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OUTCOMES OF HYPOSPADIAS RECONSTRUCTION WITH BUCCAL MUCOSAL GRAFT IN CHILDREN — A SYSTEMATIC REVIEW OF RANDOMIZED CONTROLLED TRIALS AND PRIMARY STUDIES

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ABSTRACT

Introduction: Buccal mucosal graft (BMG) is the dominant extragenital substitute for urethral reconstruction in severe, proximal and re-operative ("redo") hypospadias, yet paediatric evidence remains fragmented across small single-centre series, and pooled estimates of its complication profile, its performance against preputial/skin and lingual grafts, and its durability through puberty are lacking. This review aimed to quantify surgical, functional, cosmetic and donor-site outcomes of BMG urethroplasty in children and to compare BMG with alternative substitutes.[1–3]

Methods: Following PRISMA 2020, primary studies published between January 2011 and September 2026 were identified using eight structured queries. Randomised controlled trials (RCTs), prospective and retrospective cohorts, case–control, cross-sectional and observational series of boys (≤18 years) undergoing

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BMG urethroplasty for hypospadias or its sequelae were eligible.[4–7]

Results: Twenty-six studies (4 RCTs, 8 comparative non-randomised studies, 14 non-comparative series; 2011–2025; 12 countries) were included, 23 of which contributed to meta-analysis. Across 1,080 BMG repairs (k = 20) the pooled composite adverse-outcome rate was 25.5% (95% CI 18.8–33.6) (I^2 = 83.3%; 95% prediction interval 6.1–64.4%), corresponding to a primary success rate of 74.5% (95% CI 66.4–81.2). Pooled rates were: urethrocutaneous fistula 8.4% (95% CI 6.2–11.4) (I^2 = 0%), meatal stenosis 8.1% (95% CI 3.6–17.2), urethral stricture 7.6% (95% CI 4.0–14.0) after excluding the tubularised-graft outlier, glans dehiscence 11.8% (95% CI 7.6–17.7), residual curvature 6.1% (95% CI 3.5–10.3), and unplanned re-intervention 14.8% (95% CI 8.3–24.9). Composite adverse outcomes were lowest after single-stage inlay/onlay BMG (16.8% (95% CI 9.9–27.1)), intermediate after staged Bracka repair (27.2% (95% CI 20.8–34.6)) and highest after free tubularised BMG (62.4% (95% CI 12.5–95.1)). Against preputial/skin grafts, BMG showed no significant difference in composite complications (RR 0.88 (95% CI 0.61–1.26); k = 5) or fistula (RR 1.07 (95% CI 0.37–3.09)), with a non-significant trend toward less meatal stenosis/stricture (RR 0.46 (95% CI 0.17–1.24)); BMG and lingual mucosal grafts performed equivalently (RR 1.01 (95% CI 0.46–2.23)). Persistent donor-site morbidity was rare (0/54). No small-study effect was detected (Egger p = 0.31). Certainty of evidence was low to very low.

Discussion: BMG provides reliable neourethral tissue in children, with roughly three in four repairs achieving an uncomplicated result and low, homogeneous fistula rates. Outcomes are driven

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more by technique and recipient-bed quality than by graft type; free tubularised grafts in scarred beds carry a stricture-dominated failure profile, whereas complications continue to accrue for up to a decade, mandating follow-up through puberty. Evidence is limited by predominantly retrospective single-centre designs, heterogeneous outcome definitions and scarce post-pubertal data.[8–10]

Conclusion: BMG urethroplasty is an effective and safe substitute for complex and redo hypospadias in children, particularly as an inlay/onlay or staged graft, with minimal long-term donor-site morbidity. Adequately powered multicentre RCTs using standardised, core-outcome definitions and follow-up into adulthood are required.

Keywords: hypospadias; buccal mucosa; oral mucosal graft; urethroplasty; Bracka two-stage repair; dorsal inlay graft; redo hypospadias; children; meta-analysis; systematic review.

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INTRODUCTION

Background

Hypospadias is among the most frequent congenital anomalies of the male external genitalia, characterised by an ectopic ventral urethral meatus, a ventrally deficient ("hooded") prepuce and, in more severe phenotypes, ventral penile curvature and a hypoplastic urethral plate. Registry data reveal wide geographical variation, with a mean prevalence of approximately 19.9 per 10,000 births in Europe and 34.2 per 10,000 in North America, and a pooled European EUROCAT prevalence of 18.61 per 10,000 births between 2001 and 2010; contemporary Chinese surveillance reports 10.18 per 10,000 male births with a rising trend.[1,11,12]

The aetiology is multifactorial, combining monogenic variants (e.g., AR, SRD5A2, MAMLD1) with environmental contributors such as low birthweight, placental insufficiency and possible endocrine-disrupting exposures. Proximal hypospadias frequently co-exists with severe chordee, a short or dysplastic urethral plate and scrotal transposition, features that limit the use of local tissue and predispose to repeated operations.[13,14]

Even after contemporary repair, the burden of re-operation is substantial. In a Finnish tertiary cohort followed for a median of 14.4 years, the cumulative unplanned re-operation rate reached 48.2%, with 5- and 15-year risks of 39.3% and 51.8%, respectively, and risk increasing with severity. Adolescent follow-up of 193 young men showed at least one re-intervention in 39.2% and a disturbed urinary or suboptimal sexual outcome in 52.9%, underscoring that short-term success does not guarantee durable function.[15,16]

When the native urethral plate and genital skin are insufficient—because of severe primary hypospadias, prior circumcision, lichen sclerosus (balanitis xerotica obliterans, BXO) or multiple failed repairs (the "hypospadias cripple")—extragenital substitutes are required. Buccal (oral) mucosa has become the graft of choice owing to its non-keratinised stratified squamous epithelium, thick elastic epithelium with a thin, highly vascular lamina propria favouring rapid inosculation, absence of hair follicles and adnexal glands, resistance to infection and tolerance of a wet environment. Comparative histology in children with proximal hypospadias has confirmed that buccal mucosa lacks the sweat and sebaceous glands, hair follicles and chronic inflammatory foci observed in preputial skin grafts, and more closely resembles native urethra.[3,17]

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BMG is deployed in several configurations in children: (i) as a dorsal inlay graft into an incised urethral plate ("grafted TIP" or Snodgraft); (ii) as a ventral onlay or patch graft; (iii) as the first-stage graft of the Bracka two-stage repair, subsequently tubularised; and (iv) as a free tubularised graft. Each configuration has distinct biological demands on the recipient bed and distinct failure modes.[18–20]

Research gap

Existing syntheses leave important questions unanswered. An umbrella review of twelve graft-related systematic reviews (9,829 patients) found that only one addressed paediatric hypospadias and rated the paediatric evidence as low quality with low GRADE certainty. A 2025 systematic review of post-pubertal outcomes after oral mucosal urethroplasty in prepubertal boys identified only three eligible studies and concluded that long-term efficacy could not be established. Meta-analyses comparing dorsal inlay graft urethroplasty with TIP have pooled inlay grafts irrespective of graft source (inner prepuce vs buccal mucosa), and the lingual-versus-buccal meta-analysis addressed predominantly adult stricture cohorts.[2,3,21–23]

Consequently, no contemporary synthesis has (a) pooled the complication spectrum of BMG urethroplasty specifically in children across all techniques; (b) quantitatively compared BMG with preputial/skin and lingual grafts in paediatric hypospadias; (c) explored technique, indication (primary vs redo) and follow-up duration as effect modifiers; or (d) integrated donor-site morbidity and functional (uroflowmetry) and cosmetic (HOSE/HOPE) outcomes in a single evidence framework.[2,3]

Objectives

The **primary objective** was to estimate the pooled rate of composite adverse outcome (any complication or failure) and its complement, primary surgical success, after BMG urethroplasty for hypospadias in children. **Secondary objectives** were to estimate pooled rates of urethrocutaneous fistula, meatal stenosis, urethral stricture, glans dehiscence, residual curvature, unplanned re-intervention and persistent donor-site morbidity; to compare BMG with preputial/skin grafts, lingual mucosal grafts and one-stage flap repair; to describe functional (Qmax) and cosmetic (HOSE/HOPE) outcomes; and to explore sources of heterogeneity.

Hypotheses

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- **H1 (primary):** BMG urethroplasty in children achieves a pooled primary success rate of at least 70%.
- **H2:** Compared with preputial or extragenital skin grafts, BMG is associated with fewer composite complications and less meatal stenosis/stricture (H0: RR = 1).
- **H3:** Buccal and lingual mucosal grafts yield equivalent urethroplasty outcomes.
- **H4:** Technique (inlay/onlay vs staged vs tubularised), indication (primary vs redo) and longer follow-up modify complication rates.

Novelty

To our knowledge, this is the first paediatric-specific quantitative synthesis restricted to BMG that (i) integrates RCTs and observational designs with design-appropriate risk-of-bias tools (RoB 2, ROBINS-I and MINORS); (ii) presents technique-stratified pooled estimates and prediction intervals; (iii) quantifies BMG-versus-skin and BMG-versus-lingual comparisons; (iv) applies meta-regression on follow-up duration, cumulative and leave-one-out analyses; and (v) explicitly flags data-integrity concerns (duplicate or reproduced data sets) that may bias earlier syntheses.

Significance and expected benefits

For paediatric urologists and surgeons, the review provides benchmark complication rates for counselling families and auditing practice, and an evidence-informed algorithm for selecting the BMG configuration. For researchers, it identifies the principal methodological deficiencies and proposes a minimum outcome data set. For health systems—particularly in low- and middle-income settings where late presentation and prior circumcision increase the need for extragenital grafts—it supports resource planning for staged surgery and long-term follow-up.[14,15]

METHODS

Protocol and reporting

This review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement. The protocol (eligibility criteria, outcomes, risk-of-bias tools and analysis plan) was specified a priori.[4]

Eligibility criteria (PICOS)

Table 1. Eligibility criteria according to the PICOS framework

Domain	Inclusion criteria	Exclusion criteria
Population	Boys ≤18 years with primary or re-	Adults or mixed cohorts without

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	operative hypospadias, or hypospadias-related sequelae (fistula, urethral/meatal stricture, LS/BXO after hypospadias repair)	separable paediatric data; epispadias; non-hypospadias strictures (trauma, iatrogenic catheter injury); disorders of sex development reported without separable data
Intervention	Urethroplasty using buccal (cheek) or labial (upper/lower lip) oral mucosal graft: dorsal inlay, ventral onlay/patch, staged (Bracka) or tubularised	Grafts of unspecified origin; lingual-only, bladder, skin-only or tissue-engineered grafts (eligible only as comparators)
Comparator	Preputial/penile/extragenital skin graft, lingual mucosal graft, one-stage flap repair, TIP without graft, or none (single-arm)	—
Outcomes	Primary: composite adverse outcome/success. Secondary: fistula, meatal stenosis, stricture, glans dehiscence, residual curvature, re-intervention, donor-site morbidity, Qmax, HOSE/HOPE	Studies reporting no extractable BMG-specific outcome
Study design	RCTs; prospective or retrospective cohort; case–control; cross-sectional; observational comparative and non-comparative series (≥8 patients)	Systematic reviews/meta-analyses (used in Discussion only), narrative reviews, editorials, case reports (<8 patients), animal studies, technique videos without outcomes
Time/language	Published January 2011 – September 2026 (≤15 years); any language with an English abstract	Published before 2011

Search Strategy

The keywords used for this research based PICO :

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PICO Element	Keyword 1	Keyword 2	Keyword 3
P (Population)	Boys with hypospadias	Children with complex or redo hypospadias	Pediatric patients undergoing urethroplasty
I (Intervention)	Buccal mucosal graft urethroplasty	Oral mucosal graft repair	Staged Bracka repair and dorsal inlay graft
C (Comparison)	Preputial or skin graft	Lingual mucosal graft	One-stage flap repair or TIP
O (Outcome)	Composite complications and success	Urethrocutaneous fistula and stricture	Donor-site morbidity and functional outcomes

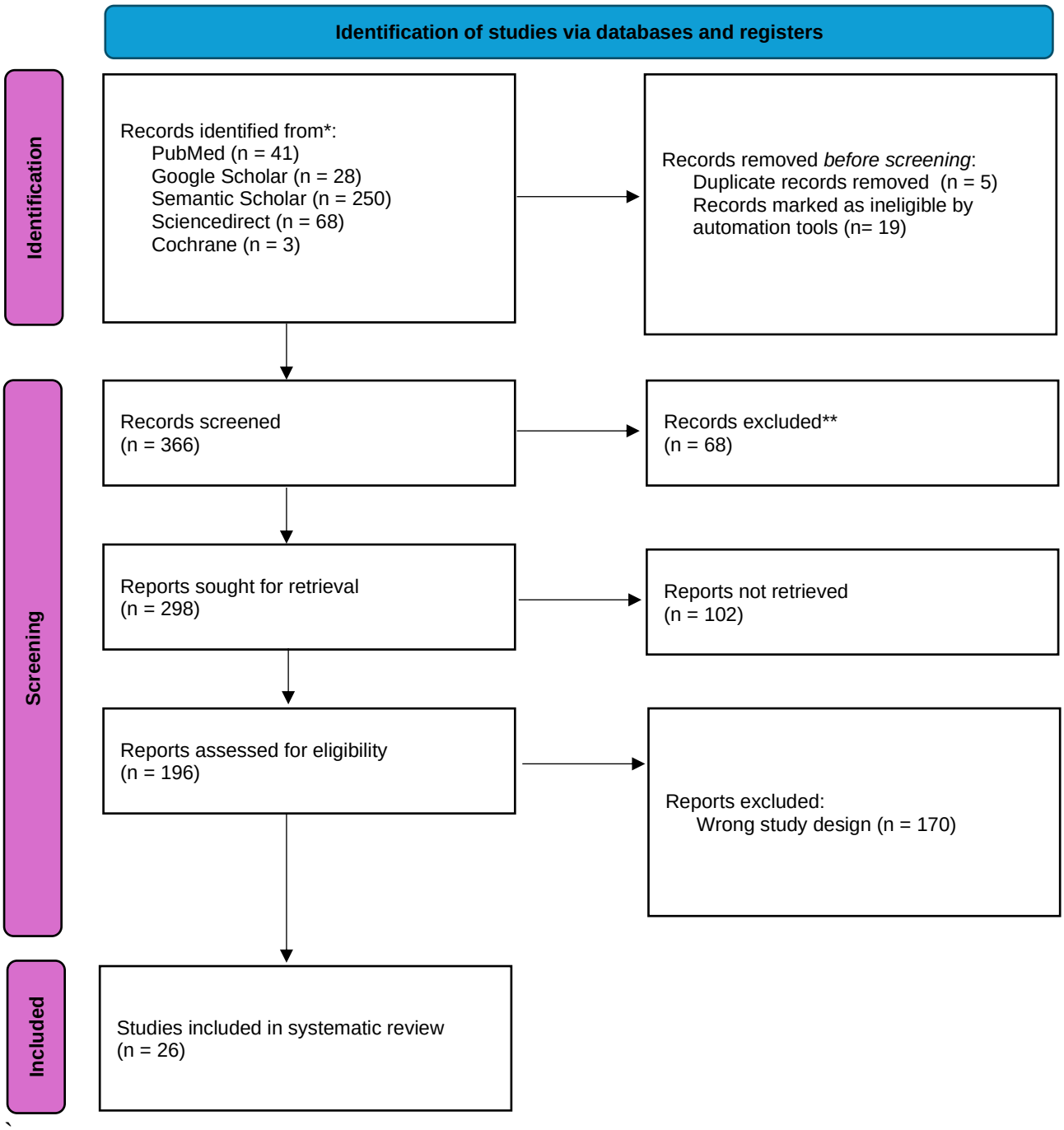
The Boolean MeSH keywords inputted on databases for this research are: *("Boys with hypospadias" OR "Children with complex or redo hypospadias" OR "Pediatric patients undergoing urethroplasty") AND ("Buccal mucosal graft urethroplasty" OR "Oral mucosal graft repair" OR "Staged Bracka repair and dorsal inlay graft") AND ("Preputial or skin graft" OR "Lingual mucosal graft" OR "One-stage flap repair or TIP") AND ("Composite complications and success" OR "Urethrocutaneous fistula and stricture" OR "Donor-site morbidity and functional outcomes")*

