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Research Article

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Posted Date: October 5th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10715212/v1>

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Additional Declarations: No competing interests reported.

A Novel V-Shaped Intraluminal Knife for Minimally Invasive Removal of Inadvertently Sutured Drainage Tubes After Lumbar Spine Surgery: A Rabbit Model Study with Clinical Application

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Abstract:

Background: Inadvertent suturing of drainage tubes during wound closure is an uncommon but troublesome complication following lumbar spine surgery. The conventional management requires reopening the incision to remove the entrapping suture, which constitutes an unplanned reoperation and carries additional risks. We developed a novel V-shaped intraluminal cutting knife fabricated from a Kirschner wire and evaluated its efficacy and safety in a rabbit model and a clinical case.

Methods: Two blade configurations were manufactured from Kirschner wires: a V-shaped blade with bilateral blunt protrusions designed to capture and guide sutures into the cutting edge, and an A-shaped blade (control) without protrusions. Ten New Zealand white rabbits (weight 2.0–2.5 kg) underwent standardized laparotomy with placement and intentional suturing of two silicone drainage tubes in the paraspinal musculature. Each rabbit received one tube assigned to V-shaped knife extraction and the other to A-shaped knife extraction, with side all

ocation determined by a random number table ($n = 10$ attempts per device). The primary outcome was extraction success rate (complete removal within 10 minutes). The secondary outcome was extraction time. A 56-year-old patient who sustained inadvertent drainage tube suturing after L4–5 posterior lumbar interbody fusion was also treated with the V-shaped device.

Results: The V-shaped knife achieved a 100% success rate (10/10) with a mean extraction time of 2.3 ± 0.4 minutes, whereas the A-shaped knife succeeded in 50% (5/10) with a mean extraction time of 6.8 ± 0.6 minutes. The difference in success rates was statistically significant (Fisher's exact test, $P = 0.033$), as was the difference in extraction times (independent-samples t-test, $t = 19.72$,

$P < 0.001$). All animals recovered uneventfully with general condition scores returning to baseline by postoperative day 6. The clinical case was managed successfully with the V-shaped knife without incision reopening or complications.

Conclusions: The V-shaped intraluminal knife with bilateral protrusions provides a safe, rapid, and minimally invasive solution for removing inadvertently sutured drainage tubes after lumbar spine surgery, offering significantly superior performance compared with simple wedge-shaped blade designs. This low-cost, technically straightforward device has the potential to eliminate the need for reoperation in this clinical scenario.

Keywords: Lumbar spine surgery; Drainage tube; Inadvertent suture; Mis-sutured drain; Minimally invasive extraction; Intraluminal knife;

Introduction

Closed suction drainage is routinely employed following lumbar posterior spinal surgery to evacuate postoperative hematoma and serous exudate. Adequate drainage prevents epidural hematoma formation—a potentially devastating complication that can cause acute neurological deterioration—and reduces the risk of surgical site infection and impaired wound healing [1–4]. Current clinical pra

ctice commonly involves the placement of one or two silicone drainage tubes in the subfascial or subcutaneous plane prior to layered wound closure.

An infrequently reported but clinically significant complication is the inadvertent passage of a closure suture through the wall of the indwelling drainage tube. When the suture needle traverses the tube lumen or wall during fascial or subcutaneous closure, the tube becomes mechanically anchored, rendering routine postoperative removal impossible [5,6]. Although precise incidence data are lacking due to underreporting, this event is well recognized among spine surgeons and can occur with any procedure involving closed suction drainage.

The traditional approach to this problem is to reopen the incision—either partially or completely—under local anesthesia, identify and divide the offending suture, and then extract the freed drainage tube [7]. This constitutes an unplanned return to the operating theater or procedure room and entails several disadvantages: increased patient discomfort and anxiety, prolonged recovery, additional consumption of medical resources, and an elevated risk of wound complications including surgical site infection, fat liquefaction, and delayed healing [8, 9]. Furthermore, such events may erode patient trust and give rise to medico-legal disputes.

