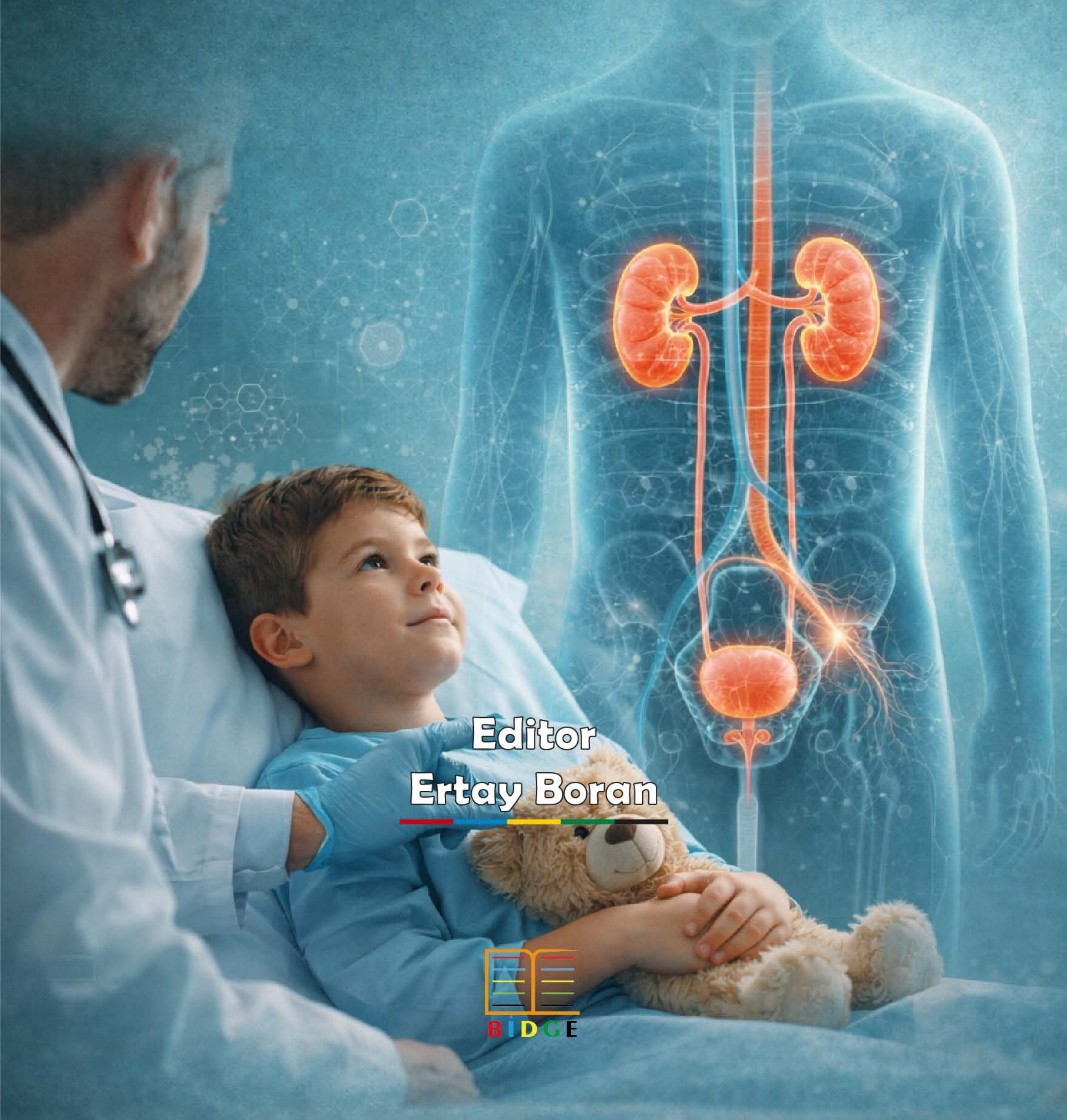
Current Approaches In Pediatric Urology



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Ertay Boran

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CONTENTS

CHAPTER 1

HISTOPATHOLOGY OF THE MEGAURETER WALL: A COMPARATIVE ANALYSIS OF REDUCED DISTAL CAJAL-LIKE CELLS, NERVE FIBERS, AND FIBROSIS

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INTRODUCTION

Megaureter is one of the leading causes of upper urinary tract dilatation in childhood, and primary obstructive megaureter (POM) and vesicoureteral reflux (VUR)–associated refluxing megaureter constitute the two principal clinical forms within this spectrum (Uysal, 2021; Shokeir & Nijman, 2000). The clinical presentation ranges widely—from antenatal hydronephrosis to recurrent febrile urinary tract infections, hypertension, and the development of

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persistent renal scarring. While spontaneous resolution may be observed in some cases, others require surgical intervention because of progression, obstructive injury, or infection (Uysal, 2021; Shokeir & Nijman, 2000).

However, it remains unclear which histopathological mechanisms are distinct or shared between these two clinical entities.

Ureteral peristalsis is predominantly a myogenic activity that, through coordination between the muscle layers and contributions from the autonomic nervous system, ensures unidirectional urine flow from the renal pelvis to the bladder (Santicioli & Maggi, 1998). It has been demonstrated that interstitial cells of Cajal (ICC/CLC), or Cajal-like cells with features similar to pacemaker cells in the gastrointestinal tract, play a role in initiating and regulating this peristaltic activity (Santicioli & Maggi, 1998; Prişcă et al., 2014). Morphological studies of the human upper urinary tract have shown that these cells form a network extending from the calyces to the distal ureter, exhibit a gradual decrease in density from proximal to distal segments, are closely associated with the muscular layer, and have a functional role in the initiation and propagation of peristaltic waves (Prişcă et al., 2014; Metzger et al., 2004). Accordingly, alterations in the number or distribution of Cajal cells are thought to be critical in the pathogenesis of congenital obstructive uropathies (Samaranayake et al., 2021; Solari et al., 2003).

Recent studies have shown that the density of Cajal-like cells is markedly reduced in obstructed segments, suggesting that this reduction may contribute to the pathophysiology of both ureteropelvic junction obstruction (UPJO) and megaureter (Samaranayake et al., 2021; Solari et al., 2003). In congenital UPJO, disrupted Cajal cell expression has been reported within the obstructed segment, whereas a compensatory increase may be observed in proximal segments (Solari et al., 2003). Similarly, studies in POM have demonstrated a significantly lower Cajal-like cell density at the ureterovesical junction (UVJ) compared with autopsy control specimens, supporting the notion that this cellular depletion may represent an important component of functional obstruction (Kart et al., 2013).

In refluxing megaureter, the pathogenesis appears to be more complex than in the obstructive form. Multiple factors have been implicated, including disruption of the histological integrity of the intramural ureteral segment that constitutes the antireflux mechanism, disorganization of the muscular layer, increased extracellular matrix deposition, and a reduction in Cajal-like cell density (Kang et al., 2009; Schwentner et al., 2005). In comparative series of refluxing and obstructive megaureter, refluxing megaureter has been associated with a marked decrease in Cajal cell density along with reduced smooth muscle content, whereas obstructive megaureter has been reported to demonstrate increased myocyte apoptosis and distinct patterns of Cajal-like cells (Kang et al., 2009). In addition, in children with VUR, both loss of Cajal-like cells and decreased expression of the gap junction protein connexin-43 at the UVJ have been identified among the key histopathological changes that may impair the peristaltic capacity of the distal ureter and weaken the antireflux mechanism (Schwentner et al., 2005).

Beyond Cajal-like cells, other structural components of the ureteral wall—particularly the intramural neural network (S100-positive nerve fibers) and stromal fibrotic remodeling—play a critical role in the pathophysiology of megaureter. Several series have shown that reduced nerve fiber density, disorganization of the smooth muscle layer, and increased collagen deposition in both POM and refluxing megaureter disrupt the normal mechanisms of peristaltic propagation and contribute to the development of functional obstruction (Uysal, 2021; Shokeir & Nijman, 2000; Kart et al., 2013; Kang et al., 2009; Schwentner et al., 2005). However, studies evaluating Cajal cell loss, reduced nerve fibers, and fibrosis in combination remain limited, and there is still a lack of comprehensive data—especially in the pediatric population—comparing UVJ-level changes with normal distal ureter tissue.

In this context, a comparative evaluation of the neuromuscular and stromal components thought to contribute to megaureter pathogenesis within the same series is important for elucidating shared and divergent histopathological patterns between POM and VUR. Therefore, in the present study, we aimed to delineate the common and distinct features of megaureter wall histopathology by comparing, at the ureterovesical junction level, Cajal-like cell density, nerve fiber distribution, and fibrotic changes in children with primary obstructive megaureter and VUR-associated refluxing megaureter using histopathological and immunohistochemical methods.

MATERIALS AND METHODS

Study Design and Patient Selection

This study was designed as a retrospective, comparative histopathological and immunohistochemical tissue analysis. Archival specimens from patients who underwent surgery for primary obstructive megaureter (POM) or vesicoureteral reflux (VUR) at the Department of Pediatric Surgery, Dr. Behçet Uz Children’s Hospital, Training and Research Hospital, between January 2000 and December 2007 were retrospectively reviewed.

A total of 34 children (11 girls, 23 boys) were included during the study period. Ages ranged from 4 months to 14 years, with a mean age of 6.1 years. A total of 43 tissue specimens obtained intraoperatively from the ureterovesical junction (UVJ) and distal narrowed segments were subjected to histopathological and immunohistochemical evaluation.

Patients were stratified into three groups according to their clinical and radiological diagnoses:

POM group: Patients diagnosed with primary obstructive megaureter with a distal ureteral narrowing (**n = 12**), all of whom underwent ureteral tapering.

VUR group (refluxing megaureter): Patients who underwent surgery with ureteral tapering for refluxing megaureter secondary to vesicoureteral reflux (**n = 9**).

Control group: Distal ureter specimens en bloc excised during surgery for benign indications in children without congenital urinary tract anomalies and confirmed to be histologically normal (**n = 10**).

Inclusion Criteria

- A confirmed diagnosis of POM or VUR based on ultrasonography and voiding cystourethrography (VCUG).
- Availability of an intraoperatively obtained tissue specimen from the UVJ or distal narrowed segment suitable for immunohistochemical analysis.
- Pediatric age (0–18 years).
- In addition, only the following cases were included:
- **POM group:** patients demonstrating an obstructive drainage pattern on MAG-3 scintigraphy.

VUR group: patients with grade 5 reflux, grade 5 hydronephrosis on ultrasonography, and 30%–40% differential renal function in the affected kidney.

Exclusion Criteria

- Presence of concomitant pathologies such as ureteropelvic junction obstruction, ureteral stone, posterior urethral valves, neurogenic bladder, or urologic tumors.
- Previous ureteral or bladder surgery.
- Insufficient paraffin blocks or inadequate tissue integrity for immunohistochemical evaluation (Table 1).

Table 1. Demographic Characteristics of the Study Cohort

Variable	**Value**
Total number of patients, n	34
Total number of pathological specimens, n	43
Sex, n (%)	Female:11(32.4) Male: 23 (67.6)
Age, years, mean (min–max)	6.1 (0.3–14)
Diagnosis	Primary obstructive megaureter (POM) and vesicoureteral reflux (VUR)

Source: This study

Tissue Processing and Histopathological Examination

Ureteral specimens obtained by resection from the UVJ and distal narrowed segments during surgery were fixed in 10% neutral buffered formalin for at least 24 hours and embedded in paraffin after routine tissue processing. Serial sections of 4–5 µm thickness were prepared from each paraffin block.

Histological Staining

Hematoxylin–eosin (H&E): The mucosal architecture, inflammation, integrity of the muscular layer, and overall tissue morphology were assessed.

Gomori trichrome: The muscle-to-collagen ratio, collagen deposition, and the degree of fibrosis were evaluated.

Fibrosis was semi-quantitatively scored on a 0–3 scale according to increased collagen deposition within the muscular layer and displacement of muscle fibers (0: absent, 3: marked). For statistical analyses, fibrosis was additionally dichotomized as a binary variable (present/absent).

All slides were independently evaluated in a blinded manner by two pathologists experienced in uropathology; discrepancies were resolved by consensus.

Immunohistochemical Analysis

To evaluate nerve fibers and interstitial Cajal-like cells (ICLCs), the following antibodies were used:

S-100: to demonstrate nerve fibers

c-Kit (CD117): to identify ICLCs

After deparaffinization and rehydration, sections underwent antigen retrieval in citrate buffer (pH 6.0). Endogenous peroxidase activity was blocked with 3% hydrogen peroxide. Following incubation with primary antibodies, an appropriate secondary antibody and a streptavidin–biotin–peroxidase detection system were applied. The reaction was visualized using DAB chromogen, and slides were counterstained with Mayer's hematoxylin.

Previously confirmed S-100– and c-Kit–positive tissues were used as positive controls, while buffer without the primary antibody served as the negative control.

Microscopic Evaluation and Quantitative Analysis

Slides were examined at ×200 and ×400 magnifications.

S-100–positive nerve fibers: counted in three independent high-power fields (HPFs, ×400) along the muscular layer, and the mean value was recorded as the **S100** count (nerve fibers per unit area).

ICLC count: c-Kit–positive spindle-shaped cells were accepted as ICLCs; the mean of three HPF (×400) counts in the same fields was calculated.

In the **POM** group, the narrowed distal segment was additionally compared with the proximally dilated segment to assess proximal-to-distal changes in ICLC density. In **POM** and **VUR** cases, S100 and ICLC counts were compared between segments with and without tapering.

Statistical Analysis

All analyses were performed using **SPSS Statistics** (IBM Corp., Armonk, NY). Continuous variables are presented as **mean ± standard deviation** or **median (minimum–maximum)**, and categorical variables as **number and percentage**.

Data distribution was assessed using the **Shapiro–Wilk test** and graphical methods. Given the small sample size and non-normally distributed data, **nonparametric tests** were predominantly used:

Mann–Whitney U test: for comparisons between two groups (S100, ICLC).

Kruskal–Wallis test: for comparisons among three groups.

Chi-square test or Fisher's exact test: for comparing the frequency of fibrosis.

Spearman correlation: to assess associations between S100 and ICLC counts and fibrosis grade.

For multiple pairwise comparisons, **Bonferroni correction** was applied, and the adjusted significance threshold was set at **$\alpha = 0.05/3 = 0.017$**. Overall statistical significance was defined as **$p < 0.05$**.

