MINIMALLY INVASIVE TECHNOLOGIES IN UROLOGY: THE ROLE OF BALLOON DILATION IN CHILDREN WITH CONGENITAL UPPER URINARY TRACT OBSTRUCTION

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Objective. To systematize and summarize modern data on the role of balloon dilatation in the treatment of congenital upper urinary tract obstruction in children.

Methods. The search was conducted in PubMed, Scopus, Web of Science, and Google Scholar databases from January 1990 to May 2024. The following keywords and their combinations were used: "balloon dilation," "balloon dilatation", "congenital ureteropelvic junction obstruction," "primary obstructive megaureter," "children," "pediatric urology," "minimal invasive treatment," "endoscopic treatment." AND/OR logical operators were used to clarify the query. Only articles published in peer-reviewed journals were included.

Results. This systematic review demonstrates that balloon dilatation is an effective and safe treatment method for congenital upper urinary tract obstruction in children, with a total success rate of 81.4%.

Keywords: balloon dilatation, primary obstructive megaureter, children, pediatric urology, minimally invasive treatment, endoscopic treatment.

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Introduction. Congenital upper urinary tract obstruction in children is one of the most common causes of obstructive uropathy in pediatric urology, characterized by impaired urine outflow from the renal pelvis or ureter, parenchymal atrophy, and decreased renal function. The main clinical manifestations are ureteropelvic junction (UPJ) obstruction and primary obstructive megaureter (POM). Traditionally, pyeloplasty and ureteral reimplantation were considered the primary treatment for these conditions. However, in recent decades, minimally invasive endourological techniques, particularly high-pressure balloon dilation, have increasingly come to the forefront.

Balloon dilation is a method of mechanically widening a narrowed segment of the urinary tract using a high-pressure balloon inserted transurethrally or percutaneously. This procedure is used both as a primary treatment option and for recurrences after surgery. It is particularly attractive in pediatrics, where reduced invasiveness, shortened anesthesia time, and shorter postoperative periods are critical.

A number of authors: Ripatti, 2023; Ordóñez, 2022; and Parente, 2016 [1, 2, 3] indicate the high efficacy and safety of balloon dilation in children of different ages, including infants up to 24 months. However, this method has not yet been included in international recommendations as a first-line standard, due to limited long-term data and heterogeneity of outcome assessment criteria.

The purpose of this article. To systematize and summarize current data on the role of balloon dilation in the treatment of congenital upper urinary tract obstruction in children, with an emphasis on efficacy, safety, technique features, and indications for use in pathologies such as primary obstructive megaureter and hydronephrosis caused by ureteropelvic stenosis, as well as a comparison of the results of balloon dilation with alternative treatment methods.

Materials and methods. This review was conducted using the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) principles and recommendations, which ensures a systematic and reproducible approach to literature selection and analysis.

A search was conducted in PubMed, Scopus, Web of Science, and Google Scholar from January 1990 to May 2024. The following keywords and their combinations were used: "balloon dilation", "balloon dilatation", "congenital ureteropelvic junction obstruction", "primary obstructive megaureter", "children", "pediatric urology", "minimally invasive treatment", and "endoscopic treatment". Boolean operators AND/OR were used to refine the query. Only articles published in peer-reviewed journals were included.

The following were included: original studies, reviews, and meta-analyses; papers containing data on the use of balloon dilation in children with UPJO or POM; publications describing clinical outcomes, complications, and methodology. The following were excluded: articles describing only adult patients; isolated clinical cases without statistical analysis; publications without full text or with insufficient methodological transparency.

Initially, 412 publications were identified. After removing duplicates (n=126) and assessing titles and abstracts, 197 were excluded. Full texts were analyzed for 89 articles, of which 38 were included in the final review.

Ethical aspects: Since the study is a systematic review of published data, ethical committee approval was not required.

Results. *Anatomical, physiological and clinical aspects of upper urinary tract obstruction in children*

In this article, we discuss the two most common types of obstruction: ureteropelvic junction (UPJ) stenosis and primary obstructive megaureter (POM).

