THERAPEUTIC ADVANCES in
Urology

Systematic Review

The role of 'artificial intelligence, machine learning, virtual reality, and radiomics' in PCNL: a review of publication trends over the last 30 years

Ther Adv Urol

2023, Vol. 15: 1–9

DOI: 10.1177/
17562872231196676

Carlotta Nedbal, Clara Cerrato, Victoria Jahrreiss, Daniele Castellani, Amelia Pietropaolo, Andrea Benedetto Galosi and Bhaskar Kumar Somani

Abstract

Introduction: We wanted to analyze the trend of publications in a period of 30 years from 1994 to 2023, on the application of 'artificial intelligence (AI), machine learning (ML), virtual reality (VR), and radiomics in percutaneous nephrolithotomy (PCNL)'. We conducted this study by looking at published papers associated with AI and PCNL procedures, including simulation training, with preoperative and intraoperative applications.

Materials and Methods: Although MeSH terms research on the PubMed database, we performed a comprehensive review of the literature from 1994 to 2023 for all published papers on 'AI, ML, VR, and radiomics' in 'PCNL', with papers in all languages included. Papers were divided into three 10-year periods: Period 1 (1994–2003), Period 2 (2004–2013), and Period 3 (2014–2023).

Results: Over a 30-year timeframe, 143 papers have been published on the subject with 116 (81%) published in the last decade, with a relative increase from Period 2 to Period 3 of +427% ($p = 0.0027$). There was a gradual increase in areas such as automated diagnosis of larger stones, automated intraoperative needle targeting, and VR simulators in surgical planning and training. This increase was most marked in Period 3 with automated targeting with 52 papers (45%), followed by the application of AI, ML, and radiomics in predicting operative outcomes (22%, $n = 26$) and VR for simulation (18%, $n = 21$). Papers on technological innovations in PCNL ($n = 9$), intelligent construction of personalized protocols ($n = 6$), and automated diagnosis ($n = 2$) accounted for 15% of publications. A rise in automated targeting for PCNL and PCNL training between Period 2 and Period 3 was +247% ($p = 0.0055$) and +200% ($p = 0.0161$), respectively.

Conclusion: An interest in the application of AI in PCNL procedures has increased in the last 30 years, and a steep rise has been witnessed in the last 10 years. As new technologies are developed, their application in devices for training and automated systems for precise renal puncture and outcome prediction seems to play a leading role in modern-day AI-based publication trends on PCNL.

Keywords: Artificial intelligence, kidney calculi, machine learning, PCNL, radiomics, simulation, urolithiasis

Received: 12 May 2023; revised manuscript accepted: 3 August 2023.

Correspondence to:
Bhaskar Kumar Somani
Professor and Consultant Urological Surgeon, University Hospital Southampton NHS Trust, Tremona Road, Southampton, SO16 6YD, UK
bhaskarsomani@yahoo.com

Carlotta Nedbal
Urology Unit, Azienda Ospedaliero-Universitaria delle Marche, Polytechnic University of Marche, Ancona, Italy

Department of Urology, University Hospitals Southampton, NHS Trust, Southampton, UK

Clara Cerrato
Department of Urology, University Hospitals Southampton, NHS Trust, Southampton, UK

Victoria Jahrreiss
Department of Urology, University Hospitals Southampton, NHS Trust, Southampton, UK

Department of Urology, Comprehensive Cancer Center, Medical University of Vienna, Vienna, Austria

Daniele Castellani
Urology Unit, Azienda Ospedaliero-Universitaria delle Marche, Polytechnic University of Marche, Ancona, Italy

Amelia Pietropaolo
Department of Urology, University Hospitals Southampton, NHS Trust, Southampton, UK

Andrea Benedetto Galosi
Urology Unit, Azienda Ospedaliero-Universitaria delle Marche, Polytechnic University of Marche, Ancona, Italy

Introduction

Advancements in technologies have led to the integration of artificial intelligence (AI) in healthcare, defined as the computational ability of a machine to mimic human cognitive tasks in medical practice. Several applications of AI can be found in the management of renal stones, especially in percutaneous nephrolithotomy (PCNL) procedures.[1]

Machine learning (ML), along with deep learning (DL), artificial neural network (ANN), and natural language processing, is an automated system, able to help with the diagnostic process and predict treatment outcomes by processing big data to obtain patient-specific information.[2] Information generated with those devices can be further incorporated into radiomic models to guide urologists through the choice of management plans.[3] Albeit these new technologies have increasingly been applied to urolithiasis, the most common usage of AI nowadays is training and simulation, with different intelligent devices such as virtual reality (VR), augmented reality (AR), mixed reality (MR), and three-dimensional patient-specific models (3D).[4] Several studies have investigated how simulation impacts the surgical training of residents, who have to face the complex steps of endourological procedures, especially with regard to PCNL.

