage can be accurately measured. This apparatus therefore attempts to model the re-attachment of the labrum to the glenoid fossa and produced a highly controlled method of studying how effective a suture is in closing the defect and then maintaining this closure.

Ten examples of the Duncan loop were tied with respectively 1 PDS ; 2 Ethibond ; 2 Panacryl and 2 Fibrewire. The same surgeon, who had extensive experience of arthroscopic knot tying, performed all knots. Each knot was tied using a Mitek knot-pusher using a technique mirroring the normal operative procedure. Each

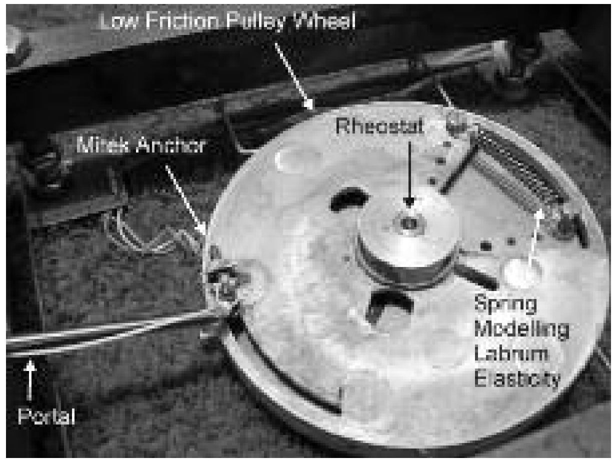

Fig. 1. — Knot testing tool

knot was tensioned to produce maximal loop closure. Tension was then released and any reverse slippage of the knot recorded. Three hitches were then performed, reversing post and direction each time, as recommended by Loutzenheimer *et al* (6). The technique for hitch insertion was as described by Snyder (12), where the knot-pusher is maintained on the same post throughout the tying process. Following insertion of hitches, loop closure was once again recorded to assess the level of reverse slippage.

The knot was then left on the apparatus under conditions of continuous loading. After 12 hours, a further measurement was made to assess for further reverse slippage or creep. Following this, the investigation was repeated using the Tennessee Slider knot combined with 1 PDS and the SMC Knot with respectively 2 Ethibond ; 2 Panacryl and 2 Fibrewire.

RESULTS

The maximum loop closure diameter was found to be 4.89 mm. The mean loop closure diameter and standard deviations for the different knots, materials and conditions are presented (table I). These means were analysed using a Student t-test with significance assigned at the $p < 0.05$ level.

Loop security, after initial snugging of the knot and prior to application of locking hitches, was highly variable. The most secure combination at this stage was Panacryl/Duncan with a mean loop diameter of 5.08 ± 0.08. At this initial stage,

Table I. — Mean loop closures initially, after application of locking hitches and after 12 hours using 4 suture materials

	Duncan loop Mean Loop diameter (mm)			SMC (Tennessee slider) knot Mean Loop diameter (mm)		
	Initial	Post hitch	Post 12 hrs	Initial	Post hitch	Post 12 hrs
PDS	8.20 ± 5.16	5.15 ± 0.08	5.28 ± 0.13	6.92 ± 4.31 (Tennessee)	5.12 ± 0.12 (Tennessee)	5.27 ± 0.15 (Tennessee)
Ethibond	7.22 ± 3.46	5.13 ± 0.24	5.23 ± 0.27	8.17 ± 4.96	5.58 ± 0.38	5.73 ± 0.38
Panacryl	5.08 ± 0.14	5.17 ± 0.13	5.29 ± 0.16	6.53 ± 0.77	5.25 ± 0.20	5.38 ± 0.18
Fibrewire	5.70 ± 1.03	5.52 ± 0.49	5.66 ± 0.50	6.65 ± 0.82	5.57 ± 0.59	5.74 ± 0.55

Panacryl/Duncan was significantly better than Panacryl/SMC ($p < 0.01$) and Fibrewire/Duncan was significantly better than Fibrewire/SMC ($p < 0.01$).

Comparisons post hitch application revealed the best performing combinations to be PDS/Tennessee at 5.12 ± 0.12 and Ethibond/Duncan loop at 5.13 ± 0.24. At this stage, the combination of Fibrewire/Duncan at 5.52 ± 0.49 was significantly inferior ($p < 0.05$) to Duncan loop with PDS, Ethibond or Panacryl. Also at the post hitch stage, PDS/Tennessee significantly outperformed Ethibond/SMC ($p < 0.01$) and Fibrewire/SMC ($p < 0.05$). Panacryl/SMC only significantly outperformed Ethibond/SMC ($p < 0.05$).