RESULTS

Patient and Specimen Characteristics

All 34 children included in the study underwent distal ureteral surgery for either POM or VUR. A total of 43 ureteral specimens obtained from these cases, together with 10 histologically normal distal ureter segments from the control group, were evaluated histopathologically and immunohistochemically. The analyses focused on S100-positive nerve fiber density, interstitial Cajal-like cell (ICLC) counts, and fibrosis grade at the UVJ and distal narrowed segments.

In all POM cases, preoperative MAG-3 scintigraphy demonstrated an obstructive drainage pattern. In the VUR group, all patients had grade 5 reflux on voiding cystourethrography. On ultrasonography, grade 5 hydronephrosis was present in all affected kidneys, with differential renal function reduced to the 30%–40% range. During postoperative follow-up, no patient developed recurrent hydronephrosis, persistent high-grade reflux, or required additional surgical intervention.

UVJ Findings in the VUR Group

According to the Mann–Whitney U test, in the VUR group:

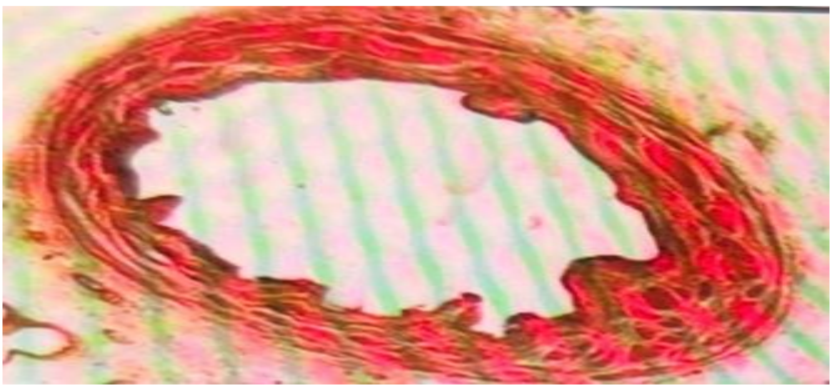
- S100-positive nerve fiber density was significantly lower than in controls (7.2 vs 10.8; $p = 0.028$).
- ICLC counts were markedly reduced compared with controls (4.52 vs 5.82; $p = 0.005$).

- Fibrosis frequency in the distal segment was significantly higher than in controls ($p < 0.001$) (Table 3).
- Table 2. Comparison of S100, ICLC, and fibrosis at the UVJ level in VUR cases versus controls

Variable (UVJ level)	VUR group	Control group	p değeri
S100-positive nerve fibers (count per HPF/area)*	7,2	10,8	0,028
Interstitial Cajal-like cells (ICLC) (count per HPF/area)*	4,52	5,82	0,005
Tricrom Fibrosis)	Fibrosis (+)	Fibrosis (–)	<0,001

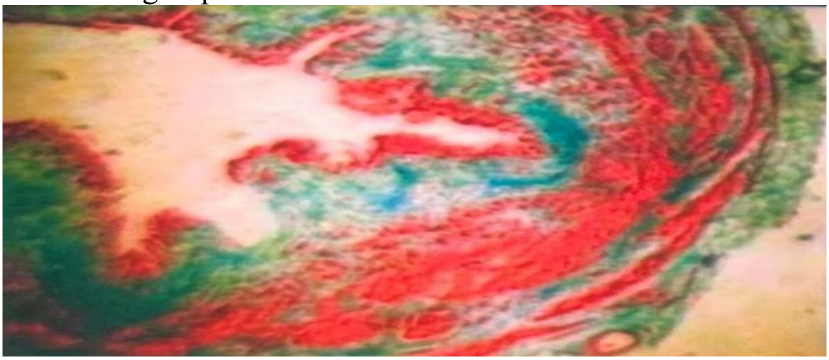
Source: This study

Figure 1. Absence of fibrosis in the control-group ureter on Gomori trichrome staining.



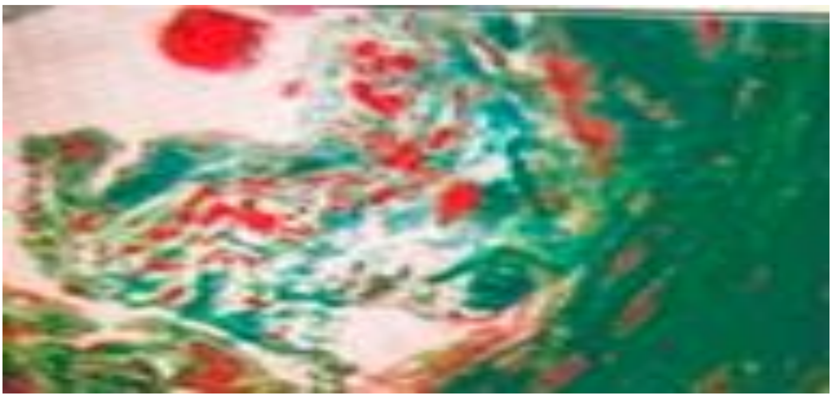
Source: This study

Figure 2. Increased collagen deposition in the distal ureter in the VUR group on Gomori trichrome staining.



Source: This study

Figure 3. Marked collagen deposition consistent with fibrosis in the distal narrowed segment of the POM ureter on Gomori trichrome staining.



Source: This study

These findings suggest pronounced degenerative changes at the UVJ level in refluxing megaureter, involving both the neural elements and the stromal compartment.

UVJ Findings in the POM Group: At the UVJ level in POM cases: S100-positive nerve fiber density was significantly lower than in controls (5.42 vs 10.8; p = 0.001). ICLC counts were lower in the POM group and showed borderline statistical significance compared with controls (4.73 vs 5.82; p = 0.019). Fibrosis frequency was significantly higher than in controls (p = 0.046) (Table 3).

Table 3. Comparison of S100, ICLC, and fibrosis at the UVJ level in POM cases versus controls

Variable (UVJ level)	POM group	Kontrol group	p value
S100-positive nerve fibers (count per HPF/area)*	5,42	10,8	0,001
İCH (Cajal-benzeri hücre sayısı)*	4,73	5,82	0,019
Tricrom (fibrozis)	Fibrosis (+)	Fibrosis (–)	0,046

Source: This study

Comparison of Narrowed vs Dilated Segments in the POM Group :

- Nerve fiber density did not differ between the narrowed and dilated segments (p = 0.553). ICLC counts showed a significant decrease from the proximally dilated segment toward the distal narrowed segment (p = 0.015).
- These findings support a progressive structural deterioration toward the distal ureter in POM and suggest a potential mechanism of "distal segment dysfunction."

Figure 4. Collagen deposition in the proximally dilated ureteral segment in the POM group on Gomori trichrome staining.

Source: This study

Comparison Between the POM and VUR Groups

At the level of the distal narrowed segment:

- S100-positive nerve fiber density was lower in POM; however, the difference did not reach statistical significance (5.42 vs 7.2; p = 0.065).
- ICLC counts did not differ between groups (4.73 vs 4.52; p = 0.89).
- Fibrosis was frequent in both groups and did not provide further discrimination between them.
- Overall, these findings suggest that POM and VUR may lead to similar remodeling patterns in the distal ureter.
- Findings Related to Ureteral Tapering
- When POM and VUR cases were subdivided according to whether tapering was performed:
- No significant differences were observed in **S100-positive nerve fiber density** or **ICLC counts**

between tapering and non-tapering subgroups (**p > 0.05**).

This result indicates that tapering may not exert an additional effect on neural structures or ICLC density (Table 5).

Table 5. Comparison of UVJ S100 and ICLC counts according to ureteral tapering in POM and VUR cases

Group	Comparative	100-positive nerve fibers (per HPF/area)*	ICLC count (per HPF/area)*
POM	with tapering vs without tapering	>0,05	>0,05
VUR	with tapering vs without tapering	>0,05	>0,05

Source: This study

*Counts were obtained as the mean of three HPFs (×400) along the muscular layer (as described in Methods). Statistical test: Mann–Whitney U test (tapering vs non-tapering within each diagnostic group).

Association Between Fibrosis Grade and Nerve/ICLC Density

No fibrosis was observed in the control group, whereas fibrosis was present in nearly all specimens in both the POM and VUR groups. In pairwise comparisons (Control vs POM and Control vs VUR), the difference in fibrosis frequency was statistically significant using Fisher's exact test ($p < 0.001$ for both comparisons).

The Kruskal–Wallis test demonstrated a significant overall difference in ICLC counts across the three groups. In post hoc pairwise analyses: In the **VUR** group, ICLC counts were significantly lower than in controls even after Bonferroni correction (**p = 0.005 < 0.017**). In the **POM** group, the reduction in ICLC counts was borderline in the unadjusted analysis, but lost significance after correction (**p = 0.019 > 0.017**). There was no difference between **POM and VUR** (**p = 0.89**).

No significant correlation was found between **fibrosis grade** and either **ICLC counts** (**p = 0.82**) or **S100-positive nerve fiber density** (**p = 0.97**) (Table 6).

Table 6. Correlation between fibrosis grade and S100 and ICLC counts at the ureterovesical junction

Variable	p value	Correlated with fibrosis grade (Spearman)
S100-positive nerve fiber density	0,97	Not significant
Interstitial Cajal-like cells (ICLC) count	0,82	Not significant

Source: This study

Statistical test: Spearman rank correlation.

This finding indicates that increasing fibrosis is not directly associated with a reduction in neural elements or ICLC density.

Overall Assessment

This study demonstrated a shared pattern of structural deterioration at the UVJ and distal ureter in both POM and refluxing megaureter. In both groups:

- **S100-positive nerve fiber density** was reduced,
- **ICLC counts** were decreased, and
- **Fibrosis** was markedly increased (Table 4).

Table 4. Comparison of S100, ICLC, and fibrosis at the UVJ level between POM and VUR cases

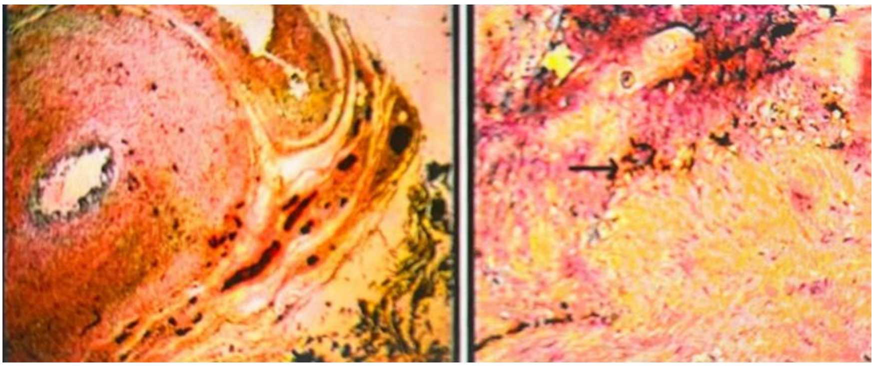
Variable (UVJ level)	POM group	VUR group	p value
S100-positive nerve fibers (count per HPF/area)*	5,42	7,2	0,065

Interstitial Cajal-like cells (ICLC) (count per HPF/area)*	4,73	4,52	0,89
Tricrom (fibrosis)	Fibrosis (+)	Fibrosis (+)	—

Source: This study

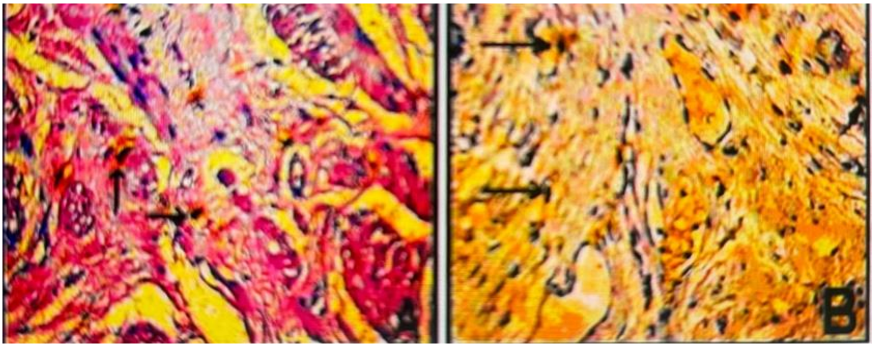
*Values are reported as provided in the Results section (summary measure not specified in the text—mean/median).

Figure 5. Reduced S100-positive nerve fibers in the distal ureter in the POM/VUR groups compared with the control group on immunohistochemical staining.



Source: This study

Figure 6. Fewer c-Kit–expressing Cajal-like cells in the distal ureter in the POM/VUR groups compared with the control group.



Source: This study

The absence of statistically significant differences between POM and VUR with respect to these parameters suggests that, despite their distinct etiologies, both conditions may elicit a similar remodeling response in the distal ureter.

DISCUSSION

In this study, we comprehensively evaluated S100-positive nerve fibers, interstitial Cajal-like cells (ICLCs), and fibrosis grade in the ureterovesical junction (UVJ) and distal ureter segments of children with primary obstructive megaureter (POM) and vesicoureteral reflux (VUR)–associated refluxing megaureter. Because the entire cohort consisted of severe cases—grade 5 hydronephrosis, a clearly obstructive drainage pattern in the POM group, and grade 5 reflux in the VUR group—the observed histopathological profile likely reflects "end-stage" remodeling in advanced disease.

Overall, our findings indicate that: (i) S100-positive nerve fibers and ICLC counts were reduced at the UVJ/distal narrowed segment in both POM and VUR compared with controls; (ii) fibrosis was markedly increased in parallel; (iii) no significant differences were detected between POM and VUR—particularly in the distal narrowed segment—with respect to nerve/ICLC density; and (iv) fibrosis grade did not correlate significantly with either S100-positive nerve fiber density or ICLC counts. Collectively, these results suggest that both obstructive and reflux-associated megaureter may converge toward a shared distal ureteral histopathological endpoint characterized by neuromuscular depletion and stromal remodeling.

Comparison of POM-Related Findings with the Literature

The etiopathogenesis of primary megaureter remains debated. Shokeir and Nijman emphasized that POM is fundamentally driven by a functional and/or anatomical obstruction at the UVJ and that ureteral peristalsis is closely dependent on the integrity of the muscular layer and its innervation at this level (Shokeir & Nijman, 2000). Previous series have reported smooth muscle disorganization, increased interstitial connective tissue between muscle bundles, and altered innervation in POM; however, consistent associations between these features and clinical course or renal outcomes have not been reliably demonstrated (Shokeir & Nijman, 2000).

