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Review Article

Current status of nomograms and scoring systems in paediatric endourology: A systematic review of literature

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Summary

Introduction
The incidence of paediatric kidney stone disease is increasing worldwide, with the requirement for endourological interventions mirroring this. Multiple nomograms, grading tools and scoring systems now exist in the adult setting, which aim to enhance the pre-operative planning and decision-making associated with these surgeries. In recent years, there has been increasing interest in nomograms dedicated for use in the paediatric setting. This study provides an up-to-date review and assessment of available paediatric endourology nomograms and scoring systems.

Methods
A comprehensive search of worldwide literature was conducted according PRISMA methodology. Studies describing paediatric-specific endourology nomograms, scoring systems or grading tools and studies externally validating these tools, or existing adult tools in a paediatric population, were evaluated and included in the narrative data synthesis.

Results
A total of 7 endourology nomograms were identified. 4 were paediatric-specific, 2 for shockwave lithotripsy, 1 for percutaneous nephrolithotomy or ureteroscopy and 1 for percutaneous nephrolithotomy specifically. Only the 2 shockwave lithotripsy nomograms have been externally validated in 4 further studies and showed efficacy in predicting treatment success. 3 adult tools, all specific to PCNL have been investigated and validated in a paediatric setting in 11 studies. In general, they showed efficacy in the prediction of stone free rate but were poor at predicting likelihood of complications.

Conclusion
A limited number of paediatric-specific endourology predictive nomograms are available to aid in the management of kidney stone disease, with the strongest evidence supporting those designed for shockwave lithotripsy. Although 3 adult tools have been implemented, there are problems applying these to the paediatric setting and further development of paediatric-specific tools is necessary.

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Introduction

Recent decades have witnessed an increase in the worldwide incidence of kidney stone disease (KSD) in children [1]. This trend is mirrored by the increasing volume of endourological interventions being performed [2]. As well as the continued advances in surgical technologies, other strategies are being investigated to improve pre-operative planning and surgical outcomes. This includes the development of predictive nomograms, which serve to optimise pre-operative planning and decision-making, thereby improving operative safety and efficacy. The need for this is not in question given the importance of achieving complete stone clearance and avoiding iatrogenic injury in children, where the risk of stone recurrence and need for repeat intervention is high [3].

In the adult setting, over 50 such tools now exist [4]. Examples include the Guys Stone Score (GSS), Clinical Research Office of the Endourological Society (CROES) nephrolithometric nomogram and Seoul National University renal stone complexity (S-ReSC) tool, which all predict stone free rate (SFR) after percutaneous nephrolithotomy (PCNL) [5—7]. However, despite increased awareness of nomograms in adults, formal evaluation and validation remains underreported in the setting of paediatric endourology and uncertainty remains as to what tools are available and whether there is sufficient evidence to support their use in clinical practice.

This article aims to answer these questions by providing an up-to-date summary of nomograms and scoring systems in the context of paediatric KSD management. It intends to highlight what is available for each treatment modality and appraise all available validation studies to give recommendations for nomogram implementation in clinical practice. This includes assessment of systems designed specifically for children as well as those developed for adults, which have subsequently been validated in the paediatric setting.

Methods

A systematic search was conducted of the MEDLINE and Embase databases from first records up to 15th September 2021. This was carried out in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology [8]. Boolean operators "AND" and "OR" were used to augment the process (Fig. 1).

Search terms were: "scoring system*" OR "grading tool*" OR "nomogram*" AND "kidney stone*" OR "kidney stone disease" OR "urolithiasis" OR "nephrolithiasis" OR "endourology" AND "p*diatric*" OR "child*" OR "infant*".

The objective of the search was to identify all scoring systems, grading tools and nomograms pertinent to the endourological management of paediatric KSD. Studies were included if they described the initial concept, design, and validation of a relevant paediatric-specific tool, if they described the subsequent external validation of a paediatric-specific tool, or if they described the validation of a pre-existing adult tool in a paediatric setting.

Titles were screened and any duplicates removed before abstracts and finally full-text articles were assessed for relevance (Fig. 1). Reference lists were also checked. Only English language articles were included. Relevant studies were evaluated by all authors and included in the narrative data synthesis.

