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Technique-Stratified Reintervention Outcomes after Surgical Reconstruction for Nutcracker Syndrome: A Single-Center Retrospective Study

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Abstract

Background

Nutcracker syndrome (NCS) is an uncommon venous compression disorder resulting from extrinsic compression of the left renal vein (LRV), either between the superior mesenteric artery (SMA) and the aorta (anterior NCS) or between the aorta and the vertebral body (posterior NCS). Owing to the wide spectrum of clinical manifestations, diagnosis is often delayed. The aim of this study was to evaluate the surgical and follow-up outcomes of patients who underwent operative treatment for NCS at our institution, with particular attention to outcomes stratified by surgical technique.

Methods

Eighteen consecutive patients (5 men [27.8%] and 13 women [72.2%]) with NCS who underwent a transabdominal surgical approach between June 2022 and April 2025 were included. Demographic data, preoperative clinical status, intraoperative findings, and postoperative outcomes were retrospectively analyzed. McNemar's exact test was used to compare paired preoperative and postoperative findings, and Fisher's exact test (with Freeman–Halton extension) was used to compare reintervention rates among surgical techniques.

Results

Mean age was 20.5 ± 7.79 years (range, 11–33); mean body weight was 51.1 ± 7.87 kg (range, 35–64). Flank pain (15 patients, 83.3%) was the most frequent symptom and microscopic hematuria (10 patients, 55.6%) the most common urinary finding. SMA syndrome was concomitant in 5 patients (27.8%). Surgical techniques were graft interposition (9 patients, 50.0%), LRV transposition with end-to-side anastomosis (5 patients, 27.8%), and gonadal/ovarian vein transposition (4 patients, 22.2%). No postoperative renal dysfunction or renal vein thrombosis occurred. During follow-up (mean, 13.5 ± 5.77 months), 7 patients (38.9%) required transcatheter reintervention; rates differed across techniques (LRV transposition, 80.0%; graft interposition, 33.3%; gonadal/ovarian vein transposition, 0%; Freeman–Halton exact $p = 0.072$). Flank pain ($p < 0.001$), hematuria ($p = 0.001$), and proteinuria ($p = 0.016$) decreased significantly versus preoperative status.

Conclusions

Surgical reconstruction is a safe and effective treatment option for NCS, with significant symptomatic relief. A trend toward higher reintervention rates after LRV transposition compared with graft interposition or gonadal/ovarian vein transposition was observed but did not reach statistical

significance in this small cohort. Close follow-up is essential, as endovascular reintervention may be required for residual or recurrent stenosis.

Background

Nutcracker syndrome (NCS) is an uncommon venous compression disorder caused by extrinsic compression of the left renal vein (LRV), most often between the superior mesenteric artery (SMA) and the abdominal aorta (anterior NCS), and less frequently between the aorta and the vertebral column (posterior NCS; Fig. 1D).

Clinical and anatomical features resembling those of LRV entrapment were first described by Grant in 1937 [1]. The radiologic appearance of LRV compression was subsequently termed the "nutcracker phenomenon" by de Schepper in 1972 [2]. Although the radiologic finding alone is referred to as a "phenomenon," the condition is designated a "syndrome" when accompanied by characteristic clinical symptoms [15].

The classic manifestations of NCS include hematuria, proteinuria, flank or abdominal pain, varicocele in male patients, and pelvic congestion syndrome in female patients [3]. Despite increasing recognition and the publication of recent expert consensus documents [4], the optimal treatment strategy remains a matter of debate. Available surgical options include LRV transposition, graft interposition, gonadal or ovarian vein transposition, and renal autotransplantation; endovascular and hybrid approaches have also been described [5, 6, 7]. In the present study, we report a single-center series of patients who underwent surgical treatment for NCS, evaluating operative techniques, perioperative outcomes, and short-term follow-up results, with a particular focus on outcomes stratified by surgical technique.

Methods

Study design and patient selection

This was a single-center retrospective cohort study. Patients with LRV stenosis were retrospectively identified through the hospital information system. Cases in which LRV stenosis was attributable to other causes—such as compression by enlarged lymph nodes or tumoral masses—were excluded. Only patients who underwent surgical treatment with a diagnosis of NCS between June 2022 and April 2025 were included. The minimum follow-up duration was 6 months. The study is reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.

Demographic data, presenting symptoms, imaging studies, operative notes, postoperative intensive care and hospital stay records, and follow-up data from outpatient visits were retrieved from patient records and reviewed in detail.