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Article Search Strategy

Database	Keywords	Hits
Pubmed	*("Boys with hypospadias") AND ("Buccal mucosal graft urethroplasty" OR "Oral mucosal graft repair" OR "Staged Bracka repair and dorsal inlay graft" AND "Composite complications and success" OR "Urethrocutaneous fistula and stricture" OR "Donor-site morbidity and functional outcomes")*	41
Elsevier	*("Boys with hypospadias" OR "Children with complex or redo hypospadias" OR "Pediatric patients undergoing urethroplasty") AND ("Buccal mucosal graft urethroplasty" OR "Oral mucosal graft repair" OR "Staged Bracka repair and dorsal inlay graft") AND ("Preputial or skin graft" OR "Lingual mucosal graft" OR "One-stage flap repair or TIP") AND ("Composite complications and success" OR "Urethrocutaneous fistula and stricture" OR "Donor-site morbidity and functional outcomes")*	28
Semantic Scholar	*("Boys with hypospadias" OR "Children with complex or redo hypospadias" OR "Pediatric patients undergoing urethroplasty") AND ("Buccal mucosal graft urethroplasty" OR "Oral mucosal graft repair" OR "Staged Bracka repair and dorsal inlay graft") AND ("Preputial or skin graft" OR "Lingual mucosal graft" OR "One-stage flap repair or TIP") AND ("Composite complications and success" OR "Urethrocutaneous fistula and stricture" OR "Donor-site morbidity and functional outcomes")*	250
Science-direct	*"Boys with hypospadias" AND "Buccal mucosal graft urethroplasty" OR "Oral mucosal graft repair" OR "Staged Bracka repair and dorsal inlay graft" AND "Composite complications and success" OR "Urethrocutaneous fistula and stricture" OR "Donor-site morbidity and functional outcomes"*	68
Cochrane	*"Boys with hypospadias" AND "Buccal mucosal graft urethroplasty" OR "Oral mucosal graft repair" OR "Staged Bracka repair and dorsal inlay graft" AND "Composite complications and success" OR "Urethrocutaneous fistula and stricture" OR "Donor-site morbidity and functional outcomes"*	3

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Article search flowchart

Study selection

Records were de-duplicated and screened on title and abstract against the PICOS criteria, followed by eligibility assessment of the retained reports. Studies with overlapping cohorts were identified by matching institution, recruitment period, sample size and outcome values; the most complete or most recent report was retained. Where two publications

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reported numerically identical results for ostensibly different populations, both were treated as a single data set and the earlier, peer-reviewed report was retained (Section 3.1).[24–26]

Data extraction

A standardised extraction form captured: first author, year, country, design, sample size (BMG and comparator), age, meatal position, indication (primary, redo or mixed), BMG configuration and donor site, follow-up, outcome definitions and event counts. Where only percentages were published, event counts were back-calculated and, where denominators were not stated, the unique integer combination consistent with the reported percentage was used and flagged; such studies were tested in sensitivity analyses. Data were extracted from the indexed abstracts and available full texts; values not reported are marked "NR".

Outcome definitions

The **composite adverse outcome** was defined as the proportion of BMG repairs with any reported complication or failure (fistula, meatal stenosis, stricture, dehiscence, graft contracture, residual curvature, diverticulum or any unplanned secondary procedure), using the study's own success definition where only success was reported (composite = 1 − success). **Primary success** was the complement. Secondary outcomes were analysed as reported. **Persistent donor-site morbidity** was defined as oral symptoms beyond two months. HOSE (Hypospadias Objective Scoring Evaluation; maximum 16, ≥14 acceptable) and HOPE were summarised descriptively.[27,28]

Risk-of-bias and quality assessment

Design-specific tools were applied. RCTs were appraised with the revised Cochrane tool (RoB 2) across five domains (randomisation process, deviations from intended interventions, missing outcome data, outcome measurement and selection of the reported result), yielding low, some-concerns or high overall judgements. Comparative non-randomised studies were appraised with ROBINS-I across seven domains (confounding, participant selection, intervention classification, deviations, missing data, outcome measurement and selective reporting). Non-comparative series were scored with the eight-item MINORS index (maximum 16; ≥10 considered acceptable).[5–7,29]

Because ROBINS-I is frequently misapplied—particularly by understating confounding—confounding by indication (e.g., BMG reserved for more severe or redo cases) was pre-specified as the critical confounder, and studies without adjustment or baseline comparability were rated at least "serious" for Domain 1.[30,31]

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Risk of bias and methodological quality

Randomised controlled trials (RoB 2)

None of the four RCTs was at low overall risk of bias. Two were judged to have some concerns and two high risk. Randomisation sequences were described only as "randomised" or by lottery, with no report of allocation concealment; blinding of surgeons was impossible and blinding of outcome assessors was not described. Elmaadawy 2022 was rated high for missing outcome data because five first-stage graft revisions and unexplained denominators precluded exact reconstruction of the analysed population, and Shahid 2020 was rated high for selective reporting because event counts were not reported and the same trial appeared in two publications.[5,37,39–41,50]

Table 2. RoB 2 domain-level judgements for randomised trials[5]

Trial	D1 Rando-misation	D2 Deviations	D3 Missing data	D4 Outcome measurement	D5 Reported result	Overall	Principal concern
Shahid 2020	Some concerns	Some concerns	Some concerns	Some concerns	High	High	Numerical results not reported; duplicate publication
Aziz 2021	Some concerns	Some concerns	Low	Some concerns	Some concerns	Some concerns	Concealment and assessor blinding NR
Mohammed 2021	Some concerns	Some concerns	Low	Some concerns	Some concerns	Some concerns	Irreproducible percentages; 6-month FU
Elmaadawy 2022	Some concerns	Some concerns	High	Some concerns	Some concerns	High	Unclear denominators after graft redo

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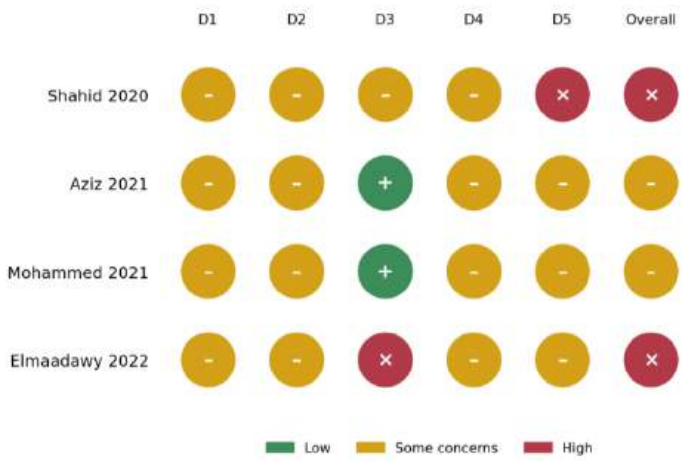


Figure 1. RoB 2 traffic-light plot for the four randomised trials. D1 randomisation process; D2 deviations from intended interventions; D3 missing outcome data; D4 measurement of the outcome; D5 selection of the reported result.[5]

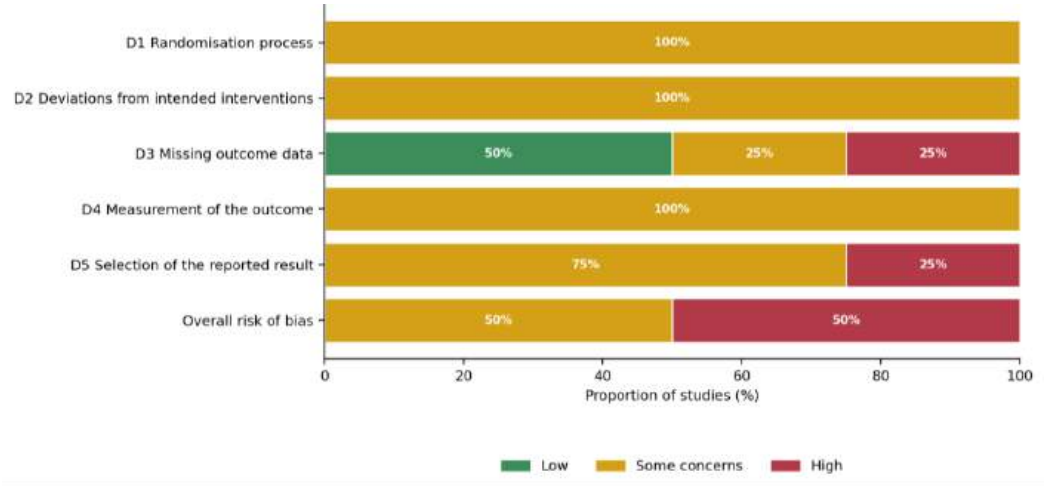


Figure 2. RoB 2 summary plot: proportion of trials at each risk level per domain.[5]

Comparative non-randomised studies (ROBINS-I)

Seven of eight comparative non-randomised studies were at serious overall risk of bias, principally from confounding by indication (Figures 7–8; Table 6). In Loloi 2020, BMG was used preferentially in redo cases; in Manasherova 2019, preputial grafts (2001–2013) and BMG (2013–2016) were used in consecutive eras, conflating graft effect with learning curve and evolving peri-operative care. Only Jin 2017 demonstrated baseline comparability for age, number of prior operations and graft dimensions and was rated moderate.[6,8,24,35]

Table 3. ROBINS-I domain-level judgements for comparative non-randomised studies[6]

Study	Confounding	Selection	Classification	Deviations	Missing data	Measurement	Reporting	Overall

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Maarouf 2013	Serious	Moderate	Low	Low	Low	Moderate	Moderate	Serious
Chen SZ 2016	Serious	Moderate	Low	Low	Moderate	Moderate	Moderate	Serious
Jin 2017	Moderate	Moderate	Low	Low	Low	Moderate	Moderate	Moderate
Manasherova 2019	Serious	Moderate	Low	Moderate	No information	Serious	Moderate	Serious
Loloi 2020	Serious	Moderate	Low	Low	Moderate	Moderate	Moderate	Serious
Shebl 2022	Serious	Moderate	Low	Low	Low	Moderate	Moderate	Serious
IPMJ 2024	Serious	Moderate	Low	Low	Low	Moderate	Moderate	Serious
Yekolla 2025	Serious	No information	Low	Low	No information	Moderate	Moderate	Serious



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Figure 3. ROBINS-I traffic-light plot. D1 confounding; D2 selection of participants; D3 classification of interventions; D4 deviations from intended interventions; D5 missing data; D6 measurement of outcomes; D7 selection of the reported result.[6]

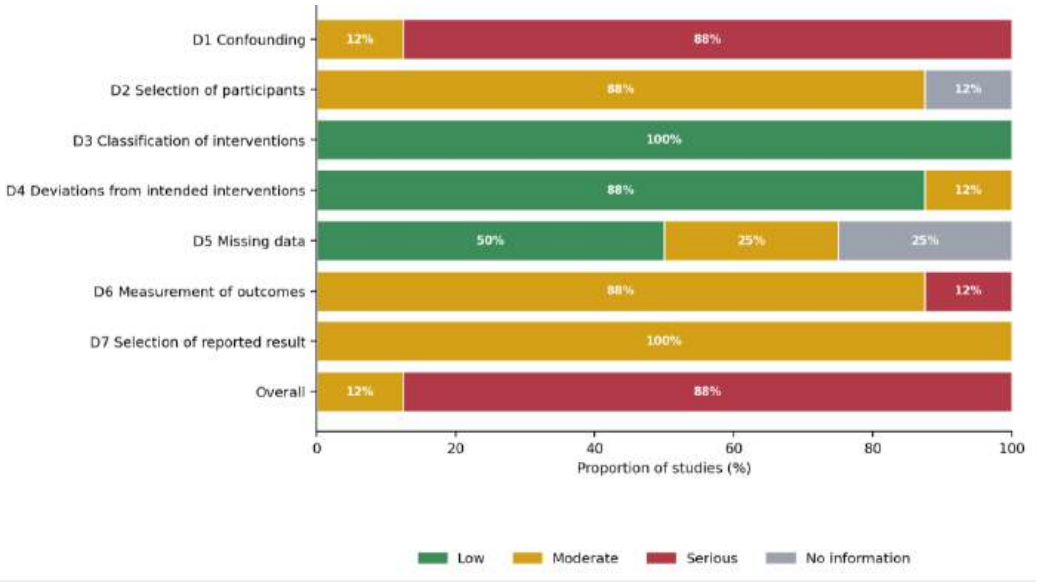


Figure 4. ROBINS-I summary plot.[6]

Non-comparative series (MINORS)

MINORS scores ranged from 7 to 11 of 16 (median 9); six of fourteen series reached the pre-specified threshold of ≥10. Universal weaknesses were the absence of blinded or independent outcome assessment and prospective sample-size calculation; losses to follow-up exceeded 5% in several cohorts (e.g., Kim 2020 excluded 21 of 69 patients; Chen SK 2020 analysed 153 of 183).[7,10,27]

Table 4. MINORS item scores for non-comparative series (0 = not reported, 1 = reported but inadequate, 2 = reported and adequate)[7]

Study	Aim	Consecutive	Prospective	Endpoints	Unbiased assessment	Follow-up	Loss <5%	Sample size	Total /16
Leslie 2011	2	2	0	2	0	2	2	0	10
Rana 2012	2	2	2	2	0	1	2	0	11
Fine 2015	2	2	0	2	0	2	1	0	9
Djordjevic 2019	2	2	2	2	0	2	1	0	11
Chen SK	2	2	0	2	1	1	0	0	8

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2020									
Kim 2020	2	2	0	2	0	2	0	0	8
Kozyrev 2020	2	1	0	2	0	1	1	0	7
Elifranji 2020	2	2	0	1	0	1	2	0	8
Khan 2022	2	2	0	2	0	0	2	0	8
Ladygina 2022	2	2	0	2	0	2	1	0	9
Tawfeeq 2022	2	2	2	2	0	1	2	0	11
Kandil 2023	2	2	2	2	0	1	1	0	10
Hammouda 2024	2	1	0	2	0	2	1	0	8
Ziylan 2025	2	2	0	2	1	2	1	0	10