Results

A total of 7 endourology tools were identified (Tables 1 and 2). 4 were paediatric-specific endourology tools: 2 for shockwave lithotripsy (SWL), 1 for ureteroscopy (URS) or

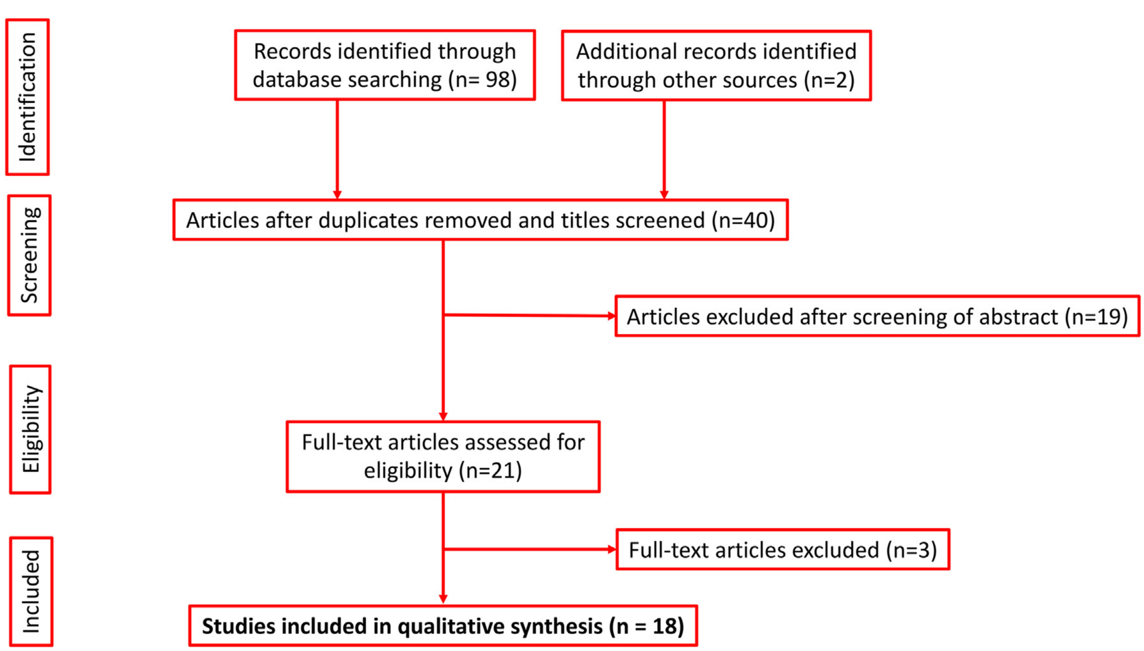

Fig. 1 PRISMA flowchart of studies.

Table 1 Nomograms available for SWL. *White = paediatric-specific* (SWL — Shockwave lithotripsy).

Tool	Procedure	Tool Variables	Advantages	Disadvantages	Externally validated in children?
Onal et al.'s Nomogram [11]	SWL	Age, stone burden, history of stone treatment, gender, stone location (females only)	Requires 5 easily available pieces of information to calculate	Does not consider stone composition, only considers radio-opaque stones, tool covers 2 full pages	Yes
Dogan et al.'s Nomogram [12]	SWL	Gender, age, stone size, stone number, stone location, sprevious intervention	Quick and practical, gives clear approximate percentage of stone free rate	No prediction of complications, does not consider stone density, skin to stone distance or infundibulopelvic angle, only considers renal stones, only predicts success after a single session	Yes

PCNL and 1 for PCNL specifically [9—12]. 4 further studies were included as they externally validated the 2 scoring systems specific to SWL [13—16]. 3 adult endourology tools, all specific to PCNL, were identified as having been investigated in 11 studies using paediatric participants [5,6,9,17—27]. These studies assessed 1 tool or multiple tools in comparison to each other. Detailed breakdowns of all validation studies are provided in Table 3 and Supplementary Table 1.

Paediatric-specific tools

Stone kidney size (SKS) score [9] (applicable for PCNL)
This nomogram was designed to aid prediction of success and complications associated with paediatric PCNL. It was developed based on retrospective data collected over 20 years at 2 institutions in Turkey. Rather than including multiple parameters, SKS includes only 2 variables in the calculation. These are stone size/kidney size on longitudinal axis and number of stones. These were determined to be the 2 factors that most accurately predicted success based on multivariate analysis of 358 patients who had undergone PCNL. The final nomogram score places patients into 1 of 3 groups (SKS 2, 3 or 4). In this initial study, these groups corresponded to SFRs of 86.4%, 73%, and 62.9%, respectively. Their definition of SFR was based on zero residual fragments on follow up imaging. Complications rates according to these groups were 13%, 22.1%, 23.8%, respectively.

While an advantage of the system is its practical simplicity, this may also represent a limitation, as it does not factor staghorn anatomy or stone location into its calculation [28]. In the initial validation, chi-square analysis showed that the SKS system was able to predict SFR ($P < 0.001$) and complications ($P < 0.018$) with a high AUC value. Comparisons were also made with adult nomograms in this study and results were positive. More detail on the comparison between tools is provided further on in the paper. Interestingly, the only true external validation study of SKS was performed in an adult population and concluded that it was inferior to S.T.O.N.E., CROES and the S-RESC system [29].