PCNL is the treatment of choice for larger renal stones (>20 mm) and lower-pole stones with unfavorable anatomy. It is a complex procedure, with different steps that require expertise and precision.[5] Moreover, the trifecta of a good minimally invasive PCNL is to perform a precise percutaneous renal access (PCA) and achieve a stone-free status with a single uncomplicated session and a short hospital stay. Complications can occur during PCA, mostly due to the risk of endangering the surrounding organs and a higher rate of bleeding during access and tract dilatation compared to other endourological procedures.[6] Still, PCNL stone-free rates are usually over 90% and it can be used to treat complex stones in both adults and children.[7]

The role of AI in PCNL procedures has been investigated by a few articles in recent years, with particular focus on the ability of VR and 3D models to help obtain a precise PCA, as well as the role of ML and radiomics in predicting treatment outcomes and conceptualize a patient-specific surgical plan.[8] Great interest has also been shown in the development of training protocols for both residents and trained urologists. VR and 3D models translate into shorter learning curves in the context of a low-risk training setting.[9] While the importance of the integration of these new technologies in PCNL is now widely acknowledged, current literature lacks analysis regarding the bibliometric trends of publications in the last decades. With the present review, we aim to fill this gap and report how the publication trends about the applications of AI and its subsets in PCNL procedures have changed over time.

Materials and methods

A review of the literature was conducted using MeSH terms, title words, and keywords in PubMed over the last 30 years, from January 1994 to February 2023 for all published papers on 'PCNL'.

The authors developed a search protocol, and the study was performed in line with the Cochrane methodology and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework.[10] All relevant abstracts regarding specific topics were collected year by year from 1994 to 2023 through research on the online database PubMed. Keywords used for searching included the following: 'Percutaneous nephrolithotomy', 'PNL', 'PCNL', 'Kidney calculi', and 'Renal stones'. MeSH terms used in this screening process were as follows: 'Artificial Intelligence', 'Radiomic', 'Virtual Reality', 'Augmented Reality', 'Mixed Reality', 'Machine Learning', 'Deep Learning', 'Artificial Neural Network', 'Natural Language Processing', 'Simulation', '3D Model', 'Robotic PCNL', and 'Automated Needle Targeting'. As the authors did not apply any language restrictions, all English and Non-English full-length articles with published abstracts in an indexed journal were included in the study. Case reports, case series, and reviews were all included. Studies without a published abstract and animal studies were excluded.

All full-length English language studies and all non-English studies with abstracts written in the English language were considered for inclusion. Inclusion criteria were listed as studies reporting on AI, machine learning, virtual reality, and radiomics in PCNL with topics: preoperative surgical planning, patient-specific protocols or models, counseling, prediction of outcomes, intraoperative application of AI for automated targeting and laser settings, and training and simulation in PCNL intervention. Studies performed on animals and studies on the application of AI in treatments other than PCNL were excluded.

Research of literature was performed independently by two authors (CN and CC) to identify studies and discrepancies were resolved after input and discussion with the senior author (BKS) (Figure 1). After inclusion in the database, each article was matched to one topic: (1) clinical (preoperative setting), (2) surgical procedure (intraoperative setting), and (3) training (simulation for educational purposes). Articles were then labeled according to the year of publication: Period 1 (1994–2003), Period 2 (2004–2013), and Period 3 (2014–2023).

Extracted data were collected in an Excel database and analyzed with XLStat statistic software. An independent *t*-test analysis was performed to evaluate the difference (Δ) of means in the number of publications between Period 1 and Period 2, and then between Period 2 and Period 3. A further statistical analysis was then executed through the Mann–Kendall trend test, to identify any positive or negative trend during the overall timeline. The threshold value of significance was assessed at $p < 0.05$.