In Uysal's study correlating UVJ histopathological alterations with clinical outcomes in pediatric POM, marked collagen accumulation and reduced neural plexus density were reported, yet no significant correlation between nerve fiber density and renal function was identified (Uysal, 20211). Similarly, in our POM cohort, fibrosis was substantially increased and S100/ICLC values were reduced compared with controls, while no correlation was observed between fibrosis grade and nerve/ICLC density. This supports the concept that POM pathogenesis cannot be explained by a single parameter; rather, it likely represents a complex process involving the muscular layer, connective tissue remodeling, innervation, and pacemaker-like cell populations.

Role of Neural Networks and Cajal-like Cells in Upper Urinary Tract Motility

Ureteral peristalsis is regulated through the interaction of myogenic and neurogenic mechanisms, requiring coordinated function of the autonomic neural network and pacemaker-like cells within the ureteral wall (Santicioli & Maggi, 19983). Santicioli and Maggi demonstrated that pyeloureteral motility is predominantly myogenic, while efferent innervation and intrinsic neural circuits exert important modulatory effects on the regulation of peristaltic waves (Santicioli & Maggi, 1998).

Morphological studies by Metzger et al. and Prişcă et al. reported that ICC/CLC populations are distributed throughout the upper urinary tract, with higher densities in the calyces and renal pelvis and progressively lower densities toward the distal ureter (Metzger et al., 2004; Prişcă et al., 2014). This distal paucity has been interpreted to mean that even modest structural disturbances at the UVJ/distal ureter may disproportionately impair peristaltic function (Metzger et al., 2004; Prişcă et al., 2014).

More recent work evaluating the relationship between upper urinary tract obstruction and Cajal-like cell alterations has suggested that reduced ICC/CLC density may represent a contributor to UPJ obstruction and megaureter pathophysiology. Solari et al. reported significantly reduced c-Kit–positive ICC counts in UPJ obstruction (Solari et al., 2003). In a systematic review and meta-analysis, Samaranayake et al. concluded that CLC density is markedly decreased in UPJ obstruction and that this reduction likely reflects a dynamic remodeling response secondary to obstruction (Samaranayake et al., 2021). In our study, lower UVJ ICLC counts in POM compared with controls support the notion that POM is not merely a mechanical narrowing but may involve broader wall pathology including pacemaker cell depletion.

Kart et al. directly assessed ICC/CLC expression in POM and demonstrated significantly reduced ICC density at the UVJ compared with autopsy controls, noting that the reduction appeared more pronounced with longstanding obstruction (Kart et al., 2013). Our findings are concordant with Kart's observations, showing decreased S100-positive nerve fibers and reduced ICLC counts in POM relative to controls. Importantly, in our segmental comparison within POM, nerve fiber density did not differ between proximal dilated and distal narrowed segments, whereas ICLC counts declined significantly from proximal to distal. This pattern suggests that pacemaker-cell depletion may be more segmental and concentrated within the distal dysfunctional zone, potentially representing a key component of segmental peristaltic failure.

Histopathological Pattern in Refluxing Megaureter and VUR

Studies focusing on refluxing megaureter and VUR have further refined our understanding of distal ureter remodeling. In a comparative series, Kang et al. reported that obstructive megaureter was characterized predominantly by increased myocyte apoptosis, whereas refluxing megaureter showed more pronounced reductions in ICC density and smooth muscle content, proposing that these distinct patterns might underlie differences in clinical trajectories (Kang et al., 2009). Schwentner et al. demonstrated that, in children with VUR, ICC loss at the UVJ is accompanied by reduced expression of the gap junction protein connexin-43, implying impairment in both pacemaker cell populations and intercellular electrical coupling (Schwentner et al., 2005).

In our VUR group, both S100-positive nerve fibers and ICLC counts were significantly reduced at the UVJ compared with controls, consistent with the concept of distal neuromuscular compromise described by Schwentner et al. (Schwentner et al., 2005). However, direct comparison between POM and VUR revealed no significant difference in ICLC counts at the distal narrowed segment and only borderline difference in S100-positive nerve fiber density ($p = 0.065$). While this does not fully exclude partially divergent upstream pathways (Kart et al., 2013; Kang et al., 2009), our results suggest that both entities may ultimately converge—at the UVJ/distal ureter level—toward a common endpoint featuring **nerve/ICLC depletion** and **fibrotic remodeling**. The consistent increase in fibrosis in both groups aligns with prior reports describing collagen accumulation and muscular layer disruption within the intravesical/intramural ureter (Uysal, 2021; Shokeir & Nijman, 2000; Schwentner et al., 2005).

Interpreting the Relationship Between Fibrosis, Neural Elements, and ICLCs

Despite prominent fibrosis in both POM and VUR, we did not identify a significant correlation between fibrosis grade and either S100-positive nerve fiber density or ICLC counts. This finding suggests that fibrotic remodeling may not simply represent a downstream consequence of neural and pacemaker-cell loss. Additional drivers—such as chronic inflammation, sustained mechanical stress, elevated intramural pressure, and potential microvascular ischemia—may contribute in parallel. In Uysal's series, reduced neural plexus density was more evident in POM cases with ongoing inflammation and marked collagen accumulation (Uysal, 2021). Although inflammatory activity was not separately scored in our study, the consistently increased fibrosis across both POM and VUR supports the concept of a shared chronic wall-injury milieu.

Notably, after Bonferroni correction for multiple comparisons, the reduction in ICLC counts remained significant for **VUR vs controls** but not for **POM vs controls**, where borderline significance was lost. In contrast, fibrosis—absent in controls and present in nearly all POM/VUR specimens—showed a strong effect by Fisher's exact testing ($p < 0.001$), reinforcing its clinical and statistical relevance irrespective of multiple-comparison adjustment.

Effect of Tapering and Surgical Approach on Histopathology

The absence of differences in S100-positive nerve fiber density and ICLC counts between cases with and without tapering suggests that tapering does not confer an additional measurable effect on these microstructural parameters at the UVJ in the examined specimens. This is consistent with the concept that tapering primarily aims to optimize ureteral geometry and mechanical compliance rather than reverse congenital or early-established neuromuscular wall pathology. As emphasized by Shokeir and Nijman, in POM, the timing of intervention and preservation of renal function may be more critical than the specific technique, given that wall pathology likely becomes established early in life and may be only partially modifiable surgically (Shokeir & Nijman, 2000).

Limitations and Strengths

These findings should be interpreted in the context of several limitations. First, the retrospective design and inclusion of only surgically treated severe cases introduce potential selection bias and limit generalizability to milder or conservatively managed POM/VUR. Second, the modest sample size and lack of formal power analysis increase the risk of type II error, particularly for borderline p-values; thus, results should be viewed as hypothesis-generating. Third, quantification was performed by manual counting in three HPFs, without automated/digital morphometry. Although blinded evaluation by two experienced uropathologists likely reduced observer-dependent variability, interobserver agreement metrics (e.g., kappa/ICC) were not reported. Finally, the immunohistochemical panel was limited to S100 and c-Kit (CD117), providing no insight into other potentially relevant pathways (e.g., connexin-43, apoptosis markers, inflammatory/ischemic mediators) (Kang et al., 2009; Schwentner et al., 2005).

Despite these limitations, the study has notable strengths: all cases were treated at a single center with comparable indications and techniques; controls consisted of pediatric, histologically normal distal ureter specimens; both UVJ and segmental (narrow vs dilated) assessments were incorporated; and all slides were reviewed in a blinded fashion by two experienced pathologists, supporting internal validity.

Clinical and Research Implications

In conclusion, our study demonstrates that both POM and VUR-associated refluxing megaureter are characterized at the UVJ/distal ureter level by **reduced S100-positive nerve fibers**, **decreased ICLC counts**, and **prominent fibrotic remodeling**. These findings support existing literature indicating that the intramural neural network and Cajal-like cells—key regulators of upper urinary tract motility—are centrally involved in megaureter pathophysiology ((Santicioli & Maggi, 1998; Prişcă et al., 2014; Metzger et al., 2004; Samaranayake et al., 2021; Solari et al., 2003; Kart et al., 2013; Kang et al., 2009) and suggest that distinct clinical subtypes may converge toward a shared distal histopathological endpoint.

These data imply that management strategies in POM and VUR may benefit from incorporating not only anatomical correction but also consideration of distal ureteral functional capacity and potential reversibility. Future studies with larger cohorts, prospective designs, and digital morphometry combined with expanded immunohistochemical panels are needed to clarify how nerve fiber density and ICLC depletion relate to long-term renal function, surgical outcomes, and the success of conservative management, ultimately enabling more individualized, pathophysiology-driven approaches to megaureter care.

CONCLUSION

This study demonstrates a marked pattern of neuromuscular and stromal remodeling in the ureterovesical junction and distal ureteral wall of children with primary obstructive megaureter (POM) and vesicoureteral reflux (VUR)–associated refluxing megaureter. The reduction in S100-positive nerve fibers and interstitial Cajal-like cell (ICLC) counts compared with controls, together with a pronounced increase in fibrosis, supports a central role of the intramural neural network and pacemaker-like cells in megaureter pathogenesis. The observed proximal-to-distal decline in ICLC density in both POM and VUR suggests that progressive loss of Cajal-like cells—most evident in the distal narrowed segment—may represent a key component of segmental peristaltic dysfunction in megaureter. The absence of significant differences between POM and VUR, particularly at the distal narrowed segment, further implies that distinct clinical subtypes—whether obstructive or reflux-related—may converge toward a shared distal histopathological endpoint. These findings indicate that surgical planning should consider not only relief of anatomical obstruction but also the functional capacity of the ureteral wall and the possibility of irreversible microstructural alterations. Larger, prospective, and quantitatively morphometric studies are warranted to better define the relationship between neural/ICLC depletion and long-term renal outcomes and surgical success.

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CHAPTER 2

ANESTHESIA IN PEDIATRIC UROLOGIC SURGERY

ERTAY BORAN[1]

INTRODUCTION

Pediatric urologic surgery comprises a wide range of diagnostic and therapeutic interventions performed from the neonatal period through adolescence, including procedures for congenital anomalies, obstructive uropathies, reconstructive surgeries, and minimally invasive or robotic techniques. The anesthetic management of these patients is inherently complex due to age-related physiological variability, procedural diversity, and the need to ensure both perioperative safety and effective analgesia while facilitating rapid recovery (Zeigler et al., 2020; Shukis & Merola, 1993).

Children undergoing urologic surgery present unique anatomical, physiological, and developmental characteristics that distinguish them fundamentally from adult patients. Immaturity of cardiovascular, respiratory, renal, and thermoregulatory systems—particularly in neonates and infants—significantly influences

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anesthetic planning and intraoperative management. These considerations are especially relevant in urologic procedures, where preservation of renal perfusion, careful fluid management, and avoidance of hemodynamic instability are critical to optimal surgical and anesthetic outcomes (Zeigler et al., 2020; Spinelli et al., 2016).

Historically, general anesthesia has been the predominant anesthetic technique for pediatric urologic surgery. However, advances in pediatric regional anesthesia and improved understanding of age-specific pharmacology have led to more individualized anesthetic approaches. Techniques such as caudal anesthesia, spinal anesthesia, and ultrasound-guided regional blocks are increasingly utilized either as adjuncts to general anesthesia or, in selected cases, as primary anesthetic modalities. These approaches have demonstrated benefits in terms of perioperative analgesia, reduced anesthetic exposure, and improved recovery profiles (Ahmad et al., 2024; Findlay et al., 2023; Ambrose et al., 2023).

Pain management represents a central component of anesthetic care in pediatric urologic surgery. Traditional reliance on systemic opioids for postoperative analgesia has raised concerns regarding opioid-related adverse effects, including respiratory depression, nausea, vomiting, delayed recovery, and the potential for longer-term consequences. As a result, contemporary practice increasingly emphasizes multimodal and opioid-sparing analgesic strategies that integrate regional anesthesia, local anesthetic techniques, and non-opioid pharmacologic agents to optimize pain control while minimizing complications (Nelson et al., 2021; Morrison et al., 2014; Hidas et al., 2015).

In parallel with developments in anesthetic and analgesic techniques, Enhanced Recovery After Surgery (ERAS) protocols have been adapted for pediatric urologic surgery. ERAS principles focus on minimizing surgical stress, maintaining physiological homeostasis, and promoting early functional recovery through evidence-based perioperative care pathways. Anesthetic management plays a pivotal role in ERAS implementation by optimizing fluid therapy, reducing opioid use, facilitating early mobilization, and supporting effective postoperative analgesia (Fung et al., 2023; Han et al., 2021).

Another important evolution in pediatric urologic anesthesia is the increasing use of office-based procedures and specialized pediatric sedation units for selected interventions. These models aim to provide safe and effective alternatives to operating room–based general anesthesia, particularly for minor or minimally invasive procedures. When supported by appropriate patient selection, standardized protocols, and multidisciplinary collaboration, office-based anesthesia and sedation units have been shown to improve efficiency, reduce healthcare costs, and maintain high levels of patient and family satisfaction (Aghababian et al., 2022; Falkiewicz et al., 2023).

Technological advancements have also transformed the landscape of pediatric urologic surgery, with growing adoption of minimally invasive and robotic-assisted techniques. While these approaches offer surgical advantages such as improved visualization and reduced tissue trauma, they introduce distinct anesthetic challenges related to patient positioning, pneumoperitoneum, ventilation strategies, and hemodynamic management. A thorough understanding of these factors is essential for anesthesiologists involved in the care of children undergoing advanced urologic procedures (Khater et al., 2024; Spinelli et al., 2016).

This chapter aims to provide a comprehensive overview of anesthesia in pediatric urologic surgery, synthesizing current evidence and clinical practice. Key topics include physiological considerations unique to the pediatric population, preoperative assessment and preparation, anesthetic techniques with an emphasis on regional and spinal anesthesia, pain management strategies, ERAS principles, and anesthetic considerations for minimally invasive and robotic surgery. By integrating data from the existing literature, this chapter seeks to support anesthesiologists and perioperative teams in delivering safe, effective, and patient-centered care for pediatric urologic patients.

Physiological Considerations in Pediatric Urologic Anesthesia

Anesthetic management in pediatric urologic surgery must be grounded in a thorough understanding of age-dependent physiological differences that influence perioperative risk and anesthetic response. Neonates, infants, children, and adolescents exhibit marked variability in cardiovascular, respiratory, renal, and metabolic function, all of which have direct implications for anesthetic technique, drug selection, and intraoperative monitoring (Zeigler et al., 2020; Shukis & Merola, 1993).