Capital Medical University Nomogram (CMUN) [10] (Applicable for PCNL and URS)
In 2021, Zhang et al. developed a nomogram to predict outcomes (SFR and complication rates) associated with endourological surgery for upper urinary tract calculi. This used prospectively collected data from URS, mini PCNL and micro PCNL. The nomogram is based on the following variables: operation type, stone mass, intraoperative irrigation, operative duration, and body mass index (BMI). Unlike SKS, this tool used computed tomography (CT) to measure stone burden, which offers less generalisability to other units treating paediatric KSD that mostly use ultrasonography (US). Furthermore, although 348 patients were included in the development analysis, a disproportionate number (275) of patients underwent URS rather than PCNL. This inevitably introduces bias and skews results. The study also excluded patients with musculoskeletal abnormalities, again limiting applicability to paediatric KSD where such comorbidities are more common. The main advantage of tool (with regards to PCNL) is that it is specific to miniaturised equipment. As mini and micro PCNL are becoming increasing precedent in the paediatric setting, this has encouraging implications for its longevity and investigation in the future. It is yet to be externally validated, however [30].

Onal et al.'s nomogram [11] (applicable for SWL)
This was the first paediatric-specific nomogram to be developed. It was achieved by performing multivariate analysis from data of 381 patients treated with SWL between 1992 and 2008. This scoring system is based on the following parameters: age, stone burden, previous stone treatment, gender and stone location. Internal validation was performed using the bootstrapping method with 200 replicates. Nomogram scores and associated predicted SFR probabilities were well correlated with actual observed stone free probabilities, based on the mean, 2.5% and 97.5%

Table 2 Nomograms available for PCNL and URS. *White = paediatric-specific, grey = adult* (URS — Ureteroscopy, PCNL — Percutaneous nephrolithotomy).

Tool	Procedure	Tool Variables	Advantages	Disadvantages	Externally validated in children?
Stone kidney size score (SKS) [9]	PCNL	Stone kidney index (SKI), number of stones	Only 2 variables, can be calculated from any imaging modality, individual specific, able to predict success and complication rates	Only longest stone diameter considered for SKI, does not consider stone location	No
Capital medical university nomogram (CMUN) [10]	Mini-PCNL, Micro-PCNL, URS	BMI percentile, operation type, stone location, intra-operative irrigation volume, operation duration	Specific to miniaturised PCNL equipment, includes BMI and irrigation volume	Not procedure specific, disproportionate number of patients treated with URS used in design and internal validation, does not consider length of tract	No
Guy's stone score (GSS) [5]	PCNL	Stone number, stone location, typical/atypical anatomy, presence of a staghorn calculus, comorbidity (spina bifida/spinal injury)	Simple 4-point score, easily applied, standardised and reproducible, able to predict complications	Based on variable imaging modalities, does not consider stone density	Yes
CROES nomogram [6]	PCNL	Stone number, stone burden, stone location, presence of a staghorn calculus, prior treatment, case volume/year	Considers surgeon experience	No prediction of complications, does not consider variant anatomy, stone density or hydronephrosis, uses KUB to determine stone free rate	Yes
S.T.O.N.E nephrolithometry [17]	PCNL	Stone size, tract length, obstruction, number of involved calyces, stone density	Simple 5-parameter score, easily applied, individual specific	No predication of complications, does not consider variant anatomy, unclear how hydronephrosis is measured, requires CT imaging	Yes

quartiles e.g., low nomogram score (0–2) predicted SFR probability after one SWL session was 76.5%, compared to an observed SFR probability of 75.7% (session 2 = 94.1/95.7%, session 3 = 98.7/97.7%). Yaneral et al. were the first group to externally validate this tool, showing that scores were significantly higher in patients with failed SWL treatment compared to those who had successful treatment (4.14 vs. 3.02, P = 0.01) [13]. Multivariate analysis showed that nomogram score was an independent factor predicting SFR associated with SWL (OR 1.747, P = 0.001, AUC 0.993, P = 0.01). These findings were replicated by Jayasimha et al., who also showed the Onal nomogram to be an independent and significant predictor of stone free status on multivariate analysis [14]. However, in the study reported by Ceyhan et al., significance was not reached in logistic regression analysis [15]. Correlation with complication rate was not investigated in any study.

