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Kelly procedure for exstrophy or epispadias patients: Anatomical description of the pudendal neurovasculature

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Summary

Introduction—Adequate penile length in males with bladder exstrophy or epispadias is a major challenge. Kelly previously described a surgical technique of a single stage reconstruction for patients with exstrophy or epispadias that potentially achieves significant penile lengthening by completely detaching the insertion of the corpora cavernosa from the ischiopubic rami. However, because of the possibility of damage to the pudendal neurovascular supply that may lead to partial or complete penile loss, this technique has not gained popularity. The aim of this study is to describe the surgical anatomic relationship of the pudendal neurovascular bundle (NVB) to the ischiopubic rami and to determine a safer approach to dissection during the Kelly procedure.

Methods—We performed meticulous dissection in three formalin-fixed and one fresh adult male cadavers to demonstrate the anatomical relationships between the pudendal neurovascular supply of the penis and the cavernosal insertion to the ischiopubic ramus.

Results and discussion—We demonstrated the relationships and distance between the NVB and the area of separation between the crus and the ischiopubic ramus at the level of the periosteum. The insertion of the crus to the ischiopubic ramus is inferior lateral, whereas the NVB lies at a superior medial position. This anatomical relationship is best visualized when the dissection is carried out starting from the distal portion of the NVB and proceeding proximally. This area of the periosteum is avascular and the NVB can be preserved safely as long as the dissection is conducted at that subperiosteal level.

Based on this cadaver dissection study, we suppose that detaching the corporal cavernosa from the pubic bones at the subperiosteal level allows for a safe distance to be maintained from the pudendal nerve at all times. We believe that if a surgeon performs the dissection inferiorly and laterally, the corpora cavernosa can be safely detached from the ischiopubic ramus and injury to the pudendal vessels and nerve can be avoided. However, it must be noted that there are limitations to applying the results from this study of normal, adult cadavers to the anatomy of children and adolescents with exstrophy or epispadias, who form the largest proportion of patients who are candidates for this procedure.

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Conflict of interest

None.

Conclusion—This anatomical study demonstrates the relationship between the pudendal NVB, the crus, and the ischiopubic ramus. We demonstrated how the separation of the crus from the ischiopubic periosteum might be performed more safely.

Keywords

Bladder exstrophy; Epispadias; Penile length; Kelly procedure

Introduction

Appropriate penile length in males with exstrophy and epispadias has always been a challenge to achieve. Some of these patients do not achieve a penile length that is satisfactory for intercourse, while others face difficulty with vaginal penetration and are limited to certain positions during intercourse. A pelvic MRI study has previously demonstrated that the overall length of the corpora cavernosa in this patient population is significantly shorter than in controls [1]. Whereas the posterior segment of the corpus cavernosum, attached to the pubic ramus, is normal in those with exstrophy or epispadias; the anterior segment of the epispadiac penis is shorter when compared with normal anatomy. This combination leaves the visible aspect of the penile shaft shorter. In addition, the distance between the pubic bones causes a wide separation of the crura. Consequently, the shorter penile length in a patient with exstrophy or epispadias is a combination of the inherent shortness of the corpora and the wide pubic diastasis.

The goals of phalloplasty include reconstruction of a ventral urethra reaching the tip of the penis, correction of dorsal chordee, and an improved cosmetic appearance. Currently, the total penile disassembly technique proposed by Mitchell, and the Cantwell procedure modified by Ransley, are the two most popular phalloplasty techniques [2,3]. Although both result in a cosmetically acceptable penis, it is still shorter and wider than a normal phallus.

In 1971, Kelley and Eraklis described a surgical technique for a single stage reconstruction for those with exstrophy or epispadias that achieved significant improvement in penile length by completely separating the insertion of the corpora cavernosa from the ischiopubic rami [4]. In the Kelly technique, the surgeon detaches the corpora cavernosa from their attachments to the ischiopubic rami and re-approximates them in the midline therein achieving an exteriorized cylindrical phallus with improved penile length.