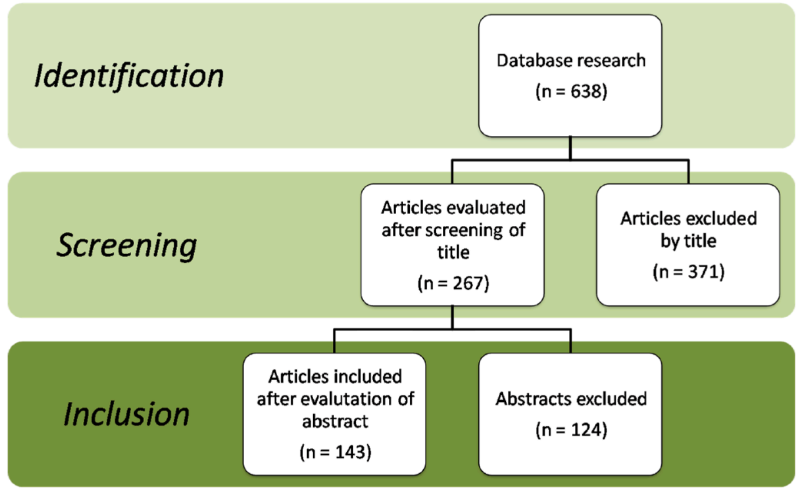

Figure 1. PRISMA flowchart for identification of the studies.

Results

In our research, 143 articles have been published over the last 30 years on the application of AI, radiomics, VR, ML, and DL in PCNL (Table 1). In total, 17 papers were written in a non-English language: four in Chinese, three in French, two in German, one in Italian, one in Polish, five in Russian, and one in Spanish.

Only five papers (3.5%) were published in Period 1, 22 (15.4%) in Period 2, and 116 (81.1%) in Period 3, with a significant increasing trend (Figure 2) in both temporal comparisons (Δ1:2 = + 340%, $p = 0.0176$ and Δ2:3 = + 427%, $p = 0.0027$). The Mann–Kendall trend test confirmed a positive trend in publications over 30 years ($p < 0.0001$).

Papers reporting on the application of AI and its subsets in a preoperative setting were 45 (31.5%). In Period 1, only two papers were found, both about the automated prediction of PCNL outcomes, while during Period 2 no article was found in this category. The remaining 43 papers were published during Period 3, with nine articles discussing 'Innovations in PCNL', 28 about 'Prediction of outcomes', and six on the development of 'Personalized protocols'. Statistical analysis found a nonsignificant decrease in publication from Period 1:2 (Δ1:2 = −100%, $p = 0.151$) and a following increasing trend in Period 3 (Δ1:3 = + 2050%) with statistical inference comparing Period 1:3 ($p = 0.0123$) and Period 2:3 ($p = 0.0090$). This positive trend was found again in 'Innovations' ($p = 0.0044$) and 'Prediction of outcomes' ($p = 0.0074$) papers between Period 2 and Period 3.

Publications on the surgical application of AI represented the largest share, with 70 papers in three decades. Among the first two periods, an increasing yet nonsignificant trend of +400% was witnessed (Period 1 $n = 2$ *versus* Period 2 $n = 15$, $p = 0.0615$). The rise in the number of published papers was indeed significant from Period 2 to Period 3, with 15 and 52 papers, respectively (Δ1:3 = + 247%, $p = 0.0055$) (Figure 3). All the papers published in this category could be also indicated as papers on 'Automated Needle Targeting' in PCNL procedures.

Papers on the application of AI for educational purposes were 28, with 21 papers published in Period 3, 7 in Period 2, and none in Period 1. Consequently, an analysis of statistical differences was performed only between the last two time periods. The increase in publication from Period 2 to Period 3 was significant at +200% ($p = 0.0161$). 39.3% of the papers used 3D-printed patient-specific models to plan and simulate a procedure, while the remaining 60.7% used VR simulators for both surgical planning and resident

Table 1. Distribution of papers published in preoperative, surgical, and training settings in different years.