Re-analysis after 12 hours revealed a similar pattern of results. All mean loop diameters demonstrated further reverse slippage over the first 12 hours. This only reached statistical significance with PDS/Duncan, 5.15 ± 0.08 to 5.28 ± 0.13 ($p < 0.05$) and PDS/Tennessee, 5.12 ± 0.12 to 5.27 ± 0.15 ($p < 0.05$). The best performing combination after 12 hours was Ethibond/Duncan at 5.23 ± 0.27. Once again, the combination of Fibrewire/Duncan loop at 5.66 ± 0.50 was significantly inferior ($p < 0.05$) to Duncan loop with PDS, Ethibond or Panacryl. Also after 12 hours, PDS/Tennessee significantly outperformed Ethibond/SMC ($p < 0.01$) and Fibrewire/SMC ($p < 0.05$). Panacryl/SMC only significantly outperformed Ethibond/SMC ($p < 0.05$).

Comparing between different knots using the same suture material also revealed some interesting observations. There was no significant difference between either the Duncan loop or the Tennessee slider when tied with PDS. The Duncan loop proved significantly better than the SMC knot with Ethibond at both post hitch ($p < 0.01$) and post 12 hour ($p < 0.01$) measurements. Combining the data for the Duncan loop and SMC using Ethibond, Panacryl and Fibrewire demonstrated the Duncan loop to be overall the superior knot at resisting reverse slippage ($p < 0.05$).

In this study, back-slippage of a suture loop greater than 2 mm was regarded as representing a significant loss of tissue security and thus is felt to predispose to potential repair failure. The data was also examined to determine how many of the 80 knots tied in this study showed a reverse slippage of greater than 2 mm (table II). Though reverse slippage is common prior to locking with hitches only one example of a loop back slipping more than 2 mm was seen after locking and this occurred when using Fibrewire/SMC combination.

Of note is the fact that none of the sutures were broken whilst performing this study. This suggests that in this study there was no advantage to using complex sutures such as Fibrewire.

DISCUSSION

There are several papers in the arthroscopic literature describing a particular new arthroscopic knot. This has often been developed by the authors and is described as being superior to other knots. In a recent paper by Burkhart *et al* (*1*) the authors set out to determine the optimal knot configuration that maximized both knot and loop security when tied with two different types of non-absorbable, braided suture. No attempt was made to model the closing

Table II. — Numbers of knots per 10 tied demonstrating reverse slippage greater than 2 mm at each time point

	Duncan loop			SMC (Tennessee slider) knot		
	Initial	Post hitch	Post 12 hrs	Initial	Post hitch	Post 12 hrs
PDS	3			2 (Tennessee)		
Ethibond	2			5		
Panacryl				2		
Fibrewire	1			6		1

of a Bankart lesion with a knot tied by an arthroscopic technique prior to testing. The various knots were simply tied over a dowel to produce a loop of consistent diameter. Tying a knot over a wooden dowel does not model the resistance due to elastic recoil experienced when closing an actual Bankart lesion. From their work, they have further highlighted the importance of using 3 locking sutures, alternating post and direction, to secure a sliding knot. Of the sliding knots tested in their study, the Roeder knot seemed to perform best in terms of both knot and loop security. With all knots tied, they showed security was better with 2 Fibrewire than 2 Ethibond.

In a further study by Macdonald *et al* (*12*) the use of monofilament and braided sutures for arthroscopic applications were compared in terms of performance and ease of manipulation. In this study, the arthroscopic procedure was modelled using a wooden practice box. Four types of suture materials were compared using the Snyder and Duncan loops. This study should be highlighted as one of the few examples where knots have been tested on a tensiometer while immersed in saline. Time taken to tie the suture was compared to loop security. Both the polypropylene and polyester sutures gave superior knot performance to PDS but polyester proved much harder to manipulate and this was reflected in the time taken to perform the tying process.

Previously it has been shown that a given knot will perform differently for different surgeons when tied in conditions approximate to the actual arthroscopic procedure (*3*). We have set out to develop an apparatus that models the closure of a Bankart lesion onto an anchor using an arthroscopic sliding knot. The incorporation of a spring into the system produces identical resistance, which must be overcome by force applied by the individual tester during tying. The incorporation of a rotary transducer allows very small quantities of reverse slippage to be measured both during and after knotting. Thus information can be given to a surgeon regarding the quality of their knot tying and indications can be given as to which stage any flaws in technique are present if apparent.