Diagnostic criteria

The diagnosis of NCS was based on duplex ultrasonography (US) and contrast-enhanced abdominal computed tomography (CT) in patients with persistent classic symptoms for at least one year. On contrast-enhanced CT, a greater than fivefold narrowing of the LRV diameter at the aortomesenteric compression site relative to the renal hilum was considered diagnostic, in keeping with previously reported imaging criteria [8, 9]. On duplex ultrasonography, a fourfold or greater reduction in LRV diameter at the compression site, together with a corresponding increase in peak systolic velocity, was considered consistent with NCS.

Before a definitive diagnosis was made, other etiologies—including pyelonephritis, nephrolithiasis, genitourinary malignancies, and protein-losing enteropathy—were systematically excluded. Concomitant SMA syndrome was diagnosed when the aortomesenteric angle was less than 35° with compression of the third portion of the duodenum [10]. Postprandial ileus-like symptoms were also evaluated in every patient.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics, version 23.0 (IBM Corp., Armonk, NY, USA), with two-tailed $p < 0.05$ considered statistically significant.

Continuous variables were tested for normality using the Shapiro–Wilk test and visual inspection of histograms and Q–Q plots. In the present cohort, all continuous variables (age, body weight, LRV cross-clamp time, follow-up duration) were normally distributed (Shapiro–Wilk $p > 0.05$) and are therefore presented as mean ± standard deviation (SD) with range. Categorical variables are expressed as frequencies and percentages.

The primary efficacy analysis compared the prevalence of clinical symptoms (flank pain) and urinary findings (hematuria, proteinuria) before and after surgery. As these were paired dichotomous variables (presence vs. absence in the same patient at two time points), McNemar's exact test was used. The exact form was selected because of the small expected number of discordant pairs, for which the asymptotic McNemar χ^2 approximation may be unreliable.

Reintervention rates across the three surgical techniques (LRV transposition, graft interposition, and gonadal/ovarian vein transposition) were compared using Fisher's exact test extended to the 3 × 2 table via the Freeman–Halton modification, which is appropriate for small samples and unbalanced group sizes. Pairwise post-hoc comparisons were performed with Fisher's exact test, and p-values were adjusted for multiple testing using the Bonferroni method.

Continuous variables (age, body weight, LRV cross-clamp time, follow-up duration) were summarized descriptively; no formal between-group comparisons were performed for these variables given the small subgroup sizes and the descriptive nature of the present series.

Transition diagrams were used to visually represent shifts in patient status for flank pain, hematuria, and proteinuria from the preoperative to the postoperative period. These diagrams illustrate the number of patients who transitioned from a positive (present) to a negative (absent) state, remained positive, or remained negative. Arrow thickness was proportional to the number of patients in each transition. Positive states are depicted in red and negative states in green.

Given the rarity of NCS and the exploratory nature of this single-center series, no formal a priori sample size calculation was performed. All eligible patients operated during the study period were included as a consecutive convenience sample.

Results

Patient characteristics

A total of 18 consecutive patients (5 men [27.8%] and 13 women [72.2%]) with NCS underwent a transabdominal surgical approach between June 2022 and April 2025. The mean age was 20.5 ± 7.79 years (range, 11–33) and the mean body weight was 51.1 ± 7.87 kg (range, 35–64). Patient characteristics are summarized in Table 1 and Table 2.

Table 1
Characteristics of patients with nutcracker syndrome.

No.	Age (y)	Sex	Weight (kg)	Clinical presentation	SMA syndrome	Surgical technique	Reintervention
1	29	M	63	Flank pain; varicocele	—	LRV transposition (end-to-side)	Balloon angioplasty
2	19	M	53	Flank pain; postprandial pain; microhematuria	+ DJ	LRV transposition (end-to-side)	Balloon angioplasty
3	16	F	48	Flank pain	—	LRV transposition (end-to-side)	—
4	15	F	46	Flank pain; microhematuria	—	LRV transposition (end-to-side)	Balloon angioplasty
5	33	F	59	Flank pain; microhematuria; proteinuria	—	Graft interposition	Balloon angioplasty
6	17	F	58	Postprandial pain; microhematuria; proteinuria	+ DJ	Graft interposition	—
7	13	F	42	Flank pain; microhematuria	—	Graft interposition	Balloon angioplasty
8	12	F	47	Flank pain; postprandial pain	+ DJ	Ovarian vein transposition	—
9	15	M	64	Microhematuria; varicocele	—	LRV transposition (end-to-side)	Balloon angioplasty
10	27	F	55	Flank pain; macrohematuria; proteinuria	—	Graft interposition	—
11	32	F	52	Flank pain; postprandial pain	+ DJ	Ovarian vein transposition	—
12	11	M	35	Flank pain; microhematuria	—	Graft interposition	—
13	13	M	45	Flank pain; microhematuria; proteinuria	—	Graft interposition	—
14	26	F	50	Flank pain; macrohematuria; proteinuria	—	Graft interposition	—