Dogan et al.'s nomogram [12] (applicable for SWL)

This tool uses 6 variables (gender, age, stone size, stone number, stone location and previous intervention) to predict SFR after a single session of SWL. This was also a retrospective study using multivariate analysis to identify these parameters as independent predictors of SFR. Internal validation was performed via the bootstrapping method with 1000 replicates. This showed the nomogram to be very close to the ideal, with a bias-corrected c-index value of 0.69. The tool was initially externally validated by Yaneral et al. [13]. Scores were shown to be significantly higher in patients with failed SWL compared to successful SWL

Table 3 Validation studies for SWL nomograms (US — Ultrasonography, KUB — Kidney-Ureter-Bladder X-Ray, IVU — Intravenous Urography, CT — Computed tomography, URS — Ureteroscopy, PCNL — Percutaneous nephrolithotomy, SWL — Shockwave lithotripsy, SFR — Stone free rate, CKD — chronic kidney disease).

Author, Year	Country	Tool(s)	Study Design	Participant Variables	Stone Variables	Imaging Variables	Treatment Variables	Methodology	Key Results
Onal et al. [11], 2013	USA	Eponymous nomogram	Concept, design, and internal validation	Total = 381 children <18years, median age = 8 years, 47% = female, 53% = male, 18% = previous stone treatment, excluded abnormal anatomy and radiolucent stones	88% = single stone, 22% = multiple stones, 65% = stone burden up to 1 cm [2], 25% = 1.1–2 cm [2], 41% = >2 cm [2], 45% = renal pelvis/upper ureter, 28.1% = calyx (any), 14.9% = mid/lower ureter, 12% = multiple	Pre-operative KUB and IVU, Post-operative IVU and US	Single operator, fluoroscopic guidance, median energy = 17.2 kV, median shocks per session = 1600	Pre-operative data and imaging was obtained for patients treated with SWL between March 1992 and February 2008 retrospectively. Stone free rate was determined by evaluating post-operative imaging performed 12 weeks post procedure. Failure was defined as residual stones after 3 sessions of SWL regardless of size. Univariate and multivariate proportional hazards models were used to analyse patient, stone and treatment variables. The multivariate model was used to create the nomogram predicting the probability of treatment success according to the number of treatment sessions and to evaluate each patient and predict their probability of success. Internal validation was performed by the	Nomogram scores and associated predicted stone-free probabilities were well correlated with observed stone free probabilities based on the mean, 2.5% and 97.5% quartiles from 200 bootstrap samples. E.g. low nomogram score (0–2) predicted/observed stone free probability after session 1 = 76.5/75.7%, session 2 = 94.1/95.7%, session 3 = 98.7/97.7%

								bootstrap method with 200 replicates.	
Dogan et al. [12], 2015	Turkey	Eponymous nomogram	Concept, design, and internal validation	Total = 383 renal units from children <8 years, mean age = 48months, 56.3% = male, 45.7% = female, 5.4% = anatomical variant, 84.6% = metabolic abnormality, 24% = previous stone treatment, excluded cysteine stones and urinary diversion	90.3% = single stone, 9.7% = multiple stones, mean size = 9 mm	Pre-operative imaging not specified, Post-operative KUB and US	US or fluoroscopic guidance, mean energy = 1.4 J, mean number of shocks per session = 1790	Pre-operative data and imaging was obtained for patients treated with SWL between January 2009 and August 2013 retrospectively. Stone free rate was determined by evaluating post-operative imaging performed at 3 months post-procedure. Univariate and multiple logistic regression analysis was used to determine variables affecting treatment success. The nomogram was developed based off this modelling. Internal validation was performed by the bootstrap method with 1000 replicates.	Internal validation showed that the nomogram was very close to the ideal with a bias-corrected c-index value of 0.69.
Yanaral et al. [13], 2018	Turkey	Onal et al.'s nomogram, Dogan et al.'s nomogram	Retrospective	Total = 219 children <18 years, mean age = 82.7 months, 49.3% = male, 50.7% = female, 14.1% = previous SWL, 5% = previous URS, 3.6% = previous PCNL, 1.8% = previous surgery, excluded radiolucent stones, abnormal	Size 1.07 ± 0.32 cm [2], 92.7% = single stone, 7.3% = multiple stones, 12.7% = upper calyx, 30.1% middle calyx, 20% lower calyx, 33.7% renal pelvis, 3.1% = multiple site	Pre-operative US and IVU, Post-operative US	Single operator, US & fluoroscopic guidance, energy = 13−20 kV, average shocks per session = 1800−2000	Scores for each system were calculated retrospectively for every patient using patient data and pre-operative imaging. Scoring was performed by an observer who was blinded to the post-SWL outcomes. Scores were then compared to residual stones	Onal scores were significantly higher in treatment failure (4.14 vs. 3.02, P = 0.01). Multivariate analysis showed Onal score was an independent factor

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Table 3 (*continued*)