During the bilateral mobilization of the corpora cavernosa, meticulous and precise technique is essential to avoid pudendal pedicle neurovascular damage. Accidental damage to the neurovascular bundle (NVB) may lead to venous congestion or arterial compromise, that could result in total or partial loss of the glans or corpora and decreased sensation. The complexity of the surgical dissection along with the complex anatomy of these patients, and the risk of damage to the NVB, has limited the widespread application of the Kelly technique [5,6].

The aim of this study is to describe the surgical anatomic relationship of the pudendal NVB and to present a safer approach to dissection, which will enhance surgeon confidence in

successfully performing the Kelly procedure for the treatment of patients with exstrophy or epispadias.

Methods

Detailed dissections were performed in three formalin and one fresh normal, adult male cadavers, demonstrating the anatomic relationship between the neurovascular supply of the penis and the cavernosal insertion to the ischiopubic ramus.

The perineal dissection was performed with cadavers in the supine position (similar to the Kelly surgical technique). We started the dissection with complete de-gloving of the penis, excising and removing the skin and dartos layers to expose the penile Buck's fascia, the suspensory ligament, and ischiopubic ramus (Fig. 1). We then proceeded to divide the suspensory ligament, exposing the pubic symphysis. Next we dissected the penile crus from a distal to proximal direction towards the inferior pubic ramus. The attachment of the crus to the ischiopubic ramus is inferior lateral, whereas the NVB lies at a superior medial position (Figs. 2 and 3). We performed this portion of the dissection in the subperiosteal plane, to reduce the likelihood of injury to the NVB.

The periosteum was incised in an elliptical fashion where the crus joined the inferior pubic ramus. We then elevated the periosteum and the attached crus off the bone in an attempt to gain greater mobility of the crus. The canal was unroofed to allow medial mobilization of the NVB. A limited dissection of Alcock's canal was also performed.

The pudendal nerve was dissected throughout its course from Alcock's canal to the dorsum of the penis. This was performed bilaterally using both perineal and trans-abdominal approaches. The branching pattern of the nerve and its topographic relationship was recorded and photographs were captured. The position of the nerve relative to the internal pudendal vessels, and to the corpora was noted at the point where the NVB exited the pelvis. During the dissection, we separated the corpora from the ischiopubic ramus at the level of the periosteum as advised in the Kelly procedure.

Ethical approval was given for this study from the University of California, Irvine.

Results

Anatomy of the pudendal nerve

The pudendal nerve arises from the sacral plexus (Fig. 4) then passes between the piriformis and ischiococcygeus muscles before exiting through the greater sciatic foramen. Near the ischial spine, the pudendal nerve pairs with the internal pudendal vessels and curves over the sacrospinous ligament, before re-entering the pelvis through the lesser sciatic foramen. The pudendal nerve, along with accompanying vessels, then passes through Alcock's canal (pudendal canal), which is located on the medial aspect of the pelvic wall and originates from the fascia of the obturator internus muscle. After leaving Alcock's canal, the distal branches of the pudendal nerve and internal pudendal vessels are responsible for supplying the surface, erectile tissue, and bulb region of the penis, perineum, inferior rectum, and posterior scrotum (Fig. 4). The proximal lateral part of the tunica albuginea of the corpus

cavernosum inserts into the periosteum of the ischiopubic ramus along its inferior medial aspect (Fig. 5).

We noted that by initiating the dissection at the distal most aspect of the NVB and proceeding proximally (from the penis towards the pelvis), these anatomic relations were more readily visualized.

By elevating the periosteum and the attached crus off the bone, excellent mobility of the crus was achieved and protection of the NVB as it entered the pelvis. Damage to the neurovascular bundle was ruled out by visual impression of the surgeon (Figs. 1–3). Visualizing the NVB from the penile side and following as it entered the pelvis, helped identify its exit point from Alcock's canal. The canal was unroofed to allow medial mobilization of the NVB to gain greater length.

During the dissection of the non-exstrophy fresh cadaver, we found that there was no additional penile mobility and length gained by opening Alcock's canal.