DJ, duodenojejunostomy; LRV, left renal vein; SMA, superior mesenteric artery.

No.	Age (y)	Sex	Weight (kg)	Clinical presentation	SMA syndrome	Surgical technique	Reintervention
15	32	F	56	Flank pain; macrohematuria; proteinuria	—	Ovarian vein transposition	—
16	12	F	40	Flank pain	—	Graft interposition	Balloon angioplasty
17	25	F	50	Postprandial pain; microhematuria	+ DJ	Graft interposition	—
18	22	F	57	Flank pain; microhematuria; proteinuria	—	Ovarian vein transposition	—

DJ, duodenojejunostomy; LRV, left renal vein; SMA, superior mesenteric artery.

Table 2
Demographic, clinical, and operative characteristics of the cohort (n = 18).

Variable	Value, n (%) or mean ± SD
Female sex	13 (72.2)
Age, years (range)	20.5 ± 7.79 (11–33)
Body weight, kg (range)	51.1 ± 7.87 (35–64)
Surgical technique	
Graft interposition	9 (50.0)
LRV transposition (end-to-side)	5 (27.8)
Ovarian/gonadal vein transposition	4 (22.2)
Clinical presentation	
Flank pain	15 (83.3)
Postprandial abdominal pain	5 (27.8)
Macroscopic hematuria	3 (16.7)
Varicocele (male patients)	2 (11.1)
Urinalysis findings	
Hematuria (total)	13 (72.2)
Microscopic	10 (55.6)
Macroscopic	3 (16.7)
Proteinuria (always with hematuria)	7 (38.9)
Concomitant SMA syndrome	5 (27.8)
LRV cross-clamp time, min	13.3 ± 1.7 (8–15)
Follow-up, months	13.5 ± 5.77
Reintervention	7 (38.9)
Postoperative ileus-like symptoms	4 (22.2)

LRV, left renal vein; SD, standard deviation; SMA, superior mesenteric artery.

The most common presenting symptom was flank pain (15 patients, 83.3%), followed by postprandial abdominal pain (5 patients, 27.8%) and macroscopic hematuria (3 patients, 16.7%). Two male patients (11.1%) presented with varicocele; both had previously undergone varicocele surgery before the diagnosis of NCS was established. On urinalysis, microscopic hematuria was identified in 10 patients

(55.6%), macroscopic hematuria in 3 (16.7%), and proteinuria in 7 (38.9%). All cases of proteinuria were accompanied by hematuria. SMA syndrome was present in 5 patients (27.8%).

One additional patient with both pelvic congestion syndrome and dyspareunia declined surgical treatment after counseling, having undergone multiple previous neurosurgical, gynecological, and general surgical procedures for persistent abdominal pain and dyspareunia; this patient was therefore not included in the operative cohort.

Operative details

Under general anesthesia, the LRV was accessed through a midline supraumbilical incision. The suprarenal, lumbar, and gonadal branches of the LRV were divided. After preparation of the LRV, heparin was administered at a dose of 100 U/kg. Anastomosis was performed under simple clamping. The stump of the LRV on the inferior vena cava (IVC) was closed primarily with sutures.

Three operative approaches were used: graft interposition between the LRV and the IVC in 9 patients (50.0%), LRV transposition with end-to-side anastomosis to a more caudal point on the IVC in 5 patients (27.8%), and gonadal or ovarian vein transposition to a distal point on the IVC in 4 patients (22.2%). An expanded polytetrafluoroethylene (ePTFE) tube graft (FlowLine Bipore, JOTEC GmbH, Hechingen, Germany) with an internal diameter of 8–10 mm was used in all graft interposition procedures. Five patients (27.8%) underwent concomitant duodenojejunostomy for SMA syndrome. The mean LRV cross-clamp time was 13.3 ± 1.7 minutes (range, 8–15). All procedures were completed without intraoperative adverse events, and all patients were extubated in the operating room (Fig. 1A–C).