	Total papers	Preoperative	Surgical	Training
1994	1		1	
1995	0			
1996	0			
1997	1	1		
1998	0			
1999	1		1	
2000	2	1	1	
2001	0			
2002	0			
2003	0			
2004	1			1
2005	2		2	
2006	2		2	
2007	0			
2008	3			3
2009	1			1
2010	2		2	
2011	1		1	
2012	3		2	1
2013	7		6	1
2014	6	1	3	2
2015	5	1	3	1
2016	7	3	3	1
2017	12	3	5	4
2018	6	1	4	1
2019	14	6	5	3
2020	18	7	7	4
2021	16	4	10	2
2022	30	16	11	3
	141	44	69	28

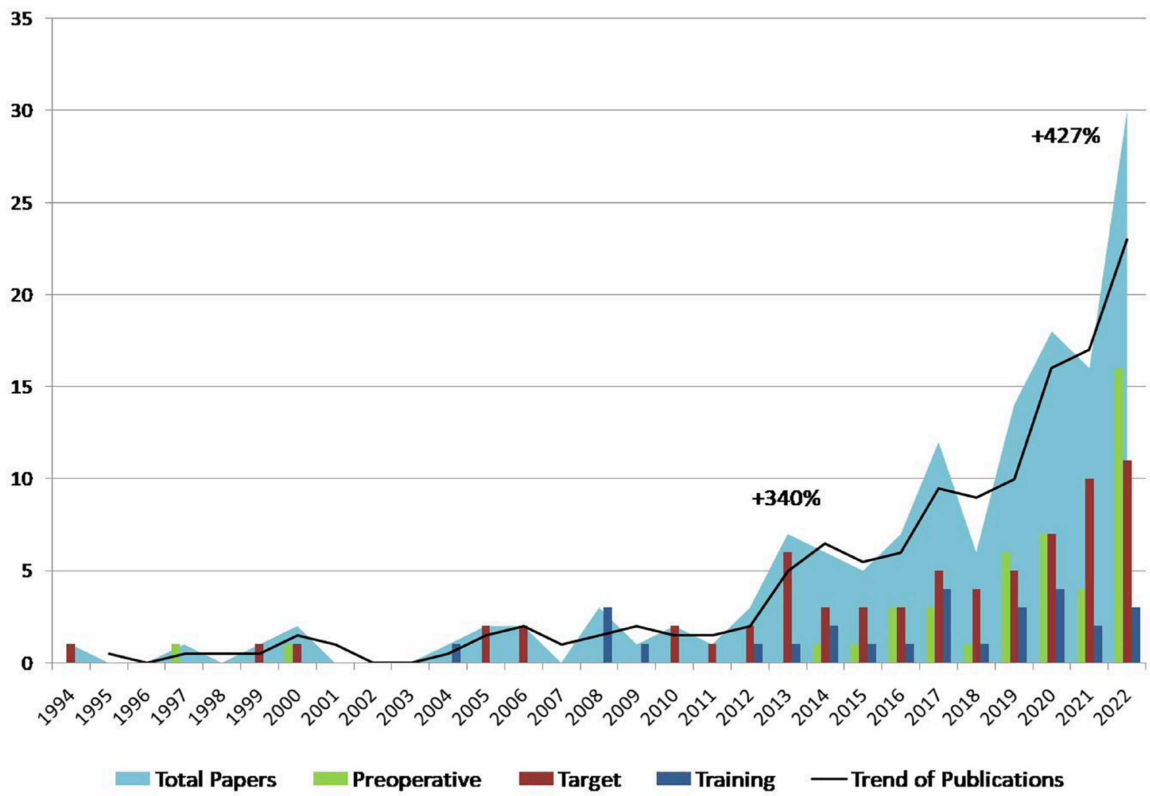

Figure 2. Number of publications in a different setting year by year. The area in light blue represents the total papers. The black line shows the increasing trend of publications.

training. The increasing number of simulations based on 3D-printed models increased by +900% from Period 2 to Period 3 ($p=0.0044$), while the higher number of published papers with VR simulators was found devoid of statistical significance (+83%, $p=0.2945$).

A statistically significant positive correlation in the trend of publications regarding the application of AI in a preoperative setting ($p=0.0001$), intraoperative setting ($p<0.0001$), and for educational purposes ($p<0.0001$) was pointed out by the Mann–Kendall trend test. Table 2 summarizes the results of the trend analysis.