Discussion

The Kelly procedure for patients with bladder exstrophy and epispadias is a technically demanding surgery that requires the surgeon to pay a great deal of attention to the penile neurovascular supply. The operation can be unforgiving, causing significant and irreversible morbidity with even minor vascular compromise.

Berrettini *et al.* were previously able to show that with careful deep dissection of the corpora cavernosa, irreversible impairment of erectile function could be reduced, and even prevented [6]. In their series, parents of children who underwent the procedure reported that their children continued to have erections after surgery in all cases. They did, however, report that two out of their nine patients experienced ischemic injuries to the glans, with glans loss following the Kelly procedure in those cases. Given this fact, that over 22% of the patients had some sort of vascular injury to the glans, it is not unreasonable to infer that the vascular pedicle may be tenuous and that patients may be at increased risk for developing significant vascular compromise during certain aspects of the radical soft tissue dissection. The highest risk is during the dissection that is usually performed at the base of the epispadiac penis, which is inherent to the Kelly procedure, and so our suggested approach to the vascular pedicle may be of great importance in minimizing this potential ischemic injury.

Cervellione *et al.* have suggested that compression of the pudendal vessels after pubic apposition and/or direct injury to the pudendal vessels with suboptimal placement of sutures through the blood supply, may play important roles in the pathogenesis of vascular compromise [8]. Direct injury to the vessels will undoubtedly compromise the integrity of the corporal and glanular tissues after surgery, as will impeded venous drainage, which may arise after closure of the pelvic bones. The reduced venous drainage may occur as closure of the pelvic bones may alter the arteriovenous pressure gradients across the capillary bed of the tenuous vascular pedicle, leading to reduced capillary inflow and tissue perfusion. Suboptimal closure of the pelvic bones may be a direct causative factor, suggest the authors

[8]. Much of these data have been gleaned from basic science work in skeletal muscle and bone and joint literature [9–11].

Our study clearly demonstrates the importance of understanding the precise anatomic relationship between the pudendal NVB and the insertion of the corpora cavernosa crura to the pubic bone in normal, non-exstrophy patients. Even though our work was done in the non-exstrophy patient with normal pelvic anatomy, it can serve as a useful guide to understand the expected landmarks when attempting the surgery in those patients with exstrophy and epispadias and open pelvis.

Detaching the corporal cavernosa from the pubic bones at the subperiosteal level allows for a safe distance to be maintained from the pudendal nerve at all times. It illustrates its relationship to the corpora cavernosa at the superior medial aspect, at which it is at greatest risk for injury. If a surgeon performs the dissection inferiorly and laterally, the corpora cavernosa can be safely detached from the ischiopubic ramus, and injury to the pudendal vessels and nerve can be avoided.

This approach also provides a novel method to achieving the basic goals that are set out in the Kelly procedure, which are essentially to alter the path of the NVB complex and allow the base of the erectile bodies to move closer to the level of the skin. We believe that approaching the surgery in this way allows the surgeon to have better access and enhanced visualization to the critical structures that have long been difficult to identify and more challenging to dissect. We believe it is for this reason that many pediatric urologists, even experienced ones, have hesitated in offering this potentially beneficial surgery, which can augment the length of the penis.

In patients with exstrophy or epispadias, the pubic rami may be significantly separated. Given that there was an obvious increase in the mobility of the erectile bodies in normal cadavers, which is clearly seen in Fig. 3, in patients with widely separated pubic rami, the Kelly procedure and the benefits of increased penile mobility may be even more impressive, with potential for a greater relative increase in length. Essentially, the benefits of the Kelly procedure would be more enhanced in exstrophy or epispadias patients, than in those with normal pelves, such as the cadavers used in this study. This needs to be confirmed, however, in subsequent studies.

During the dissection of the non-exstrophy fresh cadaver, we found that there was no additional length gained by opening Alcock’s canal. This may not hold true in exstrophy patients, however, as their pubic bones and the ischiopubic rami are widely divergent and thus Alcock’s canal is located more laterally. The corpora cavernosa must also travel a greater distance to join at the midline.