Postoperative course and follow-up

A prophylactic subcutaneous dose of low-molecular-weight heparin was administered 6 hours postoperatively. Rivaroxaban was prescribed as oral anticoagulation at discharge and continued for 3 months; in patients undergoing reintervention, anticoagulation was extended to 6–12 months. All patients were discharged without complications.

Surveillance CT angiography (CTA) was performed at the end of the anticoagulation period, and follow-up CTA was repeated at 6 and 12 months and annually thereafter. Symptomatic patients underwent earlier imaging. The mean follow-up duration was 13.5 ± 5.77 months.

During follow-up, 7 patients (38.9%) required transcatheter reintervention. All reinterventions were performed electively; no urgent procedures were required, and no reinterventions were performed within the first 3 postoperative months. Reintervention consisted of balloon angioplasty without stenting, and was technically successful in all cases. Imaging at reintervention demonstrated caval ostial stenosis in 3 patients and graft stenosis in 4 patients. Among patients with graft stenosis, one had risk factors for thrombosis (smoking and oral contraceptive use) and another was found to have mutations in the protein C (PROC) and protein S (PROS) genes.

Reintervention rates differed substantially across surgical techniques, with the highest rate observed after LRV transposition (4 of 5 patients, 80.0%) compared with graft interposition (3 of 9 patients, 33.3%) and gonadal/ovarian vein transposition (0 of 4 patients, 0%). The overall difference assessed by the Freeman–Halton extension of Fisher's exact test approached but did not reach statistical significance (p = 0.072), likely reflecting the small sample size. Pairwise Fisher's exact tests showed a difference between LRV transposition and gonadal/ovarian vein transposition (uncorrected p = 0.048; Bonferroni-corrected p = 0.143). Detailed data are presented in Table 4.

Table 4
Reintervention rates stratified by surgical technique.

Surgical technique	Patients (n)	Reintervention (n)	Rate (%)	Pairwise comparison (vs. LRV transposition)
LRV transposition (end-to-side)	5	4	80.0	Reference
Graft interposition	9	3	33.3	p = 0.266 (0.797)*
Ovarian/gonadal vein transposition	4	0	0	p = 0.048 (0.143)*
Total	**18**	**7**	**38.9**	**Overall p = 0.072†**
LRV, left renal vein. All reinterventions were performed electively by balloon angioplasty without stenting.				
**Pairwise comparisons performed with Fisher's exact test; Bonferroni-corrected p-values shown in parentheses.*				
†Overall comparison across the three groups performed with the Freeman–Halton extension of Fisher's exact test.				
Table.1 Characteristics of patients with Nutcracker syndrome				

Postoperative ileus-like symptoms were observed in 4 patients (22.2%), all of whom had undergone concomitant duodenojejunostomy for SMA syndrome. All cases of ileus resolved with conservative management; no patient required reoperation.

Symptom and urinary outcomes

Postoperatively, flank pain, hematuria, and proteinuria decreased significantly compared with the preoperative state (Fig. 2). Flank pain resolved in 11 of 15 patients (p < 0.001), hematuria resolved in 10 of 13 patients (p = 0.001), and proteinuria resolved in 6 of 7 patients (p = 0.016). No new-onset proteinuria or hematuria was observed after surgery. Comparative data are presented in Table 3.

Table 3
Preoperative and postoperative clinical and urinary findings.

Finding	Preoperative, n (%)	Postoperative, n (%)	McNemar p
Flank pain	15 (83.3)	4 (22.2)	< 0.001
Hematuria	13 (72.2)	3 (16.7)	0.001
Proteinuria	7 (38.9)	1 (5.6)	0.016
Statistical comparison performed using McNemar's exact test for paired dichotomous variables.			

Discussion

In this single-center retrospective series of 18 patients undergoing surgical reconstruction for NCS, all three operative techniques produced significant improvement in symptoms and urinary findings, with no postoperative renal dysfunction or graft loss. The overall transcatheter reintervention rate was 38.9%, and reinterventions were technically successful in every case. Of note, reintervention rates were not uniform across techniques: LRV transposition with end-to-side anastomosis was associated with the highest reintervention rate (80.0%), followed by graft interposition (33.3%) and gonadal/ovarian vein transposition (0%). Although this difference did not reach statistical significance in our small cohort (Freeman–Halton p = 0.072), the magnitude of the effect is consistent with recent comparative reports [11] and warrants further investigation in larger series.