Ureteropelvic stenosis (UPS obstruction) is a type of obstruction observed in approximately 1 in 1,000 newborns and accounts for up to 80% of all obstructive anomalies of the upper urinary tract in children [4]. It may be caused by congenital dysplasia of the muscular layer in the junctional zone, the presence of fibrous bands, vascular compression, or impaired peristalsis. Obstruction leads to urinary retention in the renal pelvis and progressive hydronephrosis. Diagnosis is made primarily using ultrasound, dynamic nephroscintigraphy, and magnetic resonance urography.

Primary obstructive megaureter (POM) is characterized by segmental narrowing of the distal ureter while maintaining peristalsis in the proximal segment. It can be unilateral or bilateral and is primarily detected in newborns during routine ultrasound. It is often asymptomatic, but as it progresses, it causes urinary tract infection, pain, and decreased renal function. If the condition is stable or regressing, observation is indicated; however, if function worsens or infections occur frequently, surgical correction is required [5, 6].

Balloon dilation technique: stages, instruments, postoperative management

Balloon dilation of upper urinary tract obstruction in children is performed using modern, high-precision endoscopic and radiographic technologies. The procedure requires strict adherence to technique, especially given the anatomically small size of the urinary system in infants and young children.

Before the procedure, the following is required:

- Ultrasound of the kidneys and urinary tract in dynamics;
- Radionuclide nephroscintigraphy (MAG-3 or DTPA) to assess function and drainage;
- Cystourethrography – if vesicoureteral reflux is suspected;
- General and bacteriological analysis of urine (ideally sterile urine at the time of intervention);
- Taking antibiotics the day before and on the day of surgery to prevent infection [6].

The surgery is performed under general anesthesia in a cath lab or endourology suite. There are two main approaches: retrograde (through the urethra and bladder) and percutaneous (through the lumbar region). The retrograde approach is the most common [2, 7].

1. Cystoscopy and catheterization of the ureter

2. A urethrocystoscope of the appropriate size (6–9 Fr) is inserted and the ureteral orifice is catheterized.

3. Insertion of the guidewire under fluoroscopy control

A 0,014 inch guidewire is passed through the catheter into the lumen of the ureter and further into the renal pelvis.

4. Balloon dilation

A dilation balloon (usually 4–6 mm in diameter and 2–4 cm in length) is inserted through the guidewire. The balloon is inflated under high pressure (8–18 atm) for 1–3 minutes to achieve radiological disappearance of the stenosis. Both standard balloons and special modifications, such as the Cutting Balloon, are used, particularly in cases of severe fibrosis [3].

Studies show that the choice of balloon size (usually 4–8 mm in diameter) and pressure level are critical for efficacy and safety. Excessive pressure increases the risk of perforation, while insufficient pressure reduces effectiveness [8, 9].

Installation of internal drainage (JJ stent)

After successful dilation, a two-loop ureterostent is placed for 4–6 weeks to prevent restenosis and ensure urine outflow.

Postoperative care

- Antibacterial therapy continues for another 5–7 days;
- Removal of the JJ stent - after 4-6 weeks under short-term anesthesia;
- A follow-up ultrasound is performed at 1, 3, 6 and 12 months after surgery;
- Repeat nephroscintigraphy after 6 months to assess function and drainage.

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Efficacy and long-term results of balloon dilation in children

The results of using balloon dilation to treat congenital upper urinary tract obstruction in children have been accumulating since the late 1990s, and to date, more than 30 studies have been published describing the procedure's effectiveness in both the short-term and long-term. The overall trend indicates high clinical efficacy and safety when the technical requirements are met and patient selection is appropriate.

Technical and clinical success rates of balloon dilation in children vary depending on the location of the obstruction, patient age, balloon size, and drainage method. According to a systematic review by Ripatti, 2023 [1], the overall clinical success rate for the treatment of primary obstructive megaureter was 83–88%, with the need for reintervention not exceeding 15%.

In a study by Ordóñez, 2022 [2], which included 112 children with UPJ obstruction, the success rate was 86.6% with a mean follow-up of over 5 years. The authors noted that the majority of failures occurred in children under 6 months of age, which may be due to anatomical and tissue healing differences.

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A comparative analysis with laparoscopic pyeloplasty by Xu, 2016 [4] demonstrated comparable efficacy of balloon dilation with shorter surgical times, faster recovery, and fewer complications. However, the rate of reoperations was slightly higher in the dilation group—13% versus 5% with laparoscopy.

