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TECHNICAL NOTE

Usefulness of the knot-tightener device following dural suturing in endonasal transsphenoidal surgery: technical report

Kosaku Amano[1] · **Yoshikazu Okada**[1] · **Takakazu Kawamata**[1]

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Abstract

Transsphenoidal surgery (TSS) has become a well-established standard surgical technique, but the cerebrospinal fluid leakage remains controversial. Direct suturing of the dura, which is a routine procedure within transcranial surgery, can be applied for closure of the sella turcica within TSS. However, as the dura is not accessible by the index finger, knot tying in the narrow and deep surgical corridor following dural suturing is extremely difficult, cumbersome, and time-consuming in TSS. Here, we present a new, simple, and effective technique for knot tying using our newly developed instrument the "knot tightener" (UC-6603: Medical U & A, Inc., Osaka, Japan) to solve this challenge. The knot tightener has a total length of 235 mm and is bayonet shaped. The tip is 5 × 10 mm in diameter and has one long arm and two short curved arms. The long arm has a dimple which can hook and hold a thread, fulfilling the role of an index finger. Together the two short curved arms make a half circle and are able to hook a thread easily. From the 28th of March 2011 to August 2018, we used the knot-tightener device for 566 patients who underwent endonasal TSS, to deliver and tie knots following stitching of the dura using 6–0 nylon. The device was able to easily deliver a knot from outside of the nostril to the sella turcica through the nasal cavity and successfully tighten it firmly. No complications were observed, confirming the safety of the newly designed instrument. The knot tightener can be considered to be an optimal tool for the challenging surgical procedure of knot tying following dural suturing in TSS. Its potential future applications may extend to include other neurosurgical procedures in anatomically restricted areas.

Keywords Transsphenoidal surgery · Dural suturing · Knot tying · Narrow and deep surgical corridor

Introduction

Transsphenoidal surgery (TSS) has become a well-established standard surgical technique for the removal of pituitary and parasellar region tumors. Accordingly, intra-operative cerebrospinal fluid (CSF) leakage, which occurs increasingly with aggressive removal of tumors, and post-operative CSF leakage remain a major problematic complication [1–4]. Various methods of fistula repair and sella reconstruction have been attempted in order to prevent CSF leakage, such as using autologous grafts, heterologous artificial materials, and vascularized mucosal flaps [1, 5–18]; however, none of these methods is yet perfect. Direct suturing of the dura is a routine procedure within transcranial surgery (TCS) and is seen as the ultimate method for achieving closure of the sella turcica in TSS [19–25]. However, as in TSS may give a more restricted surgical field, compared to TCS, standard tools and even those instruments dedicated to TSS cannot always easily reach the necessary surgical fields while maintaining free manipulability [26]. Dural suturing within TSS is further complicated by the narrow and deep working space requiring increased effort to complete. Additionally, the limited surgical corridor also means that knot tying itself is also extremely difficult following dural suturing [22, 25, 27–29] as the dura is not accessible by the surgeon's finger. Performing dural suturing and knot tying in such a surgical field is technically challenging and

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✉ Kosaku Amano
kamano@twmu.ac.jp

Yoshikazu Okada
yokada@twmu.ac.jp

Takakazu Kawamata
tkawamata@twmu.ac.jp

[1] Department of Neurosurgery, Tokyo Women's Medical University, 8-1 Kawada-cho, Shinjuku-ku, Tokyo 162-8666, Japan

time-consuming. In this report, we present a new, simple, and effective technique for knot tying using our newly modified instrument the “knot tightener” (UC-6603: available for purchase through Medical U & A, Inc., Osaka, Japan). The device enables a knot to be easily slid deep into the suturing point and tied firmly, even within the narrow and deep working space for TSS.

Materials and methods

Concept of the knot tightener

A knot tightener was constructed intended to enable the smooth delivery of a knot to the sella turcica during TSS, before tying it firmly deep within the surgical field. The surgical field can be visualized with a rigid endoscope but is not easily accessible nor does it allow good operability with conventional instrumentation. Therefore, our aim in designing the shape of the knot-tightener device was for it to be capable of easily catching a knot, smoothly sliding it to the sella turcica, and tightening it firmly without fault. Our objective was to use the instrument to facilitate the necessary surgical procedures in the severely limited endoscopic surgical field.