Although NCS is considered a rare condition, its true prevalence in the general population remains unclear. In a study analyzing 1,000 contrast-enhanced CT examinations, the nutcracker phenomenon was identified in approximately 4% of cases [8]. However, when patients with radiologic LRV stenosis were clinically re-evaluated, only 9% exhibited otherwise unexplained proteinuria and hematuria. As emphasized in the recent Delphi consensus by Heilijgers and colleagues [4], the diagnosis should never be established solely on the basis of imaging; rather, syndrome-specific symptoms must be thoroughly assessed before a definitive diagnosis is made.

Prolonged arterial pulsation and pressure on the LRV over months to years results in intimal fibrosis and the formation of venous spurs, further exacerbating venous outflow obstruction and ultimately producing irreversible stenosis [1, 2]. This mechanical obstruction predisposes patients to renal vein thrombosis, chronic venous stasis, and venous hypertension.

The classic symptoms of NCS include abdominal and left flank pain as well as macroscopic or microscopic hematuria and proteinuria [10]. In men, varicocele may be an associated finding, whereas female patients may present with pelvic congestion syndrome and dyspareunia. Pain—the most common symptom—is thought to result from increased intravascular pressure within the LRV, leading to renal capsular distension. Hematuria is believed to result from erythrocyte extravasation (erythrodiapedesis) directly into the renal collecting system from the engorged venous network of the kidney [13]. Persistent venous hypertension may also impair renal perfusion and lead to long-term

nephron loss. In rare cases, NCS may even contribute to refractory hypertension [14]. In the present series, the most common symptom was flank pain (83.3%), and the most common urinary finding was microscopic hematuria (55.6%), in line with the published literature.

Our routine first-line diagnostic work-up includes complete urinalysis, plain abdominal radiography, renal vein duplex US, and contrast-enhanced CT. When these tests fail to correlate with the clinical picture, additional evaluations—cystoscopy, ureteroscopy, urography, and renal biopsy—are performed. Venography and pressure measurements are reserved for cases of persistent diagnostic uncertainty. Unlike some published series, intravascular ultrasound (IVUS) was not used in our cohort. IVUS has greater diagnostic specificity than conventional venography and is generally preferred when endovascular treatment is being planned.

Although caution is generally advised when considering surgery in patients younger than 18 years [16]—on the rationale that retroperitoneal fat deposition during growth may relieve LRV compression—fewer than 30% of patients in some series experienced symptomatic improvement with weight gain. Based on our experience, surgical intervention should not be uniformly deferred until the age of 18, particularly when symptoms significantly impair daily activities or school attendance. Moreover, since both SMA syndrome and NCS share a narrow aortomesenteric angle as their primary anatomic substrate, we favor earlier surgical intervention in patients with concomitant disease. In the present cohort, 5 patients (27.8%) had concomitant SMA syndrome and underwent simultaneous duodenojejunostomy. The relatively high rate of postoperative ileus-like symptoms among these patients is attributable to this combined procedure.

Both endovascular and open surgical treatment are valid management strategies for NCS. In their recent systematic review including 24 studies and 578 patients, Sarikaya and colleagues [5] reported that open surgery, laparoscopic, robotic, and endovascular approaches all yielded acceptable outcomes, but with differing reintervention profiles. Although endovascular treatment appears less invasive, it carries a distinct complication profile, including stent migration, stent fracture, in-stent restenosis, and renal vein erosion, with notable rates of reintervention reported in endovascular cohorts [17, 18, 19, 25]. While the goal of every treatment strategy is to reduce LRV pressure, the anatomy of NCS is unfavorable for primary endovascular treatment in many patients. Open surgical reconstruction allows direct repair or bypass of the diseased segment and offers durable long-term results. Nevertheless, endovascular techniques play an indispensable complementary role in managing postoperative complications, as demonstrated by the 7 transcatheter reinterventions in our cohort. Considering the early and late risks associated with both modalities, we propose that open surgery should remain the first-line treatment for NCS in most patients.

Surgical strategy and stratified outcomes

Reported surgical techniques for NCS include gonadal vein transposition, LRV transposition, graft interposition, renal autotransplantation, and various modifications thereof [20, 21, 22].

