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Published in:
Journal of Pediatric Urology

DOI (link to publication from Publisher):
10.1016/j.jpurol.2022.05.001

Publication date:
2022

Document Version
Publisher's PDF, also known as Version of record

Journal of Pediatric Urology (2022) **18**, 481.e1–481.e8

An objective hypospadias classification system

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Keywords
Hypospadias; Classification; Urethral defect; Urethral hypoplasia; Objective

Received 31 January 2022
Revised 22 April 2022
Accepted 5 May 2022
Available online 11 May 2022

Summary

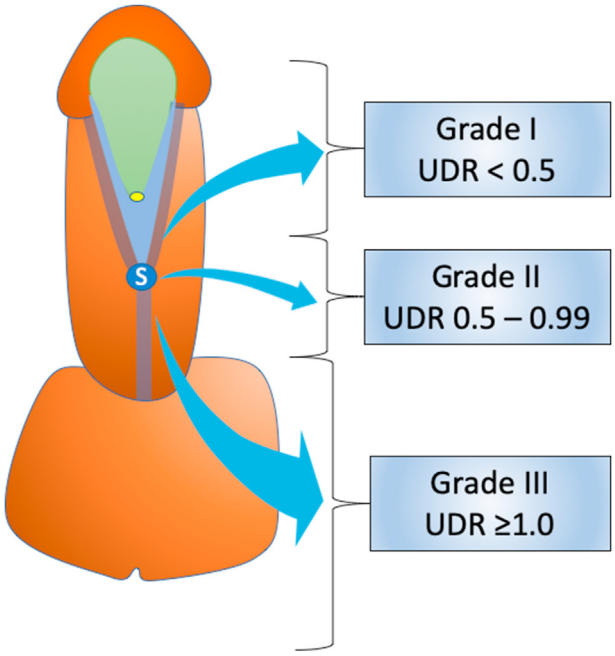
Objective
Current approaches to classifying hypospadias severity are based on meatus position. These classification tools lack precise reflection on the degree of urethral hypoplasia and extent of urethral underdevelopment hence are not good representative of hypospadias severity. Here, an alternative classification system is introduced that objectively reflects the developmental pathology underlying this condition. The study goal was to appraise location of bifurcation in the corpus spongiosum (BCS) relative to the penile shaft as an indicator of hypospadias severity.

Patients and methods
Patients aged <18 years with primary hypospadias were included in the study. Urethral defect ratio (UDR) was calculated by dividing the extent of urethral defect (distance between the glandular knobs and BCS) relative to stretched penile length (SPL). Hypospadias severity was then categorized into three distinct grades (UDR <0.5, 0.5–0.99, ≥1.0). The Inter-Class Correlation (ICC) was evaluated to assess the intra- and inter-rater agreement between the reviewers of UDC ratio. Linear regression analysis was performed to estimate the correlation between UDC ratios and either plate objective scoring tool (POST) and Curvature degrees.

Results
A total of 67 patients aged 12.3 ± 3.7 months with primary hypospadias were enrolled. UDR ranged between 0.2 and 1.3. A significant difference in hypospadias level was observed between UDR grades, which further correlated degree of curvature ($P < 0.0001$), urethral plate quality ($P < 0.0001$), and associated anomalies ($P < 0.05$). The Inter-Class Correlation (ICC) value to examine the intra- and inter-rater agreement between the two reviewers in UDC ratio was 0.998 (95% CI 0.998, 0.999). Regression analysis revealed that UDR and both POST and Curvature degree were significantly associated ($P < 0.001$).