Recognizing the need for a minimally invasive alternative, our group previously reported the preliminary development of a specialized intraluminal cutting device fabricated from a standard Kirschner wire [10]. The principle of the device is straightforward: it is inserted retrogradely through the lumen of the entrapped drainage tube, advanced until the blade contacts the retaining suture, and then manipulated to transect the suture, thereby freeing the tube for atraumatic removal. This concept eliminates the need for incision reopening entirely. The device has been granted a Chinese National Utility Model Patent (No. CN201620124058.1) [11].

In the present study, we compared a V-shaped blade with bilateral blunt protrusions with a simple wedge-shaped blade in a rabbit model to optimize the blade geometry, and then applied the preferred device in a patient who had an

inadvertently sutured drainage tube after lumbar instrumentation and successfully extracted it.

Materials and methods

Device design and fabrication

The specialized knife was fabricated from a medical-grade stainless steel Kirschner wire with a diameter selected to match the internal diameter of the clinical drainage tube (approximately 2.0–2.5 mm). The Kirschner wire was machined such that one end retained a smooth, blunt tip for atraumatic probing of the tube lumen to localize the retaining suture. The opposite end was ground into a cutting blade using a dental micromotor and fine abrasive wheels.

Two blade configurations were manufactured (Figure.1): V-Shaped Blade (Study Device): The blade tip is V-shaped with an included angle of approximately 60°. At the apex of each arm of the “V”, a small blunt protrusion (approximately 0.3 mm in height) extends laterally. These bilateral protrusions function to capture and funnel the suture filament into the V-shaped notch, where the honed inner edges transect the suture upon axial rotation or gentle traction of the device. A-Shaped Blade (Control Device): The blade tip is A-shaped (simple wedge/arrowhead configuration) with a central ridge and tapering edges. It lacks lateral protrusions and relies solely on direct edge contact to divide the suture.

Both devices were sterilized by ethylene oxide gas prior to use in animal experiments and by autoclave sterilization for the clinical case.

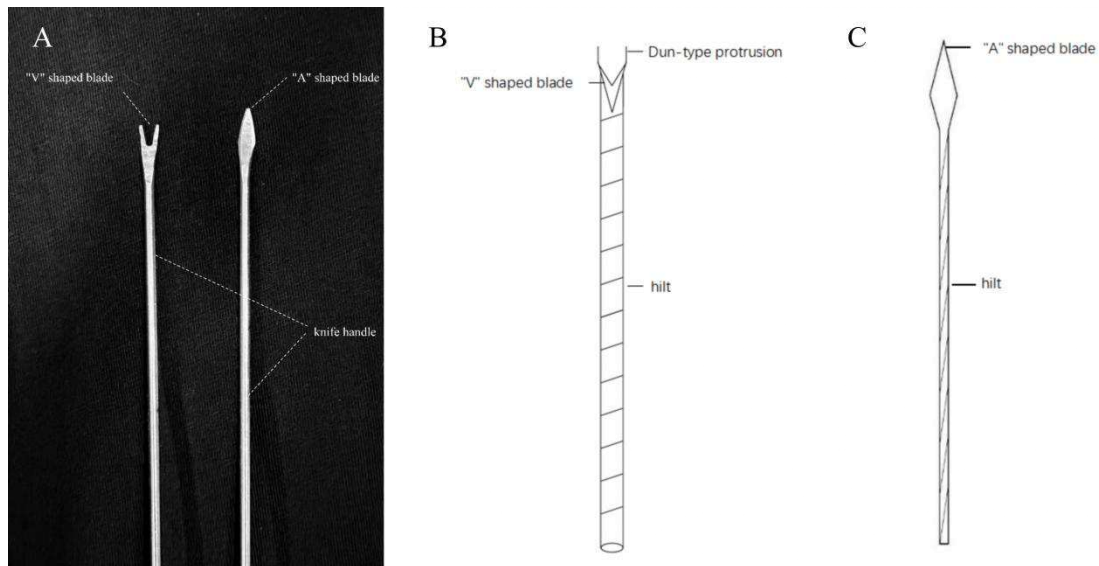


Figure.1 Physical and structural schematic diagrams of the A-shaped blade and V-shaped blade. (A) Physical comparison photographs of the A-shaped blade and V-shaped blade. (B) Schematic diagram of the V-shaped blade, annotated with knife handle, hilt, and Dun-type protrusion. (C) Schematic diagram of the A-shaped blade, annotated with knife handle and hilt.

