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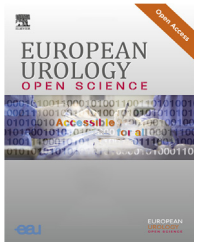

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Review – Education

Evaluation of Clinical Research on Novel Multiport Robotic Platforms for Urological Surgery According to the IDEAL Framework: A Systematic Review of the Literature

Vincenzo Ficarra [a,b,*], *Marta Rossanese* [c], *Gianluca Giannarini* [d], *Nicola Longo* [e], *Silvia Viganò* [c], *Domenico Russo* [c], *Gabriele Sorce* [b], *Alchiede Simonato* [f], *Riccardo Bartoletti* [g], *Alessandro Crestani* [d], *Ettore Di Trapani* [c]

[a] *Department of Clinical and Experimental Medicine, Urologic Section, University of Messina, Messina, Italy;* [b] *Department of Oncology, Urologic Section, AOU G. Martino, Messina, Italy;* [c] *Gaetano Barresi Department of Human and Paediatric Pathology, Urology Section, University of Messina, Messina, Italy;* [d] *Urology Unit, Santa Maria della Misericordia University Hospital, Udine, Italy;* [e] *Department of Neurosciences, Sciences of Reproduction and Odontostomatology, Federico II University of Naples, Naples, Italy;* [f] *Department of Precision Medicine in Medical, Surgical and Critical Care, Urology Unit, University of Palermo, Palermo, Italy;* [g] *Department of Translational Research and New Technologies in Medicine and Surgery, Urology Unit, University of Pisa, Pisa, Italy*

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Abstract

Background and objective: Several novel multiport robotic systems have been developed and introduced in clinical practice after regulatory approval. The objective of this systematic review was to assess the evolution status of novel robotic platforms approved for clinical use in urological surgery according to the IDEAL framework.

Methods: A systematic review was conducted using the Medline and Scopus databases according to the updated Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (CRD42024503227). Comparative or non-comparative studies reporting on any urological procedures performed with novel robotic platforms (Hugo RAS; Versius, KangDuo, Senhance, REVO-I, Avatera, Hinotori, Dexter, or Toumai) were selected and included in the analysis.

Key findings and limitations: Seventy-four eligible studies were included, of which 67 (90.5%) were noncomparative surgical series representing developmental or exploratory studies according to the IDEAL criteria. Only one randomised controlled trial (comparing KangDuo vs da Vinci robot-assisted partial nephrectomy) was included. The trial showed comparable perioperative outcomes between the two robotic systems. Four studies assessed clinical outcomes for patients undergoing urological procedures using a REVO-I (1 study), Senhance (2 studies), or Hinotori (1 study) system in comparison to the same procedures performed using a da Vinci system. All studies revealed outcomes comparable to those with the da Vinci system. Limitations include the small sample size in all studies, and

* Corresponding author. Department of Clinical and Experimental Medicine, Urologic Section, University of Messina, Azienda Ospedaliera Universitaria Policlinico Gaetano Martino, Via Consolare Valeria 1, 98125 Messina, Italy.
E-mail address: vincenzo.ficarra@unime.it (V. Ficarra).

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assessment of first-generation novel platforms versus the fourth-generation multiarm da Vinci system in most of the comparative studies.
Conclusions and clinical implications: A few poor-quality studies have compared the use of novel robotic platforms to da Vinci systems in urological surgery and demonstrated comparable results. Most studies can be classified as developmental or explorative, representing the initial steps of clinical research. Large multicentre series are needed to understand whether these novel robots could offer advantages beyond cost reductions over the da Vinci systems.
Patient summary: We reviewed research on new robotic systems for surgery in urology. Several studies have shown the feasibility and safety of these new robots during the most common procedures. Very few studies have assessed clinical outcomes with the new robots in comparison to the reference standard, which is a fourth-generation da Vinci robot. Large multicentre studies are needed to understand whether the new robots could offer advantages other than cost savings over the da Vinci robot.