Conclusions
A hypospadias severity scoring system based on embryological etiology and urethral hypoplasia and assessed relative to the penile shaft represents an objective, feasible, and consistent tool. These results clearly indicate that the reviewers have had excellent consistency/reliability across their consecutive readings. This new system can facilitate objective description of hypospadias-spectrum anomalies and thus support precise communication between individual surgeons and centers.

https://doi.org/10.1016/j.jpurol.2022.05.001



Summary Figure

Introduction

Degrees of hypospadias can occur over a wide spectrum that impacts disease severity and treatment options. Numerous classification systems have therefore been developed to assess hypospadias severity based on position of the urethral meatus opening. However, these classification systems lack precision and do not reliably consider the true site of spongiosal bifurcation. Specifically, some variants of distal hypospadias are associated with proximal spongiosal hypoplasia and penile curvature (which may require complex surgical repair), while other apparently severe cases of proximal hypospadias can present less of a surgical challenge where favorable anatomy is existing [1—3]. Indeed, it has long been recognized by hypospadias surgeons that external meatal position does not reliably indicate severity or complexity of the surgical repair required [4,5]. Furthermore, Arlen et al. conducted a multivariate analysis that showed meatal location does not predict incidence of postoperative complications, thus highlighting the need to consider the entire hypospadias complex rather than evaluating meatal position alone [6]. An objective method of determining hypospadias severity therefore remains a high priority within the field [7].

The current literature lacks both a clear definition of severe hypospadias and a widely accepted, standardized method of classification. Here, a new system to characterize spongiosal anatomy is introduced that aims to overcome the above-mentioned limitations based on easily measurable features, thereby achieving a higher index of objectivity and reproducibility. By describing hypospadias severity with greater precision, this updated scoring tool will lead to improved communication between surgeons, researchers, and affected patients.

Patients and methods

We performed a retrospective review of medical charts for children who underwent hypospadias repairs between January 2019 and November 2021. Patients aged <18 years and with primary hypospadias were included in the study. Data collected included patient age at time of surgery, degree of ventral curvature after penile degloving, surgical techniques including urethroplasty, genital defects (e.g. undescended testis, bifid scrotum), placental insufficiency and extragenital malformations. The diagnosis of placental insufficiency was made antenatally based on Sonographic findings including absent or reversed end-diastolic flow velocities (AREDV) in the umbilical arteries; elevated head/abdomen circumference ratio above the 95th centile for gestational age indicating asymmetrical IUGR; reduced amniotic fluid volume (amniotic fluid index <5 cm); abnormal placental shape (small/thick) and texture; bilateral abnormal uterine artery Doppler [8].

Stretched penile length (SPL) was measured along the lateral aspect of the penile shaft from the tip of the glans to the upper border of the pubic bone (stretch was applied using a 5—0 Prolene stay suture and metal ruler). The site of bifurcation in the corpus spongiosum (BCS) was evaluated with the patient in supine position after full degloving of the penile skin to identify the true extent of hypospadias. Distance between the glandular knobs (B—B imaginary line) and the BCS was designated as the urethral defect (UD) while the urethral defect ratio (UDR) was calculated as UD divided by SPL (Fig. 1A; Equation (1)).

$$\text{Urethral Defect Ration (UDR)} = \frac{\text{Urethral Defect (UD)}}{\text{Strecthed Penile Length (SPL)}} \quad (1)$$

Hypospadias severity was then categorized using UDR-based classification (UDC) to define three grades: UDR <0.5, 0.5—0.99 and ≥ 1 respectively. Fig. 1B. "All the surgeries were performed by one surgeon and the measurements for each patient were performed by the surgeon then his assistant in triplicates and blinded to the results of each other. The results were then captured as the average of the six measurements and the intra- and inter-rater agreement evaluated separately." In all cases, hypospadias meatus position was evaluated according to the Duckett 1989 classification method [9]. Fig. 1C.

To objectively quantify the urethral plate (UP), we applied the plate objective scoring tool (POST) [10—13]. Briefly, three key anatomical points were marked on the glans (A) distal extent of the urethral plate at the mucocutaneous junction (B) glanular knobs where the A-B line deviates laterally and outlines the side boundaries of the UP, and (C) where the start of the coronal border instigates alongside the B—C line. POST ratio is calculated as follows (equation (2)):

$$\text{POST} = \frac{\text{AB distance}}{\text{BC distance}} \quad (2)$$

Following penile skin degloving, curvature was measured using a standardized approach together with a mobile application [14]. Briefly, a lateral image was captured during saline-induced erection test from a distance of