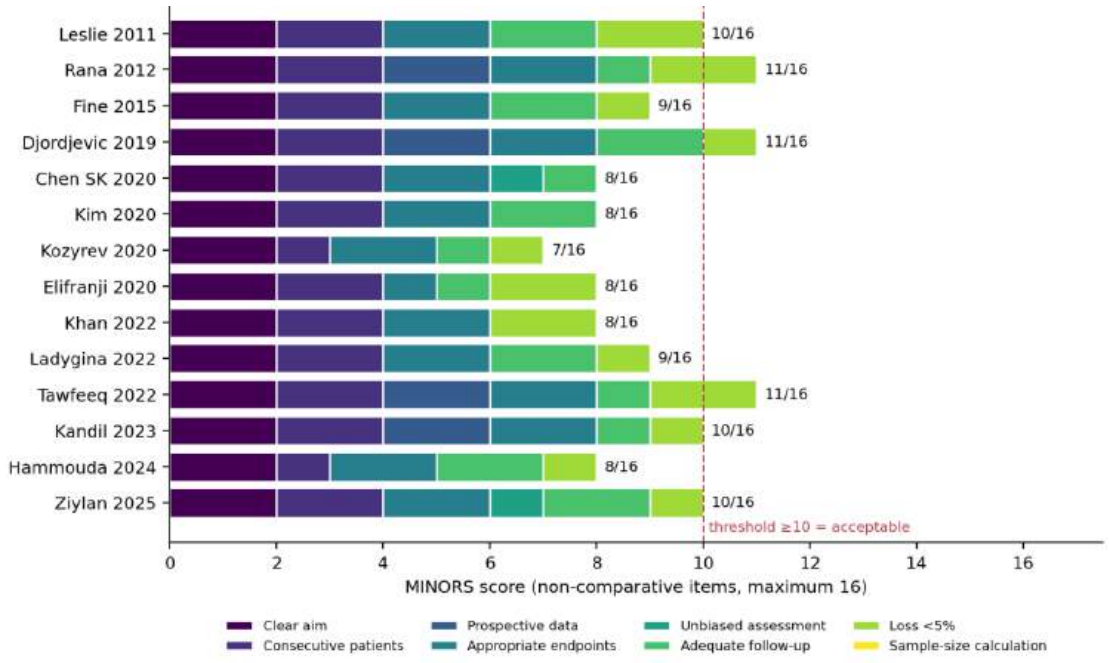


Figure 5. Stacked MINORS item scores for non-comparative series; the dashed line marks the ≥10/16 acceptability threshold.[7]

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Statistical synthesis

Single-arm proportions were logit-transformed (0.5 continuity correction for zero or complete cells) and pooled with DerSimonian–Laird random-effects models; individual study confidence intervals used the Wilson method. Comparative dichotomous outcomes were pooled as risk ratios (RR) on the log scale with the same model. Heterogeneity was quantified with Cochran's Q, I^2 and τ^2, and 95% prediction intervals were computed for $k \geq 3$. Pre-specified subgroup analyses (technique, indication, design) were tested with a between-subgroup Q statistic. Robustness was assessed by leave-one-out analysis, exclusion of the tubularised-graft outlier and of studies with reconstructed denominators, and cumulative meta-analysis by publication year. Random-effects meta-regression examined follow-up duration (log months), publication year and sample size. Small-study effects were assessed visually with funnel plots and statistically with Egger's regression and Begg's rank correlation ($k \geq 10$). Analyses were performed in Python (NumPy/SciPy) with purpose-written, validated code; two-sided $p < 0.05$ denoted significance.[4]

Certainty of evidence

Certainty for each principal outcome was graded with the GRADE approach, starting from "high" for RCT evidence and, when ROBINS-I is used, also from "high" with subsequent downgrading for risk of bias, inconsistency, indirectness, imprecision and publication bias.[31]

RESULTS

Characteristics of included studies

The 26 studies were published between 2011 and 2025 and originated from 12 countries (three did not state the country), most frequently Egypt (n = 6), China, Russia (n = 3 each), Iraq and the United States (n = 2 each). Designs comprised four RCTs, four prospective and four retrospective comparative studies, and fourteen non-comparative series; the BMG arms comprised 1,352 boys. Techniques were staged (Bracka-type) repair (n = 14), single-stage inlay/onlay/patch grafting (n = 8) and free tubularised BMG (n = 2), with two studies reporting mixed or unspecified configurations. Eight studies addressed primary repair, twelve redo repair and six mixed populations.[8–10,19,20,24,27,28,32–49]

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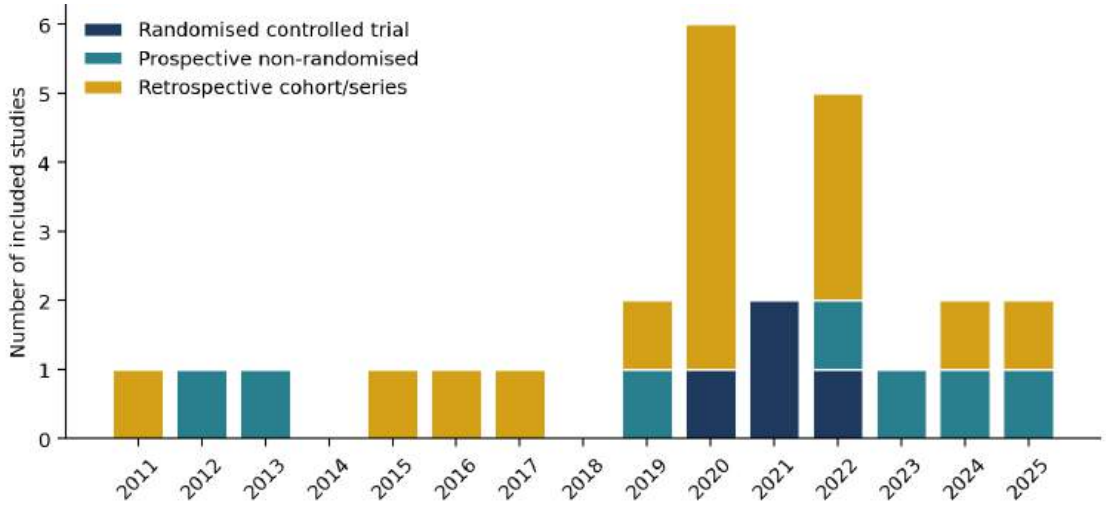


Figure 6. Temporal distribution and design of included studies (2011–2025).

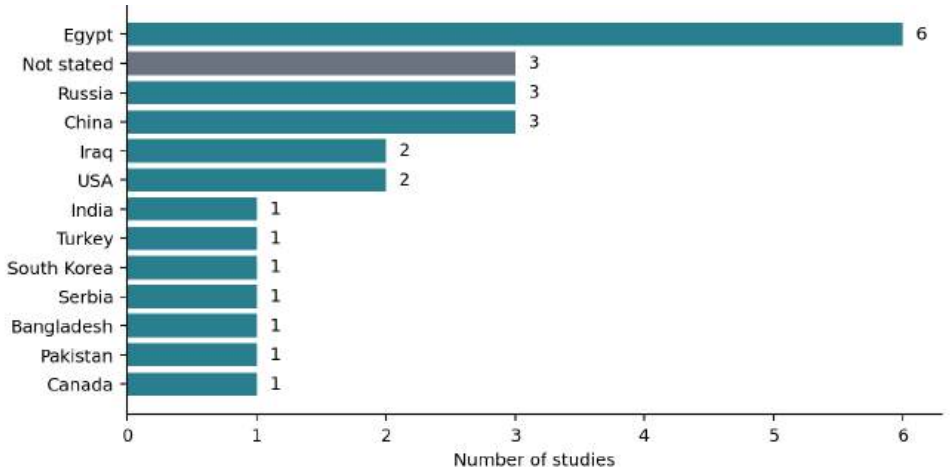


Figure 7. Country of origin of included studies.

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Table 5. Characteristics of the 26 included primary studies[8–10,19,20,24,27,28,32–49]

Study (country)	Design	Sample (BMG; comparator)	Age	Meatus / phenotype	Indication	BMG technique	Donor site	Follow-up
Randomised controlled trials								
Shahid 2020 (Bangladesh)	RCT (lottery randomisation); 2011–2016	189 (BMG 61; dorsal transposition flap 69; flip-flap 59)	2–13 y	Failed repair with large/multiple fistulae	Redo	Staged BMG substitution	Cheek	NR
Aziz 2021 (Egypt)	RCT	40 (BMG 20; modified Koyanagi 20)	NR (paediatric)	Proximal	Primary	Two-stage BMG	Cheek	6–18 mo
Mohammed 2021 (Egypt)	RCT (3 arms)	64 (TIP 20; preputial DIG 21; BMG DIG 23)	NR (paediatric)	Mid/distal penile	Primary	TIP + dorsal inlay BMG	Cheek	6 mo
Elmaadawy 2022	Prospective randomised	50 (BMG 25; preputial	Mean 8.7 mo (BMG) vs 9.5 mo	Proximal/penoscrotal/scrotal/perineal	Primary	Two-stage Bracka	Cheek	NR

(Egypt)	comparative	25)						
Comparative non-randomised studies								
Maarouf 2013 (Egypt)	Prospective comparative	44 (BMG 23; LMG 21)	NR	Complex, scarred skin	Redo	Ventral onlay	Cheek vs tongue	Mean 20.8 mo
Chen SZ 2016 (China)	Retrospective comparative	508 (TIP 198; BMG inlay 150; preputial inlay 160)	Median 1.6 y (1–4)	Distal/moderate	Primary	Dorsal inlay (grafted TIP)	Cheek	Mean 18 mo
Jin 2017 (China)	Retrospective comparative	62 (BMG 29; LMG 33)	4–9.2 y (BMG)	Multiply failed	Redo (2–3 prior)	One-stage inlay	Cheek vs tongue	5–12 mo
Manasherova 2019 (Russia)	Retrospective comparative (historical control)	220 (BMG 112; preputial 108)	Children	Proximal	Primary	Two-stage Bracka	Cheek	NR
Loloi 2020 (USA)	Retrospective comparative	47 (BMG 19; preputial 28)	16 mo (primary); 110 mo (redo)	Unfavourable glans	Mixed	Dorsal inlay (ingraft)	Cheek	Up to 10 y
Shebl 2022 (Egypt)	Retrospective comparative	28 (BMG 15; skin 13)	NR	Complex	Mixed	Two-stage	Cheek	Median 14 mo
IPMJ 2024	Prospective	18 (oral	Mean 9.7 y (BMG)	Proximal	Mixed (6	Two-stage	Oral	6 mo per

(Iraq)	comparative	mucosa 8; inner preputial 10)			primary, 2 redo)			stage
Yekolla 2025 (India)	Comparative cohort	21 (BMG 11; skin 10)	NR	Multiply failed	Redo	Two-stage	Cheek	NR
Non-comparative cohorts and series								
Leslie 2011 (Canada)	Retrospective cohort	30 patients / 32 repairs	Mean 7 y (1–17)	Proximal 44%, mid 39%, distal 16%	Redo (9 BXO)	Staged BMG	Cheek	Mean 25 mo
Rana 2012 (NR)	Prospective cohort	21	Mean 6.6 y (2–15)	Penile	Primary	TIP + BMG + double dartos	Cheek	Mean 8.4 mo
Fine 2015 (USA)	Retrospective cohort	37 (34 with >1 y FU)	NR	Proximal	Primary (staged shaft)	Tunnelled BMG tube	Cheek	>12 mo
Djordjevic 2019 (Serbia)	Prospective series	35	10–22 mo	Scrotal with severe chordee	Primary	One-stage ‘watch’ BMG + dorsal flap	Cheek	10–63 mo (mean 29)
Chen SK 2020 (China)	Retrospective cohort	153 (of 183 treated)	≤1.5 y; prepubertal; pubertal	Proximal	Mixed	Modified staged BMG	Cheek	NR

Kim 2020 (Korea)	Retrospective cohort	48 (of 69)	Mean 9.0 y	Failed hypospadias	Redo (mean 1.9 prior)	Free BMG tube	Cheek	Mean 73.1 mo
Kozyrev 2020 (Russia)	Retrospective cohort	126	Children	Proximal	Mixed	Staged Bracka	Cheek	Near/long term
Elifranji 2020 (NR)	Retrospective series	24 patients / 25 harvests	Children	Redo urethroplasty	Redo	Upper-lip graft	Upper lip	≥2 mo
Khan 2022 (Pakistan)	Retrospective cohort	60	Mean 6.6 ± 7.5 y	NR	Mixed	Two-stage BMG	Cheek	6 wk
Ladygina 2022 (Russia)	Retrospective cohort	34	Children/adolescents	Post-hypospadias stricture (LS 16)	Redo	Two-stage BMG	Cheek	Mean 16 mo
Tawfeeq 2022 (Iraq)	Prospective series	10	5–12 y	Recurrent fistula	Redo	BMG patch + dartos	Cheek	6 mo
Kandil 2023 (NR)	Prospective series	60	Children	Failed penile	Redo	Two-stage Bracka	Cheek	NR
Hammouda 2024 (Egypt)	Retrospective cohort	164 (BMG 96: staged 80, DIGU 16)	Mean 91.3 mo	Failed repairs	Redo	Staged BMG / DIGU	Cheek	Mean 41.3 mo
Ziylan 2025	Retrospective	122	Children	Mid-penile to perineal	Redo	Two-stage	Lower	Median

(Turkey)	cohort				(median 2 prior)		lip 64%, cheek+lip 17%, cheek 12%, upper lip 7%	121 mo

BMG, buccal mucosal graft; BXO, balanitis xerotica obliterans; DIG(U), dorsal inlay graft (urethroplasty); FU, follow-up; LMG, lingual mucosal graft; LS, lichen sclerosus; NR, not reported in the accessible record; TIP, tubularised incised plate. Country is reported where stated in the record or unambiguous from the institution.

Table 6. Extracted outcome data for BMG arms (events/N, %)

Study	Composite adverse outcome	Fistula	Meatal stenosis	Stricture	Glans dehiscence	Residual curvature	Re-intervention	Donor-site morbidity	Other key findings
Leslie 2011	11/32 (34.4)	3/32	—	5/32	3/32	—	4/32 regrafting	0/30	Graft fibrosis/induration → 82% vs 19% complications (p<0.001)
Rana 2012	5/21 (minor)	0/21	1/21	—	—	2/21 (<30°)	1/21	—	Success 95%; wound infection 2/21
Maarouf	5/23 failure	—	—	—	—	—	—	Tightness/numbness	Success 78.2% vs

2013								(BMG only)	76.1% LMG
Fine 2015	11/34 (32.4)	5/34	2/34	4/34	—	—	—	—	70% complications first 10 vs 16% next 24
Chen SZ 2016	9/150 (6.0)	5/150	4/150	—	—	—	—	—	Preputial inlay 12/160; TIP 12/198
Jin 2017	5/29 (17.2)	2/29	—	2/29	—	1/29	—	—	HOSE 14.28 ± 1.03; Qmax 9.2 mL/s
Manasherova 2019	23/112 (20.5)	reported	—	—	—	—	—	—	Preputial 33/108 (31%); better HOPE with BMG
Djordjevic 2019	5/35 (14.3)	3/35	2/35	—	—	0/35	5/35 minor	—	Satisfactory 30/35 (86%)
Shahid 2020	NR (fewer re-fistulae with BMG, p<0.05)	—	—	—	—	—	—	—	Objective score gain 182 vs 112 vs 89
Chen SK 2020	36/153 (23.5)	—	—	—	—	—	—	—	HOSE 16 in 76%; prior surgery predicts complication