1. Introduction

Robotic surgery for urological procedures has been the technological innovation with the greatest impact in the field in the past two decades. Since its US Food and Drug Administration (FDA) approval in 2000 for the USA, the da Vinci robotic surgical system (Intuitive Surgical, Sunnyvale, CA, USA) has profoundly transformed the field of minimally invasive surgery, shortened the learning curve, and simplified the reconstructive steps for multiple procedures in comparison to traditional laparoscopy. According to data released by Intuitive Surgical, as of quarter 4 in 2023, there were 8606 da Vinci systems installed worldwide [1].

Several urological procedures are currently performed robotically on a routine basis, as supported by the most representative international guidelines [2,3]. It has been shown that robotic surgery significantly reduced blood loss, transfusion rated, length of stay, and postoperative complications in comparison to open surgery and traditional laparoscopy in both pelvic and renal surgery [4–6]. However, the costs of the da Vinci platforms and robotic instruments have always been considered a downside of this technology and have acted as a barrier to adoption by many hospitals and health systems worldwide. The development of novel robotic platforms was flagged as early as 2009 as an opportunity to mitigate the Intuitive Surgical monopoly and reduce costs [7].

In the past decade, several novel multiport robotic systems have been developed and introduced into clinical practice following regulatory approval. The Senhance robotic system, followed by REVO-I, Versius, Avatera, Hinotori, and Hugo robot-assisted surgery (RAS) systems, were granted approval between 2014 and 2022 in various regions, including Europe, Korea, the UK, Japan, and the USA [8]. Assessment of the evolution of clinical research on novel robotic platforms in urology is essential to establish their real impact and potential for dissemination.

Several methodological criticisms have been raised regarding the quality of clinical research in surgery in the past decades. For this reason, in 2009 a panel involving surgeons and evidence-based medicine experts developed the IDEAL framework, which is a credible description of the evolutionary process for innovative treatments in surgery [9]. It is only very recently that the same expert consortium proposed recommendations for the evaluation of surgical robotic systems during the development, comparative effectiveness, and clinical monitoring phase [10]. The evaluation of novel surgical robotics has been recognised as particularly challenging because multiple stakeholders (developers, clinicians, patients, and health care systems) are involved and multiple factors must be considered, including economics, surgical training, human factors, ethics, patient perspectives, and sustainability.

The objective of this systematic review of the literature was to examine the status of the evolution research on novel robotic platforms approved for clinical use in urological surgery according to the IDEAL framework.

2. Methods

This systematic review was conducted in accordance with the updated Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [11]. The protocol was registered on the International Prospective Register of Systematic Reviews (PROSPERO; CRD42024503227).

2.1. Search strategy

A literature search was conducted up to January 5, 2024 using the Medline and Scopus databases. The Medline search involved a free-text protocol using the following terms: [Hugo robot-assisted surgery]; [Versius robot]; [KangDuo robot]; [Senhance robot]; [REVO-I robot]; [Avatera robot]; [Hinotori robot]; [Dexter robotic]; [Toumai robot]. All the records retrieved in each search were grouped in the PubMed clipboard to exclude duplicate papers. The following limits were used: humans; English

language; and publication date from inception to the search date. The Scopus search was performed using the same free-text protocol and keywords, and studies not retrieved via the Medline search were selected and added to the list. Three independent authors manually performed initial screening of the studies available. Additional studies of potential interest cited in the reference list of selected papers were also screened. A critical evaluation of the selected studies was performed, and relevant reports were subjected to a full-text review. All discrepancies were resolved via consensus among all the authors.

2.2. Inclusion and exclusion criteria and data extraction

Only comparative and noncomparative studies analysing any type of urological procedure were selected and included in the systematic review. Preclinical studies, meeting abstracts, case reports, editorials, letters, reviews, and articles not published in English were excluded. Data were manually extracted independently by three authors for the following variables: first author's name, publication year, country, type of surgical procedure investigated, study design, number of patients included, patients characteristics, available intraoperative and postoperative outcomes, and, when applicable, functional and oncological outcomes. Retrieved data were stored in an electronic database, and quality control of the data was performed for a random sample of papers accounting for approximately 15% of the total. All discrepancies were resolved via consensus among all the authors.