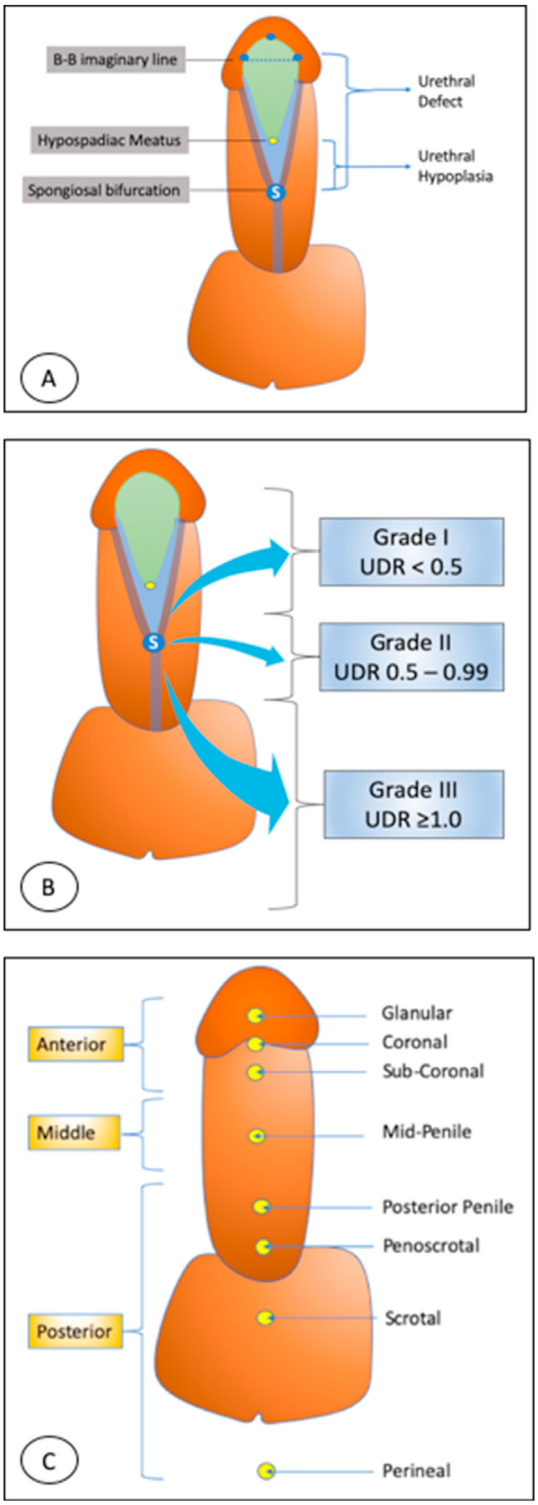


Fig. 1 (A–C) (A) Diagrammatic representation of the key anatomical definitions studied (B) Grades of hypospadias severity as defined by the new UDR-based classification (UDC) system. (3) Types of hypospadias according to meatal position-based classification (MPC) (Duckett 1989 [8]).

~25 cm, and curvature was measured after defining three key landmarks on the resultant image (defining the base, distal tip, and area of maximum curvature). Any residual ventral curvature 20–50° degrees after degloving was corrected by dorsal midline plication followed by 1-stage hypospadias repair (either TIP or DTIP according to the quality of the urethral plate) [10,15]. Patients with more severe ventral curvature (>50°) underwent transection of the urethral plate and mobilization of the transected urethral plate/corpus spongiosum from the corpora cavernosa, with multiple deep transverse incisions of the tunica albuginea (DTITAs) [16]. Patients requiring transection of urethral plate underwent 2-stage repairs.