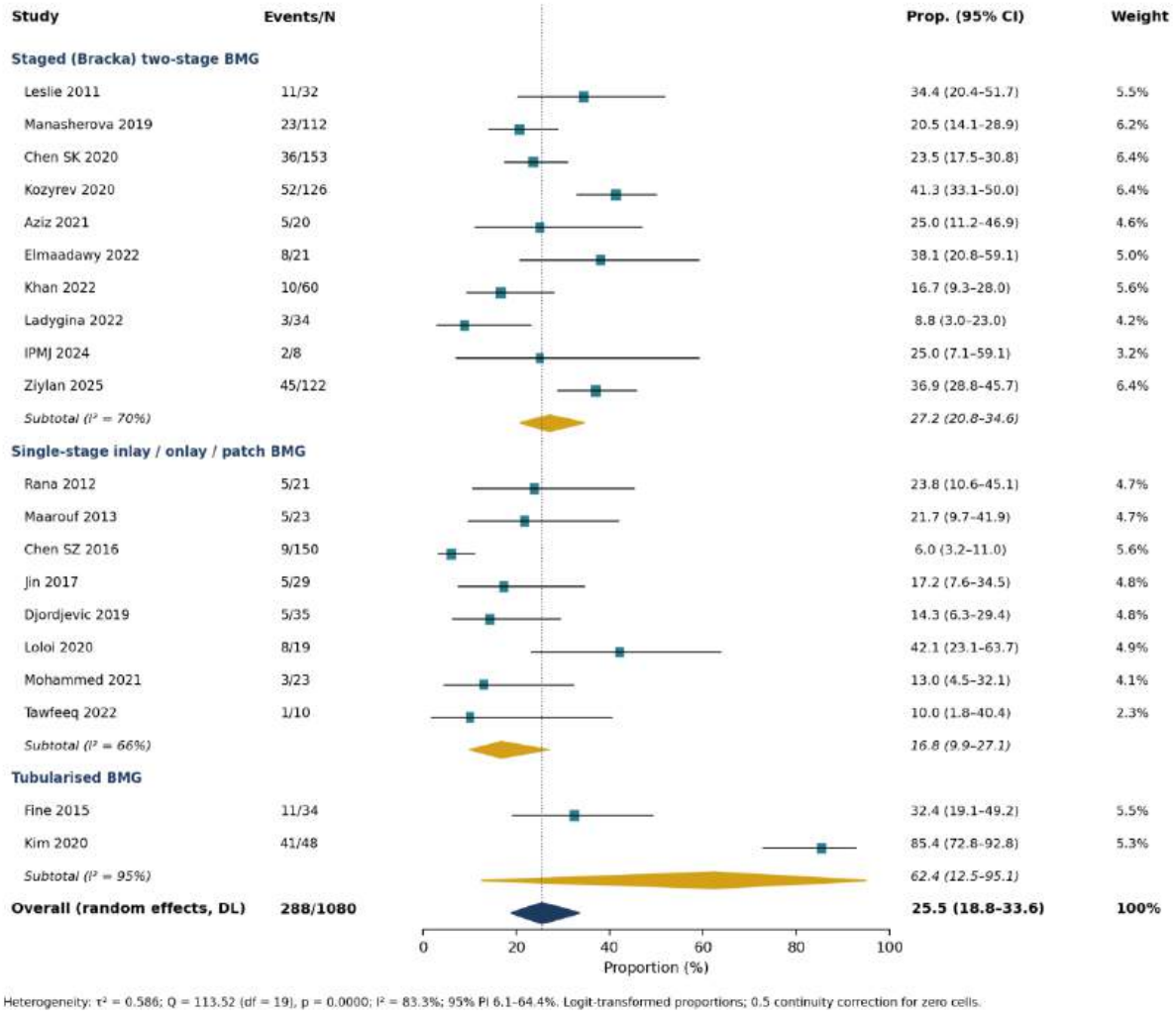
									(p=0.016)
Kim 2020	41/48 (85.4)	—	—	37/48	—	—	41/48	—	Stricture-free 50%, 35.4%, 27% at 1, 3, 12 mo
Loloi 2020	8/19 (42.1)	—	—	—	—	—	—	—	Primary 6/10 vs redo 2/9; preputial 6/28
Kozyrev 2020	≈52/126 (41)*	main complication	—	—	—	—	—	—	Good 51%, satisfactory 9%
Elifranji 2020	—	—	—	—	—	—	—	1/25 early pain; 0/24 persistent	No numbness, trismus or contracture
Aziz 2021	5/20 failure	2/20	8/20	2/20	—	1/20	—	—	MK arm: failure 8/20, fistula 6/20
Mohammed 2021	3/23 failure*	—	—	—	—	—	—	—	Success 87% vs 85% TIP vs 91.5% preputial
Elmaadawy 2022	≈8/21 failure*	—	—	—	—	—	—	—	Success 62% vs 54.5% preputial
Shebl 2022	—	lower (NS)	0/15	0/15	—	—	0/15	Lower than skin (p=0.003)	Skin: stenosis 4/13, stricture 4/13
Khan 2022	10/60 (16.7)	reported	—	—	—	—	—	—	Success 53/60

									(88.3%)
Ladygina 2022	3/34 (8.8)	2/34	—	—	—	—	—	—	Graft scarring 1/34; LS in 16/34
Tawfeeq 2022	1/10 (10.0)	1/10 recurrence	—	—	—	—	—	0/10	Fistula healed 9/10
Kandil 2023	NR (high success, low complications)	—	—	—	—	—	—	—	Good cosmetic appearance
IPMJ 2024	2/8 (25.0)	1/8	—	—	1/8	—	—	—	Preputial 2/10; graft take 100%
Hammouda 2024	NR	—	—	—	—	—	—	—	Staged BMG for proximal redo after ≥2 failures
Yekolla 2025	—	0/11	1/11	0/11	—	—	—	Lower than skin	Graft loss 0/11 vs 2/10
Ziylan 2025	45/122 (36.8)	13/122	13/122	2/122	15/122	8/122	29/122	—	~90% acceptable HOSE/PPS; graft contracture 3/122

*Back-calculated from reported percentages; Elmaadawy 2022 denominators reconstructed (13/21 = 61.9% BMG; 12/22 = 54.5% preputial) and tested in sensitivity analysis. Mohammed 2021 preputial-arm success (91.5% of 21) cannot be reproduced by an integer count and was therefore excluded from comparative pooling. HOPE, Hypospadias Objective Penile Evaluation; HOSE, Hypospadias Objective Scoring Evaluation; MK, modified Koyanagi; NS, not significant; PPS, Penile Perception Score.

Primary outcome: composite adverse outcome and primary success

Twenty studies (1,080 BMG repairs; 288 events) contributed to the primary analysis. The pooled composite adverse-outcome rate was 25.5% (95% CI 18.8–33.6), with substantial heterogeneity (I^2 = 83.3%; τ^2 = 0.586; $p < 0.001$) and a 95% prediction interval of 6.1–64.4%. The corresponding pooled primary success rate was 74.5% (95% CI 66.4–81.2), supporting hypothesis H1. Individual estimates ranged from 6.0% after dorsal inlay BMG in primary distal hypospadias to 85.4% after free BMG tube grafting in redo cases.[10,34]

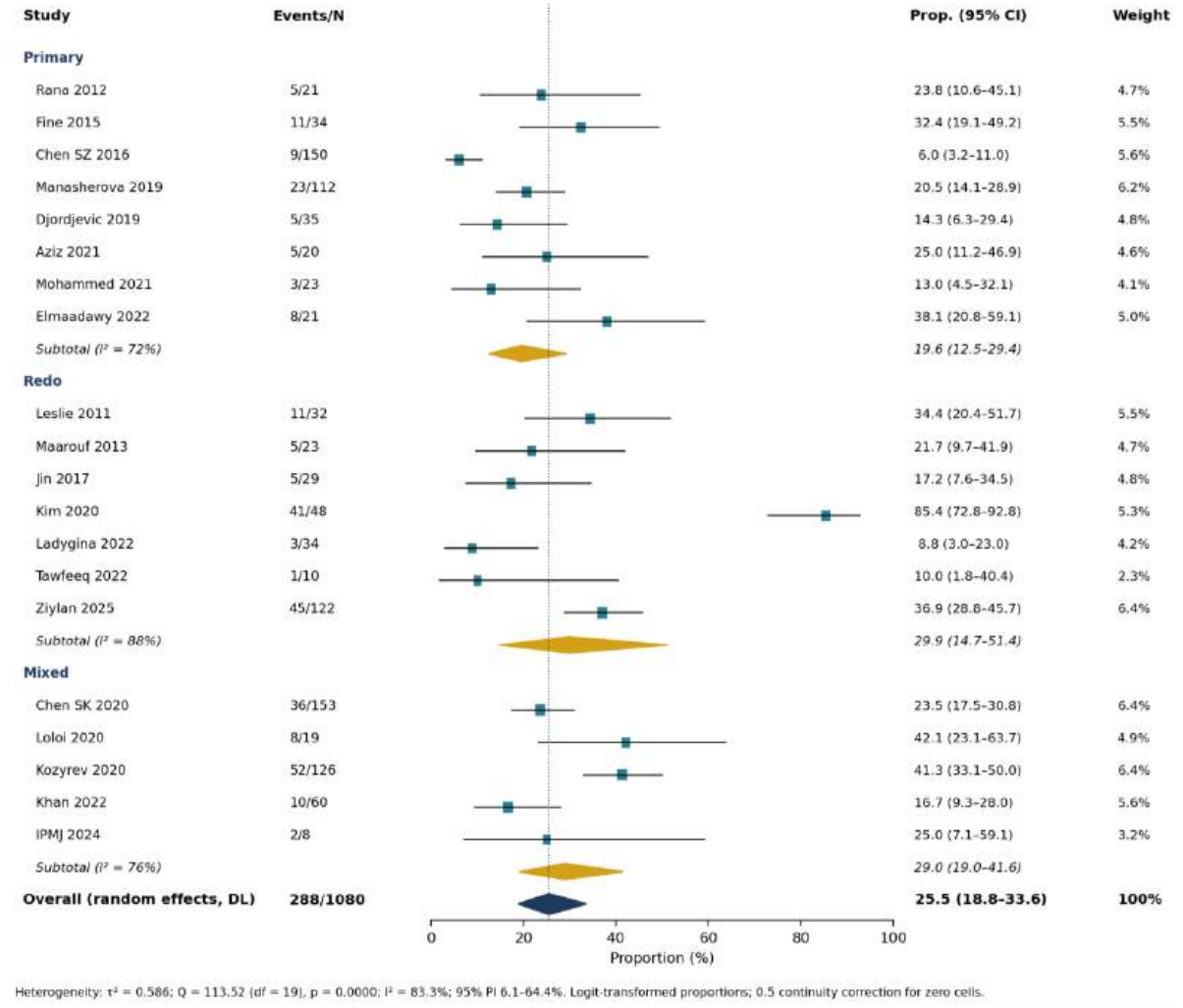


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Figure 8. Forest plot of the composite adverse outcome after BMG urethroplasty, stratified by technique (random-effects, DerSimonian–Laird; logit transformation). Square size is proportional to study weight; diamonds represent subgroup and overall pooled estimates.[8–10,19,20,24,27,32–36,38–41,43–45,47]

Excluding the tubularised-graft outlier (Kim 2020) reduced the pooled estimate to 23.0% (95% CI 17.8–29.3) and heterogeneity to I^2 = 73.8%, identifying this study as the single largest contributor to between-study variance.[10]

Stratification by indication showed a lower composite rate for primary than for redo repairs.



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Figure 9. Forest plot of the composite adverse outcome stratified by indication (primary, redo, mixed).

Secondary outcomes

Table 7. Pooled single-arm estimates for BMG urethroplasty in children (random-effects)

Outcome	k	Events/N	Pooled % (95% CI)	I^2 (%)	τ^2	p (Q)	95% PI (%)
Composite adverse outcome	20	288/1080	25.5 (18.8–33.6)	83.3	0.586	<0.001	6.1–64.4
Composite (excluding Kim 2020)	19	247/1032	23.0 (17.8–29.3)	73.8	0.327	<0.001	7.9–51.3
Primary success	20	792/1080	74.5 (66.4–81.2)	83.3	0.586	<0.001	35.6–93.9
Urethrocutaneous fistula	12	37/506	8.4 (6.2–11.4)	0.0	0.000	0.623	5.9–11.9
Meatal stenosis	8	31/408	8.1 (3.6–17.2)	72.8	0.961	<0.001	0.6–55.0
Urethral stricture (all)	8	52/311	10.7 (2.6–34.9)	91.1	3.995	<0.001	0.1–95.7
Urethral stricture (excluding Kim 2020)	7	15/263	7.6 (4.0–14.0)	35.1	0.283	0.160	1.6–29.6
Glans dehiscence	3	19/162	11.8 (7.6–17.7)	0.0	0.000	0.899	0.6–74.9
Residual/recurrent curvature	5	12/227	6.1 (3.5–10.3)	0.0	0.000	0.735	2.5–14.1
Unplanned re-intervention (all)	6	80/273	20.3 (6.1–49.8)	91.5	2.394	<0.001	0.2–96.6
Re-intervention	5	39/225	14.8 (8.3–	45.4	0.226	0.120	2.7–

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(excluding Kim 2020)			24.9)				52.3
Persistent donor-site morbidity	2	0/54	1.8 (0.3–11.7)	0.0	0.000	0.914	—

CI, confidence interval; PI, prediction interval; k, number of studies. Zero-event cells handled with a 0.5 continuity correction on the logit scale.

Urethrocutaneous fistula

Twelve studies (506 repairs, 37 fistulae) yielded a pooled fistula rate of 8.4% (95% CI 6.2–11.4) with no detectable heterogeneity (I^2 = 0%; 95% PI 5.9–11.9%), making fistula the most consistent outcome across techniques, indications and continents. Rates ranged from 0% after TIP with BMG and double dartos cover and after staged redo repair to 14.7% after tunnelled tube grafting early in a learning curve.[9,19,20,24,32,34,36,39,44,45,47,49]

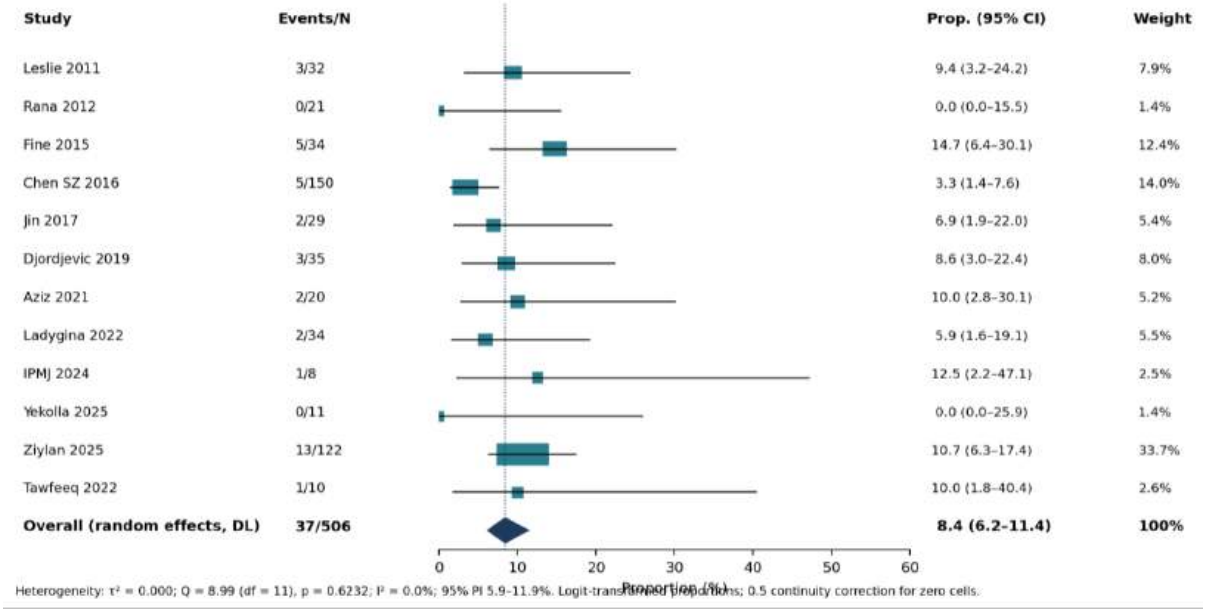


Figure 10. Forest plot of urethrocutaneous fistula after BMG urethroplasty.