The level of evidence for each study was assigned independently by three authors according to the Oxford Centre for Evidence-Based Medicine criteria [12]. The quality and risk of bias for randomised controlled trials (RCTs) was assessed using the Jadad score, with score $\geq$4 considered to indicate high quality [13]. The quality of nonrandomised comparative studies was assessed using the Newcastle-Ottawa Scale for quality assessment [14]. Finally, the clinical research stage for each new robotic platform was assessed according to the IDEAL framework, in which stage 1 is proof of concept; stage 2a is development; stage 2b is exploration; stage 3 is assessment; and stage 4 is a long-term study [9]. Any discrepancies were resolved via consensus among all the authors.

3. Results

Our literature search identified a total of 273 relevant records in the PubMed and Scopus databases. After exclusion of 166, 107 records were screened. Notably, 151 studies analysing non-urological surgical procedures were excluded. A full-text assessment was performed for 96 studies, after which another 31 studies were excluded. Nine studies identified from reference lists in the studies included were further added. Therefore, 74 eligible studies were included in the systematic review (Fig. 1). In detail, these were one RCT [15]; four nonrandomised comparative studies using propensity scores for matching procedures to select a control group [16–19]; and ten comparative studies using control groups that were not optimal [20–29]. Table 1 summarises the level of evidence and the quality of comparative studies included in the review.

The remaining 59 studies included in our systematic review were noncomparative surgical series or case reports [30–88].

3.1. Hugo RAS system

The Hugo RAS system (Medtronic, Minneapolis, MN, USA) was approved for clinical use in Europe for urological procedures in 2022 and is awaiting FDA approval in the USA.

Twenty-six studies reporting clinical data for the Hugo RAS system were included in our review [20–25,30–49]. Table 2 summarises data from studies on urological surgical procedures performed using the Hugo RAS system according to the IDEAL framework.

Only four nonrandomised studies compared the use of da Vinci and Hugo RAS systems for robot-assisted radical prostatectomy (RARP) [20–23]. Ragavan et al [23] compared 17 RARPs performed with the Hugo RAS versus 17 RARPs performed with a da Vinci system and demonstrated overlapping perioperative outcomes. Olsen et al [22] compared 11 da Vinci RARPs versus 19 Hugo RAS RARPs and observed overlapping console times, estimated blood loss (EBL), and complication rates. The 3-mo urinary continence rate was 90% after da Vinci RARP and 61% after Hugo RAS RARP. Conversely, the 3-mo potency rate was 18% after da Vinci RARP and 26% after Hugo RAS RARP. All patients had undetectable prostate-specific antigen (PSA) 3 mo after surgery [22]. Bravi et al [20] compared 164 consecutive RARP procedures performed with the Hugo RAS system and 378 RARPs performed with a da Vinci platform (X or Xi) during the same period or the year before. Multivariable analysis revealed overlapping results between the two systems in terms of operative time, EBL, Clavien-Dindo grade $\geq$2 complications, and 3-mo urinary continence rates [20]. Antonelli et al [21] recently compared 50 RARPs performed with the Hugo RAS system to a contemporary control group of 50 RARPs performed with a da Vinci system. The authors reported a greater number of malfunction events and a longer console time for the Hugo RAS group [21]. In all previous comparative studies, controls were not selected using appropriate matching procedures as recommended in the IDEAL framework. Therefore, all the studies did not meet the criteria for classification as assessment studies. However, Bravi et al [20] included a large sample size and used a multivariable model to compare procedures performed with the two systems (stage 2b–3).

Initial case reports (stage 1) on robot-assisted simple prostatectomy (RASP) with the Hugo RAS system were published in India in 2022 and in Belgium in 2023 [30,39]. A development study (stage 2a) analysing clinical data for 20 consecutive cases was published in 2023 [40]. Notably, the same cases were compared to 20 da Vinci RASP procedures in the context of a nonrandomised study using a historical control group, which demonstrated overlapping results between the two systems [24].