This study was approved by the hospital IRB office, and informed consent was waived given the retrospective nature of the study without reporting any personal identifiable information. Descriptive statistics were used to summarize and determine the sample characteristics and distribution of various considered parameters related to objective hypospadias classification system studied in this cohort of patients. The normally distributed data and results were reported with mean and standard deviation (SD), whereas median and interquartile range (IQR) were used in case of skewed data. Categorical data were summarized using frequencies and percentages. Associations between two or more qualitative variables (family history, placental abnormalities, associated anomalies) across various independent groups were examined and assessed using Pearson Chi-square or Yates corrected Chi-Square tests as appropriate. Quantitative outcomes (POST and curvature) measured across various independent groups were analyzed using one-way analysis of variance (ANOVA) or Kruskal–Wallis test as appropriate. All statistical P values presented were two-tailed, and P values < 0.05 was considered as statistically significant. The Inter-Class Correlation (ICC) analysis was utilized to examine the intra- and inter-rater agreement between the two reviewers in UDC ratio. ICC values < 0.5 are indicative of poor reliability, 0.5–0.75 indicate moderate reliability, 0.75–0.9 indicate good reliability, and >0.90 indicate excellent reliability [17]. Linear regression analysis was performed to estimate the correlation between UDC ratios and either POST and Curvature degrees. All Statistical analyses performed using statistical packages SPSS version 27.0 (Armonk, NY: IBM Corp).

Results

A total of 67 patients aged 12.3 ± 13.7 months with primary hypospadias were evaluated in this study. Patient clinical histories and anatomical variables were analyzed across disorder subgroups using both meatal position-based classification (MPC) and UDR-based classification (UDC). Family history of hypospadias was scattered within the different subgroups as graded by MPC, with no significant patterns being detected ($P = 0.756$), while a higher degree of correlation was observed with increasing grades of UDC ($P = 0.051$). Using either classification system, degree of curvature increased steadily across the different subgroups, but UDC showed a strong ability to predict the likelihood of curvature of >20° ($P < 0.0001$) which is often used as a cut-off for surgical correction. POST values varied significantly under both classification systems, though a stronger trend was observed for UDC (ANOVA $F = 29.38$) than for MPC (ANOVA $F = 5.5$). Both methodologies detected the presence of antenatal placental

Table 1 Clinical parameters, physical examinations, and intraoperative variables of the hypospadias patients evaluated using MPC and UDR-based classification systems.

		Classification systems													
		Duckett 1989 (MPC)									Abbas 2022 (UDR)				
		Glanular	Coronal	Sub coronal	Mid-penile	Posterior Penile	Peno-scrotal	Scrotal	Perineal	Test-statistic	*P*-value[a]	Grade I	Grade II	Grade III	Test-statistic	*P*-value[b]
Patient number N (%)		4	19	18	11	6	6	2	1			32	26	9		
Family history N (%)		1 (25)	8 (42)	6 (33)	1 (9)	1 (17)	0	1 (50%)	0	$\chi^2 = 4.20$	0.756	13 (41)	4 (15)	1	$\chi^2 = 5.97$	**0.051**
Placental abnormalities		0	0	0	2 (18%)	5 (83)	5 (83)	2 (100)	1 (100)	$\chi^2 = 31.22$	0.0001	0	6	9	$\chi^2 = 40.44$	**<0.0001**
POST		1.1 ± 0.2	1.3 ± 0.22	1.1 ± 0.29	1.1 ± 0.32	0.9 ± 0.17	0.7 ± 0.33	0.57	0.62	ANOVA F = 5.50	<0.0001	1.2 ± 0.14	0.9 ± 0.30	0.6 ± 0.22	ANOVA F = 29.38	**<0.0001**
Curvature	N (%) (>20°)	1 (50)	6 (31)	11 (61)	6 (55)	5 (83)	6 (100)	2 (100)	1 (100)	$\chi^2 = 8.66$	0.278	12 (38)	21 (81)	9 (100)	$\chi^2 = 17.67$	**<0.0001**
	X°	25	24 ± 2.3	28.1 ± 3.3	26 ± 5.4	32 ± 6.8	42 ± 6.3	87	70.5	ANOVA F = 72.67	<0.0001	24 ± 3.3	36 ± 3.4	65 ± 8.05	ANOVA F = 335.89	**<0.0001**
Associated anomalies	Genital N (%)	0	0	0	0	1 (17)	2 (33)	2 (100)	1 (100)	$\chi^2 = 16.76$	0.019	0	5	9	$\chi^2 = 42.57$	**<0.0001**
	Extragenital N (%)	0	0	1 (6)	0	0	1 (17)	2 (100)	1 (100)	$\chi^2 = 16.79$	0.019	0	0	2	$\chi^2 = 6.14$	**0.046**