We recognize, as previously alluded to, limitations to performing an anatomic dissection of normal, adult cadavers and applying the results from this study to the anatomy of children and adolescents with exstrophy or epispadias, who make up the greatest proportion of potential candidates for this procedure. Ideally this study would have been conducted in pediatric cadavers with exstrophy or epispadias. However, this would be extremely difficult to achieve. Other limitations include the use of formalin-fixed cadavers rather than all fresh

cadavers. Ideally, this approach, which we believe could be performed in live patients, would actually have been performed in live patients; however, the time required to perform this type of dissection and exposure needed to optimize collection of audio and visual educational media would not be practical or ethical in the real-life surgical theater.

Conclusions

We believe that this study will help the experienced pediatric urologist safely perform the Kelly procedure, which has the potential advantages of being a single stage reconstruction for those with exstrophy or epispadias.

This study demonstrates that the pudendal NVB is located in a superior medial position relative to the corpora cavernosa. If dissections of the crura are initiated at the level of the ischiopubic periosteum, damage to the NVB may be reduced and even avoided entirely. We hope that this detailed demonstration will aid experienced pediatric urologists, who wish to perform this highly technical and challenging Kelly procedure, to achieve increased penile length in males with exstrophy or epispadias more safely.

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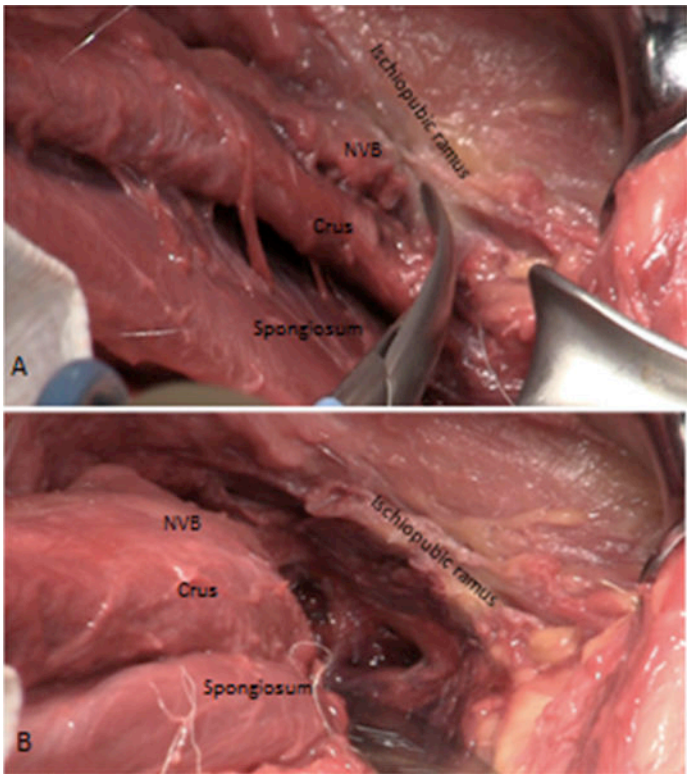

Figure.

Fresh cadaver dissection (A) before incision of the crus from the ischiopubic ramus, and (B) after incision of the crus from the ischiopubic ramus.