Clinical Case

A 56-year-old male patient (height 172 cm, weight 78 kg, BMI 26.4 kg/m²) presented with a 1-year history of low back pain with neurogenic claudication. Magnetic resonance imaging demonstrated severe central canal stenosis at the L4–5 level. The patient underwent L4–5 posterior lumbar interbody fusion with pedicle screw instrumentation and L4 laminectomy for neural decompression.

One 3-mm diameter silicone drainage

tube was placed in the subfascial plane parallel to the incision prior to wound closure.

On postoperative day 4, when the 24-hour drainage output had decreased to less than 30 mL, attempted removal of the drainage tubes encountered firm resistance. The diagnosis of inadvertent suture entrapment was made clinically. The V-shaped intraluminal knife was employed as described in Section 2.5. (Figure.2) Written informed consent was obtained from the patient for the proced

ure and for publication of the clinical details.

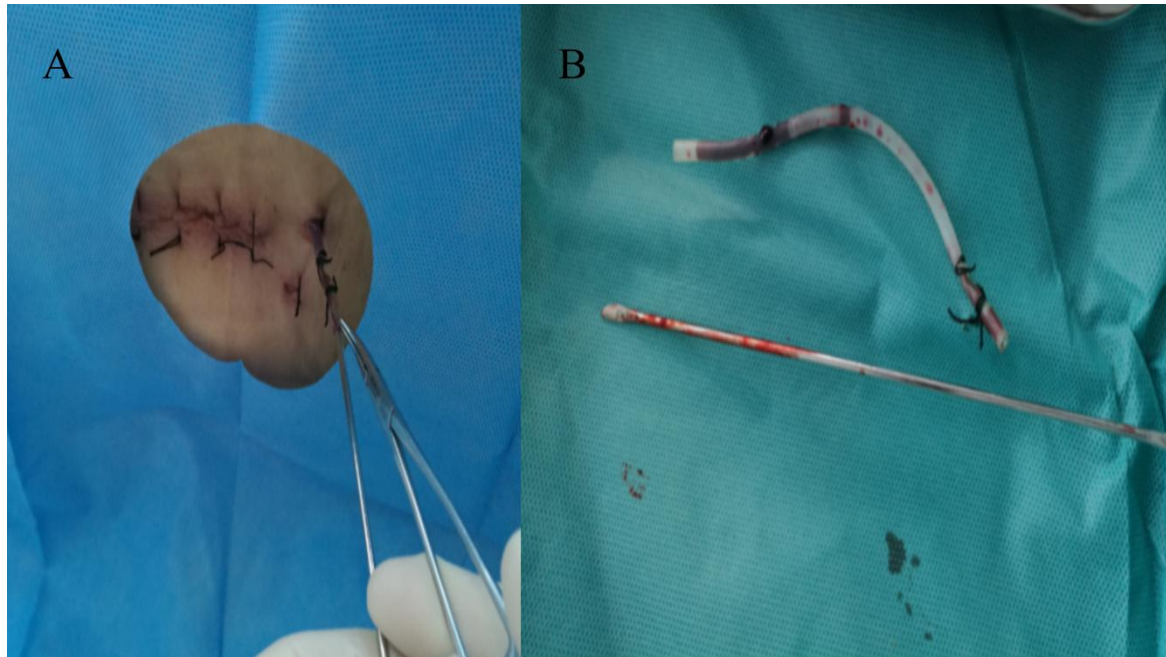


Figure.2 Clinical application of the V-shaped intraluminal knife in a 56-year-old male patient with an inadvertently sutured drainage tube after L4–5 posterior lumbar interbody fusion. (A) The drainage tube was transected 1.5 cm from the skin surface after antiseptic preparation and draping of the exit site. A hemostat was used to stabilize the tube wall while the knife was inserted retrogradely into the lumen. (B) The successfully extracted intact drainage tube alongside the V-shaped specialized knife.