Author, Year	Country	Tool(s)	Study Design	Participant Variables	Stone Variables	Imaging Variables	Treatment Variables	Methodology	Key Results
				anatomy, and urinary diversion				rates post-SWL. Failure was defined as residual stones after 3 sessions of SWL on post-operative imaging.	predicting SWL failure (OR 1.747, 95% CI 0.081–0.424, P = 0.001) Dogan scores were also significantly higher in treatment failure (167.44 vs. 120.87, P = 0.01). Multivariate analysis showed Dogan score was an independent factor predicting SWL failure (OR 1.683, 95% CI 0.19–1.787, P = 0.001)
Jayasimha et al. [14]. 2021	India	Onal et al.'s nomogram, Dogan et al.'s nomogram	Retrospective	Total = 66 children <15 years, mean age = 5.5 years, 76.3% = male, 23.6% = female, mean BMI = 14.5, 10.5% = CKD, 55.2% = hydronephrosis, 21% = prior stone treatment	36.84% = <1 cm, 38.16% = 1–1.5 cm, 9.2% = >1.5 cm, 9.2% = staghorn, median stone size = 12 mm, median stone burden = 70 mm [2]	Pre-operative US and IVU or CT Post-operative US and/or KUB	Single operator, US or fluoroscopic guidance, energy = 12–16 kV, frequency = 60 shocks/min, shocks per session = 1500 for renal stone, 2000 for ureteric stone	Scores for each system were calculated by the first author retrospectively for every patient using patient data and pre-operative imaging. Scores were then compared to success rates. Success was defined as no residual fragments seen on post-operative imaging.	Multivariate analysis showed both nomograms were independent and significant predictors of treatment success (Onal after 1 SWL: OR 0.53, 95% CI 0.29–0.96, P = 0.037. Onal after 3 SWL: OR 0.56, 95% CI 0.38–0.82, P = 0.003. Dogan:

									OR 0.992, 95% CI 0.984 −0.999, P = 0.048).
Ceyhan et al. [15], 2021	Turkey	Onal et al.'s nomogram, Dogan et al.'s nomogram	Retrospective	Total = 415 renal units from children <18, median age = 64.7 months, 52.7% = male, 47.3% = female, 22.7% = prior stone treatment, excluded 'anomalous' kidneys	78.8% = single stone, 21.2% = multiple stones, mean size = 10 ± 3.7 mm, mean surface area = 380 ± 72.7 mm [2], Renal pelvis = 52.3%, upper pole = 3.6%, middle calyx = 14%, lower pole = 16.1%, ureter = 14%	Pre-operative KUB, US or CT, Post-operative US and KUB	US or fluoroscopic guidance, frequency = 60 shocks/min, shocks per session = 1500-2500	Scores for each system were calculated retrospectively for every patient using patient data and pre-operative imaging. Scores were then compared to residual stones rates post-SWL (assessed on imaging performed 1 week and 4 weeks post-operatively).	Estimated SFR with the Dogan nomogram was higher in stone-free children (median 60 vs 50, P = 0.000). Stone-free children had lower Onal stone-free probability score (median 76.5 vs 44.7, P = 0.001). Inter-class correlation coefficient between nomograms was 0.61 (95% CI 0.53−0.68, P = 0.000). In logistic regression analysis only Dogan score was an independent predictor of stone free status (OR 1.013, 95% CI 1.001−1.025, P = 0.045).
Cetin et al. [16], 2020	Turkey	Dogan et al.'s nomogram	Retrospective	Total = 68 children <18 years, median age = 50 months, 41.2% = male,	89.7% = single stone, 10.3% = multiple stones, mean size = 10.05 ± 3.48 mm, upper	Pre-operative JUN and US or IVU, Post-operative KUB and US	Fluoroscopic guidance, median energy = 2 J, median shocks per	Each variable in the nomogram was determined retrospectively using patient data and pre-	Only age and stone size were significantly associated with treatment

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Table 3 *(continued)*

Author, Year	Country	Tool(s)	Study Design	Participant Variables	Stone Variables	Imaging Variables	Treatment Variables	Methodology	Key Results
				58.8% = female, 16.2% = prior stone treatment	calyx = 10.3%, middle calyx = 5.9%, lower calyx = 10.3%, renal pelvis = 55.9%, ureter = 17.6%		session = 2000	operative imaging). These variables were then compared to stone free rate (assessed on imaging 2 weeks after treatment).	failure on multiple logistic regression analysis (Age <18: OR 2.28, 95% CI 1.19 −42.04, P = 0.031. Stone size: OR 7.68, 95% CI 2.76 −21.40, P < 0.001). Bias-corrected c-index value of 0.698.

(167.44 vs. 120.87, P = 0.01) and multivariate analysis showed nomogram score was an independent factor predicting SWL success (OR 1.683, P = 0.001, AUC 0.699, P = 0.01). Concurrent results were reached in 3 subsequent studies [14–16]. Correlation with complication rate was not investigated in any of these studies.