Renal autotransplantation has been advocated as a definitive treatment with a reported 91% success rate in a recent multicenter analysis [22]. However, the need for anastomosis of the renal artery, renal vein, and ureter significantly increases the technical complexity and associated morbidity. For this reason, autotransplantation was not used in our series. SMA transposition has also been proposed; however, given the critical territory supplied by the SMA and the potentially catastrophic consequences of mesenteric ischemia, we have not employed this technique in our practice. In addition, persistent stenosis at the LRV–IVC junction may develop after SMA transposition.

Gonadal or ovarian vein transposition is a useful alternative [23] but is not applicable in all patients, as it requires the gonadal vein to have an internal diameter of approximately 8–10 mm to ensure adequate venous outflow. When the gonadal vein is of suitable caliber, an autologous reconstruction with a single anastomosis can be performed, providing dual venous drainage—a principle that has recently been extended to robotic-assisted approaches with promising early outcomes [24]. In our series, ovarian vein transposition was performed in 4 patients (22.2%); no reinterventions were required in this subgroup during follow-up. Although autologous reconstruction is advantageous, the need for an additional incision and longer operative time remain limitations. Alternative autologous conduits include intra-abdominal ovarian or gonadal veins, colic veins, and the saphenous vein.

LRV transposition with direct end-to-side anastomosis is another established option. Mobilizing the LRV caudally along the IVC after transection widens the aortomesenteric angle and allows the vein to be repositioned away from the compression site. When direct anastomosis is performed, careful intraoperative assessment is essential to minimize anastomotic tension, and re-anastomosing the LRV at a more caudal point may help reduce postoperative complications. Reed and colleagues reported that 30–40% of patients undergoing LRV transposition required percutaneous reintervention during long-term follow-up [12]. In a more recent series by Sarikaya et al. [11] from Turkey comparing LRV transposition and endovascular stenting, the 1- and 3-year primary patency rates after surgery were 91% and 81%, respectively. In our experience, the reintervention rate after LRV transposition was higher than in these reports (4 of 5 patients, 80.0%) and was associated with recurrent stenosis from intimal hyperplasia. Importantly, patients undergoing this technique should be counseled regarding the possibility of subsequent endovascular reintervention.

In our practice, graft interposition was the most frequently used technique (9 of 18 patients, 50.0%), with a reintervention rate of 33.3%. When autologous venous grafts are unavailable or size-mismatched, and given the relatively high reintervention rate after direct LRV anastomosis, LRV reconstruction with a synthetic vascular graft remains a reasonable option that, in our experience, produces favorable outcomes. The stratified reintervention data presented in Table 4 suggest a hierarchy of durability—gonadal/ovarian vein transposition (when anatomically feasible) > graft interposition > LRV transposition—although this trend did not reach statistical significance in our small sample (Freeman–Halton $p = 0.072$) and requires confirmation in larger multicenter studies.

Anticoagulation strategy

Antiplatelet or anticoagulant therapy is generally recommended in the early and intermediate postoperative period after LRV reconstruction. In our cohort, partial graft thrombosis developed in 2 patients receiving prophylactic anticoagulation. In one of these patients, a thrombophilic condition (PROC/PROS mutations) was identified on subsequent work-up. This experience raises concerns regarding the adequacy of prophylactic-dose rivaroxaban in selected patients. Both patients were subsequently treated with therapeutic-dose rivaroxaban, and follow-up imaging demonstrated thrombus regression.

Warfarin remains a commonly used anticoagulant, but a substantial proportion of patients fail to maintain therapeutic INR values during long-term follow-up, supporting the use of direct oral anticoagulants in selected cases. Accordingly, our institutional protocol consists of prophylactic low-molecular-weight heparin during the inpatient stay, followed by rivaroxaban after discharge, with intensification to therapeutic dosing in patients with documented thrombosis or thrombophilia.

Limitations

Several limitations should be acknowledged. First, this is a retrospective single-center study with a relatively small sample size. Second, the mean follow-up duration of 13.5 months is insufficient to assess long-term durability and patency; longer follow-up is warranted, particularly given that residual or recurrent stenosis may become clinically manifest years after the index operation. Third, a non-operative comparator group was not included, precluding direct comparison with conservative or endovascular treatment. Fourth, patient-reported outcome measures and quality-of-life instruments were not used; future studies should incorporate these to better quantify clinical benefit. Fifth, subgroup numbers were small: although a clear trend toward higher reintervention rates was observed after LRV transposition, the Freeman–Halton exact test did not reach statistical significance, and the pairwise comparison between LRV transposition and gonadal/ovarian vein transposition lost statistical significance after Bonferroni correction. These findings should therefore be interpreted with caution and confirmed in larger, ideally multicenter, prospective cohorts.