Meatal stenosis and urethral stricture

Meatal stenosis was pooled at 8.1% (95% CI 3.6–17.2) (k = 8; I^2 = 72.8%), with the highest value (40%) in the staged arm of the Aziz RCT. Urethral stricture was pooled at 10.7% (95% CI 2.6–34.9) across all eight studies but was dominated by the 77% stricture incidence after free tube

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grafting; after its exclusion the estimate was 7.6% (95% CI 4.0–14.0) with moderate heterogeneity (I^2 = 35.1%. In Kim 2020, stricture-free survival fell to 50%, 35.4% and 27% at 1, 3 and 12 months, although 25 of 37 strictures were managed endoscopically and 95.8% of patients ultimately voided normally.[9,10,19,20,24,39,42,49]

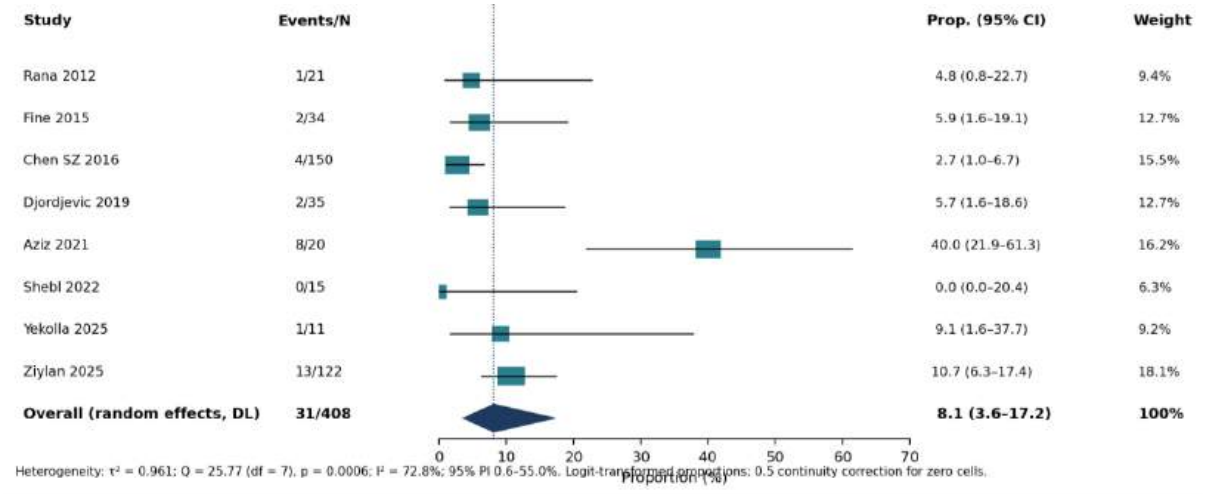


Figure 11. Forest plot of meatal stenosis after BMG urethroplasty.

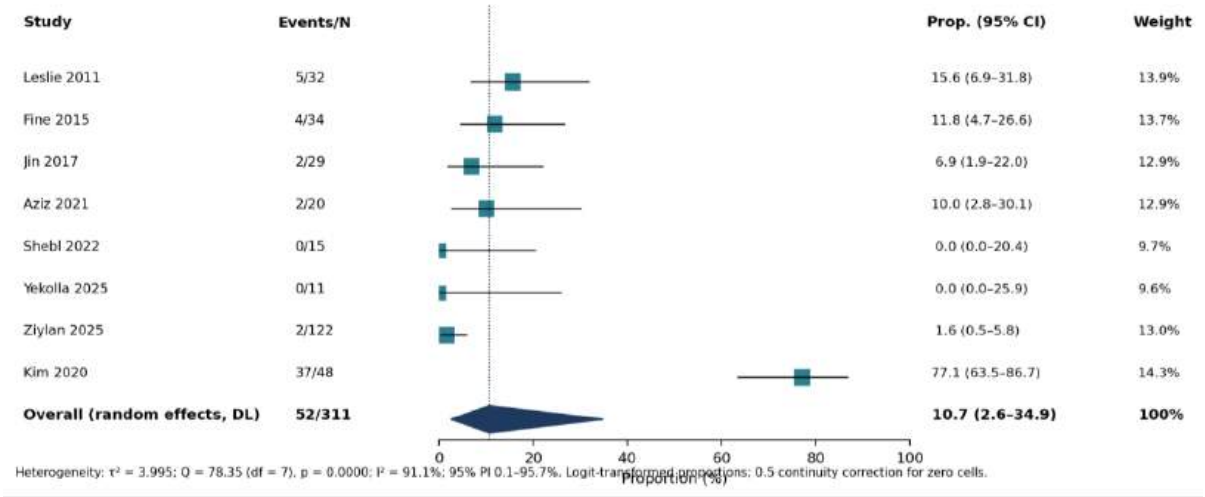


Figure 12. Forest plot of urethral stricture/neourethral stenosis after BMG urethroplasty (the tubularised-graft series of Kim 2020 is the principal source of heterogeneity).[10]

Glans dehiscence, residual curvature and re-intervention

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Glans dehiscence was pooled at 11.8% (95% CI 7.6–17.7) (k = 3; I^2 = 0%), largely reflecting the long-term Ziylan cohort in which it was the most frequent complication (12.3%). Residual or recurrent curvature was uncommon at 6.1% (95% CI 3.5–10.3) (k = 5; I^2 = 0%). Unplanned re-intervention occurred in 14.8% (95% CI 8.3–24.9) of repairs after excluding the tube-graft series (k = 5; I^2 = 45.4%); in Ziylan 2025, the median interval from second-stage repair to re-intervention was 10 months (range 4–30), and Leslie 2011 found that graft fibrosis or induration after the first stage predicted second-stage complications (82% vs 19%; p < 0.001).[9,19,24,32,36,39]

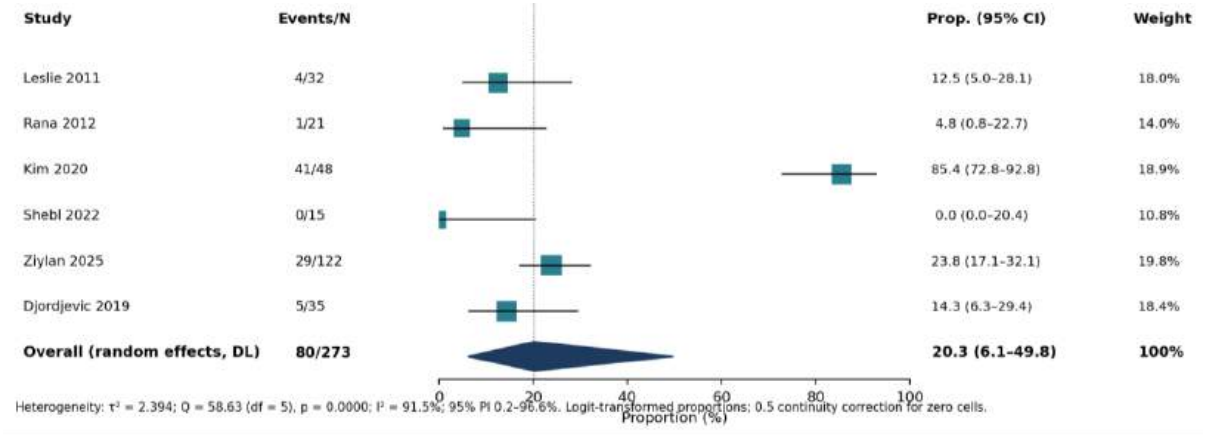


Figure 13. Forest plot of unplanned re-intervention after BMG urethroplasty.

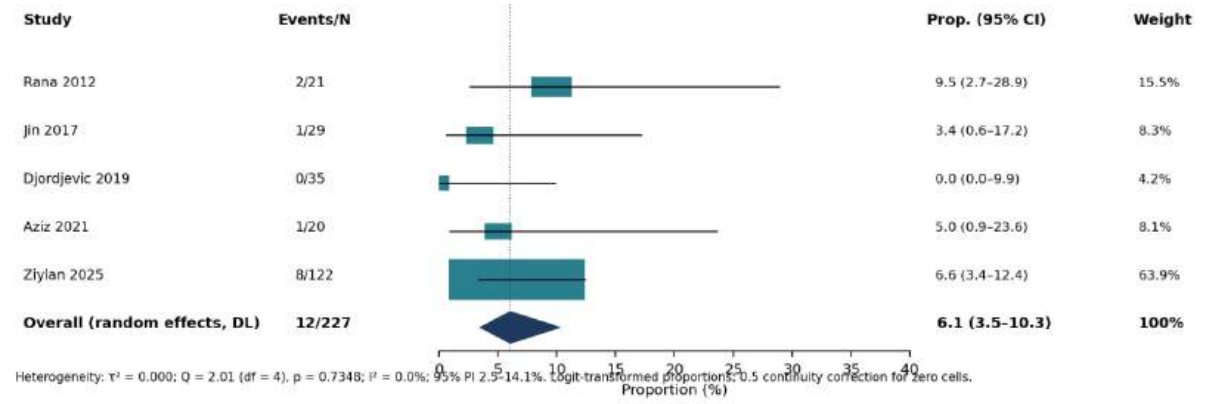


Figure 14. Forest plot of residual or recurrent penile curvature.

Comparative analyses

BMG versus preputial/skin grafts

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Five studies (310 BMG vs 328 preputial/skin grafts) reported composite complications. The pooled RR 0.88 (95% CI 0.61–1.26) (p = 0.475; I^2 = 14.2%) did not demonstrate a significant difference, so hypothesis H2 was not confirmed for the composite endpoint. The point estimate was driven by Manasherova 2019 (42.3% weight; RR 0.67, 0.42–1.07); after its exclusion the RR was 1.06 (0.68–1.65), and after excluding the reconstructed Elmaadawy data it was 0.94 (0.56–1.57). Loloi 2020, in which BMG was preferentially used for primary repairs with unfavourable glans and for redo cases, showed the opposite direction (RR 1.96, 0.81–4.76), consistent with confounding by indication.[8,34,35,41,47]

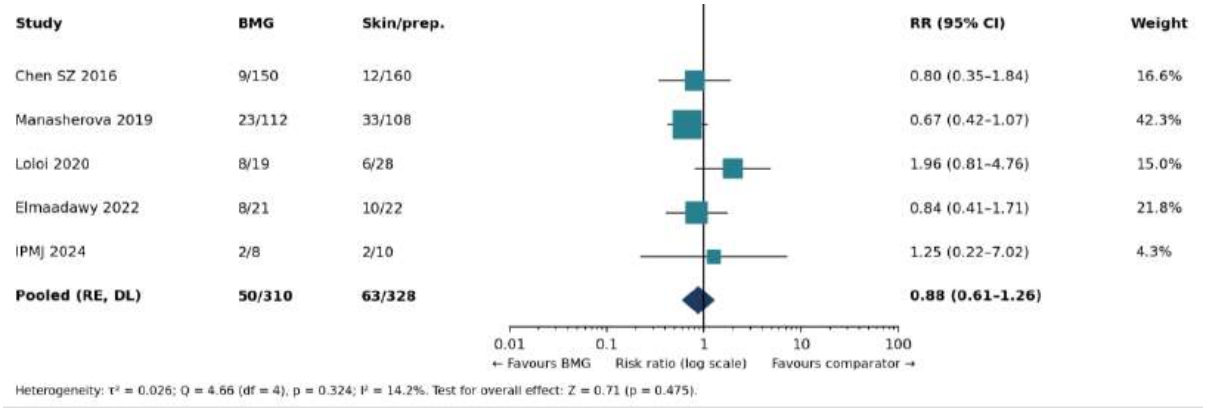


Figure 15. Forest plot of composite complications, BMG versus preputial/skin graft (risk ratio, random effects).

For fistula, the pooled RR 1.07 (95% CI 0.37–3.09) (k = 3; I^2 = 0%) was null (Figure 18A). For meatal stenosis or stricture, BMG showed a non-significant 54% relative reduction (RR 0.46 (95% CI 0.17–1.24); p = 0.125; I^2 = 0%), directionally consistent with Shebl 2022 (0% vs 30.8% for both meatal stenosis and stricture; p = 0.02) and with the lower incidence of graft loss (0% vs 20%) reported by Yekolla 2025. Donor-site morbidity was significantly lower with BMG than with extragenital skin harvest in Shebl 2022 (p = 0.003).[34,42,47,49]

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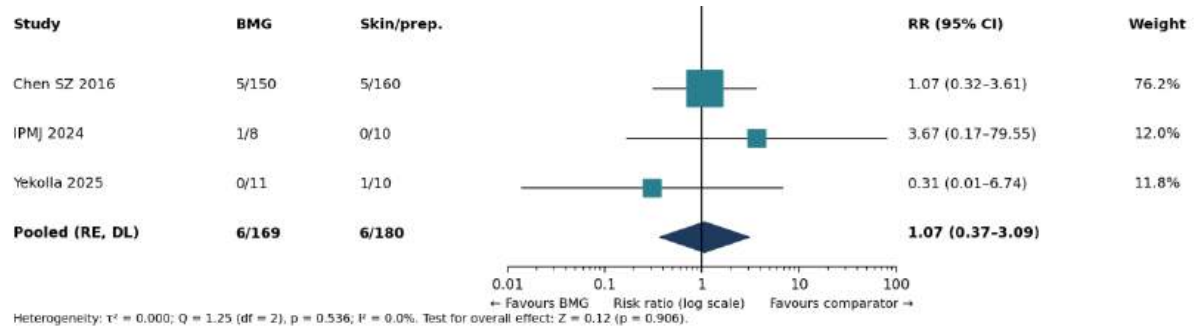


Figure 16. Forest plot of fistula, BMG versus preputial/skin graft.

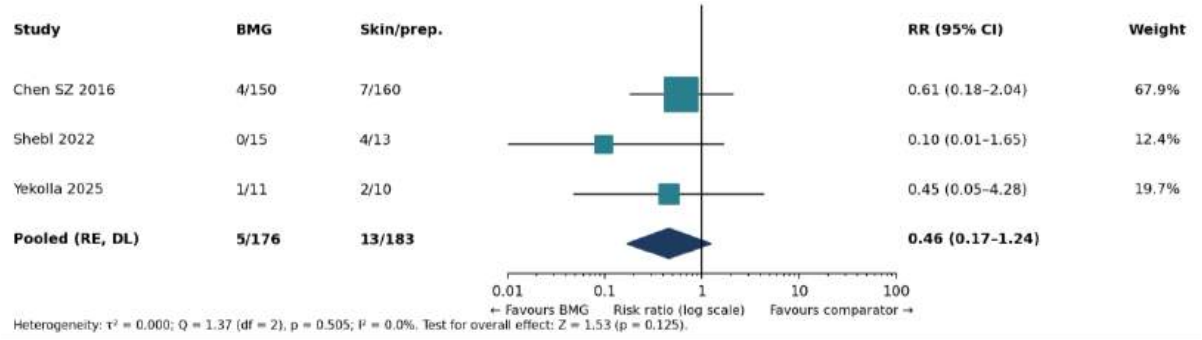
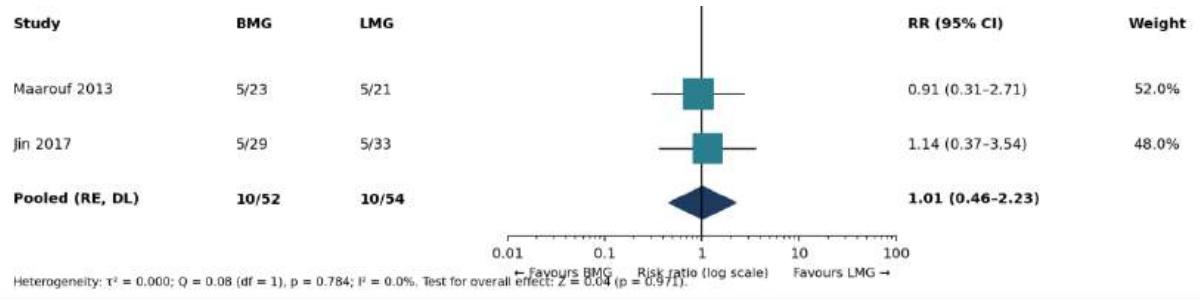


Figure 17. Forest plot of meatal stenosis/stricture, BMG versus preputial/skin graft.