Adult tools

Guys Stone Score (GSS) [5] (applicable for PCNL)

This was the first adult nomogram designed for PCNL. It was developed based on previously published data and expert opinion. The result is a simple and reproducible four grade system, which also takes account of complex patients e.g., spinal injury.

A key difference is that it includes all the stones in the affected renal unit and not only the target stone. 10 Studies have subsequently investigated the efficacy of GSS in paediatric patients [9,18–26]. 5 of these studies were comparative to other nomograms and a detailed discussion of these results is included further on in the paper [9,21–24]. The remaining 5 studies considered GSS independently [18–20,25,26]. Results were supportive for the predictive accuracy of SFR in 4 studies, with Yadav et al. and Ebeid et al. also finding a significant correlation between GSS and complication rate [18–20,26]. However, these findings are contradicted by Goyal et al., who failed to demonstrate a significant association between GSS and complications on multivariate analysis in their study looking exclusively at pre-operative variables and association with complications [25].

Clinical research of Endourological Society (CROES) nomogram [6] (applicable for PCNL)

This nomogram was designed using data from a worldwide registry, which included more than 2800 patients. As such, an advantage of the nomogram is global applicability, however it has received criticism because the dataset was not purposefully collected for the purpose of designing a nomogram. An obvious difference of CROES compared to other tools is its use of a continuous scoring scale rather than separate groups. It also takes into consideration the surgical case volume and centres performing less than 10 PCNL procedures per year were excluded from the study. 5 studies have subsequently validated CROES in paediatric patients [9,21–24]. On multivariate analysis, CROES was found to be an independent predictor of PCNL success in all 5 studies and it compared favourably when compared to other tools. However, it appears to be less effective in predicting likelihood of complications, with only 1 study finding it to be a significant independent predictor of complication rate (P < 0.001) [9]. Results of the 5 studies that compared CROES to another nomogram are described more fully further on in the paper.

S.T.O.N.E nephrolithometry [17] (applicable for PCNL)

Based on CT imaging, 5 variables make up this system; Stone size (S), Tract length (T), Obstruction, or hydronephrosis (O), Number of stones (N) and Essence, or stone density (E). The system has become increasingly popular in clinical practice and is also available as an online calculator. Limitations include that it was developed in a small, single-surgeon cohort and that there also are other tools available in endourology which share the same name. Its reliance on CT may also limit applicability to paediatric KSD management. 4 studies have so far examined S.T.O.N.E in paediatric patients [9,23,24,27]. As with CROES, it has had promising results with regards to prediction of SFR when assessed in comparison to other nomograms. Assessed in isolation, Doulian et al. showed that S.T.O.N.E scores did correlate with operative complexity, but they failed to give concrete evidence relating scores to complication rates [27]. Furthermore, none of the other 3 comparative studies showed S.T.O.N.E to be a significant predictor of post-operative complications.

Comparison of nomograms and scoring systems by treatment modality

SWL

2 predictive nomograms (Onal and Dogan), both developed specifically for children, are available for SWL [11,12]. No adult nomograms have yet been applied to the paediatric setting. 3 studies directly compared the 2 tools [13—15]. In multivariate regression analysis, Yaneral et al. showed both tools to be independent predictors of SFR ($P = 0.001$) and both predicted SWL success with good accuracy (AUC 0.699 and 0.793, respectively) [13]. Jayasimha et al.'s multivariate analysis also showed both nomograms were independent and significant predictors of treatment success (Onal score after 1 session of SWL: OR 0.53, $P = 0.037$. Onal score after 3 sessions of SWL: OR 0.56, $P = 0.003$. Dogan: OR 0.992, $P = 0.048$) [14]. The Dogan nomogram had a higher specificity (93.3% vs. 66.2%), leading the authors to conclude it had a slight advantage over the Onal nomogram. This conclusion was also reached by Ceyhan et al. [15]. In their study, the inter-class correlation coefficient between nomograms was 0.61 ($P = 0.000$), but in logistic regression analysis only the Dogan score was an independent predictor of SFR (OR 1.013, $P = 0.045$). AUC for the Dogan nomogram was 0.628 ($P < 0.000$), whereas the AUC for Onal's nomogram was 0.580 ($P < 0.009$).

Overall, results are promising and supportive for both tools, but current evidence indicates that Dogan's nomogram is superior to Onal's. Dogan's tool also benefits from being developed with a more homogenous cohort and had more rigorous internal validation (1000 vs. 200 replicates in bootstrapping). Nevertheless, both have limitations that should be considered. Dogan's nomogram only predicts SFR after a single SWL session and Onal's nomogram does not consider number of stones and covers an entire 2 pages, limiting its practical value. Notably, neither tool includes parameters such as anatomical variation, stone composition and treatment settings (energy, number of shocks etc.). The output of both is only prediction of SFR, with no prediction of other post-operative variables, including complications.