The first development studies (stage 2a) on robot-assisted partial nephrectomy (RAPN) were published in 2023 [41,42]. Gallioli et al [41] described perioperative out-

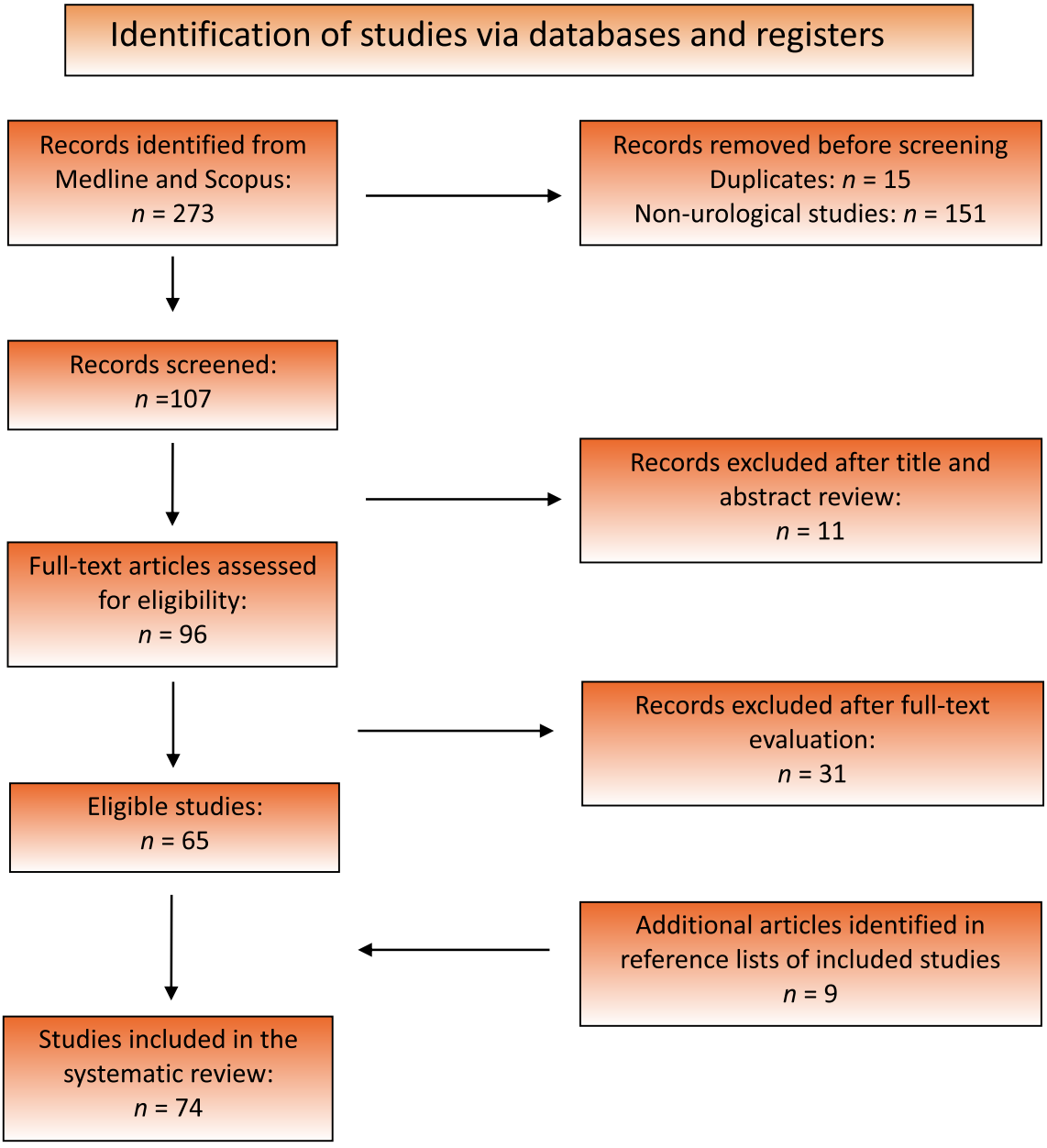

Fig. 1 – Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow chart detailing the study selection process.

comes for ten consecutive patients who underwent RAPN. In this initial experience, the median tumour size was 3 cm and the median PADUA score was 9. The median operating room time (ORT), warm ischaemia time, and EBL were 138 min, 13 min, and 90 ml, respectively (stage 2a). In the largest published series, which included 25 off-clamp procedures, the median ORT was 175 min and median EBL was 175 ml. Postoperative complications were observed in 10% of cases [44].

The first structured surgical series (stage 1) of five Hugo RAS sacrocolpopexy procedures in women with pelvic organ prolapse was published in 2023 [45]. The same team published a development study (stage 2a) in 2023 that included 15 cases [25]. Although previous patients were compared to a contemporary/historical control group of 23 da Vinci sacrocolpopexy cases, methodological limitations did not allow us to consider this nonrandomised trial as an assessment study. The clinical data reported reveal overlapping results between the da Vinci and Hugo RAS systems [25].