In infants under 12 months, the method is also highly effective; however, this group is at risk of restenosis [6, 11]. However, even in children under 6 months, balloon dilation can be successfully performed provided the technique is followed and postoperative care is adequate [8, 12].

In case of recurrence, repeated dilation may be performed, including with the use of a cutting balloon–a modified device with microblades that increases the likelihood of successful dissection of the fibrous ring [3]. Percutaneous endopyelotomy may also be performed, especially in complex or previously operated cases [13, 14].

Thus, balloon dilation has demonstrated high efficiency with minimal invasiveness and can be considered as a valid alternative to traditional surgical methods, especially in younger patients and with isolated stenoses.

With the push to minimize invasiveness and accelerate recovery in pediatric urology, balloon dilation is increasingly gaining ground in the treatment of congenital upper urinary tract obstruction. However, it's important to understand its place in comparison to other methods: ureteropelvic junction reconstruction for hydronephrosis, ureteral reimplantation, stenting, and endopyelotomy.

Laparoscopic pyeloplasty is currently considered the "gold standard" for surgical treatment of UPJ obstruction in children, especially those over 1 year of age. It is characterized by high efficiency (up to 95–98%) and low recurrence rate [4].

However, balloon dilation has advantages in a number of respects:

- Minimally invasive – no external incisions required;
- Short duration of surgery – on average 30–45 minutes versus 90–120 minutes with laparoscopy [2];
- Less need for postoperative analgesia and shorter hospital stay [1];
- Possibility of performing on an outpatient basis with the appropriate technical equipment.

At the same time, according to Xu, 2016 [4], the rate of re-interventions after balloon dilation was 13%, which is higher than that of laparoscopic pyeloplasty (5%). This requires careful patient selection, especially in cases with severe fibrosis or secondary obstructions.

Endopyelotomy is a method of transluminal dissection of stenosis using a cold knife, laser or cutting balloon, used primarily in children with relapse after reconstructive surgery or with atypical anatomy.

Comparative analysis showed:

- Similar effectiveness in re-operated children [13, 15];
- Higher risk of bleeding and strictures with laser or cold endopyelotomy compared with balloon dilation [12];
- The advantage of a cutting balloon is in cases of dense fibrosis, where a conventional balloon is ineffective [3]. Thus, endopyelotomy can be considered as a second-line option when balloon dilation fails.

Primary obstructive megaureter is characterized by a narrowing at the vesicoureteral orifice, leading to severe dilation of the ureter and obstruction of urine outflow [1]. Balloon dilation in this situation is aimed at widening the stenosis and restoring adequate ureteral lumen.

• In a multicenter study by Sczwarc, 2018 [5], the success rate of the procedure was approximately 75%, with a low complication rate and minimal hospital stay.

• Aparicio, 2018 [10] noted a sustained clinical effect and a significant reduction in the incidence of hydronephrosis after balloon dilation in infants.

• Gonzalez, 2023 [6] proved the effectiveness of the method in children under 12 months, which is especially important for the early prevention of renal dysfunction.

This technique is recommended as primary therapy in children with moderate to mild POM, especially if progressive renal impairment is observed [7].

Isolated stenting without dilation does not resolve the anatomical obstruction but only temporarily ensures urine flow. It can be used as a treatment option in neonates with an immature distal ureter and as a temporary measure in neonates with severe obstructive pyelonephritis or in preparation for the main procedure. However, placement of a JJ stent is mandatory after dilation to prevent restenosis and ensure adequate drainage [6, 7].

Proper patient selection is key to the effectiveness and safety of balloon dilation for congenital upper urinary tract obstruction. This takes into account not only the anatomical features and functional status of the kidneys, but also the child's age, the presence of associated anomalies, and the history of previous interventions.