Discussion

The interest in publications regarding the aid of AI in PCNL procedures has risen in the last three decades, and in particular in the last 10 years.[11] This interest reflects a growing number of published articles that can be found in the literature. The present review is one of the first studies to analyze the increasing bibliometric trend on this subject.

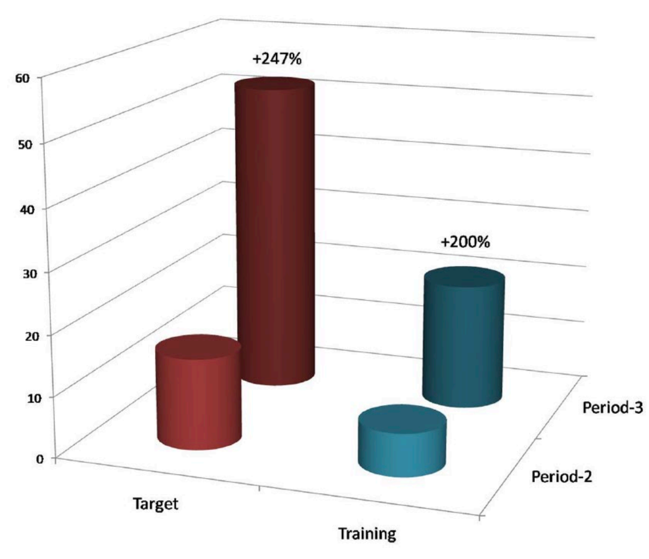

Figure 3. Comparison of the number of publications in Period 2 *versus* Period 3, in both 'Automated Needle Targeting' papers (purple) and 'Training' papers (blue).

Numerous published articles in the last decades have discussed the role of AI in the preoperative

Table 2. Results of the statistical analysis performed. Independent *t*-test analysis shows the significance of the change in a number of total publications and of each subset between the first two decades (1994 and 2003 *versus* 2004–2013) and the last two time periods (2004–2013 versus 2014–2023). The relevance of the positive trend of increased publication during the 30-year timeline is shown by Mann–Kendall test.

Subject	Period 1 *versus* Period 2		Period 2 *versus* Period 3		Mann–Kendall tend test
	Increase (%)	Independent *t*-test	Increase (%)	Independent *t*-test	Positive trend (p)
Total publications	+340%	$p=0.0176$	+427%,	$p=0.0027$	$p<0.0001$
Preoperative setting	−100%	$p=0.151$	N/A	$p=0.0090$	$p=0.0001$
Intraoperative setting	+400%	$p=0.0615$	+247%	$p=0.0055$	$p<0.0001$
Training	N/A	N/A	+200%	$p=0.0161$	$p<0.0001$

management of renal stones, pointing out the improvements in clinical practice, driven by the introduction of ML, ANN, DL, and radiomics in the diagnostic process.[12] Algorithms can be used to precisely diagnose renal calculi and characterize their features. Automated systems have in fact been repeatedly recognized as valid and superior to the human eye diagnostic ability.[13] More recently, the capability of AI in predicting surgical outcomes has been explored. ML techniques and algorithms have been applied to develop decision support systems that can comprise variables from the patient's history, laboratory findings, and stone composition to predict postoperative stone-free status and risk of stone recurrence.[14]

With regard to the preoperative setting, some studies have also focused on the usage of 3D models in counseling. It has in fact been studied on how a realistic and specific model could help patients understand their own anatomical features and thereby the procedure itself, with positive reflection on expectations and postoperative satisfaction.[15] These promising results may lead to the embedding of 3D models in patient counseling and consent, with improvement in patient–doctor relationships.

As our review pointed out, one of the main areas of publication was the application of AI in renal access. Performing a correct PCA is often challenging, especially in the case of complex staghorn stones or anatomical anomalies.[16] 3D-printed models have been introduced in the preoperative management of renal stones to better understand the possible puncture site and angle, and thereby avoid major complications.[17] Randomized controlled studies have reported improvement in surgical outcomes with regard to operating time, blood loss, and complications.[18] VR, MR, and AR simulators are indeed more expensive compared to 3D models but come with the advantage of intraoperative applicability of simulation images overlapped to real-time features. These devices allow the surgeons to improve their understanding of the three-dimensional anatomical structures, helping them in performing a more accurate PCA.[19]