Structures of the knot tightener

The newly developed knot tightener has the following structures and functions. It has a total length of 235 mm and is bayonet shaped (Fig. 1a). The instrument is long enough to be placed into the surgical field, the sella turcica, through the nostril over a rigid endoscope. The tip is 5 × 10 mm in diameter and has one long arm and two short curved arms. The long arm has a dimple which allows hooking and holding of a thread, fulfilling the role of an index finger. The two short curved arms make a half circle and are able to hook a thread easily. When inserted into the nasal cavity appropriately, the device is able to grab a thread without difficulty, using either the long arm or short arms (Fig. 1b–d).

Clinical applications and usage of the knot tightener

Tests were performed before surgery to investigate the safety of the knot tightener as well as its maneuverability, including manipulation, fixation, and balance of the tip when inserted into the nasal cavity. Informed consent of using the knot tightener was performed to patients preoperatively.

In the TSS procedure, a deep suturing needle holder (8055-02, 8055-03, FUJITA, Tokyo, Japan) specifically designed for TSS and a small needle (5 mm in diameter, 1/2 circle) with 6–0 monofilament nylon (polyvinylidene fluoride suture: Asflex®; Kono Seisakusho Co., Ltd., CROWNJUN, Japan) is used for stitching the dura. The lower and upper edges of the dura, which are everted during tumor resection, are approximated together, held into the center, and replaced to their original position after the tumor resection, so as to obliterate the fistula point. The dura is sometimes sutured with fat, muscle, or sphenoid sinus mucosa when a watertight closure is required.

Figure 2 is a schematic diagram demonstrating how to slide and tighten knots. After threading the dura, a first knot is made manually outside the nostril. Next, one end of the suture filament is held by an assistant and the other end by an operator. A knot is then hooked by any of the three arms of the knot tightener (Fig. 3a) and slid through the nasal cavity deep into the surface of the dura (Fig. 3b). A second knot is made outside of the nostril and both sides of the suture filaments pulled up. Keeping tension on both strings, the first knot, located close to the dura, is hooked by the dimple of the long arm and tightened to the dura as if using an index finger (Fig. 3c). Subsequently, without pausing, and while maintaining tension on both strings, the second knot is hooked, slid deep into the dura (Fig. 3d), and firmly tightened. Another third knot is

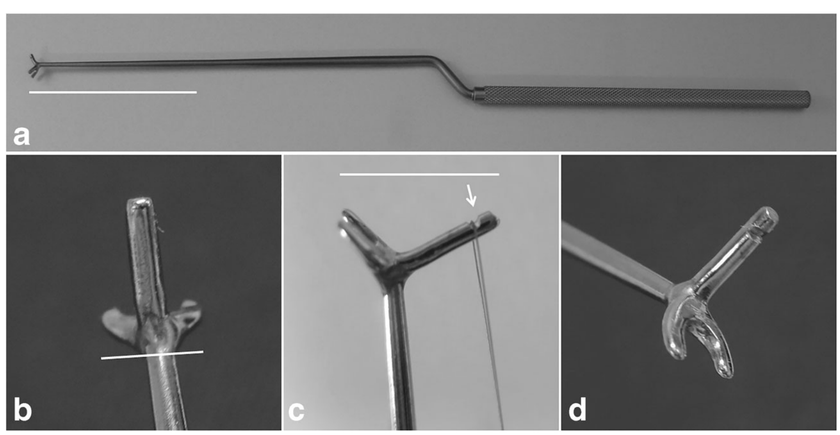


Fig. 1 **a** The knot tightener has a total length of 235 mm and is bayonet shaped. The white straight line indicates 50 mm. **b** Overhead view demonstrates the one long arm and two short arms. The white straight line indicates 5 mm. **c** The lateral view of the tip of the knot tightener, hooking of a 6–0 nylon. The arrow shows the dimple which hooks the thread. The white straight line indicates 10 mm. **d** Right lower oblique view