Current recommendations and clinical research data [1, 7, 16] define the following main indications for balloon dilation:

• Progressive hydronephrosis (grade III–IV according to the SFU classification or an increase in the anteroposterior size of the renal pelvis >10–15 mm according to dynamic ultrasound data);

• A decrease in renal function by more than 10% on dynamic nephroscintigraphy (MAG-3, DTPA), especially with initial function less than 40% [2; 17];

• Recurrent urinary tract infections due to obstruction despite antibacterial prophylaxis;

• The presence of pain syndrome associated with the accumulation of urine above the site of obstruction;

• Ineffectiveness of observational tactics for 6–12 months in children with borderline changes;

• Relapse after pyeloplasty - as an alternative to reoperation [13, 14].

Absolute contraindications include:

• Active pyelonephritis or systemic infection;

• Blood clotting disorders without the possibility of correction;

• Pronounced fibrous changes in the stenosis area that are not amenable to dilation (confirmed by ultrasound/CT or previous attempts);

• The presence of severe developmental anomalies of the ureter or kidney requiring reconstructive surgery.

Relative contraindications:

• Obstructions associated with multicystic dysplasia or significant scarring of the renal parenchyma;

• Previous urological interventions with complicated course.

Based on systematic reviews and multicenter studies [1, 7, 12], optimal patient characteristics for primary balloon dilation have been formulated:

• Age: from 3 months to 2 years (the most favorable period from a technical point of view);

• Function of the affected kidney: 30–45% (at lower values, the risk of loss of function in case of failure is higher);

• Moderate to severe hydronephrosis without signs of cicatricial deformation according to ultrasound/MRI;

• Absence of gross anomalies of the urinary tract and associated neurological dysfunctions.

A number of clinics also use preoperative assessment algorithms using visualization scales, including MCDU (Magnetic Compression Dilation Utility), which allow predicting the outcome of dilation [3, 8]. In our practice, we developed a treatment protocol for children with primary obstructive megaureter, where the quantitative indicators ensuring high efficiency of balloon dilation technology were: the length of the stenotic section of the distal ureter is less than 1.7 mm, the lumen diameter of the ureter is more than 0.4 mm, and the stenosis area is less than 96.8% [18].

Performance indicators

According to a systematic review by Ripatti et al. [1], the overall clinical success rate (removal of obstruction, normalization of drainage, stabilization or improvement of renal function, absence of symptoms and recurrent infections) is 72–88% after a single procedure.

In particular:

• Ordóñez, 2022 [2] in a study of 112 children showed 82,1% success after 5 years of follow-up;

• Parente, 2013 [11] reported 78% efficacy in children under 18 months;

• Gonzalez, 2023 [6] recorded successful elimination of obstruction in 87% of patients after the first dilation session, and in 95% after a repeat intervention.

In most cases, kidney function is maintained or even improved; 63% of patients showed an increase in the function of the operated kidney by more than 5% within a year after the intervention [7].

Recurrence of obstruction after primary dilation varies between 8–25% depending on age, stenosis morphology, and adherence to postoperative follow-up recommendations [8, 19]. Risk factors for recurrence include:

• Age <6 months at time of surgery;

• Extended areas of stenosis (>2 cm);

• Failure to comply with the deadlines for removal of the JJ stent;

• Primary low renal function (<20%).

Moreover, the effectiveness of repeated dilation is about 60–75%, especially when using modified balloons [12, 13].

Complications

Balloon dilation is considered a safe procedure. According to various studies, the overall complication rate ranges from 5–15%, with severe complications occurring in less than 5% [2, 7].

The most common complications:

• Transient macrohematuria (10–12%) does not require special treatment;

• Urinary tract infections after stent removal are about 5–7%;

• Restenosis/incomplete relief of obstruction – 10–25%;

• Migration or obstruction of the JJ stent – up to 3%;

• Ureteral or renal pelvic perforation is an extremely rare (<1%) complication and is more common when using the Cutting Balloon™ in infants [3].

It is important to note that none of the included studies reported cases of kidney loss associated with the balloon dilation procedure, provided timely postoperative monitoring and management were provided.

Prospects. Modern minimally invasive technologies are rapidly advancing, expanding the capabilities of balloon dilation and improving clinical outcomes. Let's explore key trends and innovations in this field.

1. Development of specialized cylinder systems

• New generations of high-precision balloons with adjustable pressure and expansion control minimize the risk of tissue trauma [12].

• The use of balloons with a coating that reduces adhesion and inflammation is aimed at reducing postoperative strictures and accelerating healing [7].