Cardiovascular Physiology

The pediatric cardiovascular system, particularly in neonates and young infants, is characterized by limited myocardial compliance and a reduced ability to augment stroke volume. Cardiac output in this population is therefore predominantly heart rate–dependent. Anesthetic agents that depress myocardial contractility or blunt sympathetic tone may precipitate hypotension more readily than in older children or adults. These considerations are especially relevant during urologic procedures that involve fluid shifts, blood loss, or changes in intraabdominal pressure, such as reconstructive or minimally invasive surgeries (Zeigler et al., 2020; Spinelli et al., 2016).

Additionally, autonomic nervous system immaturity may impair compensatory responses to hypovolemia or vasodilation.

Careful titration of anesthetic depth, vigilant hemodynamic monitoring, and judicious fluid management are therefore essential to maintain adequate organ perfusion, including renal blood flow, throughout the perioperative period (Shukis & Merola, 1993; Zeigler et al., 2020).

Respiratory Physiology

Developmental differences in respiratory anatomy and physiology significantly influence anesthetic management in pediatric patients. Infants and young children have higher oxygen consumption, lower functional residual capacity, and more compliant chest walls compared with adults. These factors predispose them to rapid oxygen desaturation during apnea or hypoventilation, particularly during induction and emergence from anesthesia (Zeigler et al., 2020).

In pediatric urologic surgery, respiratory considerations become even more pronounced during minimally invasive and robotic procedures, where pneumoperitoneum and patient positioning may impair diaphragmatic excursion and pulmonary compliance. Anesthesiologists must adjust ventilation strategies to maintain adequate oxygenation and carbon dioxide elimination while minimizing the risk of barotrauma or volutrauma (Spinelli et al., 2016; Khater et al., 2024).

Renal Physiology and Fluid Balance

Renal physiology undergoes significant maturation during early childhood. Neonates and infants have reduced glomerular filtration rate, limited concentrating ability, and immature tubular function, which affect fluid and electrolyte handling as well as drug excretion. These factors are of particular importance in pediatric urologic surgery, where preservation of renal function is often a primary surgical objective (Zeigler et al., 2020; Shukis & Merola, 1993).

Anesthetic agents and adjunct medications that are renally excreted may exhibit prolonged effects in younger patients. Moreover, both fluid overload and hypovolemia can adversely affect renal perfusion and postoperative outcomes. Consequently, individualized fluid management strategies based on patient age, weight, surgical complexity, and intraoperative losses are critical components of anesthetic care in this population (Zeigler et al., 2020).

Thermoregulation and Metabolic Considerations

Pediatric patients, particularly neonates and infants, are highly susceptible to perioperative hypothermia due to a high surface area–to–body weight ratio, limited subcutaneous fat, and immature thermoregulatory mechanisms. Hypothermia can increase oxygen consumption, alter drug metabolism, impair coagulation, and prolong recovery from anesthesia. These risks are heightened during prolonged urologic procedures or minimally invasive surgeries, where exposure and insufflation of cold gases may exacerbate heat loss (Shukis & Merola, 1993; Spinelli et al., 2016).

Maintenance of normothermia through active warming measures is therefore an essential aspect of pediatric anesthetic management. In addition, metabolic rate and glucose homeostasis vary with age, necessitating careful monitoring and management to avoid hypoglycemia or hyperglycemia, particularly in younger children undergoing longer procedures (Zeigler et al., 2020).

Implications for Anesthetic Technique Selection

The unique physiological characteristics of pediatric patients underscore the importance of tailoring anesthetic techniques to individual patient needs and surgical requirements. Regional and neuraxial anesthesia techniques, including caudal and spinal anesthesia, may offer physiological advantages by reducing systemic anesthetic exposure, maintaining more stable hemodynamics, and providing effective analgesia with minimal respiratory compromise when appropriately applied (Findlay et al., 2023; Ambrose et al., 2023; Stangl-Kremser et al., 2025).

Understanding developmental physiology is therefore fundamental to optimizing anesthetic care in pediatric urologic surgery and forms the basis for subsequent discussions of anesthetic techniques, pain management strategies, and enhanced recovery protocols addressed in this chapter.

PREOPERATIVE ASSESSMENT AND PREPARATION IN PEDIATRIC UROLOGIC SURGERY

Preoperative assessment is a critical component of anesthetic management in pediatric urologic surgery and plays a central role in optimizing perioperative safety and outcomes. A comprehensive evaluation must account for the child's age, developmental status, underlying medical conditions, and the specific urologic pathology requiring intervention. In pediatric patients, thorough preoperative planning is particularly important given the limited physiological reserve and age-dependent variability in response to anesthetic agents (Zeigler et al., 2020; Shukis & Merola, 1993).

Medical History and Physical Examination

A detailed medical history should focus on perinatal factors, prior anesthetic exposure, congenital anomalies, and comorbid conditions that may influence anesthetic risk. Particular attention should be given to children with urologic conditions associated with syndromic features, renal dysfunction, or recurrent urinary tract infections, as these factors may have implications for fluid management, drug selection, and perioperative monitoring (Zeigler et al., 2020).

The physical examination should include careful assessment of airway anatomy, cardiovascular and respiratory status, hydration, and growth parameters. Identification of potential airway challenges is essential, especially in younger children or those with craniofacial anomalies, to facilitate safe induction and airway management (Shukis & Merola, 1993).

Psychological Considerations and Family-Centered Care

Preoperative anxiety is common among pediatric patients and their caregivers and has been associated with increased anesthetic requirements, adverse behavioral changes, and poorer postoperative recovery. In pediatric urologic surgery, where many procedures are elective, strategies to reduce anxiety are an important component of preoperative preparation. Family-centered approaches, including parental presence during induction and age-appropriate communication, have been shown to improve patient cooperation and satisfaction (Zeigler et al., 2020).

Pharmacologic premedication may be considered for selected patients, particularly those with high anxiety levels or previous negative healthcare experiences. The choice of premedication should be individualized, balancing anxiolytic efficacy with potential side effects such as respiratory depression or delayed recovery (Shukis & Merola, 1993; Zeigler et al., 2020).

Fasting Guidelines and Perioperative Hydration

Adherence to age-appropriate fasting guidelines is essential to minimize the risk of pulmonary aspiration while avoiding unnecessary dehydration and metabolic stress. In pediatric patients, prolonged fasting may increase the risk of hypoglycemia, irritability, and hemodynamic instability. Contemporary anesthetic practice emphasizes minimizing fasting times through clear communication with caregivers and adherence to evidence-based guidelines (Zeigler et al., 2020).

Perioperative hydration strategies should be tailored to the child's age, weight, renal function, and surgical complexity. This is particularly important in pediatric urologic surgery, where renal perfusion and fluid balance directly affect surgical outcomes and postoperative recovery (Zeigler et al., 2020).

Patient Selection for Ambulatory and Office-Based Procedures

Advances in anesthetic and procedural techniques have expanded the range of pediatric urologic interventions that can be safely performed in ambulatory or office-based settings. Appropriate patient selection is critical to the success of these models and requires careful consideration of patient age, comorbidities, procedural complexity, and anticipated analgesic requirements (Aghababian et al., 2022; Falkiewicz et al., 2023).

Children undergoing office-based procedures should be medically stable, with minimal comorbid conditions and a low likelihood of airway or anesthetic complications. Standardized protocols, trained personnel, and immediate access to emergency equipment are essential to maintaining safety in these settings (Aghababian et al., 2022).

Risk Stratification and Multidisciplinary Planning

Risk stratification is an integral part of preoperative assessment and should involve close collaboration between anesthesiologists, pediatric urologists, nursing staff, and, when appropriate, pediatric subspecialists. Complex cases, such as those involving reconstructive surgery, renal impairment, or anticipated prolonged operative time, benefit from multidisciplinary planning to anticipate potential intraoperative and postoperative challenges (Zeigler et al., 2020).

Effective preoperative communication among team members facilitates the selection of appropriate anesthetic techniques, postoperative analgesia plans, and recovery pathways, including consideration of ERAS principles when applicable (Fung et al., 2023; Han et al., 2021).

ANESTHETIC TECHNIQUES IN PEDIATRIC UROLOGIC SURGERY

The selection of anesthetic techniques in pediatric urologic surgery requires careful consideration of patient age, physiological maturity, surgical complexity, and anticipated postoperative analgesic needs. While general anesthesia remains the most commonly employed modality, contemporary practice increasingly integrates regional and neuraxial techniques to enhance perioperative analgesia, reduce opioid exposure, and facilitate faster recovery. Evidence-based selection of anesthetic approaches is essential to optimize outcomes and ensure patient safety (Zeigler et al., 2020; Shukis & Merola, 1993).

General Anesthesia

General anesthesia is widely used in pediatric urologic surgery due to its reliability, versatility, and ability to provide optimal surgical conditions across a broad range of procedures. Induction may be achieved via inhalational or intravenous techniques, depending on patient age, cooperation, and venous access. Maintenance typically involves volatile anesthetics, intravenous agents, or balanced techniques, with careful titration to minimize hemodynamic instability and respiratory depression (Zeigler et al., 2020).

Airway management strategies should be tailored to the procedure and patient characteristics, with options ranging from face mask ventilation and supraglottic airway devices to endotracheal intubation. In longer or more complex urologic surgeries, particularly those involving laparoscopy or robotic assistance, endotracheal intubation is generally preferred to ensure airway protection and controlled ventilation (Spinelli et al., 2016; Khater et al., 2024).

Despite its effectiveness, general anesthesia is associated with potential disadvantages, including postoperative nausea and vomiting, delayed recovery, and increased opioid requirements for pain control. These considerations have driven growing interest in adjunctive regional and neuraxial techniques to mitigate anesthetic-related morbidity (Zeigler et al., 2020; Nelson et al., 2021).

Regional Anesthesia Techniques

Regional anesthesia plays an increasingly important role in pediatric urologic surgery as part of a multimodal anesthetic strategy. Techniques such as caudal epidural anesthesia, peripheral nerve blocks, and ultrasound-guided regional anesthesia have been shown to provide effective intraoperative and postoperative analgesia while reducing systemic anesthetic and opioid requirements (Ahmad et al., 2024; Zeigler et al., 2020).

Ultrasound guidance has significantly improved the safety and accuracy of regional blocks in pediatric patients by allowing real-time visualization of anatomical structures and local anesthetic spread. Systematic reviews have demonstrated that ultrasound-guided regional anesthesia is associated with improved block success rates and reduced complications in pediatric urologic procedures (Ahmad et al., 2024).

Caudal Epidural Anesthesia

Caudal epidural anesthesia is one of the most commonly utilized regional techniques in pediatric urologic surgery, particularly for infraumbilical procedures. It provides reliable analgesia for surgeries involving the lower urinary tract and genitalia and is frequently used as an adjunct to general anesthesia. Benefits include improved postoperative pain control, reduced opioid consumption, and smoother emergence from anesthesia (Zeigler et al., 2020; Morrison et al., 2014).

While caudal anesthesia is generally safe, careful attention must be paid to dosing, local anesthetic selection, and patient monitoring to avoid complications such as motor blockade, urinary retention, or local anesthetic systemic toxicity. These risks are minimized through adherence to weight-based dosing and standardized protocols (Zeigler et al., 2020).

Spinal Anesthesia

Spinal anesthesia has re-emerged as a viable alternative to general anesthesia for selected pediatric urologic procedures, particularly in neonates, infants, and young children. Spinal anesthesia offers several potential advantages, including stable hemodynamics, minimal respiratory compromise, and avoidance of airway manipulation. These benefits are especially relevant in patients at higher risk for respiratory complications or postoperative apnea (Findlay et al., 2023; Ambrose et al., 2023).

Comparative studies have demonstrated that spinal anesthesia can provide outcomes comparable to general anesthesia for certain urologic procedures, with similar or improved recovery profiles and high levels of patient and family satisfaction (Ambrose et al., 2023). Recent innovations, such as the use of spinal anesthesia with caudal catheter placement, have further expanded its applicability in pediatric urologic surgery (Stangl-Kremser et al., 2025).

Integration of Anesthetic Techniques

Optimal anesthetic care in pediatric urologic surgery often involves a tailored combination of general and regional techniques rather than reliance on a single modality. Integration of regional anesthesia into general anesthetic plans allows for reduced anesthetic depth, improved analgesia, and alignment with opioid-sparing and ERAS principles (Zeigler et al., 2020; Fung et al., 2023).

The choice of anesthetic technique should be individualized based on patient factors, surgical requirements, institutional expertise, and available resources. A thorough understanding of the advantages and limitations of each approach enables anesthesiologists to deliver safe, effective, and patient-centered care in pediatric urologic surgery.

Spinal and Regional Anesthesia: Indications and Outcomes

Spinal Anesthesia in Pediatric Urologic Surgery: Indications, Techniques, and Outcomes

Spinal anesthesia has gained renewed interest in pediatric urologic surgery as an effective alternative to general anesthesia for selected procedures. Advances in anesthetic techniques, improved understanding of pediatric neurophysiology, and growing concerns regarding potential neurodevelopmental effects of general anesthetics have contributed to the increasing utilization of spinal anesthesia in infants and young children. In appropriately selected patients, spinal anesthesia offers reliable surgical conditions, effective analgesia, and favorable recovery profiles (Findlay et al., 2023; Ambrose et al., 2023; Zeigler et al., 2020).

Indications for Spinal Anesthesia in Pediatric Urology

Spinal anesthesia is most commonly indicated for infraumbilical pediatric urologic procedures, including inguinal hernia repair, orchiopexy, hypospadias repair, and select lower urinary tract interventions. These procedures are well suited to neuraxial techniques due to their limited surgical field and predictable analgesic requirements. Spinal anesthesia is particularly advantageous in neonates and former preterm infants, in whom avoidance of airway manipulation and systemic anesthetic exposure is desirable (Cronin et al., 2023; Findlay et al., 2023).

Additional indications include patients with comorbidities that increase the risk associated with general anesthesia, such as chronic lung disease or a history of postoperative apnea. In these populations, spinal anesthesia may reduce perioperative respiratory complications and the need for postoperative ventilatory support (Ambrose et al., 2023; Zeigler et al., 2020).

Technique and Practical Considerations

The successful application of spinal anesthesia in pediatric patients requires familiarity with age-specific anatomical and physiological considerations. In infants and young children, the conus medullaris is positioned more caudally than in adults, necessitating careful selection of puncture level and needle depth. Hyperbaric or isobaric local anesthetic agents are commonly used, with dosing adjusted according to patient weight and age to achieve adequate sensory and motor block while minimizing the risk of high spinal anesthesia (Stangl-Kremser et al., 2025; Findlay et al., 2023).