Experimental Animals

Ten healthy 10-month-old New Zealand white rabbits (weight 2.0–2.5 kg, male or female) were obtained from the Experimental Animal Center of Ningxia Medical University (Certificate No. SCXK [Ning] 2015-0001). All animals were housed individually in standard cages under controlled environmental conditions (temperature $22 \pm 2^{\circ}\text{C}$, relative humidity $50 \pm 10\%$, 12-hour light/dark cycle) with ad libitum access to standard rabbit chow and water. Animals were allowed to acclimatize for 7 days prior to experimentation. Preoperatively, animals were fasted for 6 hours with free access to water for 4 hours prior to induction of anesthesia.

Surgical Procedure and Animal Model

Anesthesia was induced by intravenous injection of 3% sodium pentobarbital (30 mg/kg) via the marginal ear vein. Following induction, the surgical field (left flank and lumbar region) was shaved and prepared with povidone-iodine solution. Local infiltration anesthesia with 0.5% lidocaine solution (5–10 mL) was administered along the planned incision line to supplement general anesthesia and reduce perioperative discomfort.

The rabbit was positioned prone. A longitudinal skin incision approximately 6 cm in length was made along the left flank, extending from the inferior margin of the 12th rib toward the iliac crest. The subcutaneous tissue and fascial layers were sequentially divided. The external oblique and internal oblique muscles were split in the direction of their fibers. Blunt dissection was performed in the retroperitoneal plane between the internal oblique and transversus abdominis muscles. The paraspinal musculature was identified and the plane between the psoas muscle and the vertebral bodies was developed, exposing the anterolateral aspect of the lumbar spine.

Two sterile silicone drainage tubes (outer diameter 3 mm) were placed within the retroperitoneal space adjacent to the lumbar vertebral bodies. Each tube was intentionally transfixed to the adjacent musculature at one point using a 3-0 silk suture passed through the tube wall, thereby simulating the clinical scenario of inadvertent suture entrapment. The wound was then closed in anatomical layers: the transversus abdominis and internal oblique were approximated with interrupted 3-0 Vicryl sutures, the external oblique fascia was closed with a running 3-0 Vicryl suture, and the skin was closed with interrupted 3-0 nylon sutures. The tubes were left exiting the skin through separate stab incisions and were secured to the skin with a single 3-0 silk stay suture to prevent premature dislodgement.

All animals received intramuscular cefazolin sodium (0.5 g, once daily) for 3 days postoperatively as infection prophylaxis.

Allocation and Extraction Procedure

For each rabbit, the two drainage tubes were randomly assigned to extraction with either the V-shaped knife or the A-shaped knife using a random number table (odd numbers: left side assigned to V-shaped, right to A-shaped; even numbers: the reverse). This design yielded 10 extraction attempts per device type, with each animal serving as its own paired control, thereby minimizing inter-individual variability.

On postoperative day 4, the extraction procedure was performed by a single investigator who was not involved in the surgical placement of the tubes and was blinded to the side-specific allocation until the moment of device use. The procedural steps were as follows:

1. The skin surrounding the drainage tube exit site was disinfected with povidone-iodine and draped.
2. The drainage tube was transected approximately 1.5 cm from the skin surface using sterile scissors.
3. A hemostat was used to gently grasp and stabilize the tube wall.
4. The appropriate knife (V-shaped or A-shaped, according to randomization) was inserted into the tube lumen with the blunt probing end first to identify the approximate depth of the retaining suture.
5. Once the suture position was identified, the knife was withdrawn, reversed, and re-inserted with the cutting end oriented toward the suture.
6. Under gentle axial rotation and/or to-and-fro manipulation, the blade was engaged with the suture and manipulated until the suture was transected—indicated by a sudden release of resistance.
7. The drainage tube was then extracted with gentle continuous traction.