During this study a number of important findings were identified. After initial snugging down of the sliding knot, loop security was highly variable. The quantity of reverse slippage deemed to be associated with significant levels of failure is currently an arbitrary value. Some studies have suggested a value of greater than 3 mm (*5*). In this paper, in an attempt to continue to raise standards we have suggested that significant back-slippage occurs beyond 2 mm. Using this value and comparing the four suture materials with the Duncan loop, all materials with the exception of 2 Panacryl demonstrated some examples of significant reverse slippage at the initial stage (table II). However, in all cases it proved possible to retighten these knots using the first locking hitch. The importance of retightening using this first hitch can not be overemphasized, as once this was in place it was observed that the remaining hitches, reversing post and direction, have no further ability to retighten the knot and act only to additionally secure what has already been achieved. Measuring loop diameter, once locking hitches were applied, revealed that all loops showed consistent retightening. As has been stated, with this model, the full loop closure was 4.89 mm. The mean values for the Duncan loop tied with 1 PDS, 2 Ethibond and 2 Panacryl were all within 0.3 mm of this value. Thus this study would support the surgeons under analysis in their use of any one of these combinations. The use of the Duncan/Fibrewire combination, with a significantly poorer mean reverse slippage of 0.7 mm, could not be supported even though no individual loops back-slipped more than 2 mm. In this study, it was decided to leave tested sutures on the model for a further 12 hours to investigate any further slippage, under conditions of loading approximating to the elastic recoil of the Bankart lesion. There are, of cause, limitations with this, as the loads applied via the spring are small and constant in nature with no attempt being made to model any larger cyclical stresses, which might be imposed on the lesion in the *in vivo* situation. Within these constraints, all Duncan loop suture combinations saw reverse slippage of approximately 0.1 mm, which reflects essentially, how secure these knots are.

This study has highlighted interesting observations with regards to the use of flip knots such as the Tennessee slider and SMC knots. The theory behind these knots has suggested that once correctly positioned a conformational change in the knot produces a knot, which can no longer slide in either direction. During the study both knots were snugged down and then flipped in the snugged position by tension applied to the running limb of the suture. During this process, the change in conformation was associated with consistent observed reverse slippage. All suture materials showed examples of reverse slippage greater than 2 mm. This was most prevalent with Ethibond/SMC (5 of 10 failures) and Fibrewire/SMC (6 of 10 failures). If the flip-knot at this stage was truly locked this would be of great concern. However, in virtually all cases, the application of additional locking hitches, reversing post and direction, was accompanied by retightening of the loop. After locking, the mean loop diameter for the combination of PDS/Tennessee was within 0.3 mm of maximum loop closure and Panacryl/SMC was within 0.4 mm. Both Ethibond and Fibrewire combinations with SMC knot showed significantly greater reverse slippage of approximately 0.7 mm. Following the knots performance over the next 12 hours, all flip-knot combinations demonstrated further reverse slippage of approximately 0.15 mm, which mirrors the situation seen with the Duncan loop. In one example of the Fibrewire/SMC combination, reverse slippage exceeded 2 mm and this was the only example of a failure in the whole study, after application of locking sutures. Throughout the study Fibrewire tended to produce inferior results compared to other sutures. This suture did appear to be more difficult to handle when used via an arthroscopic technique and it does not appear to function well as a material for arthroscopic suturing. Similar observations, using complex polyester sutures in models of arthroscopic surgery, have been noted by other workers (*4*).

CONCLUSION

Thus in summary, for the surgeon under test, this work has shown highly variable initial loop security for both slip and flip knots. The conformational change during the tying of the SMC knot is associated with consistent reverse slippage. Passing of the first locking hitch allows both Duncan and SMC to be re-tightened but no further tightening is possible with further hitches. Overall this study has shown a superior performance of the Duncan loop over the SMC knot. It is not the intention of this paper to make recommendations about which arthroscopic knot is best. If recommendations were to be made comparing different knots, then a methodology, as presented here where the forces opposed in tying the knot are highly consistent, would be useful. It is much more important to realise that some surgeons are better at tying a particular knot than others. Thus, there is probably no such thing as the perfect arthroscopic knot. What surgeons require is a methodology for helping them to define their ideal knot. This paper thus presents such a methodology. These standards must be reached by trainee surgeons prior to them commencing surgery on patients.

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