Sedation may be used adjunctively to facilitate patient cooperation during block placement, although excessive sedation should be avoided to preserve spontaneous ventilation and airway reflexes. Continuous monitoring of cardiovascular and respiratory parameters is essential throughout the procedure, as hemodynamic changes may occur, particularly in younger infants with limited autonomic reserve (Cronin et al., 2023; Zeigler et al., 2020).

Safety Profile and Complications

Spinal anesthesia in pediatric urologic surgery has been associated with a favorable safety profile when performed by experienced providers. Reported complications are generally infrequent and include transient hypotension, inadequate block, and rare post–dural puncture headache in older children. Serious neurological complications are exceedingly rare in contemporary practice (Findlay et al., 2023; Stangl-Kremser et al., 2025).

Importantly, spinal anesthesia has been shown to significantly reduce the incidence of postoperative apnea in high-risk infants compared with general anesthesia. This benefit supports its use in selected neonatal and infant populations undergoing urologic surgery (Cronin et al., 2023; Ambrose et al., 2023).

Outcomes and Comparison with General Anesthesia

Comparative studies evaluating spinal versus general anesthesia in pediatric urologic surgery demonstrate comparable surgical success rates and overall outcomes. Spinal anesthesia is associated with shorter recovery times, reduced opioid requirements, and earlier readiness for discharge in many cases. These advantages align with contemporary perioperative care models emphasizing rapid recovery and resource optimization (Ambrose et al., 2023; Zeigler et al., 2020).

While general anesthesia remains necessary for complex or prolonged procedures, spinal anesthesia represents a valuable component of the anesthetic armamentarium for pediatric urologic surgery. Appropriate patient selection, technical expertise, and institutional support are critical determinants of successful outcomes (Findlay et al., 2023; Stangl-Kremser et al., 2025).

In conclusion, spinal anesthesia offers a safe and effective alternative to general anesthesia for selected pediatric urologic procedures. Its use may reduce anesthetic exposure, minimize respiratory complications, and enhance postoperative recovery, particularly in high-risk infant populations. Continued research and standardized protocols will further define its role in modern pediatric urologic anesthesia practice (Cronin et al., 2023; Zeigler et al., 2020).

Regional Anesthesia Techniques in Pediatric Urologic Surgery

Regional anesthesia constitutes a fundamental component of contemporary anesthetic management in pediatric urologic surgery. The increasing emphasis on opioid-sparing strategies, enhanced recovery pathways, and improved postoperative comfort has led to broader adoption of neuraxial and peripheral regional anesthesia techniques in this population. When appropriately applied, regional anesthesia provides effective analgesia, attenuates the surgical stress response, and contributes to improved perioperative outcomes (Nelson et al., 2021; Zeigler et al., 2020).

Rationale for Regional Anesthesia in Pediatric Urology

Pediatric urologic procedures are often associated with significant postoperative pain, particularly following reconstructive or major open surgeries. Historically, opioid-based analgesia was the mainstay of postoperative pain management; however, concerns regarding opioid-related adverse effects, including respiratory depression, nausea, vomiting, and prolonged hospitalization, have prompted a shift toward multimodal and regional analgesic techniques (Morrison et al., 2014; Nelson et al., 2021).

Regional anesthesia reduces perioperative opioid requirements and improves pain scores across a range of pediatric urologic procedures. In addition, regional techniques may facilitate earlier mobilization, improve patient and caregiver satisfaction, and align with enhanced recovery after surgery (ERAS) protocols (Ahmad et al., 2024; Zeigler et al., 2020).

Neuraxial Techniques: Caudal and Spinal Blocks

Caudal epidural anesthesia remains one of the most commonly used regional techniques in pediatric urologic surgery due to its relative ease of administration and reliable analgesic coverage for infraumbilical procedures. Caudal blocks are frequently utilized as adjuncts to general anesthesia and provide effective postoperative analgesia for procedures such as hypospadias repair and orchiopexy (Morrison et al., 2014; Zeigler et al., 2020).

Spinal anesthesia, although discussed separately as a primary anesthetic technique, may also be considered within the broader framework of regional anesthesia. When used alone or in combination with minimal sedation, spinal anesthesia can eliminate the need for general anesthesia in select cases and further reduce opioid exposure (Ahmad et al., 2024; Zeigler et al., 2020).

Ultrasound-Guided Peripheral Regional Anesthesia

The use of ultrasound guidance has significantly expanded the application and safety of peripheral regional anesthesia in pediatric patients. Ultrasound-guided techniques allow direct visualization of neural structures, surrounding anatomy, and local anesthetic spread, thereby improving block success rates and reducing complications (Ahmad et al., 2024).

Commonly employed ultrasound-guided blocks in pediatric urologic surgery include ilioinguinal–iliohypogastric nerve blocks, transversus abdominis plane (TAP) blocks, and penile nerve blocks. These techniques are particularly effective for inguinal and lower abdominal procedures and contribute to substantial reductions in postoperative opioid consumption (Ahmad et al., 2024; Nelson et al., 2021).

Continuous Local Anesthetic Infusion Techniques

Continuous local anesthetic infusion via incisional catheters represents an additional regional analgesic modality for major pediatric urologic surgeries. This technique involves the placement of a catheter along the surgical incision to deliver continuous local anesthetic postoperatively. Evidence suggests that continuous incisional infusion can significantly reduce pain scores and opioid requirements following major reconstructive urologic procedures (Hidas et al., 2015).

In a prospective randomized controlled trial, continuous incisional local anesthetic infusion was associated with improved analgesia and reduced systemic analgesic use without an increase in complications, supporting its role as a valuable adjunct in multimodal pain management strategies (Hidas et al., 2015).

Impact on Opioid Consumption and Recovery

The integration of regional anesthesia into pediatric urologic anesthetic care has been consistently associated with reductions in perioperative opioid use. Opioid-sparing approaches are particularly important in pediatric populations, given the heightened sensitivity to opioid-related adverse effects and the growing emphasis on responsible opioid stewardship (Nelson et al., 2021; Morrison et al., 2014).

By improving pain control and minimizing opioid exposure, regional anesthesia supports faster recovery, earlier discharge readiness, and improved overall perioperative experience for pediatric patients and their families (Ahmad et al., 2024; Zeigler et al., 2020).

Limitations and Considerations

Despite its benefits, regional anesthesia in pediatric urologic surgery requires specialized expertise, appropriate equipment, and institutional support. Potential limitations include block failure, local anesthetic systemic toxicity, and procedure-specific contraindications. Careful patient selection, weight-based dosing, and adherence to established safety protocols are essential to minimize risks (Ahmad et al., 2024; Zeigler et al., 2020).

In conclusion, regional anesthesia plays a critical role in modern pediatric urologic surgery, offering effective analgesia while supporting opioid reduction and enhanced recovery. Continued advances in ultrasound technology and standardized training are likely to further expand its application and optimize patient outcomes (Nelson et al., 2021; Ahmad et al., 2024).

COMPARISON OF SPINAL VERSUS GENERAL ANESTHESIA IN PEDIATRIC UROLOGIC SURGERY

The choice between spinal and general anesthesia in pediatric urologic surgery remains an important clinical decision influenced by patient characteristics, surgical complexity, and institutional expertise. Both anesthetic techniques have demonstrated safety and efficacy; however, they differ in their physiological effects, perioperative risk profiles, and recovery characteristics. Recent literature has increasingly explored spinal anesthesia as an alternative to general anesthesia, particularly for infraumbilical pediatric urologic procedures (Findlay et al., 2023; Ambrose et al., 2023).

Clinical Indications and Patient Selection

General anesthesia continues to be the most commonly used anesthetic technique in pediatric urologic surgery due to its versatility and ability to provide controlled airway management, immobility, and reliable anesthetic depth across a wide range of procedures. It is particularly indicated for complex, prolonged, or upper abdominal urologic surgeries, as well as in patients who are unlikely to tolerate neuraxial techniques (Zeigler et al., 2020).

In contrast, spinal anesthesia is primarily utilized for short-duration infraumbilical procedures in neonates, infants, and young children. Patient selection is critical, with ideal candidates being those without contraindications to neuraxial anesthesia and with anticipated surgical times within the effective duration of spinal block. The avoidance of airway manipulation and systemic anesthetic exposure represents a key advantage in this population (Findlay et al., 2023; Stangl-Kremser et al., 2025).

Perioperative Physiological Effects

General anesthesia is associated with dose-dependent respiratory depression, alterations in ventilation–perfusion matching, and potential hemodynamic instability, particularly in younger infants. These effects necessitate careful intraoperative monitoring and postoperative observation, especially in patients at risk for apnea or respiratory compromise (Zeigler et al., 2020).

Spinal anesthesia, by contrast, preserves spontaneous ventilation and avoids the use of inhalational or intravenous general anesthetic agents. Although transient hypotension may occur due to sympathetic blockade, clinically significant hemodynamic instability is uncommon in pediatric patients when appropriate dosing and monitoring are employed (Findlay et al., 2023; Ambrose et al., 2023).

Postoperative Recovery and Outcomes

Several comparative studies have demonstrated favorable recovery profiles associated with spinal anesthesia. These include reduced postoperative apnea, shorter recovery room stays, and decreased need for postoperative opioids when compared with general anesthesia in selected pediatric urologic procedures (Ambrose et al., 2023; Findlay et al., 2023).

General anesthesia, while associated with predictable anesthetic conditions, may result in prolonged emergence, postoperative nausea and vomiting, and increased opioid requirements, particularly in the absence of regional analgesia. However, advances in anesthetic agents and multimodal analgesic strategies have mitigated many of these disadvantages (Zeigler et al., 2020).

Safety and Complication Rates

Both spinal and general anesthesia demonstrate low complication rates in pediatric urologic surgery when performed by experienced teams. Serious complications related to spinal anesthesia, such as neurological injury or infection, are exceedingly rare. Minor complications, including block failure or transient hypotension, are more commonly reported but are typically manageable without long-term sequelae (Stangl-Kremser et al., 2025; Findlay et al., 2023).

General anesthesia carries risks related to airway management, anesthetic drug exposure, and postoperative respiratory events, particularly in high-risk infant populations. These risks underscore the importance of individualized anesthetic planning and vigilant perioperative care (Zeigler et al., 2020).

Clinical Decision-Making and Future Perspectives

The selection of spinal versus general anesthesia should be individualized, taking into account patient age, comorbidities, surgical requirements, and provider expertise. Rather than viewing these techniques as mutually exclusive, many centers employ a complementary approach, integrating spinal anesthesia within a broader multimodal anesthetic framework (Ambrose et al., 2023; Findlay et al., 2023).

Future research is expected to further clarify patient selection criteria, refine techniques, and evaluate long-term outcomes associated with spinal anesthesia in pediatric urologic surgery. Ongoing innovation and evidence-based practice will continue to shape anesthetic decision-making in this evolving field (Stangl-Kremser et al., 2025; Zeigler et al., 2020).

PAIN MANAGEMENT AND OPIOID-SPARING STRATEGIES IN PEDIATRIC UROLOGIC SURGERY

Effective pain management is a fundamental component of anesthetic care in pediatric urologic surgery and has a direct impact on postoperative recovery, patient satisfaction, and overall outcomes. Inadequate analgesia may lead to increased stress responses, delayed mobilization, prolonged hospital stay, and adverse behavioral changes in children. Conversely, excessive reliance on systemic opioids is associated with well-recognized risks, including respiratory depression, nausea, vomiting, ileus, and prolonged sedation. These considerations have driven a paradigm shift toward multimodal and opioid-sparing analgesic strategies in contemporary pediatric urologic anesthesia (Zeigler et al., 2020; Nelson et al., 2021).

Principles of Multimodal Analgesia

Multimodal analgesia involves the use of multiple analgesic modalities that act through different mechanisms to achieve effective pain control while minimizing opioid requirements. In pediatric urologic surgery, this approach typically combines regional anesthesia techniques, non-opioid systemic analgesics, and judicious use of opioids when necessary. Evidence supports that multimodal analgesia improves pain control and reduces opioid-related adverse effects without compromising patient safety (Zeigler et al., 2020; Morrison et al., 2014).

Non-opioid analgesics, including acetaminophen and nonsteroidal anti-inflammatory drugs, are commonly incorporated into perioperative pain management protocols for pediatric urologic procedures. When appropriately dosed and selected based on patient age and renal function, these agents contribute significantly to baseline analgesia and reduce the need for rescue opioid administration (Zeigler et al., 2020).

Opioid-Sparing Strategies

Opioid-sparing strategies have gained increasing importance in pediatric urologic surgery due to heightened awareness of opioid-related morbidity and the potential for long-term consequences of early opioid exposure. Contemporary practice emphasizes minimizing opioid use through careful anesthetic planning and incorporation of alternative analgesic modalities. Studies evaluating pediatric urologic surgery have demonstrated that reduced opioid exposure is achievable without compromising pain control when multimodal strategies are implemented (Nelson et al., 2021).

Institutional protocols aimed at reducing perioperative opioid prescribing have been associated with lower opioid consumption both in the hospital and after discharge. These protocols often include standardized analgesic regimens, provider education, and increased utilization of regional anesthesia techniques (Nelson et al., 2021; Morrison et al., 2014).

Role of Regional and Local Anesthetic Techniques

Regional anesthesia plays a central role in opioid-sparing pain management for pediatric urologic surgery. Techniques such as caudal epidural anesthesia, peripheral nerve blocks, and local anesthetic infiltration provide targeted analgesia that can significantly reduce postoperative pain scores and opioid requirements. These benefits are particularly pronounced in procedures involving the lower urinary tract and genitalia (Zeigler et al., 2020; Morrison et al., 2014).

The use of continuous local anesthetic techniques has also been explored in major pediatric urologic surgery. Prospective randomized studies have demonstrated that continuous incisional infusion of local anesthetics can provide effective postoperative analgesia and reduce opioid consumption following extensive reconstructive procedures (Hidas et al., 2015). Such approaches may be especially valuable in patients undergoing complex surgeries associated with significant postoperative pain.

Procedure-Specific Pain Management Considerations

Pain management strategies should be tailored to the specific urologic procedure being performed, as analgesic requirements vary widely across different surgeries. Minor procedures, such as circumcision or diagnostic interventions, may be adequately managed with local or regional anesthesia and non-opioid analgesics. In contrast, major reconstructive surgeries often require a more comprehensive multimodal approach, incorporating regional techniques and scheduled non-opioid medications with limited opioid rescue therapy (Zeigler et al., 2020; Morrison et al., 2014).

Individualization of pain management plans based on patient age, developmental status, and comorbidities is essential to optimize analgesic efficacy while minimizing adverse effects. Ongoing assessment and adjustment of analgesic regimens throughout the perioperative period further enhance safety and effectiveness (Zeigler et al., 2020).