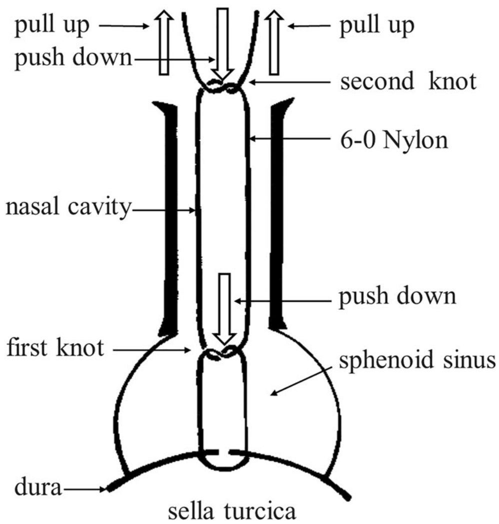


Fig. 2 The schematic diagram demonstrating how to slide and tighten knots

made again outside of the nostril, slid into the dura, and tightened; however, at that point, it is no longer necessary for tension in both strings to be maintained. Finally, the excess suture filaments are cutoff at the end. Further details of the procedures are demonstrated in the supplemental video.

Results

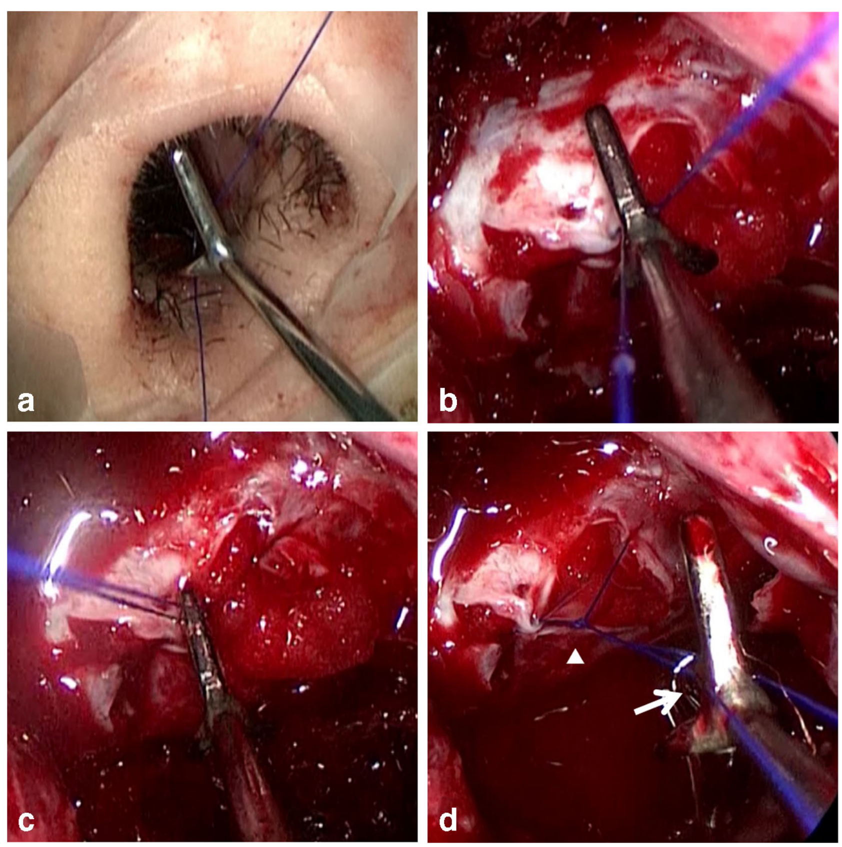
From the 28th of March 2011 to August 2018, we used the knot-tightener device for 566 patients who underwent endonasal TSS, to tie knots following stitching of the dura using 6–0 nylon.

The knot tightener was able to deliver knots easily from outside of the nostril to the sella turcica through the nasal cavity. Conventional TSS instruments, such as ring curettes and tumor forceps, are not able to hook knots stably, nor be easily manipulated at the sella turcica. The inserted knot was successfully tightened and fixed firmly using the device. No complications arising from the use of the knot tightener were observed in the present series, confirming the safety of the newly designed instrument.