Only a few robot-assisted radical cystectomy (RARC) procedures have been performed with the Hugo RAS system (stage 1) [46,47]. Finally, Raffaelli et al [49] reported on an initial surgical series of five patients who underwent robot-assisted adrenalectomy (stage 1) in 2023.

3.2. *Versius robotic system*

The Versius Cambridge Medical Robotics (CMR) surgical system was approved in the UK in 2018.

Table 1 – Level of evidence and quality of selected comparative studies

Study	Robotic systems	Study design	Surgical procedure	IDEAL stage	LE	Jadad score	NOS score
Li 2023 [15]	Kangduo vs da Vinci	RCT	RAPN	3	2b	4	NA
Alip 2022 [16]	REVO-I vs da Vinci	MPA	RARP	3	3b	NA	8
Lin 2023 [17]	Senhance vs da Vinci	MPA	RARP	3	3b	NA	8
Glass Clark 2023 [18]	Senhance vs da Vinci	MPA	SCP	3	3b	NA	8
Motoyama 2023 [19]	Hinotori vs da Vinci	MPA	RAPN	3	3b	NA	8
Bravi 2023 [20]	Hugo vs da Vinci	Comparative (MVA)	RARP	2b-3	4	NA	7
Antonelli 2024 [21]	Hugo vs da Vinci	Comparative	RARP	2b	4	NA	7
Olsen 2023 [22]	Hugo vs da Vinci	Comparative	RARP	2a	4	NA	6
Ragavan 2023 [23]	Hugo vs da Vinci	Comparative	RARP	2a	4	NA	6
Balestrazzi 2023 [24]	Hugo vs da Vinci	Comparative	RASP	2a	4	NA	6
Collà Ruvolo 2023 [25]	Hugo vs da Vinci	Comparative	SCP	2a	4	NA	6
Fan 2022 [26]	KangDuo vs da Vinci	Comparative	Pyeloplasty	2a	4	NA	6
Fan 2023 [27]	KangDuo vs da Vinci	Comparative	RARP	2a	4	NA	6
Kulis 2022 [28]	Senhance vs LRP	Comparative	RARP	2b	4	NA	7
Nakayama 2024 [29]	Hinotori vs da Vinci	Comparative	RARP	2b	4	NA	7

LE = level of evidence; NOS = Newcastle-Ottawa Scale for quality assessment; LRP = laparascopic radical prostatectomy; RCT = randomised controlled trial; MPA = matched pair analysis; MVA = multivariable analysis; RARP = robot-assisted radical prostatectomy; SCP = sacrocolpopexy; NA = not applicable; RAPN = robot-assisted partial nephrectomy; RASP = robot-assisted simple prostatectomy.

Eight studies reporting clinical data for the Versius robotic system were included in our review [50–57] (Table 3). The first publication describing use of the Versius robot for urological surgery in real patients was by Reeves et al [50] in 2022 (stage 1–2a). The first development study (stage 2a), which involved 18 consecutive RARP cases, was published in 2023 [52]. The median console time was 201 min and median RBL was 140 ml. Only two (11%) postoperative complications (1 grade 2; 1 grade 3b) were reported. Notably, although a positive surgical margin (PSM) was observed in 83% of cases, 94.4% of patients had undetectable PSA 2 mo after surgery. The 2-mo full urinary continence rate was 72.2% [52]. Sighinolfi et al [56] recently reported results from another development study that included 22 RARP cases. The median ORT was 201 min and median EBL was 140 ml. Notably, two technical issues were reported and 13.6% of patients experienced postoperative complications [56].

The Versius Surgical Registry collected data for 177 urological procedures (stage 2b) and represents the large series published in the literature. Urological procedures accounted for less than 10% of all surgical procedures included in the registry. Among these, the intraoperative complication rate was 1.1% (2/177), including one bleed and one fatal myocardial infarction. Conversion to an alternative technique occurred in 16.6% (29/175) of cases, with 18/29 converted to laparoscopic surgery. Blood loss exceeded 500 ml in 7.4% (13/175) of procedures. The mean ORT was 303.3 ± 12 2.4 min [54]. Meneghetti et al [57] recently reported clinical data for 15 consecutive patients who underwent RAPN in two Italian centres. The median console time was 75 min and median EBL was 200 ml. Interestingly, 13% of cases were converted to radical nephrectomy for oncological reasons. The PSM rate was 7.6% [57].