[a] P-value computed using Yates corrected Chi-Square test (for qualitative data variables) and one-way ANOVA test (for quantitative data variables).
[b] P-value computed using Pearson Chi-Square test (for qualitative data variables) and one-way ANOVA test (for quantitative data variables).

abnormalities and associated defects related to proximal subtypes/grades of hypospadias. Table 1.

Repair type included the following procedures: n = 22 (33%) tubularized incised plate urethroplasty (TIPU), n = 35 (52%) dorsal inlay TIP (DTIP), and n = 10 (15%) staged repair. UDR-based classification was able to anticipate the type of surgical procedure required with a high predictability index, whereas the meatal position-based system was less effective in this respect. Fig. 2.

The obtained ICC value to examine the intra- and inter-rater agreement between the two reviewers in UDC ratio was 0.998 (95% CI 0.998, 0.999). These results clearly indicate that the reviewers have had excellent consistency/reliability across their consecutive readings. Regression analysis revealed that UDC and both POST and Curvature degree were significantly associated ($P < 0.001$). Fig. 3.

Discussion

Traditionally, external meatal location has been the key factor used to classify hypospadias, without considering the true site of spongiosal bifurcation. This is problematic for conventional preoperative evaluation, especially in cases where an apparently distal meatal position is later revealed to be more proximal during surgery, and thus needing more complex repair.

Smith was first to classify hypospadias according to location of the urethral meatus, while Sheldon and Duckett considered meatus position after chordee had been released [18]. Even when scoring only clear-cut cases of distal, proximal, and scrotal hypospadias, reliance on meatal position to determine severity leads to inconsistency, since this approach does not account for the underlying pathology or extent of urethral hypoplasia. Most