Success was defined as complete, unbroken extraction of the drainage tube within 10 minutes of the first insertion attempt. Extraction time was recorded from the moment of initial blade insertion into the lumen until complete removal of the tube. (Figure.3) A single independent observer timed all procedures using a digital stopwatch.

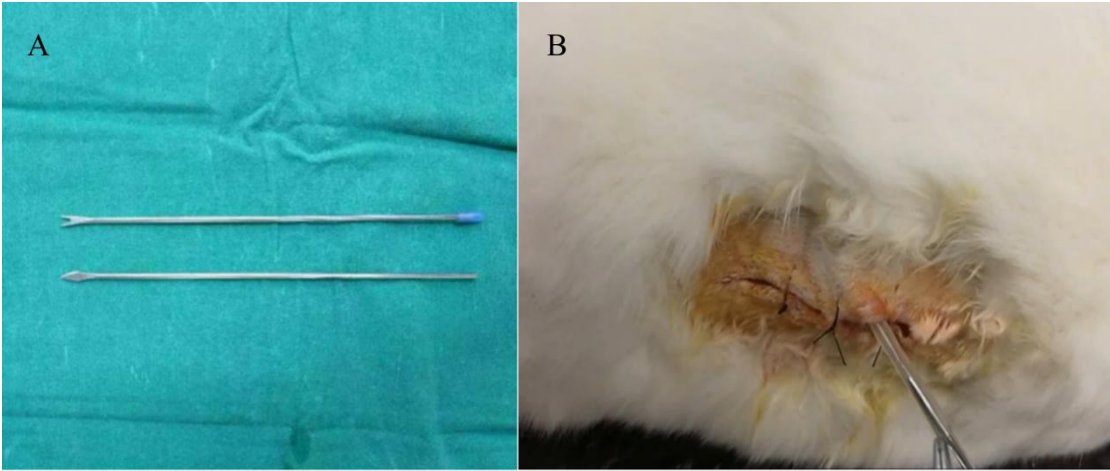


Figure.3 Animal experiment extraction procedure. (A) Photograph of the V-shaped and A-shaped specialized knives used in the experiments. (B) Intraprocedural photograph demonstrating insertion of the intraluminal knife into the drainage tube in the rabbit model.

Animal General Condition Assessment

The general condition of each rabbit was assessed at four time points: preoperative day 1, and postoperative days 1, 3, and 6. Assessment was performed by an investigator blinded to the extraction outcomes using a validated composite scoring system (maximum score = 8 points) incorporating four domains [12](Table.1):

Table.1 Composite Scoring System for General Condition Assessment

Domain	2 Points	1 Point	0 Points
Mental status	Alert and responsive	Lethargic	Obtunded / non-responsive

Food intake	Normal	Reduced by ~50%	Minimal or absent
Spontaneous activity	Unrestricted movement	Moderately restricted	Severely reduced
Response to external stimuli	Prompt response	Diminished response	No response

Note: Higher scores indicate better general condition. Maximum total score = 8 points.

Statistical Analysis

Statistical analyses were performed using SPSS version 22.0 (IBM Corp., Armonk, NY, USA). Continuous variables are expressed as mean $\pm$ standard deviation (SD). The primary outcome—comparison of extraction success rates (binary: success/failure)—was analyzed using Fisher's exact test, which is appropriate for 2×2 contingency tables with small expected cell frequencies. The secondary outcome—extraction time—was compared between groups using the independent-samples t-test following confirmation of normality (Shapiro-Wilk test) and homogeneity of variance (Levene's test). Animal general condition scores across the four time points were compared using repeated-measures analysis of variance (ANOVA) with post-hoc Bonferroni correction for pairwise comparisons. A two-tailed P Value < 0.05 was considered statistically significant. Given the exploratory nature of this study and the lack of prior data on the expected effect size, no formal a priori sample size calculation was performed.