Discussion

During transcranial surgery (TCS), watertight suturing of the dura is done routinely in order to prevent CSF leakage, which is a constant potential problem that may result in serious sequelae. This procedure is a simple, practical, and common method performed at the end of surgery and is the most reliable and ideal means for primary closure of a fistula. It goes

Fig. 3 **a** Making the first knot outside of the nostril and hooking the knot using any of the arms of knot tightener. **b** Sliding the first knot through the nasal cavity and sending it close to the dura. **c** After making a second knot outside the nostril, hooking and tightening the first knot using the long arm of knot tightener with both threads pulled up. **d** Hooking sliding a second knot using the any of the arms of knot tightener while keeping tension on both threads. Triangle, first knot on the dura; arrow, second knot. In the end, hooking and tightening the second knot firmly using the long arm of knot tightener with both threads pulled up as (**c**)



without saying that suturing of the dura for TSS must also be carried out as a routine procedure. As suturing of the sella dura through TSS has been performed routinely at our facility since 1998, the accurate comparison between before and after the procedure is difficult and we were not able to directly demonstrate the efficacy of dural suturing in TSS. However, previous reports have shown a reduction in the rate of CSF leakage resulting from dural suture in TSS [19, 20, 22, 23]. This technique is not a stand-alone method for sella reconstruction but would be an effective means in TSS for complete repair of a small to large fistula to help prevent CSF leakage. On the occasion that CSF leakage was identified during surgery, we utilized oxidative cellulose (Surgicel®), gelatin sponges (Gelfoam®), and/or fibrin glue for tumor bed packing and sutured the dura. In patients with large dural defects, and major, high pressure, or massive intra-operative CSF leakage, we utilized autologous grafts, such as a fat, fascia, or sphenoid sinus mucosa as means to fill the dural defects and accomplish watertight dural closure with suturing [1]. Additionally, we also use a pedicled flap, such as sphenoid sinus flap or nasal septal flap, in case these procedures alone were not sufficient to prevent CSF leakage [1, 14, 16]. During surgery, we routinely put at least one or two stitches between two counterpart corners of the crosswise-incised dura, even in cases where there was only a minor CSF leak, or no evidence of CSF leakage at all.

The purpose of dural suturing is (1) reduction of the "gap" of dural defects and facilitation of dura regeneration, (2) maintaining sufficient tension of the dura to resist CSF pulsatile pressure, (3) supporting the intra-extra sella graft to prevent migration occurring, (4) watertight closure. Although watertight closure was not achieved, nor needed, in every case, narrowing of the dural defect, maintaining the tension of the dura, and supporting the intra-sella graft was achieved in all patients. If the dura was sutured tightly, then autologous grafts were only utilized to ensure watertight closure when major CSF leakage developed. Suturing the sella dura in TSS is one method to consider which reduces the risk of CSF leakage and carries fewer disadvantages.

However, due to the restricted working chamber and deep and narrow surgical corridor, achieving complete suturing of the dura in TSS is technically challenging, cumbersome, difficult, and a time-consuming [19, 21, 24, 27]. TCS, on the other hand, has a shallow and wide surgical field and allows access of the index finger. Hence, it is vital that the surgeon becomes familiar with the use of dural suturing instruments in potentially conflicting situations. This explains why dedicated instruments are in development to optimize these surgical procedures, help surgeons improve the effectiveness of the approach, work with easier and surer movements, shorten the surgical times, and save effort. In general, dedicated long, bayoneted instruments that accommodate manipulation within a narrow deep space are essential for TSS. Furthermore, when instruments are introduced, their degree of freedom is limited greatly by the presence of the endoscope, making instrumental manipulations difficult and often ineffective. We developed the knot-tightener device to overcome or minimize, these maneuverability issues even in endoscopic procedures for TSS. The knotting technique used in TSS is the same as that for skin or dural suturing in TCS and aims to replicate the same procedure. The main and biggest problem in TSS is that both sides of strings cannot be stretched to their opposing sides, making it difficult to push the knot from outside to inside of the nasal cavity, slide it to the dura, and tighten it at the sella turcica, as an index finger cannot access the narrow and deep corridor. To solve these problems, the knot-tightener device delivers the knot from outside of nostril to the dura without stretching the strings and tightens it at the dura using the long arm of knot tightener in place of an index finger.