Impact on Recovery and Outcomes

Effective pain control using opioid-sparing strategies contributes to improved postoperative recovery, earlier mobilization, reduced incidence of postoperative nausea and vomiting, and enhanced patient and family satisfaction. These benefits align closely with ERAS principles and support broader efforts to optimize perioperative care in pediatric urologic surgery (Fung et al., 2023; Han et al., 2021).

In summary, pain management in pediatric urologic surgery has evolved toward a multimodal, opioid-sparing paradigm that emphasizes safety, efficacy, and patient-centered care. Integration of regional anesthesia, non-opioid analgesics, and selective opioid use represents current best practice and serves as a foundation for enhanced recovery and improved perioperative outcomes in this population (Zeigler et al., 2020; Nelson et al., 2021).

ENHANCED RECOVERY AFTER SURGERY (ERAS) IN PEDIATRIC UROLOGY: ANESTHETIC PERSPECTIVES

Enhanced Recovery After Surgery (ERAS) represents a multimodal, evidence-based approach to perioperative care aimed at reducing surgical stress, preserving physiological function, and accelerating postoperative recovery. Although ERAS protocols were initially developed for adult surgical populations, increasing evidence supports their adaptation and implementation in pediatric urologic surgery. Anesthetic management plays a central role in ERAS pathways, influencing intraoperative stability, postoperative pain control, early mobilization, and overall patient outcomes (Fung et al., 2023; Han et al., 2021).

Core Principles of ERAS in Pediatric Urologic Surgery

The core principles of ERAS include preoperative optimization, standardized anesthetic and analgesic strategies, early enteral nutrition, and proactive postoperative care. In pediatric urology, ERAS protocols emphasize minimizing fasting times, reducing perioperative opioid exposure, maintaining normothermia, and promoting early return to baseline function. These elements are particularly relevant in children, who may experience greater physiological and psychological stress in response to surgery and hospitalization (Fung et al., 2023; Zeigler et al., 2020).

Anesthetic techniques that support rapid emergence, stable hemodynamics, and effective pain control are integral to successful ERAS implementation. Tailoring anesthetic care to align with ERAS principles requires close collaboration between anesthesiologists, pediatric urologists, and perioperative care teams (Han et al., 2021).

Preoperative ERAS Considerations and Anesthetic Planning

From an anesthetic perspective, preoperative ERAS considerations include patient and family education, anxiety reduction strategies, and avoidance of prolonged fasting. Clear communication with caregivers regarding perioperative expectations and pain management plans has been shown to improve compliance and satisfaction, which are critical components of ERAS success in pediatric populations (Fung et al., 2023).

Anesthetic planning within ERAS frameworks prioritizes techniques that reduce perioperative stress responses and facilitate early recovery. This includes consideration of regional anesthesia, opioid-sparing analgesia, and individualized fluid management strategies, all of which contribute to improved postoperative outcomes (Zeigler et al., 2020; Han et al., 2021).

Intraoperative Anesthetic Management within ERAS Pathways

Intraoperative anesthetic management is a key determinant of ERAS outcomes in pediatric urologic surgery. Balanced anesthetic techniques that minimize excessive anesthetic depth and avoid unnecessary opioid administration are preferred. The integration of regional anesthesia, such as caudal or spinal techniques, supports effective analgesia while reducing systemic opioid exposure and associated adverse effects (Fung et al., 2023; Zeigler et al., 2020).

Maintenance of normothermia and hemodynamic stability is essential, as intraoperative hypothermia or hypotension may delay recovery and increase postoperative complications. Goal-directed fluid therapy, adapted to pediatric physiology, further supports renal perfusion and overall physiological stability during urologic procedures (Han et al., 2021).

Postoperative Recovery and Analgesia

Postoperative care within ERAS pathways focuses on early mobilization, prompt resumption of oral intake, and ongoing multimodal pain management. Effective postoperative analgesia is critical to achieving these goals and relies heavily on the anesthetic strategies implemented intraoperatively. Opioid-sparing regimens incorporating regional anesthesia and non-opioid analgesics have been associated with improved recovery profiles and reduced length of hospital stay in pediatric urologic surgery (Fung et al., 2023; Han et al., 2021).

Continuous evaluation of pain, nausea, and functional recovery allows for timely intervention and adjustment of analgesic regimens. This proactive approach aligns with ERAS objectives and supports a smoother transition from hospital to home for pediatric patients and their families (Zeigler et al., 2020).

Evidence and Outcomes of ERAS in Pediatric Urology

Emerging evidence suggests that ERAS implementation in pediatric urologic surgery is associated with favorable outcomes, including reduced opioid consumption, shorter hospital stays, and high levels of patient and family satisfaction. Studies focusing on reconstructive urologic procedures have demonstrated that ERAS protocols, when combined with optimized anesthetic care, can be safely and effectively applied in pediatric populations (Han et al., 2021; Fung et al., 2023).

Despite these promising findings, continued research is needed to further refine ERAS pathways and establish procedure-specific recommendations for pediatric urologic surgery. Anesthesiologists play a critical role in this process by contributing to protocol development, implementation, and outcome evaluation (Fung et al., 2023).

OFFICE-BASED PROCEDURES AND PEDIATRIC SEDATION UNITS IN UROLOGIC SURGERY

The scope of pediatric urologic surgery has expanded to include a growing number of procedures performed outside the traditional operating room setting. Advances in anesthetic techniques, patient monitoring, and procedural efficiency have facilitated the safe performance of selected pediatric urologic interventions in office-based environments and dedicated pediatric sedation units. These models aim to optimize resource utilization, reduce healthcare costs, and improve patient and family satisfaction while maintaining high standards of safety and clinical effectiveness (Aghababian et al., 2022; Falkiewicz et al., 2023).

Rationale for Office-Based Pediatric Urologic Procedures

Office-based pediatric urologic procedures are typically limited to minimally invasive or low-complexity interventions that require short procedural times and predictable analgesic needs. The rationale for performing these procedures outside the operating room includes reduced exposure to general anesthesia, avoidance of hospital admission, and increased procedural convenience for patients and families. When appropriate patient selection criteria are applied, office-based anesthesia and sedation have been shown to be safe and effective alternatives to traditional operating room–based care (Aghababian et al., 2022).

From an anesthetic perspective, minimizing anesthetic exposure is particularly appealing in pediatric populations. Office-based settings often employ sedation or limited anesthetic techniques rather than full general anesthesia, which may reduce recovery time and facilitate earlier discharge (Zeigler et al., 2020).

Patient Selection and Safety Considerations

Careful patient selection is the cornerstone of safe office-based pediatric urologic anesthesia. Candidates should be medically stable, with minimal comorbidities and low risk for airway or anesthetic complications. Children with significant cardiopulmonary disease, complex syndromic conditions, or anticipated difficult airway management are generally not suitable for office-based procedures and should instead be managed in fully equipped operating room environments (Aghababian et al., 2022; Zeigler et al., 2020).

Safety considerations extend beyond patient factors to include procedural complexity, anticipated pain levels, and the availability of trained personnel and emergency equipment. Standardized protocols, continuous monitoring, and immediate access to resuscitative resources are essential to ensure patient safety in office-based and sedation unit settings (Falkiewicz et al., 2023).

Pediatric Sedation Units

Dedicated pediatric sedation units represent a structured and standardized approach to providing anesthesia and sedation for outpatient urologic procedures. These units are typically staffed by trained anesthesia providers and supported by protocols designed to ensure consistent care delivery and rapid response to adverse events.

Studies evaluating pediatric sedation units for urologic procedures have demonstrated high levels of safety, effectiveness, and patient satisfaction, supporting their role as viable alternatives to general anesthesia in selected cases (Falkiewicz et al., 2023).

Sedation units also allow for efficient patient throughput and may reduce the need for operating room resources. From an anesthetic standpoint, the use of standardized sedation regimens and recovery criteria contributes to predictable outcomes and facilitates early discharge (Zeigler et al., 2020; Falkiewicz et al., 2023).

Anesthetic and Sedation Techniques

Anesthetic techniques used in office-based and sedation unit settings are selected to balance patient comfort, procedural conditions, and rapid recovery. These techniques may include minimal to moderate sedation, deep sedation, or limited general anesthesia depending on patient age, cooperation, and procedural requirements. Continuous monitoring of vital signs and level of consciousness is mandatory to detect and manage potential complications promptly (Zeigler et al., 2020).

The choice of anesthetic or sedative agents should prioritize rapid onset and offset, minimal respiratory depression, and favorable recovery profiles. Clear discharge criteria and post-procedural follow-up instructions are essential components of safe practice in these settings (Aghababian et al., 2022).

Outcomes and Patient Satisfaction

Available evidence suggests that office-based pediatric urologic procedures and sedation unit–based care are associated with high levels of patient and family satisfaction. Reduced waiting times, avoidance of hospital admission, and faster recovery contribute positively to the overall care experience. Importantly, when appropriate safety measures are in place, complication rates remain low and comparable to those observed in traditional operating room settings (Aghababian et al., 2022; Falkiewicz et al., 2023).

In summary, office-based procedures and pediatric sedation units represent important components of contemporary pediatric urologic anesthesia. With careful patient selection, standardized protocols, and multidisciplinary collaboration, these models offer safe, effective, and patient-centered alternatives to traditional anesthesia care for selected pediatric urologic interventions (Zeigler et al., 2020).

MINIMALLY INVASIVE AND ROBOTIC PEDIATRIC UROLOGIC SURGERY: ANESTHETIC CONSIDERATIONS

Minimally invasive and robotic-assisted techniques have become increasingly integral to pediatric urologic surgery, offering advantages such as reduced tissue trauma, improved visualization, and potentially faster recovery compared with open surgical approaches. These techniques, however, introduce distinct anesthetic challenges that require specialized knowledge and careful perioperative management. Anesthesiologists must account for the physiological impact of pneumoperitoneum, patient positioning, and prolonged operative times when caring for pediatric patients undergoing minimally invasive or robotic urologic procedures (Spinelli et al., 2016; Khater et al., 2024; Zeigler et al., 2020).

Physiological Effects of Pneumoperitoneum

The creation of pneumoperitoneum during laparoscopic and robotic surgery has significant physiological implications in pediatric patients. Increased intraabdominal pressure can reduce venous return, alter cardiac output, and impair renal perfusion, effects that may be more pronounced in infants and young children due to limited cardiovascular reserve. Careful monitoring of hemodynamics and judicious control of insufflation pressures are therefore essential to minimize adverse cardiovascular effects (Spinelli et al., 2016; Khater et al., 2024).

Pneumoperitoneum also affects respiratory mechanics by elevating the diaphragm and decreasing lung compliance and functional residual capacity. These changes necessitate adjustments in ventilatory strategies to maintain adequate oxygenation and carbon dioxide elimination while avoiding excessive airway pressures (Zeigler et al., 2020; Spinelli et al., 2016).

Ventilatory Management

Ventilatory management during minimally invasive and robotic pediatric urologic surgery requires careful balancing of oxygenation, ventilation, and lung protection. Controlled mechanical ventilation is typically employed, with adjustments in tidal volume, respiratory rate, and positive end-expiratory pressure based on patient age, size, and intraoperative conditions. End-tidal carbon dioxide monitoring is critical, as carbon dioxide absorption from the pneumoperitoneum may lead to hypercapnia if not adequately managed (Spinelli et al., 2016; Zeigler et al., 2020).

In neonates and infants, the risk of rapid desaturation and hypercapnia underscores the importance of vigilant respiratory monitoring and prompt ventilatory adjustments. Anesthetic agents should be titrated to maintain adequate depth while preserving respiratory stability (Zeigler et al., 2020).

Patient Positioning and Its Anesthetic Implications

Robotic pediatric urologic surgery often requires specific patient positioning, such as steep Trendelenburg or lateral decubitus positions, to optimize surgical exposure. These positions can exacerbate the physiological effects of pneumoperitoneum by further compromising respiratory mechanics and venous return. Prolonged positioning may also increase the risk of pressure injuries and nerve compression, particularly in smaller children (Khater et al., 2024).

Anesthesiologists play a key role in ensuring safe positioning through careful padding, secure patient fixation, and ongoing assessment of hemodynamic and respiratory status. Collaboration with the surgical team is essential to balance optimal surgical exposure with patient safety (Khater et al., 2024; Zeigler et al., 2020).

Hemodynamic Management and Fluid Therapy

Hemodynamic stability is a primary anesthetic goal during minimally invasive and robotic pediatric urologic surgery. The combined effects of pneumoperitoneum, positioning, and anesthetic agents may predispose pediatric patients to hypotension or reduced organ perfusion. Goal-directed fluid therapy, adapted to pediatric physiology, can help maintain intravascular volume and support renal perfusion without causing fluid overload (Zeigler et al., 2020; Khater et al., 2024).

Invasive monitoring is rarely required for routine minimally invasive pediatric urologic procedures but may be considered in complex or prolonged cases. Continuous noninvasive monitoring and frequent clinical assessment remain the mainstays of intraoperative management in most patients (Zeigler et al., 2020).

Analgesia and Recovery Considerations

Effective analgesia is essential to support early recovery following minimally invasive and robotic urologic surgery. Regional anesthesia techniques, including caudal blocks and peripheral nerve blocks, are commonly used to supplement general anesthesia and reduce postoperative opioid requirements. These approaches align with ERAS principles and contribute to improved recovery profiles in pediatric patients (Fung et al., 2023; Zeigler et al., 2020).

In summary, anesthetic management of minimally invasive and robotic pediatric urologic surgery requires an understanding of the unique physiological challenges posed by pneumoperitoneum and patient positioning. Through careful planning, vigilant monitoring, and integration of multimodal analgesic strategies, anesthesiologists can support safe and effective perioperative care in this evolving surgical landscape (Spinelli et al., 2016; Khater et al., 2024; Zeigler et al., 2020).

Perioperative Safety, Monitoring, and Complications in Pediatric Urologic Anesthesia

Ensuring perioperative safety is a fundamental objective of anesthetic care in pediatric urologic surgery. Pediatric patients present unique anatomical and physiological characteristics that increase vulnerability to anesthetic-related complications, necessitating meticulous monitoring and proactive risk management. Comprehensive perioperative strategies encompassing preoperative assessment, intraoperative monitoring, and postoperative surveillance are essential to optimize outcomes and minimize adverse events (Zeigler et al., 2020; Shukis & Merola, 1993).