The most recent innovation for PCA is represented by robotic-assisted PCNL, a system that combines 3D visualization of detailed anatomy with the accurate movement of robotic arms.[20] This device uses AI to integrate fluoroscopic images with markers of stone position, allowing automated needle targeting and gaining a hyper-accurate PCA. Even if a manual identification of the targeted calyx is needed, the progress reached by robotic PCNL is undeniable.[21] The attraction garnered from this device is proven by the high number of randomized trials and reviews published in the last few years, to assess the real value of the automated needle targeting.[22]

Finally, we report an increasing interest in AI-based training studies. From the first bench simulators, with low fidelity in terms of realism and patient-specific anomalies, great strides have been made. One of the most analyzed simulators for PCNL education is the PERC mentor,[23] a VR simulator especially developed for PCA that has attracted attention and been used in several validation studies. Training on simulators enables residents to practice high-fidelity models in a low-stress environment, gaining the fundamental skills required for difficult endoscopic procedures like PCA.[24] Interest in simulation-based training has led to the development of standardized protocols that can be introduced in residents' education and evaluation, with implications in well-known training programs worldwide.[25] Thereby, the benefits given to both patients and trainees are remarkable.

While the applications of AI in the medical field as well as in the management of urolithiasis and in particular with PCNL are being researched and developed in various parts of the world, the extent of their worldwide adoption may vary.[26] Countries with more funds available to invest in research have understandably been at the forefront of AI adoption in medicine since its first introduction, while it is more difficult for developing countries to invest in research and trials.[27] The United States is still the leader in the application of this new technology, with Food and Drug Administration (FDA) approving AI-based medical devices and algorithms.[28] The Asian continent closely follows, where China, India, and Japan have made significant investments in AI medical research, developing devices for early disease detection, image analysis, and telemedicine. Several countries in Europe, such as the United Kingdom, Germany, and France, are also exploring AI's potential, gradually including it in educational programs and diagnostic tools.[29] These examples represent a fraction of global AI adoption in medicine, and many other countries are actively implementing AI technologies in their healthcare systems. On the other hand, aside from an economic barrier to AI application in medicine, other factors still represent an obstacle to its spread worldwide. Potential barriers can be classified as technological and methodological, for example, the high cost associated with the development and maintenance, and the limited reproducibility due to the complexity of the methods. The lack of awareness and political commitment, with the low level of acceptance and consent by patients and medical professionals, represents regulatory and political compliance issues. Finally, there is a barrier related to the human factor, in the lack of adequate skills for applying AI methods in outcomes research, the lack of adequate training to generate AI-guided scientific evidence, and the lack of agreement on AI-guided methods and the use of scientific evidence.[30] All of these factors combine to slow the rise of the global application of a resource that could implement health systems.

With this review, we aimed to evaluate the increasing trend of PCNL and AI publications in the last decades, presenting a comprehensive report of bibliometric trends. As both English and non-English language papers were included in the study, this review sought to be as inclusive as possible. One limitation of this is represented by the fact that articles published in a non-index journal may have been missed. But we feel confident that this study correctly reflects the bibliometric trend of publications just using PubMed alone as a research database.[31] Hence, by evaluating the rising trend of publications in the last 30 years, this review demonstrates the acknowledged impact and the widespread applications of AI in PCNL procedures and training, and something likely to be included in guidelines soon.[32]

Conclusion

The number of published papers analyzing the role of AI and its subsets in the surgical management of renal stones through PCNL has increased significantly in the last decade. The main focus of publications in an intraoperative setting is represented by the development of new technologies for automated needle targeting toward precise renal access and prediction of surgical outcomes. The use of simulators for PCNL training has risen in the last few years, with a great impact on residents' educations. With the potential of improving patient-specific care in endourology, more publications on AI in PCNL are to be expected in the future.

Declarations

Ethics approval and consent to participate

The research protocols performed in this study complied with the ethical principles of the Declaration of Helsinki. As this is a review article, no ethical or consent issues were there.

Consent for publication

Not applicable.

Author contributions

Carlotta Nedbal: Conceptualization; Formal analysis; Methodology; Writing – original draft.

Clara Cerrato: Formal analysis; Methodology; Writing – original draft.

Victoria Jahrreiss: Formal analysis; Methodology; Writing – original draft.