Buccal versus lingual mucosal grafts

Two comparative studies in children with failed hypospadias (52 BMG vs 54 LMG) showed equivalent urethroplasty failure (RR 1.01 (95% CI 0.46–2.23); $I^2 = 0\%$), supporting H3. Functional (Qmax 9.2 vs 9.3 mL/s) and cosmetic (HOSE 14.28 vs 14.34) outcomes were also comparable. Donor-site profiles differed qualitatively: mouth tightness, perioral numbness and persistent oral discomfort occurred only after buccal harvest, whereas slurred speech and difficult tongue protrusion occurred only after lingual harvest, with faster recovery after LMG.[24,33]



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Figure 18. Forest plot of urethroplasty failure, buccal versus lingual mucosal graft.

Two-stage BMG versus one-stage flap repair and TIP

In the only RCT comparing two-stage BMG with the modified Koyanagi one-stage flap for proximal hypospadias (n = 20 per arm), success was 75% vs 60% (RR for failure 0.63, 0.25–1.58), fistula was less frequent with BMG (2 vs 6; RR 0.33, 0.08–1.46) whereas meatal stenosis was more frequent (8 vs 2; RR 4.00, 0.97–16.55); none of these differences reached significance. In the three-arm RCT of mid/distal hypospadias, TIP with dorsal inlay BMG achieved 87% success versus 85% for TIP alone, without significant differences in complications. In the Bangladeshi RCT of redo repair for large or multiple fistulae, BMG substitution yielded significantly fewer re-fistulae, less devascularisation and dehiscence, and higher objective score gains than dorsal transposition or flip-flap repair.[37,39,40,50]

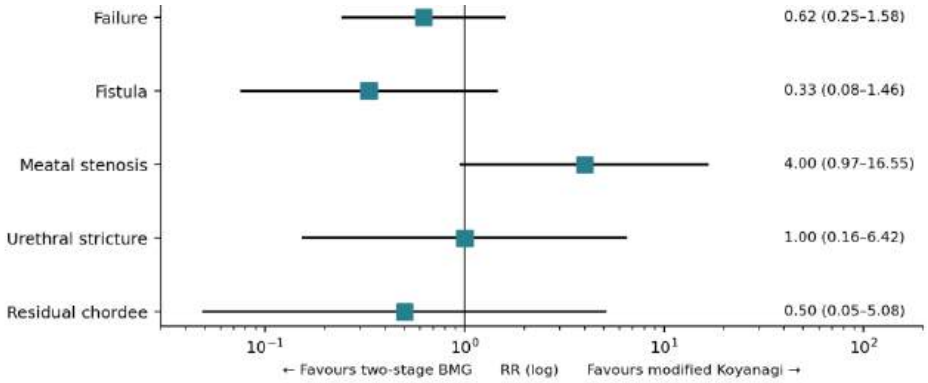


Figure 19. Outcome-specific risk ratios from the Aziz 2021 RCT (two-stage BMG vs modified Koyanagi).[39]

Table 8. Summary of comparative meta-analyses

Comparison / outcome	k	BMG events/N	Comparator events/N	RR (95% CI)	p	I^2 (%)
BMG vs skin/preputial — composite	5	50/310	63/328	0.88 (0.61–1.26)	0.475	14.2
sensitivity: excluding Manasherova 2019	4	27/198	30/220	1.06 (0.68–1.65)	0.813	0.0

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sensitivity: excluding Elmaadawy 2022	4	42/289	53/306	0.94 (0.56–1.57)	0.816	35.6
BMG vs skin/preputial — fistula	3	6/169	6/180	1.07 (0.37–3.09)	0.906	0.0
BMG vs skin/preputial — meatal stenosis/stricture	3	5/176	13/183	0.46 (0.17–1.24)	0.125	0.0
BMG vs lingual — failure	2	10/52	10/54	1.01 (0.46–2.23)	0.971	0.0
Two-stage BMG vs modified Koyanagi — failure (single RCT)	1	5/20	8/20	0.63 (0.25–1.58)	0.32	—

Small-study effects and publication bias

The funnel plot for the composite outcome was visually symmetrical, with the outlying tube-graft series lying outside the pseudo-95% limits. Neither Egger's regression (intercept -1.30, SE 1.24; $p = 0.311$) nor Begg's test (Kendall $\tau = -0.11$; $p = 0.542$) indicated small-study effects. The fistula funnel was likewise symmetrical (Egger $p = 0.385$). The five-study comparative funnel is shown for completeness but is underpowered for formal testing.[10]

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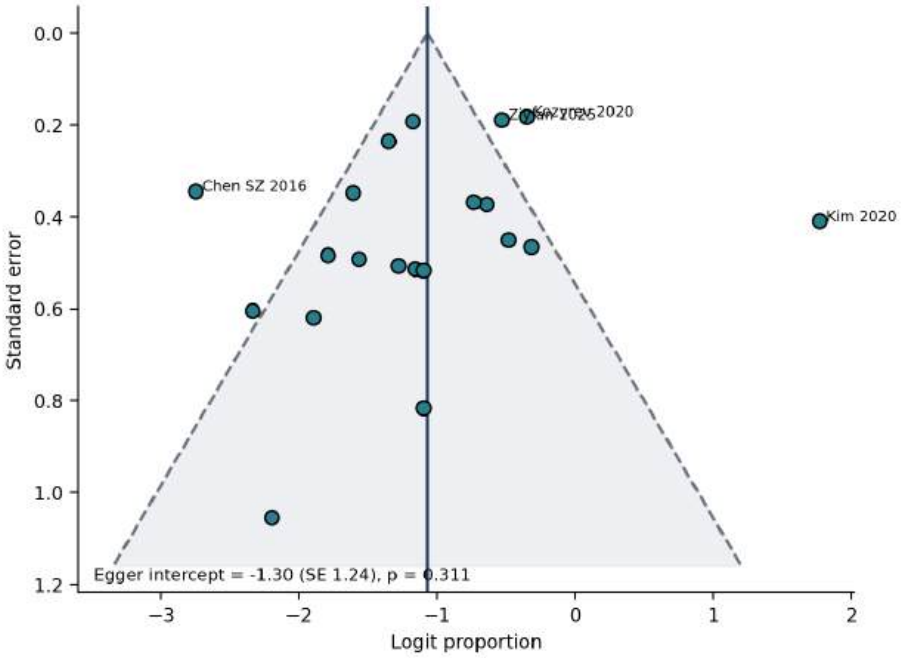


Figure 20. Funnel plot with pseudo-95% confidence limits for the composite adverse outcome.

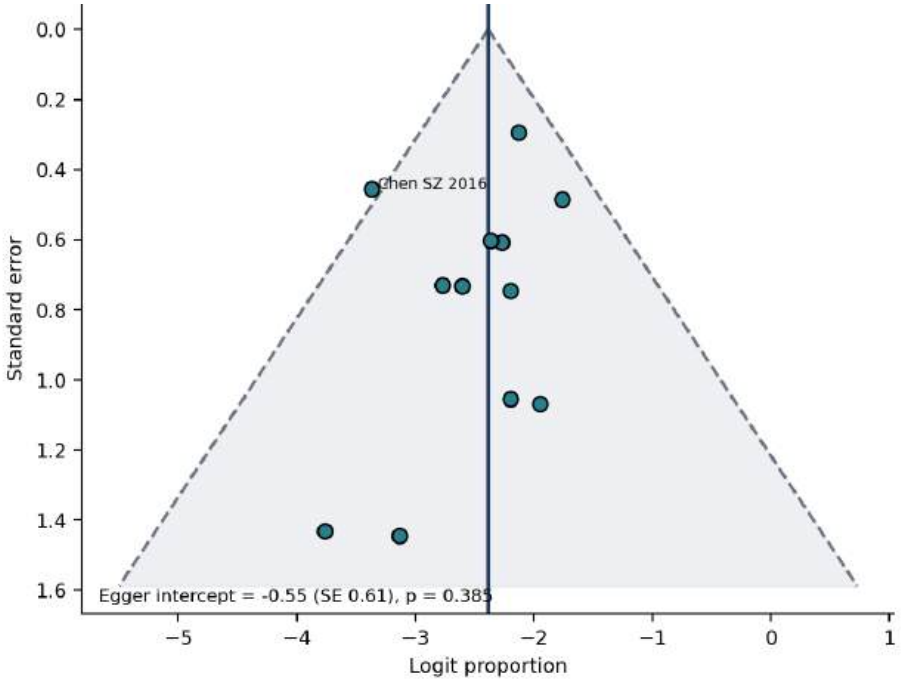


Figure 21. Funnel plot for urethrocutaneous fistula.

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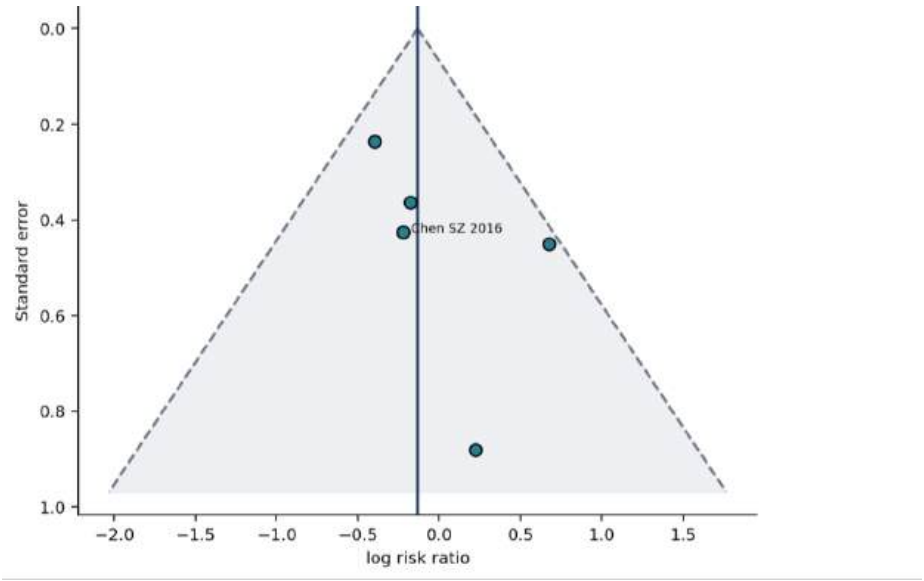


Figure 22. Funnel plot for the BMG-versus-skin comparison (composite complications).

Sensitivity analyses, cumulative meta-analysis and meta-regression

Leave-one-out analysis showed a stable composite estimate ranging from 23.0% (omitting Kim 2020) to 27.7% (omitting Chen SZ 2016); no single study altered the inference. The cumulative meta-analysis stabilised after 2020 at 25–28%, with progressively narrowing confidence intervals, suggesting that additional small series are unlikely to change the pooled estimate materially.[10,34]

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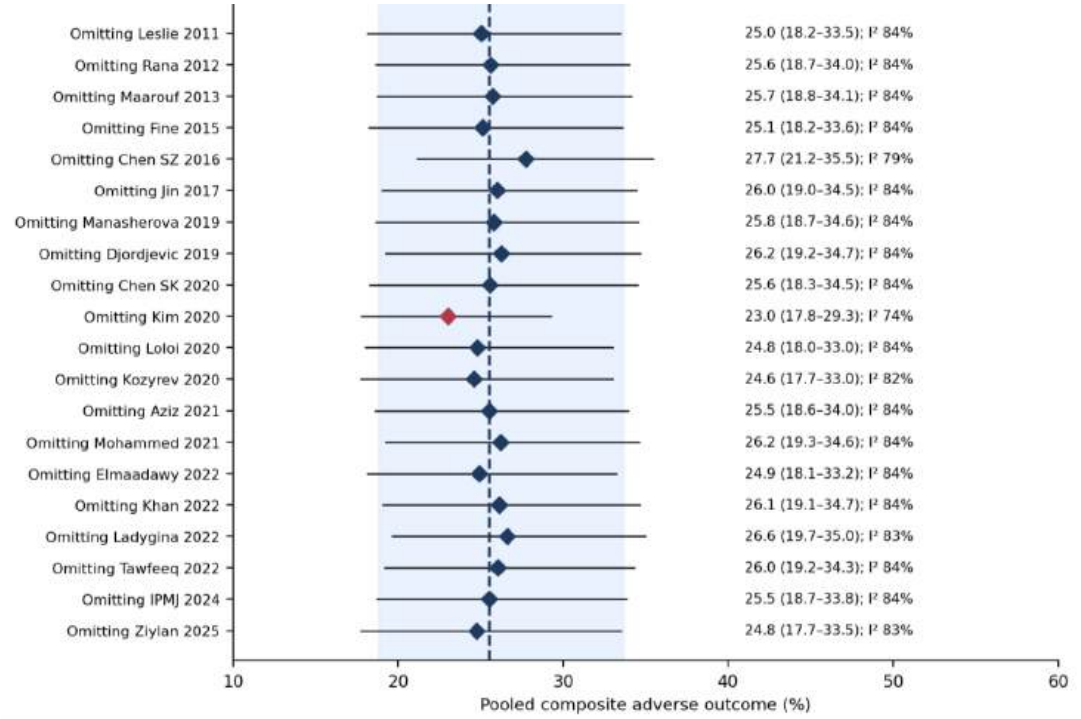


Figure 23. Leave-one-out sensitivity analysis of the composite adverse outcome (shaded band: overall 95% CI).

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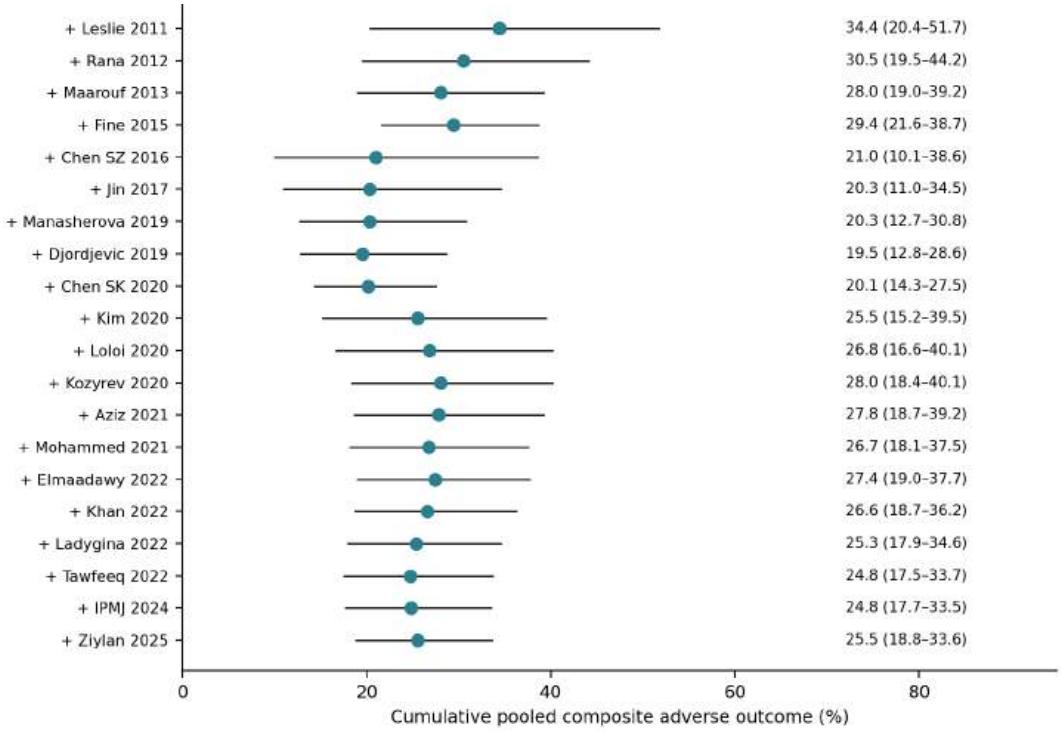


Figure 24. Cumulative random-effects meta-analysis ordered by year of publication.