Preoperative Risk Assessment and Optimization

Thorough preoperative evaluation is critical for identifying patient-specific risk factors, including prematurity, congenital anomalies, cardiopulmonary comorbidities, and previous anesthetic complications. In pediatric urologic surgery, particular attention should be paid to renal function, electrolyte balance, and associated congenital conditions that may influence anesthetic management (Zeigler et al., 2020).

Risk stratification enables tailored anesthetic planning and facilitates appropriate allocation of resources, such as postoperative monitoring in high-dependency or intensive care settings for high-risk patients. Parental counseling and informed consent further contribute to perioperative safety by aligning expectations and enhancing cooperation (Shukis & Merola, 1993).

Intraoperative Monitoring Standards

Continuous intraoperative monitoring is essential to detect early physiological changes and prevent complications. Standard monitoring includes electrocardiography, noninvasive blood pressure measurement, pulse oximetry, capnography, and temperature monitoring. In pediatric patients, maintaining normothermia is particularly important due to their increased susceptibility to hypothermia and associated metabolic disturbances (Zeigler et al., 2020; Spinelli et al., 2016).

Advanced monitoring techniques may be warranted in complex or minimally invasive procedures, including invasive arterial pressure monitoring or end-tidal carbon dioxide trend analysis during laparoscopic and robotic surgeries. These measures support timely intervention in response to hemodynamic or respiratory instability (Spinelli et al., 2016).

Airway Management and Respiratory Complications

Airway management remains a critical aspect of pediatric urologic anesthesia. Anatomical differences, such as a proportionally larger tongue and higher laryngeal position, increase the risk of airway obstruction and difficult intubation in children. Careful airway assessment and the availability of age-appropriate equipment are essential to minimize airway-related complications (Zeigler et al., 2020).

Respiratory complications, including hypoventilation, laryngospasm, and postoperative apnea, are among the most common adverse events in pediatric anesthesia. Vigilant monitoring and appropriate postoperative observation are particularly important in neonates and former preterm infants undergoing urologic procedures (Shukis & Merola, 1993; Zeigler et al., 2020).

Cardiovascular Stability and Fluid Management

Maintaining cardiovascular stability requires careful titration of anesthetic agents and judicious fluid management. Pediatric patients have limited physiologic reserve, and both hypovolemia and fluid overload can adversely affect perioperative outcomes. Balanced crystalloid solutions are commonly used, with fluid administration guided by patient weight, surgical losses, and hemodynamic parameters (Zeigler et al., 2020).

In minimally invasive procedures, pneumoperitoneum-induced changes in venous return and cardiac output necessitate close cardiovascular monitoring and prompt adjustment of anesthetic and ventilatory strategies (Spinelli et al., 2016).

Postoperative Surveillance and Complications

Postoperative monitoring is essential to identify early complications such as respiratory depression, hemodynamic instability, nausea, vomiting, and inadequate pain control. The risk of postoperative apnea and desaturation remains a key concern in infants, underscoring the importance of extended monitoring in high-risk populations (Zeigler et al., 2020).

Effective postoperative pain management, incorporating multimodal and regional analgesic strategies, contributes to improved safety by reducing opioid-related adverse effects. Early recognition and management of complications are critical components of high-quality perioperative care in pediatric urologic anesthesia (Shukis & Merola, 1993; Zeigler et al., 2020).

Quality Improvement and Safety Culture

The establishment of standardized protocols, team communication, and continuous quality improvement initiatives enhances perioperative safety in pediatric urologic anesthesia. Simulation training, adverse event reporting, and multidisciplinary collaboration support the ongoing refinement of anesthetic practice and complication prevention strategies (Zeigler et al., 2020).

In summary, perioperative safety in pediatric urologic anesthesia relies on comprehensive monitoring, meticulous anesthetic management, and a proactive safety culture. Adherence to evidence-based practices and continued vigilance are essential to minimizing complications and optimizing outcomes in this vulnerable patient population.

FUTURE DIRECTIONS AND EMERGING TRENDS IN PEDIATRIC UROLOGIC ANESTHESIA

Pediatric urologic anesthesia continues to evolve in response to advances in surgical techniques, growing emphasis on patient safety, and increasing demand for individualized perioperative care. Emerging trends focus on minimizing anesthetic exposure, enhancing recovery, optimizing analgesia, and integrating novel technologies into routine clinical practice. These developments aim to further improve outcomes while maintaining the highest standards of safety in this vulnerable patient population (Zeigler et al., 2020; Khater et al., 2024).

Expansion of Neuraxial and Regional Anesthesia Techniques

One of the most significant trends in pediatric urologic anesthesia is the expanding role of neuraxial and regional anesthesia as both primary and adjunctive techniques. Recent studies highlight increasing utilization of spinal anesthesia, including novel approaches such as spinal anesthesia combined with caudal catheter placement, as alternatives to general anesthesia for selected procedures. These strategies may further reduce systemic anesthetic exposure and perioperative respiratory complications, particularly in infants and young children (Stangl-Kremser et al., 2025; Zeigler et al., 2020).

Continued refinement of ultrasound-guided regional anesthesia techniques is expected to improve block success rates and safety. As expertise and training expand, regional anesthesia is likely to play an increasingly central role in pediatric urologic anesthetic practice (Khater et al., 2024).

Integration of Enhanced Recovery Pathways

Enhanced recovery after surgery (ERAS) protocols are anticipated to become more widely adopted and standardized in pediatric urologic surgery. Future ERAS pathways will likely incorporate procedure-specific anesthetic strategies, refined multimodal analgesia protocols, and individualized perioperative care plans based on patient risk profiles. The anesthesiologist's role in coordinating these pathways will remain critical to their success (Fung et al., 2023; Zeigler et al., 2020).

Ongoing research is expected to clarify optimal ERAS components for different pediatric urologic procedures and age groups, facilitating broader implementation and improved outcome measurement (Fung et al., 2023).

Technological Advances and Monitoring Innovations

Advancements in perioperative monitoring and anesthetic technology are expected to further enhance safety in pediatric urologic anesthesia. Improved noninvasive monitoring tools, refined ventilatory strategies, and enhanced depth-of-anesthesia monitoring may support more precise anesthetic titration and early detection of physiological instability. These innovations are particularly relevant in minimally invasive and robotic pediatric urologic surgery, where access to the patient may be limited (Khater et al., 2024; Zeigler et al., 2020).

The integration of data-driven decision support systems and quality improvement initiatives may also contribute to safer and more consistent anesthetic care across institutions.

Focus on Long-Term Outcomes and Neurodevelopment

Concerns regarding the potential neurodevelopmental effects of anesthetic exposure in early childhood continue to influence anesthetic decision-making. Although definitive conclusions remain elusive, there is increasing emphasis on strategies that limit anesthetic exposure duration and frequency. The growing use of spinal anesthesia, regional techniques, and office-based procedures aligns with this goal and represents an important area of future investigation (Zeigler et al., 2020; Stangl-Kremser et al., 2025).

Long-term outcome studies focusing on neurodevelopment, quality of life, and functional recovery are needed to inform evidence-based practice and guide anesthetic choices in pediatric urologic surgery.

Education, Training, and Multidisciplinary Collaboration

Future progress in pediatric urologic anesthesia will depend on ongoing education, specialized training, and multidisciplinary collaboration. Simulation-based training, standardized protocols, and cross-disciplinary communication between anesthesiologists, urologists, and nursing staff are essential to implementing emerging techniques safely and effectively (Khater et al., 2024; Zeigler et al., 2020).

As pediatric urologic surgery continues to advance, anesthetic practice must adapt accordingly, balancing innovation with patient safety and evidence-based care.

CONCLUSION

In conclusion, pediatric urologic anesthesia is undergoing significant evolution driven by advancements in regional anesthesia, enhanced recovery protocols, minimally invasive surgery, and patient-centered care models. Future directions emphasize individualized anesthetic strategies, opioid-sparing approaches, and continued efforts to minimize anesthetic-related risks while optimizing perioperative outcomes. Ongoing research, technological innovation, and interdisciplinary collaboration will play pivotal roles in shaping the future of anesthetic care in pediatric urologic surgery (Fung et al., 2023; Khater et al., 2024; Stangl-Kremser et al., 2025; Zeigler et al., 2020).

Chapter Highlights / Key Points

• Pediatric urologic surgery requires anesthetic strategies tailored to the unique physiological characteristics, developmental stages, and perioperative vulnerabilities of pediatric patients.

• Advances in general anesthesia techniques, combined with refined airway management and monitoring strategies, have significantly improved perioperative safety in pediatric urologic procedures.

• Regional and neuraxial anesthesia, including spinal and ultrasound-guided regional techniques, provide effective analgesia and represent viable alternatives or adjuncts to general anesthesia in selected pediatric urologic surgeries.

• Multimodal and opioid-sparing analgesic strategies play a critical role in reducing postoperative opioid exposure while maintaining effective pain control in pediatric urologic patients.

• Enhanced Recovery After Surgery (ERAS) protocols in pediatric urology contribute to improved postoperative recovery, reduced hospital length of stay, and optimized anesthetic outcomes.

• Office-based and sedation-unit models for selected pediatric urologic procedures offer safe and effective alternatives to traditional operating room anesthesia when appropriate patient selection and monitoring are ensured.

• Minimally invasive and robotic pediatric urologic surgeries introduce unique anesthetic challenges, including positioning, pneumoperitoneum management, and physiologic alterations, necessitating specialized anesthetic considerations.

• Ongoing innovation, evidence-based practice, and multidisciplinary collaboration are essential for optimizing anesthetic care and improving perioperative outcomes in pediatric urologic surgery.

Take-Home Messages

• Pediatric patients undergoing urologic surgery require anesthetic management that accounts for age-specific physiological differences, perioperative stress responses, and developmental considerations.

• General anesthesia remains the most commonly used technique in pediatric urologic surgery; however, spinal and regional anesthesia can be safely and effectively applied in selected patients and procedures.

• Ultrasound-guided regional anesthesia enhances block accuracy, improves postoperative analgesia, and contributes to reduced opioid consumption in pediatric urologic surgeries.

• Multimodal analgesia and opioid-sparing strategies should be incorporated into routine practice to minimize opioid-related adverse effects while maintaining adequate pain control.

• Enhanced Recovery After Surgery (ERAS) pathways in pediatric urology support faster recovery, earlier mobilization, and improved perioperative outcomes when combined with appropriate anesthetic techniques.

• Office-based and sedation-unit approaches may offer safe and effective alternatives to general anesthesia for selected minor pediatric urologic procedures with appropriate patient selection and monitoring.

• Minimally invasive and robotic pediatric urologic surgeries demand specific anesthetic considerations, including careful management of pneumoperitoneum, patient positioning, and intraoperative physiologic changes.

• Continuous evaluation of emerging evidence and multidisciplinary collaboration between anesthesiologists and pediatric urologists are essential for optimizing perioperative care and outcomes.

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CHAPTER 3

PELVIC FLOOR REHABILITATION IN BLADDER–BOWEL DYSFUNCTION IN CHILDREN

ALİYE KANDIRICI [1]

INTRODUCTION

Bladder–bowel dysfunction (BBD) is a common clinical condition in childhood in which both voiding and defecation functions are affected. It may present with symptoms such as daytime urinary incontinence, increased voiding frequency, urgency, enuresis, constipation, and fecal incontinence. These symptoms adversely affect the quality of life of the child and family. If left untreated, BBD may lead to recurrent urinary tract infections (UTIs), vesicoureteral reflux (VUR), psychosocial problems, a marked decline in quality of life, and progressive, potentially permanent damage.

The pathophysiology of BBD is multifactorial and is related to impaired coordination among the bladder, bowel, pelvic floor muscles, and the central nervous system. Therefore, single-target

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therapeutic approaches are often insufficient, and multidisciplinary, holistic strategies come to the fore. (Aguiar & Franco, 2018)

As part of a multidisciplinary approach, pelvic floor rehabilitation comprises first-line interventions and has been increasingly used in the treatment of childhood BBD in recent years. (Altunkol et al., 2018) However, studies regarding its clinical effectiveness, indications, and its place within treatment algorithms are ongoing.

Pathophysiology of Bladder–Bowel Dysfunction

Introduction and Definition

Bladder–bowel dysfunction (BBD) refers to the coexistence of lower urinary tract symptoms with constipation and/or fecal incontinence. It is common in childhood, constitutes a substantial proportion of pediatric urology consultations, and is an important risk factor for recurrent UTIs and the development of VUR. (Austin et al., 2016; Burgers et al., 2010)

Shared Embryological, Anatomical, and Neural Basis

The bladder and distal bowel originate from the cloacal structure during embryological development and are anatomically adjacent within the pelvic floor. Functional control relies on the complex interaction of the parasympathetic (S2–S4), sympathetic (T11–L2), and somatic (pudendal nerve) nervous systems. This shared innervation enables bladder and bowel functions to be regulated along a common axis and provides the basis for dysfunction in one system to affect the other. (Chase et al., 2010; Austin et al., 2016)

Effects of Rectal Distension and Constipation on Bladder Function

In functional constipation, stool accumulation and chronic rectal distension develop. This may: reduce functional bladder capacity by exerting mechanical pressure on the bladder, and trigger detrusor overactivity via sacral reflex pathways.

Burgers and colleagues demonstrated that rectal distension has significant, but individually variable, effects on bladder sensation, capacity, and detrusor activity in children. (Bush et al., 2013) It has also been reported that increased rectal diameter on ultrasonography is associated with enuresis and overactive bladder findings. (Kaye & Palmer, 2008)

Holding Behavior and Pelvic Floor Dysfunction

A key pathophysiological component of BBD is learned holding behavior. In children, a history of painful defecation, avoiding school toilets, or postponing voiding/defecation for social reasons may, over time, lead to involuntary co-contraction of the pelvic floor muscles. This results in the clinical picture of dysfunctional voiding, characterized by failure of the pelvic floor to relax during voiding. (Combs et al., 1998)

As a consequence of pelvic floor dysfunction: Increased outlet resistance during voiding, Intermittent/staccato voiding, and Increased post-void residual urine may develop, thereby sustaining bladder–bowel dysfunction. (dos Santos et al., 2017)

Bidirectional Relationship Between Overactive Bladder and Bowel Dysfunction

A substantial proportion of children diagnosed with overactive bladder (OAB) have concomitant constipation. Many studies have reported that treating bowel dysfunction can yield marked improvement in urinary symptoms. (Feldman & Bauer, 2006; Jansson & Nevéus, 2018)

However, laxative therapy alone is not always sufficient; in a randomized controlled trial, polyethylene glycol showed only limited superiority over placebo for urinary urgency symptoms. (Halachmi & Farhat, 2008) These findings support that BBD pathophysiology is multi-component rather than single-factor.