The tip of knot tightener is designed to facilitate knot sliding and tightening and so as not to interfere with the surgical view, or the endoscope and/or any other instrumentation present in the narrow surgical field. The use of refined dedicated instruments makes the surgical procedure easier and more effective. Our newly modified knot tightener enables procedures to be carried out in the nasal cavity, sphenoid sinus, and sella turcica more easily and more securely. We acquire the ability to make, deliver, and tie knots within a few minutes in TSS with knot tightener.

Recent advances in extended endoscopic endonasal surgery, in which large dural defects and massive intra-operative CSF leakage have been encountered, have increasingly demanded more secure reconstruction procedures to ensure complete closure [22, 30–33]. This has led to the proposal of numerous and varied techniques for the repair and prevention of CSF leakage in TSS, such as the packing or patching autologous grafts and/or artificial materials. Reconstructive techniques have progressed further since the introduction of extended TSS for the removal of suprasella and huge tumors. Use of the vascularized mucoseptal flap and sphenoid sinus mucosal flap is reliable and simple methods for preventing CSF leakage [1, 12–18]; however, they are still not perfect. In addition, utilization of a vascularized mucoseptal flap may not be possible in some situations, such as recurrent cases with septum perforation, and is not effective for all cases [1]. Accordingly, suturing techniques of the sella dura employed some kind of graft materials to cover the fistula point or to pack up the free space adjacent to it. Therefore, watertight closure by patch grafting with nylon sutures is an excellent and ideal expedient [23]. In our study, we found that the knot tightener was critically useful in endoscopic suturing to fix graft patches with absolute accuracy through the endonasal route, even in extended TSS. In this regard, the knot tightener may be able to overcome these drawbacks.

Once the dura has been successfully stitched, within the deep and narrow surgical field, the knot must be delivered to the dura smoothly and tightened surely to avoid the knot coming loose and the considerable effort involved being wasted. Ahn JY and Kim SH, and Jimbo H et al. already proposed the same concept and procedures, and similar instrument for tying the knot in TSS [25, 27]. However, our methods and knot tightener are easy to use even under endoscopic manipulation and perceived intuitively because it can be used as same as the index finger. Furthermore, in case the dura was thin and fragile, it can adjust the tension to threads and dura delicately so that the dura is not cut or torn. Previously, there also have been other reports on knotting technique without instrument following dural suturing for TSS, such as “knot-tying technique” [22], “easy slip-knot” [28], and “sliding-lock-knot technique” [29]. In all of these techniques, the knot is made outside of the nostril, before being slid deep into the operative field. Although they are simple and effective techniques, as not all thread is smooth enough to it slides freely, the knot risks becoming stuck or loosening. Furthermore, as the materials being sutured, such as dura, fat, fascia, and mucosa, are fragile and soft, excessive tension on the thread risks tearing. We are confident that in such cases, our newly modified knot-tightener device is able to succeed in sliding and tightening a knot securely at the sella turcica. The single point which the surgeon and assistant should however take care with is not to pull the string too strongly, but just hold it until the knot is pressed by the knot tightener, in order not to rip the dura. Furthermore, this technique can also be used in situations other than TSS where a surgeon may need to tie a suture in a deep surgical area, such as spinal surgery, posterior fossa surgery, and paraclinoid surgery among others. If the device were optimally used for other skull base surgeries and spine surgeries, we believe its future applications could be widely expanded.

Our new method to deliver and tie knots using knot tightener following dural suturing for TSS is an extremely simple, reproducible, and secure technique. This instrument enables dural suturing of sella closure to be significantly easier, certain, and require less effort. We believe that dural suturing techniques should be mastered by every pituitary surgeon in order to prevent potential CSF leakage and that our knot-tightener device is the necessary instrument to achieve this procedure.

Conclusion

The knot tightener is a safe, simple, effective, helpful, and optimal tool for the challenging surgical procedure of knot tying following dural suturing in transsphenoidal surgery. It facilitates maneuverability in anatomically restricted areas. In the future, its potential applications may be expanded to include other neurosurgical procedures.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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