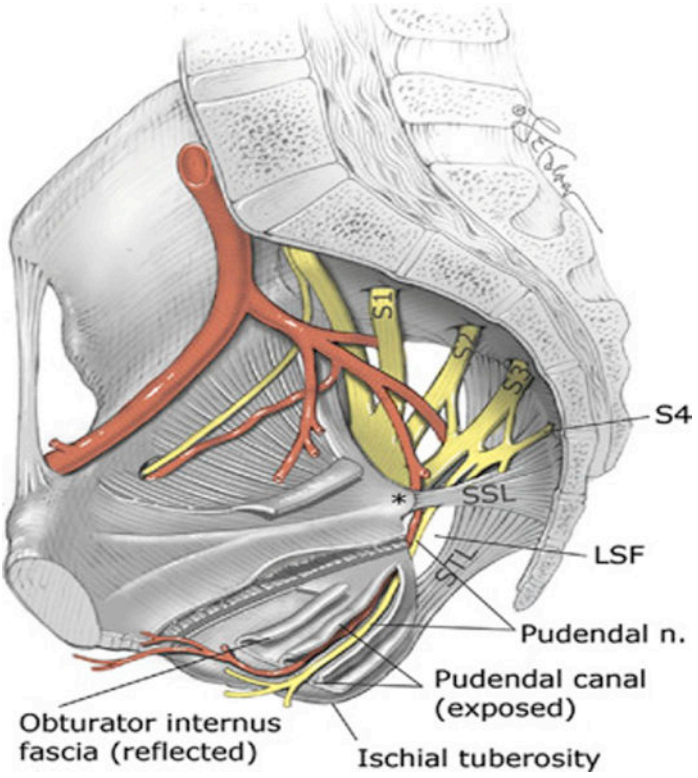

Figure 1.

Course of the pudendal nerve (n) in the pudendal canal. * = ischial spine; LSF = lesser sciatic foramen; SSL = sacrospinous ligament; STL = sacrotuberous ligament; S1–S4 = first through fourth sacral nerves. ©Elsevier [7].

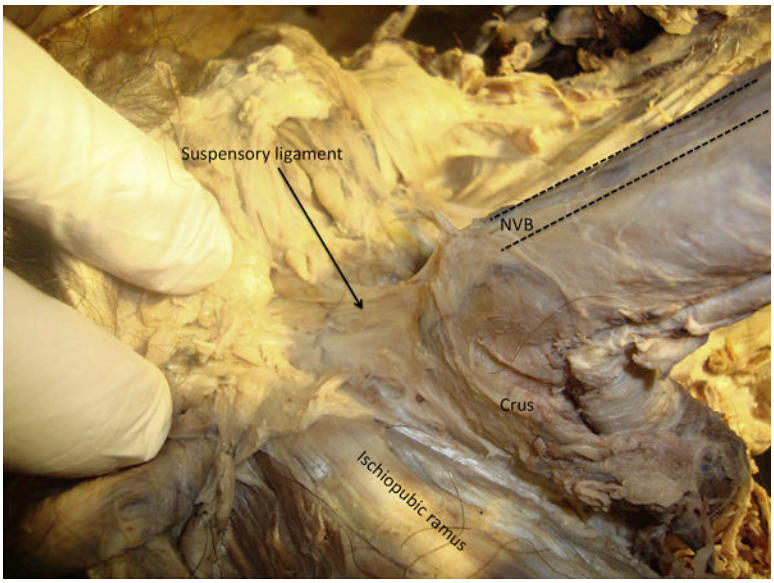

Figure 2.
Formalin cadaver dissection showing the penile base after removal of the skin and subcutaneous tissue. NVB = neurovascular bundle.

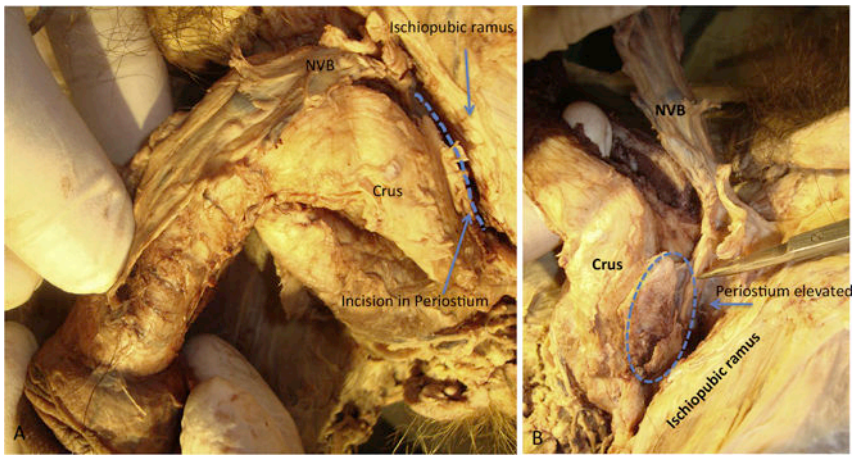

Figure 3.