Results

Animal General Condition

All 10 rabbits survived the surgical procedure and the postoperative observation period without mortality, wound dehiscence, surgical site infection, or other

er major complications. The mean composite general condition scores at the four assessment time points are presented in Table.2.

Table.2 Animal General Condition Scores Over Time (n = 10)

Time Point	Mean Score $\pm$ SD	Range	P Value*
Preoperative Day 1	8.00 $\pm$ 0.00	8 – 8	—
Postoperative Day 1	5.34 $\pm$ 0.47	5 – 6	< 0.05
Postoperative Day 3	6.31 $\pm$ 0.36	6 – 7	< 0.05
Postoperative Day 6	8.00 $\pm$ 0.00	8 – 8	NS

*P Values vs. preoperative Day 1 (repeated-measures ANOVA with Bonferroni correction). NS = not significant.

Postoperative day 1 scores were significantly lower than preoperative scores ($P < 0.001$), reflecting the expected transient impact of surgery and anesthesia. Scores on day 3 remained significantly below baseline but showed clear recovery ($P = 0.003$ vs. preoperative; $P = 0.002$ vs. day 1). By postoperative day 6, all animals had returned to the maximum score of 8, indicating complete recovery to baseline status.

Extraction Outcomes

The comparative extraction outcomes for the two blade configurations are summarized in Table.3.

Table.3 Comparison of Extraction Outcomes Between V-Shaped and A-Shaped Knives (n = 10 per group)

Outcome	V-Shaped Knife	A-Shaped Knife	Statistical Test	P Value
Success rate, % (n/N)	100% (10/10)	50% (5/10)	Fisher's exact test	0.033
Extraction time, min (mean $\pm$ SD)	2.3 $\pm$ 0.4	6.8 $\pm$ 0.6	Independent t-test	< 0.001

Note: Success was defined as complete, unbroken extraction of the drainage tube within 10 minutes of the first insertion attempt. Extraction time was recorded from the moment of initial blade insertion into the lumen until

complete removal of the tube.

The V-shaped knife achieved successful extraction in all 10 attempts (100% success rate), compared with only 5 of 10 attempts (50% success rate) for the A-shaped knife. This difference was statistically significant (Fisher's exact test, $P = 0.033$). Among successful extractions, the mean extraction time for the V-shaped device (2.3 ± 0.4 min, range 1.8–3.1 min) was significantly shorter than that for the A-shaped device (6.8 ± 0.6 min, range 5.9–7.5 min; $t = 19.72$, $P < 0.001$). The five failures with the A-shaped knife were attributable to the inability of the blade to securely capture and transect the retaining suture within the 10-minute time limit; in all five cases, subsequent crossover to the V-shaped knife resulted in successful extraction.

Clinical Case Outcome

In the 56-year-old male patient, the V-shaped intraluminal knife was employed on postoperative day 4. The blunt probing end was first used to locate the retaining suture, which was identified at approximately the proximal one-third of the intraluminal length of the drainage tube. The device was then reversed, and the V-shaped cutting end was advanced to the suture position. Under gentle manipulation, the suture was captured by the lateral protrusions, guided into the V-notch, and transected. The drainage tube was subsequently removed intact without resistance (Figure.3). The patient reported no significant discomfort during the procedure aside from mild pressure sensation. The extraction site healed uneventfully. At the 3-month follow-up, the patient demonstrated satisfactory clinical improvement with no wound complications, no neurological deterioration, and radiographically confirmed satisfactory implant position.