In random-effects meta-regression (16 studies reporting follow-up), each unit increase in log follow-up months was associated with a higher logit composite rate (slope 0.48, SE 0.25; $p = 0.051$; $R^2 = 12\%$), a borderline association indicating that complications continue to accrue with longer surveillance. Neither publication year ($p = 0.72$) nor study size ($p = 0.94$) explained heterogeneity.

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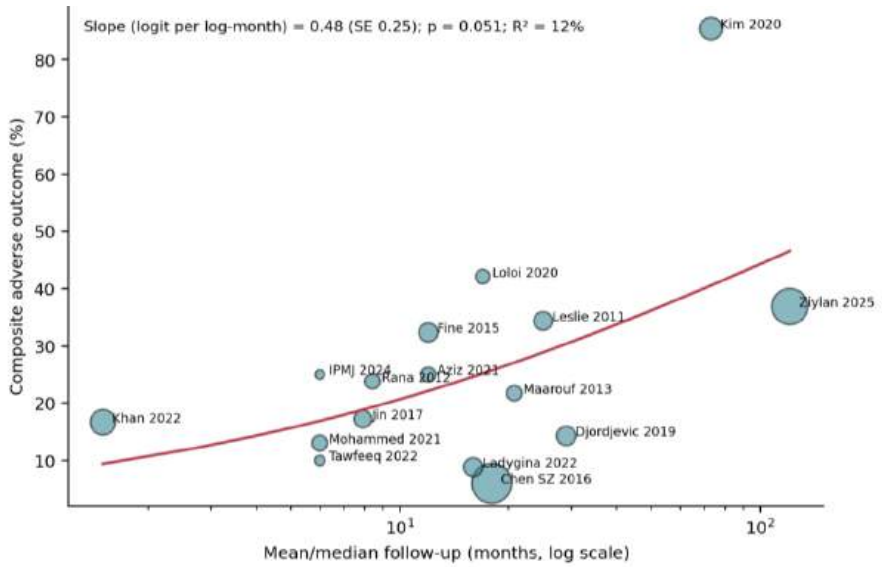


Figure 25. Bubble plot of random-effects meta-regression of the composite adverse outcome on follow-up duration (bubble area proportional to sample size).

Table 9. Sensitivity analyses

Analysis	**k**	**Pooled estimate (95% CI)**	**I^2 (%)**	**Interpretation**
Primary analysis (composite)	20	25.5% (18.8–33.6)	83.3	Reference
Excluding tubularised BMG (Kim 2020)	19	23.0% (17.8–29.3)	73.8	Largest single influence; heterogeneity reduced
Leave-one-out range	19	23.0–27.7%	74–84	Robust
Stricture excluding Kim 2020	7	7.6% (4.0–14.0)	35.1	Heterogeneity largely explained
BMG vs skin, excluding historical-control study	4	RR 1.06 (0.68–1.65)	0.0	No difference persists
BMG vs skin, excluding	4	RR 0.94 (0.56–	35.6	No difference persists

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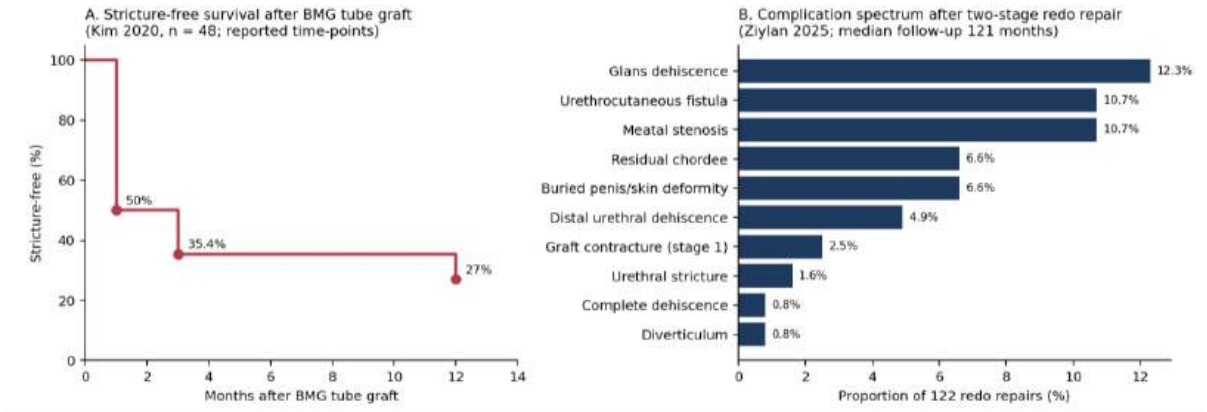
reconstructed denominators		1.57)		

Table 10. Random-effects meta-regression of the composite adverse outcome (logit scale)

Covariate	Studies	Slope (SE)	p	Residual τ^2	R^2 (%)
Follow-up (log months)	32,21,23,34,150,29,35,48,19,20,23,60,34,10,8,122	0.484 (0.248)	0.051	0.839	12.4
Publication year	20	0.019 (0.054)	0.721	0.614	0.0
Sample size (log n)	20	-0.019 (0.246)	0.939	0.637	0.0

Long-term and time-dependent outcomes

Two cohorts with follow-up exceeding six years provided time-dependent data. After free BMG tube grafting, only 14.5% of children remained complication-free over a mean of 73 months, and single prior surgery and catheter calibre >8 Fr predicted stricture-free survival. After two-stage redo repair followed for a median of 121 months, the overall complication rate was 36.8% and 23.8% required further intervention, dominated by glans dehiscence, fistula and meatal stenosis rather than stricture. In the dorsal ingraft series, complications appeared up to 10 years after repair.[8–10]



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Figure 26. (A) Reported stricture-free proportions after BMG tube grafting; (B) complication spectrum after two-stage redo repair with >5-year follow-up.[9,10]

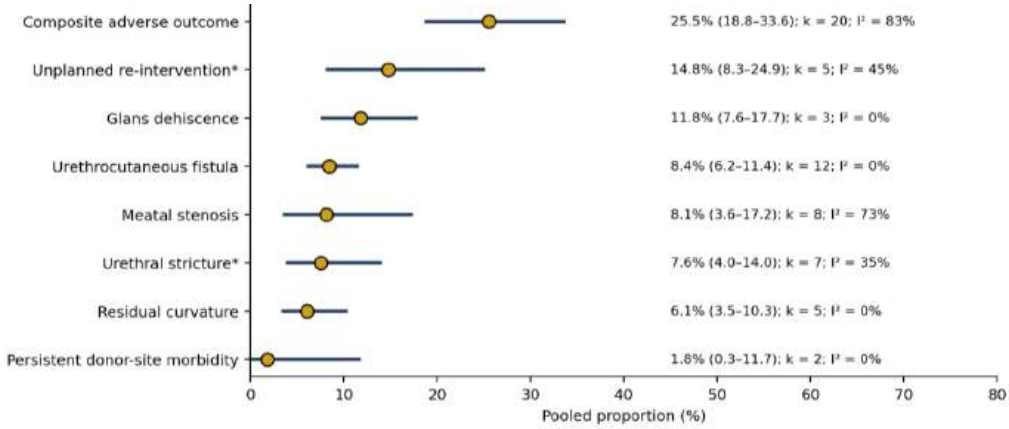


Figure 27. Summary dot plot of all pooled single-arm estimates.

Functional, cosmetic and donor-site outcomes

Mean Qmax after staged BMG was 11.8, 13.2 and 13.6 mL/s in children aged ≤1.5 years, pre-pubertal and pubertal, respectively ($p = 0.199$), and 76% achieved the optimal HOSE score of 16; uncomplicated patients scored higher than those with complications (15.8 vs 15.3; $p < 0.001$). After one-stage inlay BMG in redo cases the mean Qmax was 9.2 mL/s, and after BMG tube grafting 9.55 mL/s with a mean post-void residual of 16 mL (Figure 29). BMG yielded more satisfactory HOPE-rated cosmesis than preputial grafts in the largest comparative series, and approximately 90% of long-term redo patients reported functionally and cosmetically acceptable HOSE/PPS outcomes.[9,10,24,27,35]

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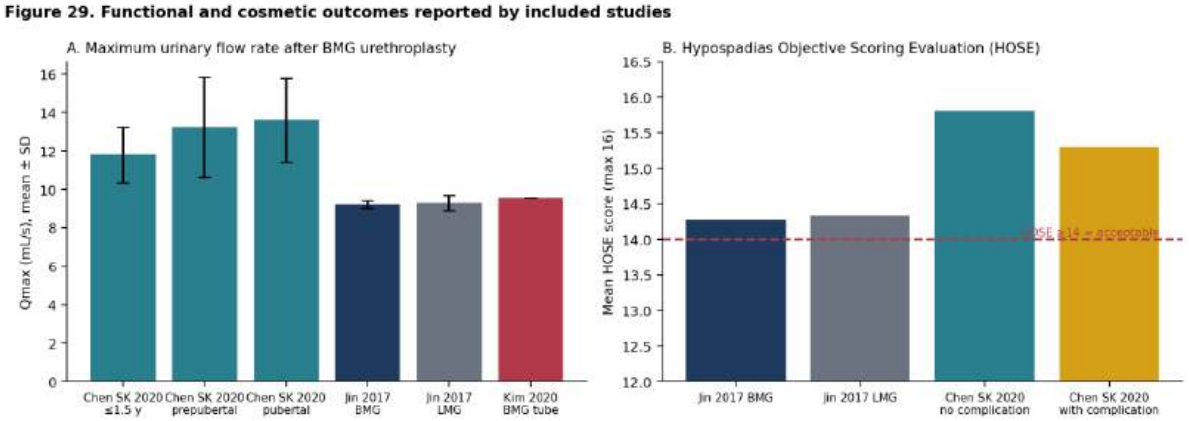


Figure 28. Functional (Qmax) and cosmetic (HOSE) outcomes reported by the included studies.[10,24,27]

Persistent donor-site morbidity was absent in both paediatric series reporting it (0/30 and 0/24; pooled 1.8% (95% CI 0.3–11.7)). Upper-lip harvest in 24 children produced transient pain within 24 h in a single case, with no perioral numbness, restricted mouth opening, contraction or salivary change after at least two months; no donor-site complications occurred in 30 children after cheek harvest for staged redo repair.[19,28]

Table 11. Donor-site outcomes in children and supporting evidence[19,28,33,42,45,51]

Study	Population	Donor site	Early morbidity	Persistent morbidity	Comment
Leslie 2011	30 children, staged redo	Cheek	NR	0/30	No donor-site complications
Elifranji 2020	24 children, 25 harvests	Upper lip	Pain 1/25 (<24 h)	0/24	No numbness, trismus, contraction or salivary change
Maarouf	Complex	Cheek	Pain both;	Tightness/numbness	Harvest time

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2013	hypospadias, BMG 23 vs LMG 21	vs tongue	faster recovery with LMG	BMG only; speech/protrusion LMG only	24 vs 19 min
Shebl 2022	BMG 15 vs skin graft 13	Cheek vs skin	—	Significantly lower with BMG (p = 0.003)	Paediatric comparative
Tawfeeq 2022	10 boys, fistula patch	Cheek	—	0/10	—
Desai 2025 (adult, context)	40 adults	Cheek	Peak pain at 1 week (70%)	Mouth-opening difficulty 7.5%	Oral health not impaired at 3–6 mo

Evidence map

The distribution of reported outcome domains is summarised in Figure 30. Success and fistula were reported by most studies, whereas donor-site morbidity, uroflowmetry, validated cosmetic scores and follow-up of five years or longer were each reported by a minority, identifying the principal gaps in the evidence base.

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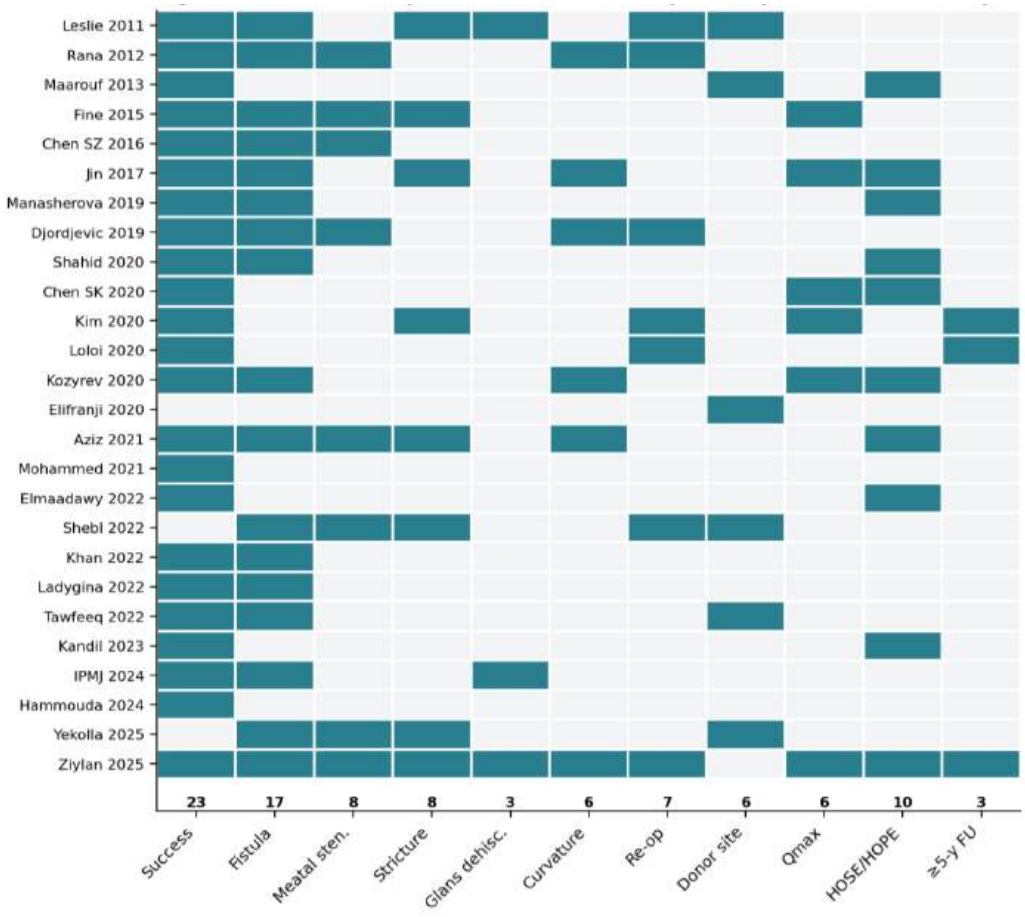


Figure 29. Evidence map of outcome domains reported by each study, illustrating sparse reporting of donor-site, functional and ≥5-year outcomes.