Formalin cadaver dissection after incision of the cavernosal crus from the ischiopubic ramus. (A) The blue line represents the line of periosteum incision. (B) The blue elliptic area represents the incised plan of cavernosal crus, after incision from the Ischiopubic rams and retraction medially.

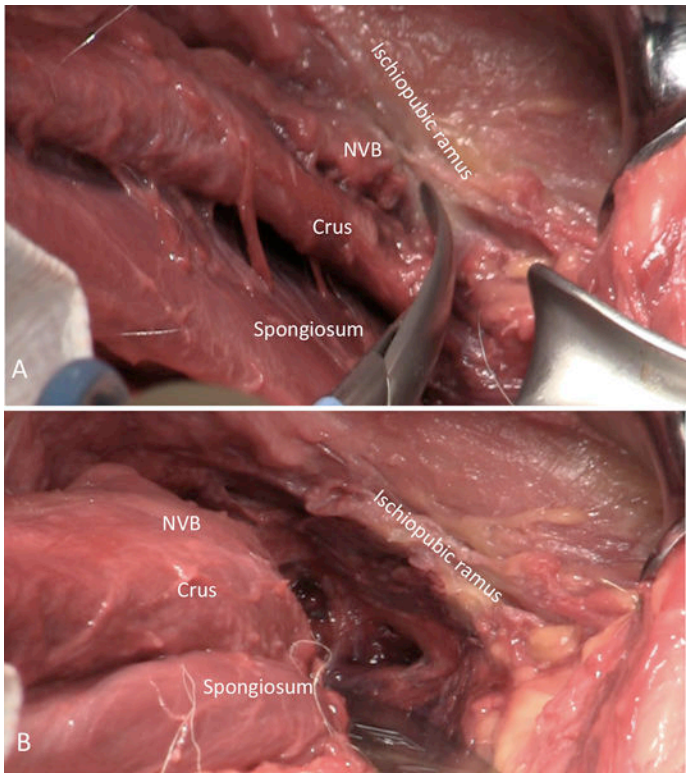

Figure 4.

Fresh cadaver dissection. (A) The IPR periosteum has been incised and the scissors elevating the crus medially. (B) After completion of release of the crus with the ischiopubic ramus periosteum from the IPR.

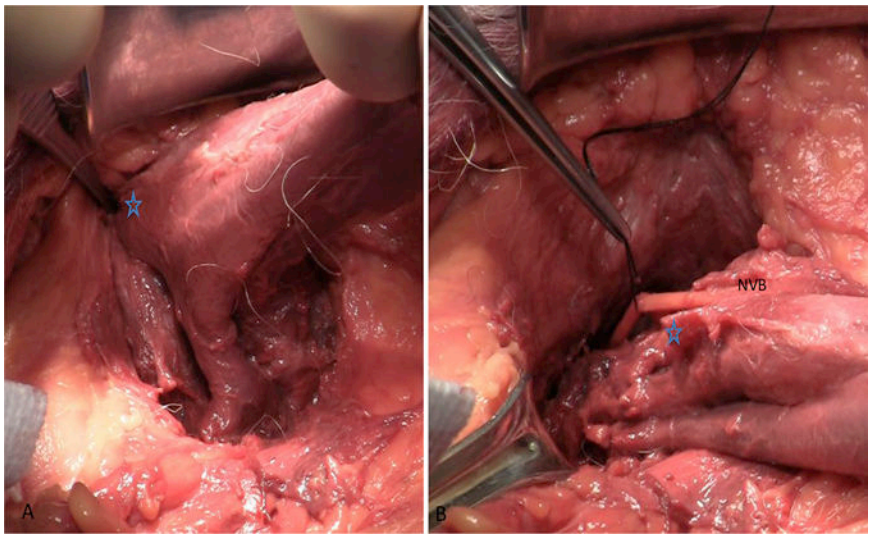

Figure 5.

Note the angulation of the crus in (A) and straightening and lengthening in (B). Also note the relationship of the NVB (in panel B) to the crus as it courses medially into the pelvis towards Alcock's canal.