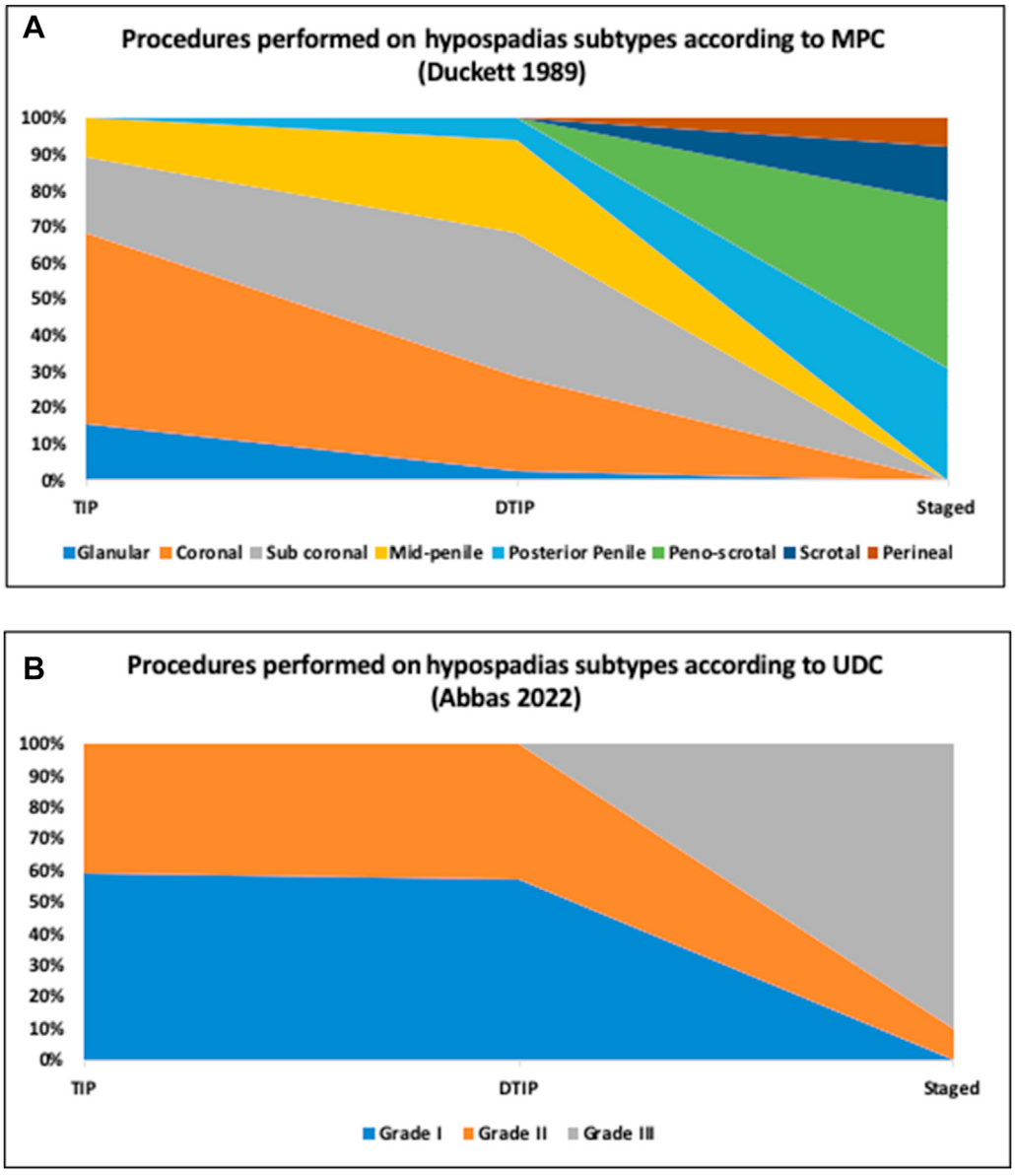


Fig. 2 (A, B) Procedures performed on hypospadias subtypes according to the different classification systems applied.

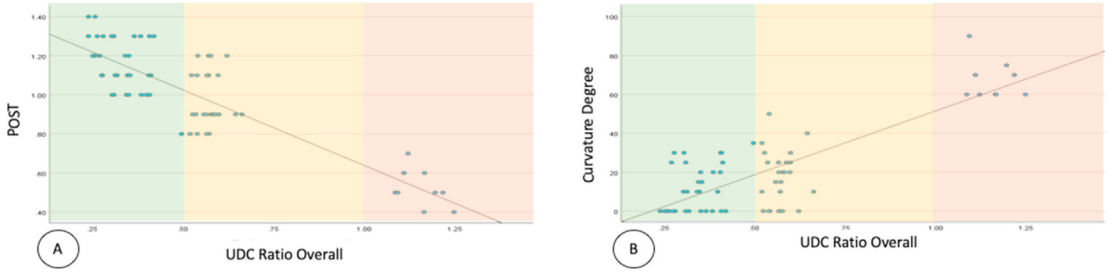


Fig. 3 (A, B) Correlation between UDC ratio and POST ratio (A) and curvature degree(B)*.*Pearson correlation test, P = 0.001.

physicians use the one proposed by Barcat and modified by Duckett, which described the location of the meatus into: anterior (glanular and subcoronal), middle (distal penile, midshaft, and proximal penile), and posterior (penoscrotal, scrotal, and perineal) [9,19]. During urethroplasty, Wong et al. [20] were able to define hypospadias repair as distal, mid-shaft, or proximal based on meatal location after cutback of hypoplastic urethra. However, it is clearly preferable to determine severity and inform clinical decision making prior to any manipulation of the urethra.