Daniele Castellani: Investigation; Methodology; Writing – review & editing.

Amelia Pietropaolo: Investigation; Methodology; Writing – review & editing.

Andrea Benedetto Galosi: Conceptualization; Writing – review & editing.

Bhaskar Kumar Somani: Conceptualization; Methodology; Writing – review & editing.

Acknowledgements
None.

Funding
The authors received no financial support for the research, authorship, and/or publication of this article.

Competing interest
The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: The Associate Editor of Therapeutic Advances in Urology is an author of this paper. Therefore, the review process was managed by alternative members of the Editorial Board and the submitting Editor had no involvement in the decision-making process.

Availability of data and materials
As it is a review, the data supporting this study are publicly available. However, they can be obtained from the corresponding author BS at bhaskar-somani@yahoo.com upon reasonable request.

ORCID iDs
Amelia Pietropaolo https://orcid.org/0000-0001-7631-3108

Bhaskar Kumar Somani https://orcid.org/0000-0002-6248-6478

References

1. Shah M, Naik N, Somani BK, *et al.* Artificial intelligence (AI) in urology-Current use and future directions: an iTRUE study. *Türk Üroloji Dergisi/Turkish Journal of Urology* 2020; 46: Supp1 S27–S39.
2. Aminsharifi A, Irani D, Tayebi S, *et al.* Predicting the postoperative outcome of percutaneous nephrolithotomy with machine learning system: software validation and comparative analysis with Guy's stone score and the CROES Nomogram. *J Endourol* 2020; 34: 692–699.
3. Lim EJ, Castellani D, So WZ, *et al.* Radiomics in urolithiasis: systematic review of current applications, limitations, and future directions. *J Clin Med* 2022; 11: 5151.
4. Hameed BMZ, Somani S, Keller EX, *et al.* Application of virtual reality, augmented reality, and mixed reality in endourology and urolithiasis: an update by YAU Endourology and Urolithiasis Working Group. *Front Surg* 2022; 9. DOI: 10.3389/fsurg.2022.866946
5. Kallidonis P, Adamou C, Ntasiotis P, *et al.* The best treatment approach for lower calyceal stones ⩽20 mm in maximal diameter: mini percutaneous nephrolithotripsy, retrograde intrarenal surgery or shock wave lithotripsy. A systematic review and meta-analysis of the literature conducted by the European section of uro-technology and young academic urologists. *Minerva Urol Nephrol* 2022; 73: 711–723.
6. Seitz C, Desai M, Häcker A, *et al.* Incidence, prevention, and management of complications following percutaneous nephrolitholapaxy. *Eur Urol* 2012; 61: 146–158.
7. Romero V, Akpinar H and Assimos DG. Kidney stones: a global picture of prevalence, incidence, and associated risk factors. *Rev Urol* 2010; 12: e86–e96.
8. Hameed BMZ, Shah M, Naik N, *et al.* The ascent of artificial intelligence in endourology: a systematic review over the last 2 decades. *Curr Urol Rep* 2021; 22: 53.
9. Cacciamani GE, Okhunov Z, Meneses AD, *et al.* Impact of three-dimensional printing in Urology: State of the Art and future perspectives. A systematic review by ESUT-YAUWP Group. *Eur Urol* 2019; 76: 209–221.
10. Moher D, Liberati A, Tetzlaff J, *et al.* Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ (Clinical Research ed.)* 2009; 339: b2535–b2535.
11. Pietropaolo A, Proietti S, Geraghty R, *et al.* Trends of 'urolithiasis: interventions, simulation, and laser technology' over the last 16 years (2000-2015) as published in the literature (PubMed): a systematic review from European section of uro-technology (ESUT). *World J Urol* 2017; 35: 1651–1658.
12. Aminsharifi A, Irani D, Pooyesh S, *et al.* Artificial Neural Network system to predict the postoperative outcome of percutaneous

nephrolithotomy. *J Endourol* 2017; 31: 461–467.

13. Rizzo S, Botta F, Raimondi S, *et al*. Radiomics: the facts and the challenges of image analysis. *Eur radiol exp* 2018; 2: 36.

14. Shabaniyan T, Parsaei H, Aminsharifi A, *et al*. An artificial intelligence-based clinical decision support system for large kidney stone treatment. *Australas Phys Eng Sci Med* 2019; 42: 771–779.