Urinary Stasis, Infection, and Inflammatory Sensitization

Urinary stasis developing secondary to pelvic floor dysfunction and voiding disorders increases the risk of UTIs. Recurrent infections may cause inflammation of the bladder mucosa and sensory hypersensitivity, thereby exacerbating urgency and frequency symptoms. The International Children's Continence Society (ICCS) emphasizes that BBD is an important and often overlooked cause of childhood UTIs. (Burgers et al., 2010)

In addition, it has been reported that VUR prevalence is higher in the presence of BBD and that reflux resolution may be delayed. (Kajbafzadeh et al., 2011)

Loss of Rectal Sensation and Mechanisms of Chronicity

In long-standing constipation, dilatation of the rectal ampulla leads to reduced rectal sensation. This suppresses the defecation reflex and results in further stool accumulation. Thus, the relationship between rectal distension and bladder dysfunction persists, and BBD may become a chronic clinical condition. (Chase et al., 2010; Bush et al., 2013)

The Pathophysiological Vicious Cycle

BBD is often explained by the following cycle: Holding behavior → constipation and rectal distension → impaired bladder filling/emptying → urinary stasis and UTI → increased urgency and fear of incontinence → further holding behavior

If left untreated, this cycle contributes to disease progression. (Austin et al., 2016; Burgers et al., 2010)

Pelvic Floor Function and Childhood-Specific Characteristics

Introduction

The pelvic floor is a dynamic musculofascial complex that plays a critical role in supporting the bladder, bowel, and genital organs; maintaining continence; and coordinating voiding and defecation. In childhood, pelvic floor function is closely related to neuromuscular maturation, toilet training, and behavioral learning processes. Therefore, pelvic floor dysfunction in children has pathophysiological and clinical characteristics that differ from those in adults. (Combs et al., 1998; Kim et al., 2011)

Anatomical and Functional Components of the Pelvic Floor

The pelvic floor mainly consists of the levator ani muscle group (pubococcygeus, puborectalis, iliococcygeus), the external urethral sphincter, and the external anal sphincter. These structures: • Provide mechanical support for the bladder and rectum, • Maintain continence at rest, and • Enable elimination through timely relaxation during voiding and defecation.

Voluntary control of pelvic floor muscles is mediated via the somatic (pudendal) nerve, whereas voiding–defecation reflexes are regulated through sacral parasympathetic pathways. Because this dual-control mechanism is not fully mature in childhood, a predisposition to dysfunction arises. (Austin et al., 2016)

Developmental Features of the Pelvic Floor in Childhood

Neuromuscular Maturation

From birth, voiding and defecation are largely under reflex control. Voluntary pelvic floor control generally develops between 2 and 4 years of age, and maturation continues until school age. During this period: • The distinction between pelvic floor relaxation and contraction is learned, and • Appropriate responses to bladder and rectal filling signals develop.

Therefore, incontinence in early childhood may be considered physiological, whereas persistent symptoms at older ages are evaluated as pathological. (Kim et al., 2011)

Toilet Training and Behavioral Learning

Toilet training is a critical period for shaping pelvic floor function. Early, coercive, or painful toilet training may lead to persistent over-contraction of the pelvic floor muscles and suppression of the relaxation reflex. In children, this forms the basis of dysfunctional voiding characterized by: • Failure of the pelvic floor to relax during voiding, • Intermittent/staccato voiding, and • Straining during voiding or defecation. (Combs et al., 1998; dos Santos et al., 2017)

Pelvic Floor Dysfunction and Bladder–Bowel Interaction

The pelvic floor represents a common "final pathway" for bladder and bowel function. In children, pelvic floor dysfunction is most commonly encountered within the framework of bladder–bowel dysfunction.

In functional constipation: • Increased tone in the puborectalis and levator ani muscles, and • Inadequate relaxation during defecation may develop. Failure of the same muscle groups to relax during voiding increases bladder outlet resistance. (Chase et al., 2010)

Experimental and clinical studies have shown that rectal distension adversely affects bladder function and is associated with detrusor overactivity and reduced bladder capacity. (Bush et al., 2013)

Clinical Manifestations: Childhood-Specific Phenotypes

In children, pelvic floor dysfunction typically presents with the following clinical phenotypes: - Dysfunctional voiding: involuntary pelvic floor contraction during voiding, associated with staccato voiding and residual urine. (Combs et al., 1998)

- Overactive bladder + pelvic floor co-contraction: urgency and daytime incontinence, frequently accompanied by constipation. (Feldman & Bauer, 2006)

- Functional constipation and encopresis: impaired pelvic floor relaxation reduces defecation efficiency and contributes to chronicity. (Chase et al., 20106)

These phenotypes frequently coexist and create a self-reinforcing pathophysiological cycle.

Relationship of Pelvic Floor Dysfunction with UTIs and Urinary Complications

Failure of the pelvic floor to relax during voiding leads to post-void residual urine and urinary stasis. In children, this is associated with: • Recurrent UTIs, • Coexistence with VUR, and • Treatment-resistant lower urinary tract symptoms.

The ICCS recommends that pelvic floor function should always be considered in the evaluation of childhood UTIs. (Burgers et al., 2010)

In childhood, pelvic floor function is shaped by the interaction of anatomical maturation, neurological development, and behavioral learning. Mislearned contraction patterns developing during this period may jointly affect bladder and bowel functions and pave the way for chronic dysfunction. Therefore, lower urinary tract and bowel symptoms in children should not be evaluated separately but through a holistic, pelvic floor-centered approach.

Pelvic Floor Rehabilitation: Definition and Components

Introduction and Definition

Pelvic floor rehabilitation encompasses behavioral, educational, and physiotherapeutic approaches aimed at improving the strength, relaxation, coordination, and timing of pelvic floor muscles (levator ani complex, external urethral and anal sphincters). In childhood, pelvic floor rehabilitation is a cornerstone of the management of lower urinary tract symptoms, functional constipation, and bladder–bowel dysfunction. (Combs et al., 1998; Krzemińska et al., 2012)

The ICCS recommends urotherapy and pelvic floor rehabilitation as first-line treatment for voiding and continence disorders in children. (Kim et al., 2011; Burgers et al., 2010)

Physiological Rationale for Pelvic Floor Rehabilitation

Pelvic floor muscles maintain continence at rest; during voiding and defecation, timely and adequate relaxation is required. A substantial proportion of pediatric dysfunctions are related to: • Mislearned contraction patterns, • Impaired relaxation–contraction coordination, and • Increased muscle tone associated with holding behavior.

The main goal of rehabilitation is to retrain this pathological motor learning and restore normal physiological patterns. (Krzemińska et al., 2012; dos Santos et al., 2017)

Core Components of Pelvic Floor Rehabilitation

Standard Urotherapy (Behavioral Foundational Approach)

Urotherapy constitutes the core of pelvic floor rehabilitation and includes: • Age-appropriate education about bladder and bowel function, • Timed voiding and defecation schedules, • Adequate fluid intake and dietary regulation, and • Teaching correct toileting posture.

It has been shown that urotherapy alone can provide meaningful improvement in daytime urinary incontinence and BBD symptoms in many children. (Kim et al., 2011; Austin et al., 2016)

Pelvic Floor Muscle Training (PFMT)

Pelvic floor muscle training aims for the child to: • Differentiate pelvic floor muscles, • Voluntarily contract and relax them, and • Learn appropriate relaxation during voiding/defecation.

Unlike in adults, PFMT in children focuses primarily on relaxation awareness rather than only increasing muscle strength. (Combs et al., 1998) Studies have shown that PFMT-based programs are effective in dysfunctional voiding and daytime incontinence. (Krzemińska et al., 2012)

Biofeedback Therapy

Biofeedback is among the best-studied components of pelvic floor rehabilitation. Using surface electromyography (EMG) or pressure sensors, the child: • Perceives pelvic floor muscle activity as visual or auditory feedback, and • Learns to consciously control contraction and relaxation.

Randomized and observational studies have reported high success rates of biofeedback, particularly in children with dysfunctional voiding and residual urine. (Krzemińska et al., 2012; Ladi-Seyedian et al., 2020)

Breathing and Posture Training

Pelvic floor muscles form a functional chain with the diaphragm and abdominal muscles. Poor posture and shallow breathing patterns may: • Increase pelvic floor tone, and • Make relaxation more difficult.

Therefore, rehabilitation programs often teach: • Diaphragmatic breathing, • Correct sitting posture on the toilet, and • Pelvis–trunk alignment.

This approach has been reported to be effective particularly in constipation and defecation dysfunction. (Li et al., 2024)

Integration with Bowel Management

Pelvic floor rehabilitation is incomplete without constipation treatment. Since rectal distension has been shown to impair bladder function, rehabilitation programs should be carried out together with: • Laxative therapy, • Behavioral defecation training, and • Approaches aimed at restoring rectal sensitivity. (Chase et al., 2010; Bush et al., 2013)

Principles of Implementation Specific to Childhood

In children, pelvic floor rehabilitation should be implemented with: Gamified exercises, Visually supported explanations, and Family participation. Treatment success is closely related to setting developmentally appropriate goals and ensuring continuity. (dos Santos et al., 2017)

Clinical Effectiveness and Level of Evidence

Systematic reviews and ICCS guidelines indicate that pelvic floor rehabilitation is an effective and safe approach in the treatment of: • Daytime urinary incontinence, • Dysfunctional voiding, and • Bladder–bowel dysfunction. (Krzemińska et al., 2012; Burgers et al., 2010)

The best outcomes are achieved with combined programs integrating urotherapy, biofeedback, and bowel management.

Summary

Pelvic floor rehabilitation is a multi-component therapeutic approach that combines education, behavioral modification, muscle training, and physiotherapeutic techniques. In the management of childhood pelvic floor dysfunction, it supports long-term success by targeting not only symptoms but also underlying mislearned motor patterns.

Clinical Effectiveness of Pelvic Floor Rehabilitation

Introduction

Pelvic floor rehabilitation is a multi-component, noninvasive treatment approach that includes standard urotherapy, pelvic floor muscle retraining, biofeedback, and bowel management. In children, it is considered a fundamental step in the treatment of dysfunctional voiding (DV), daytime urinary incontinence, and bladder–bowel dysfunction. The ICCS recommends pelvic floor rehabilitation in this patient group before pharmacological therapies. (Kim et al., 2011; Krzemińska et al., 2012)

Outcome Measures for Clinical Effectiveness

Clinical effectiveness has been evaluated in the literature in a multidimensional manner. The most commonly used clinical and objective measures include: • Reduction in episodes of daytime incontinence and urgency, • Increased continence days and improvement in voiding frequency, • Improvement of flow pattern (staccato/intermittent) on uroflowmetry, • Decrease in pelvic floor EMG activity during voiding, • Reduction in post-void residual urine volume, and • Decrease in recurrent UTIs.

Evaluating these parameters together indicates that rehabilitation improves not only symptoms but also the underlying dysfunctional motor patterns. (Combs et al., 1998; Krzemińska et al., 2012)

Clinical Effectiveness of Standard Urotherapy

Standard urotherapy includes education, timed voiding, adequate fluid intake, and correct toileting posture. Various observational studies and reviews have shown that urotherapy alone can yield meaningful symptom improvement in a considerable proportion of children. (Kim et al., 2011; Austin et al., 2016)

In children with bladder–bowel dysfunction, urotherapy constitutes the basis of pelvic floor rehabilitation; the effectiveness of more advanced physiotherapeutic approaches largely depends on this behavioral foundation. (dos Santos et al., 2017)

Effectiveness of Pelvic Floor Muscle Training and Biofeedback

Effect on Dysfunctional Voiding

Biofeedback-supported PFMT is among the interventions with the strongest evidence base for DV. Combs and colleagues reported that biofeedback reduced pelvic floor muscle activity during voiding and resulted in marked improvement in clinical symptoms. (Nevéus et al., 2006) Subsequent prospective studies and clinical series have also demonstrated high success rates, particularly in DV cases resistant to standard urotherapy. (Ramsay & Bolduc, 2017)

Randomized Controlled Trials

In a randomized study by Vasconcelos and colleagues comparing pelvic floor exercises and biofeedback therapy, both methods reduced incontinence episodes and UTIs. The study suggests that biofeedback may provide a faster clinical response by teaching muscle relaxation more effectively. (Meena et al., 2020)

Altunkol and colleagues reported that adding biofeedback to urotherapy was associated with higher success in symptom improvement compared with urotherapy alone. (Yang et al., 2018)

Meta-Analyses and Systematic Reviews

Recent systematic reviews and meta-analyses have shown that biofeedback therapy has positive effects on symptom improvement and urodynamic parameters in children with non-neurogenic dysfunctional voiding. However, heterogeneity across studies regarding protocols and outcome measures has been emphasized. (Li et al., 2024)

Daytime Incontinence, UTIs, and Upper Urinary Tract Findings

Pelvic floor rehabilitation may affect not only symptoms but also complications. Biofeedback and home-based pelvic floor exercises have been shown to reduce residual urine and improve clinical outcomes in children with mild-to-moderate hydronephrosis accompanying dysfunctional voiding. (Ladi-Seyedian et al., 2020)

In addition, studies have reported a decrease in the frequency of recurrent UTIs in children receiving pelvic floor rehabilitation. (Meena et al., 2020; Krzemińska et al., 2012)

Clinical Effectiveness in the Presence of Concomitant Bowel Dysfunction

In the presence of bladder–bowel dysfunction, the effectiveness of pelvic floor rehabilitation increases markedly when implemented together with bowel management. Because rectal distension is known to impair bladder function, incorporating constipation treatment into rehabilitation programs improves clinical outcomes. (Chase et al., 2010; Bush et al., 2013)

Animated and game-based biofeedback approaches have been reported to have positive effects on both voiding and defecation symptoms and to increase adherence. (Vasconcelos et al., 2006)

Factors Determining Treatment Response

Key factors influencing response to pelvic floor rehabilitation include: • Family and child adherence, • Simultaneous and effective treatment of constipation, • Adequate treatment duration, and • Presence of a dysfunctional voiding phenotype.

ICCS reports emphasize that treatment success will be limited if these factors are overlooked. (Burgers et al., 20104)

CONCLUSION

Pelvic floor rehabilitation may be beneficial in selected cases for the management of bladder–bowel dysfunction in children, although the evidence base remains limited. Clinical success is often more closely related to behavioral regulation and cognitive maturity than to pelvic floor muscle control alone. Therefore, pelvic floor rehabilitation should be considered within multidisciplinary and individualized treatment approaches.

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