Subgroup analyses

Technique was the strongest effect modifier: composite adverse outcomes were 16.8% (95% CI 9.9–27.1) after single-stage inlay/onlay/patch BMG (k = 8), 27.2% (95% CI 20.8–34.6) after staged repair (k = 10) and 62.4% (95% CI 12.5–95.1) after free tubularised BMG (k = 2), although the between-subgroup test did not reach significance (Q = 4.63, df = 2, p = 0.099). By indication, rates were 19.6% (95% CI 12.5–29.4) for primary, 29.9% (95% CI 14.7–51.4) for redo and 29.0% (95% CI 19.0–41.6) for mixed cohorts (p = 0.346); by design, 25.5% (95% CI 13.6–42.6) in RCTs, 19.2% (95% CI 12.4–28.4) in prospective non-randomised studies and 27.9% (95% CI 18.8–39.3) in retrospective studies (p = 0.404). Partial support for H4 was therefore obtained.

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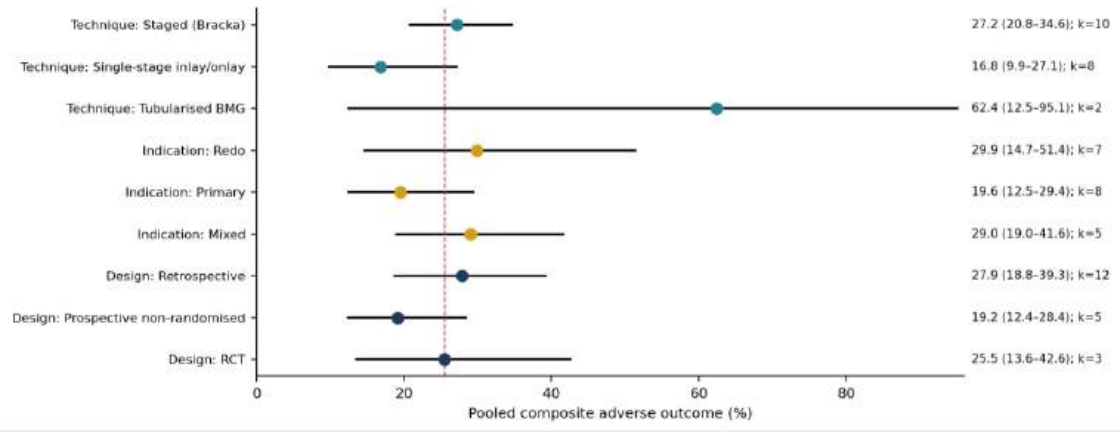


Figure 30. Summary of subgroup-specific pooled estimates; the dashed line shows the overall pooled estimate.

Table 12. Subgroup analyses of the composite adverse outcome

Subgroup	**k**	**Events/N**	**Pooled % (95% CI)**	**I^2 (%)**
Technique				
Staged (Bracka)	10	195/688	27.2 (20.8–34.6)	70.0
Single-stage inlay/onlay	8	41/310	16.8 (9.9–27.1)	65.7
Tubularised BMG	2	52/82	62.4 (12.5–95.1)	95.2
Test for subgroup differences: Q = 4.63, df = 2, p = 0.099				
Indication				
Redo	7	111/298	29.9 (14.7–51.4)	87.9
Primary	8	69/416	19.6 (12.5–29.4)	71.6
Mixed	5	108/366	29.0 (19.0–41.6)	76.0
Test for subgroup differences: Q = 2.12, df = 2, p = 0.346				
Design				
Retrospective	12	254/919	27.9 (18.8–39.3)	89.4

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Prospective non-randomised	5	18/97	19.2 (12.4–28.4)	0.0
RCT	3	16/64	25.5 (13.6–42.6)	41.9
Test for subgroup differences: Q = 1.81, df = 2, p = 0.404				

Certainty of evidence (GRADE)

Table 13. GRADE summary of findings: BMG urethroplasty for hypospadias in children[31]

Outcome	**Studies (patients)**	**Effect**	**Risk of bias**	**Inconsistency**	**Imprecision**	**Certainty**
Composite adverse outcome	20 (1,080)	25.5% (18.8–33.6)	Serious	Serious (I^2 83%)	Not serious	⨁◯◯◯ Very low
Urethrocutaneous fistula	12 (506)	8.4% (6.2–11.4)	Serious	Not serious (I^2 0%)	Not serious	⨁⨁◯◯ Low
Meatal stenosis	8 (408)	8.1% (3.6–17.2)	Serious	Serious	Serious	⨁◯◯◯ Very low
Urethral stricture (excl. tube graft)	7 (263)	7.6% (4.0–14.0)	Serious	Not serious	Serious	⨁◯◯◯ Very low
Composite: BMG vs skin/preputial	5 (638)	RR 0.88 (0.61–1.26)	Serious	Not serious	Serious	⨁◯◯◯ Very low
Failure: BMG vs lingual	2 (106)	RR 1.01 (0.46–	Serious	Not serious	Very serious	⨁◯◯◯ Very low

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		2.23)				
Persistent donor-site morbidity	2 (54)	0/54 events	Serious	Not serious	Serious	⨁◯◯◯ Very low

Observational evidence assessed with ROBINS-I starts at high certainty and is downgraded; single-arm proportions are inherently at serious risk of bias because of the absence of a comparator.

DISCUSSION

Summary of principal findings

This systematic review synthesised 26 primary studies published in the last 15 years on BMG urethroplasty in children with hypospadias. Four principal findings emerge. First, approximately three quarters of paediatric BMG repairs achieve an uncomplicated primary result, with a pooled composite adverse-outcome rate of 25.5% that is remarkably stable across sensitivity and cumulative analyses. Second, urethrocutaneous fistula—the index complication of hypospadias surgery—occurs in about one in twelve BMG repairs with no between-study heterogeneity. Third, technique and recipient bed, rather than graft type, determine outcome: inlay/onlay grafting performs best, staged repair is intermediate and free tubularised grafting fails predominantly through stricture. Fourth, BMG is not demonstrably superior to preputial/skin grafts for overall complications but shows a consistent, non-significant signal toward less stenosis, and it is equivalent to lingual mucosa.[10,24,33–35]

Biological rationale for the observed outcome profile

The low and homogeneous fistula rate is biologically plausible. Buccal mucosa has a thick, non-keratinised epithelium that tolerates urine and a thin, richly vascular lamina propria that permits early plasmatic imbibition and inosculation, and the neourethra it forms is free of hair follicles and adnexal glands. In children with proximal hypospadias, histology of the neourethra after Bracka repair showed that preputial skin grafts retained keratinising epithelium, dilated sweat and sebaceous glands with inflammation and hair follicles, whereas buccal grafts preserved typical mucosal architecture—offering a mechanistic explanation for the lower stenosis signal and better HOPE-rated cosmesis with BMG.[3,17,35]

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Conversely, free grafts depend entirely on the recipient bed. When BMG is tubularised and tunnelled through scarred tissue, the circumferential dependence on imbibition predisposes to ischaemic contraction; this explains the 77% stricture incidence and 27% stricture-free survival at one year after free tube grafting, and the pronounced learning curve (70% complications in the first 10 vs 16% in the subsequent 24 tunnelled tube grafts). Similarly, graft fibrosis or induration before second-stage tubularisation strongly predicted complications in staged redo repair, emphasising that graft quality at the interval assessment is the key decision node.[10,19,20]

Comparison with previous systematic reviews

Our pooled success of 74.5% sits below the >80% success reported for BMG in the adult-dominated umbrella review, which is expected given that paediatric BMG is reserved for the most unfavourable anatomy and redo situations, and that hypospadias outcomes incorporate cosmetic and glanular endpoints absent from adult stricture series. The umbrella review's pooled odds ratios comparing BMG with penile skin (OR 0.83, 0.55–1.23) and lingual grafts (OR 1.18, 0.79–1.77) are strikingly concordant with our paediatric risk ratios (0.88 and 1.01), suggesting that the relative performance of oral mucosa is consistent across age groups even if absolute risks differ.[3]

Two meta-analyses comparing dorsal inlay graft urethroplasty with TIP in primary hypospadias found no difference in overall complications, while the more recent synthesis demonstrated a significant reduction in meatal/neourethral stenosis with inlay grafting. Neither analysed buccal and preputial inlays separately. Our data add that BMG inlay achieves among the lowest composite rates of any configuration (6.0% in 150 primary distal repairs; 13% in a three-arm RCT) and that the stenosis-protective signal extends to BMG. A 2026 RCT of 579 children confirmed that inlay grafting reduces neourethral/meatal complications specifically in narrow plates of 4–8 mm, whereas plates wider than 8 mm do not benefit; its graft source was not specified and it was therefore not included.[21,22,34,40,52–54]

The lingual-versus-buccal meta-analysis of 632 predominantly adult patients found equivalent urethroplasty outcomes but divergent early donor-site morbidity: more speech difficulty and impaired tongue protrusion after lingual harvest, and more swelling, mouth-opening difficulty and numbness up to six months after buccal harvest. The two paediatric comparative studies in our

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review reproduce both findings, supporting lingual mucosa as a valid alternative when buccal tissue is insufficient or previously harvested.[23,24,33,55,56]

Finally, the 2025 systematic review of post-pubertal outcomes after oral mucosal urethroplasty in prepubertal boys identified only three moderate-quality studies with mixed outcomes, including meatal stenosis, stricture and fistula. Our review extends this evidence with two cohorts followed for 6–10 years and a borderline positive meta-regression slope for follow-up duration, reinforcing that paediatric BMG outcomes must be judged beyond puberty.[2,9,10]

Staged versus single-stage strategies

The higher composite rate after staged repair (27.2%) than after single-stage inlay/onlay grafting (16.8%) must not be misinterpreted as evidence against staging; it reflects case-mix, because staged BMG is reserved for absent or fibrotic plates, curvature >30°, LS/BXO and multiply failed repairs. Where single-stage and staged approaches were compared within the same institution, staged repair produced fewer re-interventions for proximal hypospadias, and a large redo cohort concluded that staged BMG is the appropriate option for proximal failures after a second or third repair, while DIGU, TIP and urethral mobilisation suit distal failures.[48,57,58]

Importantly, staged BMG in the most complex redo patients achieved ~90% acceptable functional and cosmetic outcomes after more than a decade, with a quarter requiring further surgery—figures comparable to the 31.1% complication and 29% re-intervention rates after two-stage primary repair with preputial grafts over similar follow-up. The residual burden after staged repair is dominated by glans dehiscence and meatal problems rather than graft failure, indicating that refinements in glansplasty, meatal design and waterproofing layers (dartos, tunica vaginalis or scrotal flaps) are the most promising targets.[9,32,59]

Redo hypospadias and lichen sclerosus

Redo repairs showed a numerically higher composite rate (29.9%) than primary repairs (19.6%). This is consistent with multivariable data identifying prior surgery as an independent predictor of complications after staged BMG ($p = 0.016$) and with poorer stricture-free survival after more than one prior operation. In LS/BXO, which affected up to half of post-hypospadias strictures in one cohort, oral mucosa is favoured because keratinised genital skin is itself susceptible

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to LS recurrence; oral mucosa onlay procedures achieved better Qmax and HOSE than other redo techniques in LS-associated hypospadias.[10,19,27,44,60]

Donor-site morbidity in children

A persistent concern in paediatric practice is oral morbidity. The paediatric data are reassuring: no persistent donor-site morbidity was recorded in 54 children, and upper-lip harvest was essentially asymptomatic after two months. Adult data, however, reveal a less benign long-term profile when systematically sought: 36% reported persistent tightness or numbness at a median of 43 months, with measurable, graft-size-dependent reductions in buccal volume, and 7.5% had long-term difficulty with mouth opening. Children's relatively larger oral cavity in proportion to genital size, and their capacity for tissue remodelling, may partly explain the difference, but the absence of validated paediatric patient-reported instruments likely leads to under-ascertainment.[19,28,51,61,62]

Functional, cosmetic and long-term perspectives

Uroflowmetry after BMG repair consistently showed Qmax values in the range expected for age (9–14 mL/s), without age-group differences in staged repair. Interpretation requires caution, however: a 12-year cohort showed that plateau-shaped prepubertal flows after hypospadias repair improved spontaneously during puberty in most boys, with Qmax rising from 11.2 to 21.4 mL/s, so that surgery should be reserved for persistent symptomatic obstruction. Post-pubertal re-examination remains essential because new curvature can emerge between pre- and post-pubertal assessments, and adult sexual dysfunction and dissatisfaction affect 12–16% of men repaired in childhood.[16,27,63–65]

Research integrity and evidence quality

During selection we identified a 2023 report whose results were numerically identical to a 2017 PLoS One cohort, including identical subgroup sizes, complication percentages and HOSE means with standard deviations, but attributed to a different hospital and period. Including both would have duplicated 62 patients in the lingual-versus-buccal comparison. This observation highlights the need for editors and reviewers to screen for reproduced data and for systematic reviewers to perform explicit duplicate detection beyond author and title matching.[24–26]

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More broadly, the evidence base is dominated by retrospective single-centre series with heterogeneous and often non-standardised definitions of success, variable inclusion of minor complications and short follow-up (as little as six weeks). All four RCTs had methodological shortcomings, and none reported allocation concealment or blinded outcome assessment. These deficiencies—rather than statistical heterogeneity alone—limit the certainty of our estimates to low or very low.[37,39–41,43]

Strengths

Strengths include a paediatric- and BMG-specific focus, inclusion of randomised and non-randomised designs with design-appropriate appraisal tools, technique-stratified pooling with prediction intervals, extensive sensitivity and meta-regression analyses, and transparent handling of reconstructed data and duplicate publications.[5–7]

Implications for practice

- Prefer BMG as a dorsal inlay (narrow plate 4–8 mm) or ventral onlay/patch when a viable plate exists; reserve staged Bracka BMG for absent/fibrotic plates, curvature >30°, LS/BXO and multiply failed repairs.[34,48,52]
- Avoid free tubularised BMG in scarred beds except in highly selected cases and experienced hands; if used, employ larger catheter calibre and anticipate endoscopic salvage.[10,20]
- Assess graft quality before second-stage tubularisation; regraft fibrotic or indurated segments rather than proceeding.[19]
- Counsel families that roughly one in four children will experience a complication and one in seven will need further surgery, with complications possible up to 10 years later.[8,9]
- Consider lingual or upper-lip mucosa when cheek mucosa is limited or previously harvested.[28,33]
- Implement structured follow-up through puberty with uroflowmetry, HOSE/PPS and donor-site assessment.[63,64]

Implications for research

Future trials should be multicentre, prospectively registered, adequately powered, and use concealed allocation with blinded outcome assessment. A minimum core outcome set should

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include standardised success definition, fistula, meatal stenosis, stricture, glans dehiscence, residual curvature (artificial erection), re-intervention (Clavien–Dindo), HOSE, PPS, uroflowmetry and validated paediatric donor-site measures, reported at 1, 5 and post-pubertal time points. Head-to-head RCTs of BMG versus inner-preputial inlay in narrow plates, and of staged BMG versus single-stage techniques in proximal hypospadias, are the highest priorities.[2,3,15]

CONCLUSION AND RECOMMENDATIONS

Buccal mucosal graft urethroplasty is an effective and safe option for complex, proximal and re-operative hypospadias in children. Approximately three quarters of repairs achieve an uncomplicated primary result, fistula is infrequent and consistent (~8%), and persistent donor-site morbidity is rare. Outcomes depend more on the configuration of the graft and the quality of the recipient bed than on the graft source: inlay/onlay and staged approaches perform well, whereas free tubularised grafts in scarred beds are prone to stricture. BMG is at least equivalent to preputial/skin and lingual grafts, with a signal toward less stenosis that warrants confirmation.[9,10,33,34]

Recommendations: (1) BMG should be the first-line extragenital substitute when local tissue is inadequate; (2) configuration should be tailored to plate width and quality, curvature and LS status; (3) free tubularised BMG should be avoided where feasible; (4) follow-up should continue into adolescence; and (5) the research community should prioritise high-quality multicentre RCTs with core outcome sets and long-term, patient-reported and donor-site outcomes.[2,48]

DECLARATIONS

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