PCNL

Two paediatric-specific nomograms are available for PCNL (SKS and CMUN) [9,10]. To date, neither has been externally validated and they have not been compared to each other. That said, in the development of the SKS tool, Citamak et al., did retrospectively compare GSS, CROES and S.T.O.N.E to the SKS nomogram in 122 patients [9]. Chi-square analysis showed that all 4 scoring systems predicted SFR ($P = 0.005$, <0.001, 0.031 and < 0.001, respectively) and all but the S.T.O.N.E score were able to predict complications (P values for GSS, CROES, S.T.O.N.E., and SKS $= 0.045$, <0.021, 0.540, and <0.018, respectively). SKS and CROES scores predicted success and complication rates with the highest AUC values (SFR/complication rate AUC for SKS, CROES, GSS, and S.T.O.N.E $= 0.716/0.657$, 0.742/0.664, 0.661/0.633 and 0.542/0.628, respectively.

2 other studies have compared all 3 adult nomograms in children, with somewhat conflicting results [23,24]. Aldaqadossi et al. found the S.T.O.N.E nomogram was most accurate in predicting SFR, with an AUC of 0.92 (GSS = 0.72. CROES = 0.78), whereas results from Shehat et al. indicate that CROES was more accurate, with an AUC of 0.847 (GSS = 0.756, S.T.O.N.E = 0.694). On decision analysis curves, the greatest net benefit was obtained when decisions were based on CROES, whereas the S.T.O.N.E nomogram demonstrated an inconsistent curve lying below the treat-all curve in the threshold probability interval between 60 and 70%. With regards to post-operative complications, Aldaqadossi et al. found only GSS was significantly correlated with complication rate ($P = 0.017$) (CROES: $P = 0.89$. S.T.O.N.E: $P = 0.437$), whilst Shahat et al. found no significant correlation with any of the tools. That said, they did demonstrate that all 3 nomograms were significantly correlated with operative time and requirement for blood transfusion.

The only other 2 studies comparing nomograms were produced by Utangac et al. and Caglayan et al. [21,22]. Both compared GSS and CROES only. Utangac et al. showed both scoring systems to be associated with SFR on multivariate analysis, however CROES was found to be more accurate with a higher AUC. Only the GSS was an independent predictor of complications (OR 1.9, $P = 0.02$). In their multivariate analysis however, Caglayan et al. showed that only the CROES score was an independent factor associated with SFR (OR 0.984, $P = 0.017$) and neither nomogram had predictive accuracy for complication rate.

Discussion

Meaning of the study

This is the first review to systematically present and evaluate all available nomograms and scoring systems in paediatric endourology. There are relatively few such tools designed specifically for children and only 2 of the 4 available have been validated externally. Furthermore, these tools were only designed for SWL. It is encouraging that, despite the small number of available tools, paediatric-specific nomograms are available for all the main treatment modalities (PCNL, SWL and URS). That said, there is still a significant paucity of studies relevant to URS. Indeed, the translation of adult PCNL nomograms to a paediatric setting has received the most interest and there has been a notable focus on SWL nomogram design and external validation from a paediatric-specific perspective.

Only one tool (CMUN) had applicability to URS, illustrating a significant void in the literature that requires attention, particularly given the increasing number of small paediatric stones that are treated ureteroscopically.

The lack of paediatric-specific tools is notable, as it is arguably of greater importance to have reliable and accurate nomograms available for the management of paediatric KSD than for adults, as complete stone clearance and minimisation of iatrogenic trauma is paramount [31—33].

Lessons can be learned from adult tools, which are available. Those that have achieved dissemination and successfully transitioned from the research setting to clinical practice include a core set of parameters and do not include too many variables. An illustrative example of a relatively impractical tool is the diagnostic acute care algorithm - kidney stones (DACA-KS), which was made for the adult setting and includes more than 20 variables. This certainly supports a personalised approach but has inherent limitations on its application in the day-to-day clinical setting and should be avoided [33].

The 'ideal' paediatric endourology nomogram must be easy and quick to use and thereby incorporate parameters that are easily obtained e.g., not reliant on complicated radiological measurements or formulae. Dependence on one type of imaging for radiological parameters or expensive software should be avoided in favour of information that can be derived from multiple and available sources, particularly US. Primary output should be prediction of SFR, but for invasive procedures this should certainly be combined with accurate prediction of complications (particularly bleeding in PCNL). Development and testing should be performed in a representative sample of paediatric stone-formers and therefore include patients with anatomical abnormalities and comorbidities associated with KSD. The tool should also be procedure-specific and be validated in studies using contemporaneous paediatric surgical equipment.