Discussion

This study presents the preclinical validation and initial clinical application

of a novel, low-cost intraluminal cutting device for the minimally invasive management of inadvertently sutured drainage tubes after lumbar spine surgery. The principal findings are: (1) the V-shaped blade configuration with bilateral blunt protrusions achieved a 100% extraction success rate in an animal model, significantly outperforming the A-shaped (simple wedge) configuration (50%); (2) extraction times with the V-shaped device were approximately one-third of those required by the A-shaped device; and (3) the technique was successfully and safely applied in a clinical case without the need for incision reopening. The marked performance difference between the two blade configurations can be explained by their respective geometric interactions with the retained suture filament. During retrograde advancement of the knife within the confined lumen of the drainage tube, the blade tip must contact the suture in a manner that reliably captures and transects it. The A-shaped (wedge) blade presents a central ridge that, upon contact with a cylindrical suture filament, tends to deflect the filament to one side or the other—much like an arrowhead glancing off a cord. This "slip-away" phenomenon underlies the 50% failure rate observed in our experiments. In contrast, the V-shaped blade incorporates bilateral blunt protrusions that extend laterally from the blade tip. These protrusions create a capture zone: as the blade is advanced and rotated, any suture filament in the vicinity is funneled into the V-shaped notch and entrapped by the protrusions. Once engaged, the filament is securely positioned against the sharpened inner edges of the V, and a combination of axial traction and rotational torque reliably transects it. This "capture-and-cut" mechanism is analogous to the function of certain endoscopic suture-cutting devices [13,14] but represents a novel application in the context of entrapped surgical drains. To the best of our knowledge, there are no commercially available instruments specifically designed for the intraluminal transection of inadvertently sutured drainage tubes. The default approach in most institutions remains reopening of the incision, suture identification, and tube removal [7,8]. This effectively constitutes an unplanned reoperation with its attendant risks. Reported alternatives include the application of sustained gentle

traction (which may cause tube breakage or subcutaneous avulsion), the use of interventional radiology techniques for percutaneous suture transection [15], and—in extreme cases—leaving the retained tube fragment in situ, which carries risks of foreign body reaction, infection, and migration. The device and technique described herein offer a middle-ground solution that is both minimally invasive and procedurally straightforward, requiring no specialized imaging equipment or interventional skill set beyond basic surgical competence.

The V-shaped intraluminal knife offers several practical advantages. First, it is fabricated from a standard Kirschner wire—a ubiquitously available and inexpensive orthopedic implant component. Any hospital with basic instrument modification capabilities can produce the device. Second, the technique has a short learning curve; the essential skills—lumen cannulation, suture localization, and controlled blade manipulation—are within the competency of any surgical resident. Third, the procedure can be performed at the bedside or in a standard treatment room under local antiseptic preparation, obviating the need for return to the operating theater. Fourth, the device and technique are potentially applicable across a wide range of surgical specialties in which closed suction drains are employed (e.g., general surgery, thoracic surgery, joint arthroplasty, neurosurgery), though additional specialty-specific validation would be required. From a health-economic perspective, avoiding an unplanned reoperation—even a minor one—yields savings in operating room time, surgical supplies, anesthesia costs, and prolonged hospitalization [16]. Furthermore, the avoidance of incision reopening preserves the integrity of the primary wound closure and may reduce the risk of surgical site infection [17,18]. While effective management of this complication is important, prevention remains paramount. Based on our clinical experience and a review of the literature, we recommend the following preventive measures:

1. Perpendicular drain placement: Traditionally, drainage tubes are placed parallel to the surgical incision. Because wound closure sutures are placed perpendicular to the incision, a parallel drain maximizes the probability of needle-drain int

ersection. Placing the drain such that it exits the skin 3–4 cm lateral to the incision midpoint creates a perpendicular intrawound trajectory, minimizing the zone of potential suture-drain contact [19].

2. Post-closure mobility check: After wound closure, the drain should be gently tugged; free movement of 1–2 cm within the subcutaneous plane suggests the absence of suture entrapment. Any undue resistance should prompt immediate investigation [20].