Conclusions

NCS is one of the most commonly overlooked causes of abdominal and flank pain, and meticulous evaluation is required to establish the diagnosis. Coexisting SMA syndrome should be actively sought, since combined surgical management may be necessary. In our experience, open surgical reconstruction is a safe and effective treatment for NCS, with significant improvement in symptoms and urinary findings. Reintervention rates appear to differ across surgical techniques, with gonadal/ovarian vein transposition and graft interposition showing more favorable durability than direct LRV transposition with end-to-side anastomosis in our cohort, although these differences require validation in larger series. Close follow-up is essential, as transcatheter reintervention may be required to manage residual or recurrent stenosis. Multicenter prospective studies with extended follow-up are warranted to validate the technique-specific differences in reintervention rates observed in this cohort and to inform evidence-based surgical decision-making in nutcracker syndrome.

Abbreviations

CT
Computed tomography
CTA
Computed tomographic angiography
ePTFE
Expanded polytetrafluoroethylene
IQR
Interquartile range
IVC
Inferior vena cava
IVUS
Intravascular ultrasonography
LRV
Left renal vein
NCS
Nutcracker syndrome
SD
Standard deviation
SMA
Superior mesenteric artery
STROBE
Strengthening the Reporting of Observational Studies in Epidemiology
US
Ultrasonography.

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the principles of the Declaration of Helsinki. The study protocol was approved by the Non-Interventional Research Ethics Committee of Izmir City Hospital (approval number: 2026/439, date: 17 June 2026). All imaging data were obtained during routine clinical care at our institution. Owing to the retrospective nature of the study, the requirement for written informed consent was waived by the ethics committee.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

MSB and OI conceptualised and designed the study. MSB, OI, AKK and MA performed the investigation and clinical assessment of patients. MSB, MA, GO and FD curated the data and extracted information from medical records. MSB,MA and GGC performed the formal statistical analysis. OA performed the radiological reassessment of imaging studies. GO and FD provided pediatric perioperative care expertise for patients younger than 18 years. OI supervised the project. MSB drafted the original manuscript. All authors critically reviewed and edited the manuscript, and all authors read and approved the final version of the manuscript.

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Not applicable.

Availability of data and materials

The datasets generated and analysed during the current study are not publicly available owing to institutional data protection policies and patient privacy considerations, but are available from the corresponding author on reasonable request.