PCNL nomograms

The results for PCNL nomograms are mixed and firm conclusions regarding quality and applicability of tools in this setting are more difficult to reach. Application of CROES to the paediatric setting may be limited by its inclusion of PCNL volume (inherently lower in paediatric compared to adult practice) and lack of consideration for anatomical variation such as pelvi—ureteric junction obstruction/malrotation or scoliosis (more frequent in paediatric stone-formers).

Overall, our results show that there is no one tool that can give accurate predictions for SFR and post-operative complications. Although critically important, morbidity is not as significant as operative success and therefore if one nomogram were to be utilised, CROES would be recommended (albeit with significant caveats, as outlined above).

Current role of adult nomograms and scoring systems

As shown, 3 adult nomograms have been externally validated in children. All 3 tools were developed for PCNL and consequently have no role when SWL or URS is considered to be the most appropriate treatment modality, limiting their overall role in paediatric endourology.

The results of comparative studies indicate that the CROES nomogram has superiority in predicting SFR, however this is tempered by problems with its applicability to the paediatric setting, which have been described previously. These concerns are not unique. Firstly, these systems were not developed to account for changes in kidney size during childhood and differences in collecting system anatomy, particularly the higher incidence of renal abnormalities in paediatric stone-formers [28]. Furthermore, a higher percentage of paediatric KSD patients can be considered non-index, which is associated with the higher incidence of comorbidities [34]. CT is the gold standard diagnostic modality in the adult setting and all adult nomograms have used it in their development. This creates a clear challenge when translating use to paediatric practice where imaging with US is typically more common. The clinical definition of 'success' may also be different in children compared to adults.

Lastly, and with specific relevance to PCNL, adult tools were developed with adult instruments, whereas miniaturised equipment is increasingly used for mini and micro PCNL in children. In general, mini PCNL is defined by access sizes of up to 20Fr, with micro PCNL being smaller still. On this basis, the use of miniaturised equipment was variable in the adult nomogram validation studies. Most used a variety of sizes, some under and some over 20Fr, and only 2 studies specifically used miniaturised equipment [22,24]. Notably, none of studies categorised outcomes by access and equipment size, which presents another problem with the interpretation of results by paediatric urologists who may only use miniaturised equipment.

Areas for future research

As stated, this review has identified a substantial shortage of predictive tools available for URS, which is a significant problem given its increasing use in paediatric KSD management, particularly in the United States. Indeed, the only nomogram applicable to URS (CMUN) was not even specific to the procedure and has not been externally validated. At present therefore, there can be no significantly meaningful comment on the use of nomograms for paediatric URS and the focus of future research in this area should be the development of paediatric and modality-specific predictive tools for this technique.

It is also clear that the predictive focus of these nomograms is the likelihood of treatment success and complications (efficacy and safety) for each treatment option. This is clearly important and enables early identification of difficulty and risk that can then be mitigated as much as possible. It also facilitates realistic and accurate discussion with patients and parents. However, their predictive value beyond this is lacking and they therefore fail to completely address all the variables and questions involved in pre-operative planning as a whole, particularly the choice of treatment modality. A particularly interesting avenue for future investigation would be the development and feasibility of tools designed to aid this decision.

Increasingly, artificial intelligence is being applied to the development of predictive tools and this is likely to be increasingly researched in future [35]. Other areas that have been explored in the adult setting and would be valuable for paediatric patients include prediction of stone recurrence risk and patient/parent reported outcome measures (PROMs), particularly as there is a shortage of tools measuring quality of life for patients with KSD [36,37]. The lack of such tools is most likely resultant of the inherent challenges of developing PROMs in a paediatric population, where there is a need for age and developmentally appropriate content in an acceptable format that is sufficiently condition-specific [38].

Conclusion

This review highlights that a limited number of paediatric-specific nomograms and scoring systems, which can be used for predicting outcomes associated with endourological interventions for KSD, are available. Furthermore, 3 adult nomograms, specific to PCNL, have been validated in a paediatric population. Nevertheless, findings show that nomograms specific to URS are lacking and under-investigated. Paediatric-specific PCNL nomograms are also limited and lack external validation. Current evidence is supportive for paediatric-specific SWL nomograms, particularly *Dogan* et al.'s nomogram, but findings are less clear and somewhat contradictory for the overall efficacy of adult PCNL nomograms in the paediatric-setting. Overall, nomograms and scoring systems take us one-step closer to a personalised approach for paediatric KSD but more paediatric-specific tools and rigorous validation studies are required, particularly for URS and PCNL.

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Consent

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Ethical approval

Not applicable.

Conflicts of interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jpurol.2022.08.021.