3. Staged closure technique: The deep fascial layer may be sutured loosely, the drain positioned under direct vision, and the fascial sutures then tightened—a technique that ensures the drain is not interposed within any suture loop [21].

4. Surgical discipline and training: Many instances of drain suturing are attributable to haste, inattention, or inadequate visualization during wound closure [22].

Dedicated education of residents and operating room staff regarding this complication and its prevention should be integrated into surgical training curricula.

This study has several limitations that warrant acknowledgment. First, the animal experiment employed a small sample size ($n = 10$ per device group), which limits the precision of the estimated success rates and precludes robust subgroup analyses. Although the difference in success rates achieved statistical significance, the wide confidence interval around the 50% estimate for the A-shaped device (95% CI: 18.7%–81.3%) reflects this imprecision. Second, the rabbit model involved a retroperitoneal (anterior) surgical approach, whereas the clinical scenario of interest involves a posterior approach with different anatomical tissue planes and suture configurations. While the fundamental mechanical interaction between the blade and the suture is approach-independent, the translational validity of the model could be questioned. A large-animal posterior spine surgery model (e.g., porcine or ovine) would provide greater anatomical fidelity. Third, only a single clinical case is reported; the safety and efficacy profile of the device in a larger, diverse patient population remains to be established. Variables such as patient body habitus, drain type and diameter, depth of suture placement, and the presence of surgical site infection could all influence device

performance. Fourth, the long-term safety endpoints—including the potential for retained metallic fragments from blade wear, inflammatory reaction at the transaction site, and late drain tract complications—were not systematically evaluated. Fifth, the study did not include a formal cost-effectiveness analysis. A prospective, multicenter clinical registry or a randomized trial comparing the intraluminal knife technique with conventional incision reopening would provide higher-level evidence to guide clinical adoption.

Conclusion

The novel V-shaped intraluminal knife fabricated from a standard Kirschner wire provides a safe, rapid, and highly effective minimally invasive method for extracting inadvertently sutured drainage tubes after lumbar spine surgery. Its

V-shaped blade with bilateral blunt protrusions reliably captures and transects intraluminal retaining sutures, achieving a 100% success rate in a rabbit model and successful clinical application. By eliminating the need for incision reopening, this low-cost, technically accessible device has the potential to reduce patient morbidity, healthcare resource utilization, and the incidence of unplanned reoperations associated with this vexing surgical complication. Further clinical evaluation in larger patient cohorts across multiple surgical specialties is warranted.

Declarations

Abbreviations

BMI: Body mass index; CI: Confidence interval; SD: Standard deviation; ANOVA: Analysis of variance.

Ethics Approval and Consent to Participate

All animal experiments were approved by the Institutional Animal Care and Use Committee of Ningxia Medical University General Hospital (Approval No.: KYLL-2024-08

67), and all animal procedures were conducted in accordance with the relevant institutional and national guidelines and regulations for the care and use of laboratory animals. The human clinical case was reviewed and approved by the Ethics Committee of Ningxia Medical University General Hospital Approval No. KYLL-2025-1125). All procedures involving the human participant were performed in accordance with the ethical standards of the institutional and national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Written informed consent to participate was obtained from the patient prior to the procedure.

Consent for Publication

Written informed consent for publication of the patient's clinical details and any identifying images was obtained from the patient. A copy of the written consent is available for review by the Editor of this journal.

Availability of Data and Materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing Interests

The authors declare that they have no competing interests.

Funding

This study did not receive any specific funding from public, commercial, or not-for-profit funding agencies.

Authors' Contributions

LS and TN contributed equally to this work. LS, TN, and LH conceived and designed the study. LS, TN, GD, ZL, and DY performed the animal experiments and acquired the data. LS and TN analyzed and interpreted the data. LH performed the clinical p

procedure and supervised the study. LS and TN drafted the manuscript. LH critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript.

Acknowledgements

The authors would like to thank the staff of the Experimental Animal Center of Ningxia Medical University for their technical assistance during the animal experiments.

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