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Figures

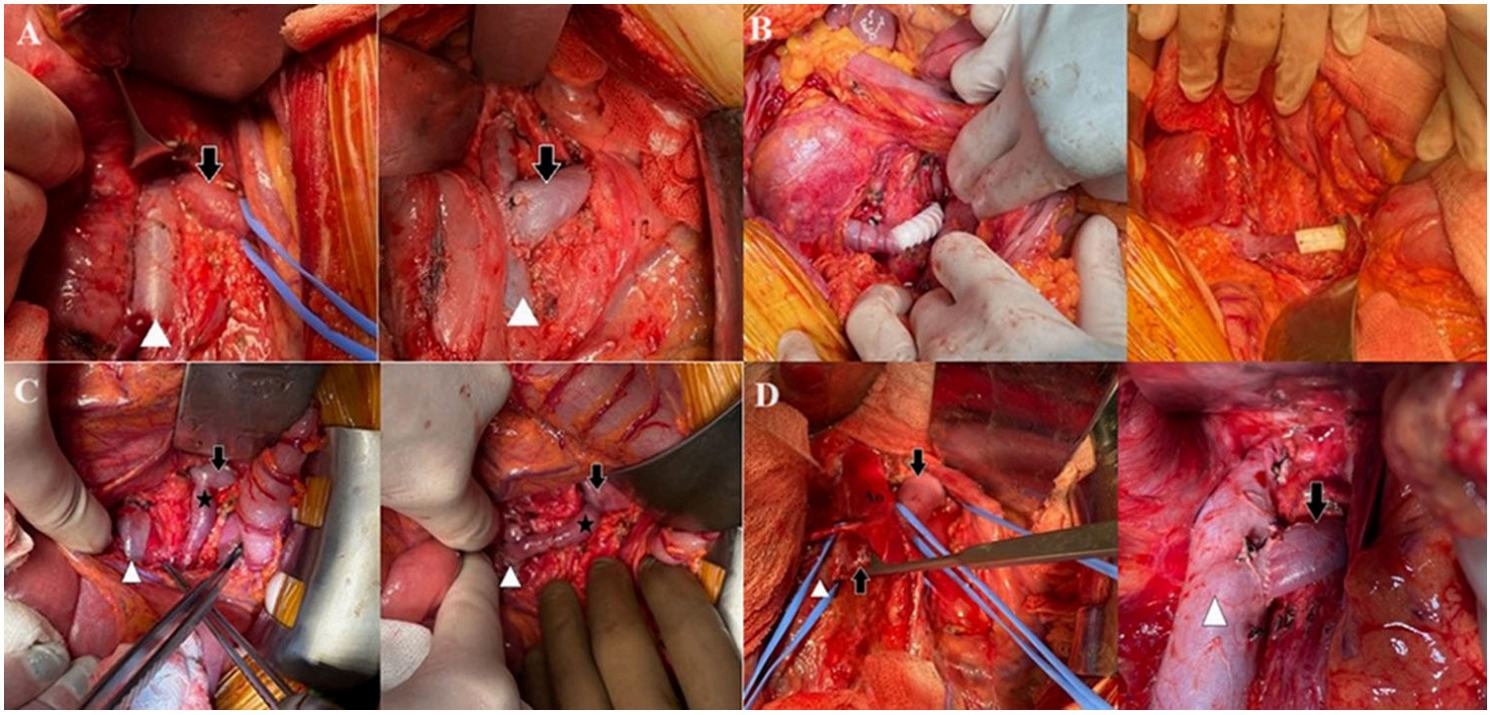


Figure 1

Preoperative and intraoperative images. (A) Left renal vein transposition with end-to-side anastomosis to the inferior vena cava; (B) graft interposition between the left renal vein and the inferior vena cava; (C) gonadal (ovarian) vein transposition to a distal point on the inferior vena cava; (D) posterior nutcracker syndrome with left renal vein compression between the aorta and the vertebral body. IVC, white arrowhead; LRV, black arrow; gonadal vein, star; abdominal aorta, white arrow.

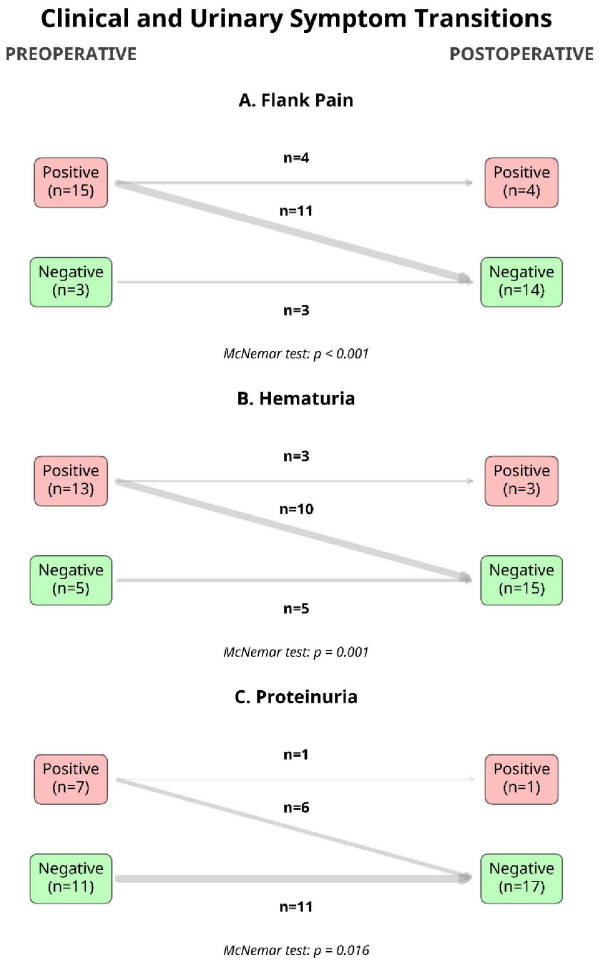


Figure 2

Preoperative to postoperative transitions in clinical and urinary findings. Panel A shows changes in flank pain; panels B and C demonstrate changes in hematuria and proteinuria, respectively. Numbers indicate patient transitions between preoperative and postoperative states.

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