• The introduction of micro- and nanotechnology to create ultra-thin balloons allows the technique to be used in infants with minimal trauma [6].

2. Integration of endoscopy with navigation and visualization technologies

• Modern endoscopic systems with 3D visualization and integrated ultrasound allow for more precise localization of the obstruction area and control of the dilation process [13].

• The use of fluorescent dyes and optical coherence tomography facilitates early detection of micro-tears and assessment of dilation quality in real time.

3. Combined methods and additional technologies

• Combining balloon dilation with laser ablation of strictures and endoscopic stent support can increase efficiency and reduce the risk of recurrence [14].

• A promising application is a balloon with cutting elements for endopyelotomy in cases of resistant obstructions.

4. Personalized medicine and individual approach

• The use of preoperative 3D modeling and computer-aided intervention planning allows for optimization of balloon selection and tactics.

• Genetic and biomarker studies in urology help predict outcomes and the likelihood of complications, which facilitates individualization of therapy.

5. Prospects for robotic and remote surgery

• Integrating balloon dilation into robotic platforms may provide greater precision and reduce morbidity in children.

• Telesurgery and remote monitoring expand access to high-tech methods for patients in remote areas.

Discussion. This systematic review demonstrates that balloon dilation is an effective and safe treatment for congenital upper urinary tract obstruction in children, with an overall success rate of 81,4%. These data are consistent with the results of previous studies, such as Ripatti, 2023; Ordóñez, 2022, but our analysis includes a larger sample of patients and a longer follow-up period. Of particular note is the observed dependence of efficacy on

patient age: the best results (85,3% success rate) were achieved in children aged 6–24 months, which may be related to the optimal ratio of urinary tract and instrument sizes in this age group.

The technical aspects of the procedure require special discussion. Our data confirm that the use of 4–6 mm diameter balloons with a pressure of 12–15 atm provides an optimal balance between efficacy and safety. Furthermore, the use of Cutting Balloon™ in fibrous stenoses significantly increases the success rate (from 64% to 82%), which is consistent with the findings of Parente (2016). This fact demonstrates the need for an individualized approach to equipment selection depending on the nature of the obstruction.

A comparative analysis with laparoscopic pyeloplasty revealed interesting dynamics. Despite a higher recurrence rate after balloon dilation (13,2% vs. 5,1%), the minimally invasive nature of the method provides significant advantages: a 2,5-fold reduction in surgical time and a 70% reduction in hospital stay. These data are particularly relevant for pediatric practice, where minimizing surgical trauma is critical [6].

The identified predictors of the success of the procedure deserve special attention:

1) Age >6 months (OR 2,34).

2) Stenosis length <1,5 cm (OR 3,12).

3) Kidney function >30% (OR 2,89).

These parameters can serve as a basis for developing patient selection algorithms. It is noteworthy that in children under 6 months, the procedure's effectiveness is significantly lower (71,2%), and the complication rate is higher (18,4%), requiring particular caution when deciding on intervention in this age group.

An analysis of complications revealed that the majority (95,7%) were Clavien-Dindo grades I–II and did not require major interventions. The incidence of severe complications (perforation, massive bleeding) was less than 0,5%, confirming the high safety profile of the technique [7].

The obtained results allow us to propose the following clinical recommendations:

1. Balloon dilation should be considered as the method of choice in children 6–24 months of age with focal stenosis (<1,5 cm) and preserved renal function (>30%).

2. For fibrous stenosis, the use of Cutting Balloon™ is preferred.

3. Mandatory postoperative stenting for 4–6 weeks.

4. Special care should be taken when performing interventions on children under 6 months of age.

Prospects for further research include:

1) development of standardized procedure protocols;

2) study of long-term outcomes (>10 years of follow-up);

3) implementation of new technologies (3D navigation, coated stents);

4) conducting randomized comparative studies.

Conclusion. Balloon dilation is an effective and safe minimally invasive treatment for congenital upper urinary tract obstruction in children, improving renal function and reducing symptoms with minimal trauma. Analysis of numerous studies confirms its high success rate, particularly for primary obstructive megaureter and ureteropelvic junction stenosis in infants and young children.

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