Merriman et al., introduced the Glans-Urethral Meatus-Shaft (GMS) classification system, which not only considers meatus location but also features of the glans including size; presence and appearance of glans groove; and the severity of ventral curvature [21]. However, there is still considerable subjectivity associated with evaluation of these clinical variables [4]. This inconsistency in evaluation and classification limits accurate comparison of outcomes between centers and surgeons despite ongoing efforts at standardization.

While the UDC system does reflect on urethral defect and hypoplasia, it does not directly appraise two key components measured by GMS, namely glans-urethral plate quality and the degree of curvature. Nonetheless, both factors displayed a strong indirect correlation with UDC in the current study, and accordingly, UDC values were also found to be strongly correlated with POST score. Indeed, POST is considered a sensitive, reproducible and precise indicator of urethral plate quality, and calculated scores differed significantly between the three UDC-defined grades described here ($P < 0.0001$). Likewise, the extent of penile curvature also correlated significantly with UDC grade, with higher degrees of curvature being observed at more complex grades ($P < 0.0001$).

While the developmental processes underpinning penile curvature are not yet fully understood, several studies have begun to shed light on key events [22]. Baskin et al. [23] found that barring the abnormal urethral spongiosum and glans, hypospadiac and normal penises show no difference in blood supply, tunica albuginea, corpora cavernosa, or neuronal innervation architecture. This may indicate that key phenotypic aspects of hypospadias (namely urethral "defect", skin abnormalities, and penile curvature), are strongly linked and thus a classification system/indicator based on one of these features can also reflect the others. Accordingly, the UDC system has been designed to consider multiple key anatomical variables during assessment of hypospadias severity, but without excessive complexity that can lead to poor reproducibility.

The concept of spongiosal bifurcation level being a key determinant of hypospadias severity has been introduced previously by other surgeons. For example, Mouriquand et al. has defined two types of hypospadias, distal and proximal, as opposed to the location of the division of the corpus spongiosum but with no clear determination of the anatomical demarcation between both and whether any other objective correlation with penile curvature or urethral plate exists [5]. Similarly, Orkiszewski has used the site of spongiosal bifurcation to classify hypospadias into either infra-pubic or suprapubic and the last into distal, middle and proximal but again with not exact anatomical reference points stated [4].

The UDC system also sheds new light on other important elements related to hypospadias, including potential etiological/genetic factors, and the presence of a family history of similar anomalies [24,25]. For example, Grade 1 is frequently associated with familial occurrence and history of a hypospadias in another family member, while grade 3 cases are obviously linked to pathologies associated with placental insufficiency and prematurity etc. [26—28] Likewise, cases of grade 3 exhibit significant risk of associated genital and extragenital malformations that should be looked for and managed appropriately [29].

When applying the MPC system, surgery type did not follow a regular pattern across the different patient groups. However, for the same cohort of patients, UDC-based classification predicted the likely surgical procedure required and could therefore be used to guide clinical decision making and assessment of post-operative outcomes.

Even for the experienced pediatric urologist, accurately defining the extent of urethral hypoplasia and subsequent UD may only be practicable at the time of surgery [30], since this is affected by curvature of the penis, conformation of any redundant skin, and crucially the extent of urethral hypoplasia. Therefore, a classification system that can be applied after degloving is useful to overcome these anatomical confounders and allow greater precision in grading hypospadias. As with any scoring tool, the ideal classification for hypospadias severity should be both objective and easily reproducible. Recently, machine learning technologies have succeeded in emulating expert human classification of patients with distal/proximal hypospadias, potentially paving the way for standardization of these technologies and future clinical applications [31].

Conclusions

The UDC severity scoring system is based on the developmental pathology of hypospadias and can be assessed relative to the penile shaft, resulting in an objective, feasible, and consistent tool able to guide surgical planning. This new system can facilitate objective description of hypospadias-spectrum anomalies and thus support precise communication between individual surgeons and centers.

Conflicts of interest

All co-authors have nothing to declare.

Ethical approval

The ethical committee approved the commencement of the presented study.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgement

This tool was introduced by TA and we do thank and appreciate the valuable help of Dr. Prem Chandra (Clinical Biostatistician, Hamad Medical Corporation, Doha, Qatar).

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