15. Choi YH, Lee S-J and Kim HY. Effect of a three-dimensional (3D) printed kidney model on patient understanding of the percutaneous nephrolithotomy procedure: a preliminary study. *Urolithiasis* 2022; 50: 375–380.

16. de la Rosette J, Assimos D, Desai M, *et al*. The Clinical Research Office of the endourological Society percutaneous nephrolithotomy global study: indications, complications, and outcomes in 5803 Patients. *J Endourol* 2011; 25: 11–17.

17. Liu Y, Song H, Xiao B, *et al*. PCNL combined with 3D printing technology for the treatment of complex staghorn kidney stones. *J Healthc Eng* 2022; 2022: 7554673–7554677.

18. Cui D, Yan F, Yi J, *et al*. Efficacy and safety of 3D printing-assisted percutaneous nephrolithotomy in complex renal calculi. *Sci Rep* 2022; 12: 417.

19. Rassweiler-Seyfried M-C, Rassweiler JJ, Weiss C, *et al*. iPad-assisted percutaneous nephrolithotomy (PCNL): a matched pair analysis compared to standard PCNL. *World J Urol* 2020; 38: 447–453.

20. Oo MM, Gandhi HR, Chong KT, *et al*. Automated needle targeting with X-ray (ANT-X) – robot-assisted device for percutaneous nephrolithotomy (PCNL) with its first successful use in human. *J Endourol* 2021; 35: e919–e919.

21. Gauhar V, Giulioni C, Gadzhiev N, *et al*. An update of in vivo application of artificial intelligence and robotics for percutaneous nephrolithotripsy: results from a systematic review. *Curr Urol Rep* 2023; 24: 271–280.

22. Taguchi K, Hamamoto S, Okada A, *et al*. A randomized, single-blind clinical trial comparing robotic-assisted fluoroscopic-guided with ultrasound-guided renal access for percutaneous nephrolithotomy. *J Urol* 2022; 208: 684–694.

23. Mishra S, Kurien A, Patel R, *et al*. Validation of virtual reality simulation for percutaneous renal access training. *J Endourol* 2010; 24: 635–640.

24. Hameed BMZ, Shah M, Pietropaolo A, *et al*. The technological future of percutaneous nephrolithotomy: a young academic urologists endourology and Urolithiasis Working Group update. *Curr Opin Urol* 2023; Publish Ahead of Print: 90–94.

25. Veneziano D, Ahmed K, Van Cleynenbreugel B, *et al*. Development Methodology of the novel endoscopic stone treatment Step 1 training/Assessment curriculum: an International Collaborative Work by European Association of Urology Sections. *J Endourol* 2017; 31: 934–941.

26. Bohr A and Memarzadeh K. The rise of artificial intelligence in healthcare applications. *Artificial intelligence in healthcare*. 2020; pp. 25–60. DOI:10.1016/B978-0-12-818438-7.00002-2.

27. Combi C, Pozzani G and Pozzi G. Telemedicine for developing countries. A survey and some design issues. *Appl Clin Inform* 2016; 7: 1025–1050.

28. Benjamens S, Dhunnoo P and Meskó B. The state of artificial intelligence-based FDA-approved medical devices and algorithms: an online database. *NPJ Digit Med* 2020; 3: 118.

29. Puaschunder JM. The Future of Artificial Intelligence in International Healthcare: An Index. *Artificial Intelligence and Human Enhancement De Gruyter* 2022; 181–206. DOI: 10.1515/9783110770216-011

30. Tachkov K, Zemplenyi A, Kamusheva M, *et al*. Barriers to use artificial intelligence methodologies in Health Technology Assessment in Central and East European countries. *Front Public Health* 2022; 10. DOI: 10.3389/fpubh.2022.921226

31. Zhao X, Jiang H, Yin J, *et al*. Changing trends in clinical research literature on PubMed database from 1991 to 2020. *Eur J Med Res* 2022; 27: 95.

32. Geraghty RM, Davis NF, Tzelves L, *et al*. Best practice in interventional management of Urolithiasis: an Update from the European Association of Urology Guidelines Panel for Urolithiasis 2022. *Eur Urol Focus* 2023; 9: 199–208.