3.3. *KangDuo surgical robot*

The KangDuo-Surgical Robot-01 system (Suzhou KangDuo Robot Company, Suzhou, China) was developed in China.

Eleven studies reporting clinical data on the KangDuo robot were included in our review [15,26,27,58–65] (Table 4). The first clinical procedure with the KangDuo surgical robot was performed in China in 2021. In this development study (stage 2a) the authors analysed 16 consecutive robotic pyeloplasty cases and reported a median ORT of 151 min without major postoperative complications [58]. A matched-pair analysis of 16 pyeloplasty cases performed with the KangDuo system and 16 da Vinci procedures revealed significantly longer ORT with the KangDuo system, with no significant differences in complication and success rates (stage 3) [26].

The first RAPN development study (stage 2a) involved 11 consecutive retroperitoneal RAPN cases and was published in 2022 [60]. In 2023, Li et al published results from a non-inferiority RCT comparing 49 KangDuo RAPN cases versus 50 da Vinci RAPN procedures (stage 3) and demonstrated the equivalence of the two systems in terms of intraoperative and postoperative outcomes [15].

The first development study demonstrating the feasibility of RARP with the KangDuo robot was published in 2022 [61]. In 2023, Fan et al [26] compared the most recent 16 RARPs performed with the KangDuo robot to the most recent 16 extraperitoneal RARPs previously performed with a da Vinci robot. Although this could be classified as a controlled interrupted-time series study, the number of cases compared is very small. The RARP ORT was significantly longer in the KangDuo group than in the da Vinci group. However, there were no significant differences between the systems in EBL, hospital stay, postoperative complications, PSM rate, biochemical recurrence, or continence recovery 3 mo after catheter removal [26].

The largest explorative surgical series with the KangDuo robot was published in 2023 and included 28 RAPNs (17 transperitoneal and 11 retroperitoneal), 41 robotic urinary tract reconstructions (26 pyeloplasties, 3 ureteral reconstructions, and 12 ureteral reimplantations), and 41 RARPs [64]. Finally, the KangDuo robot was also assessed in a developmental study (stage 2a) involving 23 patients who underwent adrenalectomy [65].

3.4. *Senhance surgical robotic system*

The Senhance robotic system (Asensus Surgical, Durham, NC, USA) was approved in Europe in 2014 and in the USA in 2017.

Table 2 – Studies evaluating robotic procedures performed using the Hugo RAS system

Study	Country	Design	Cases	IDEAL stage	Preoperative characteristics	ORT (min)	EBL (ml)	POPCs	LOS (d)	Pathology	Functional outcomes
Robot-assisted radical prostatectomy											
Ragavan 2022 [30]	India	Case series	3	1	Age 67 yr; PSA 16; GS 3+3 Age 60 yr; PSA 27; GS 7 Age 76 yr; PSA 11; GS 3+4		100 150 100	0 0 0	1 1 1	pT3b pT3b pT3a	
Bravi 2022 [31]	Belgium	Case series	5	1	Age: 64 (57–65) BMI: 26 (26–27) PSA: 6 (5–7.8) 1 GG1, 4 GG2 PV: 30 (28–50)	120 (110–150)	400 (400–700)	1 (20%)	3 (2–4)		
Totaro 2022 [32]	Italy	Case series	7	1		122					
Alfano 2023 [33]	Brazil	Case series	15	1–2a	Age: 62 yr (59–67) BMI: 25 (23–28) PSA: 7.3 (4.8–8.1) GG1 47%, GG2 40%, GG>2 13%	235 (213–271)	300 (100–310)	1 (6%)	2	PSM: 5 (33%) pT2: 74% pT3: 26% GG1–2: 87% GG3: 6.5% GG4: 6.5%	4-wk UCR 61% 4-wk uPSA 100%
Bravi 2023 [34]	Belgium	Case series	112	2b	Age: 65 yr (60–70) BMI: 26 (24–29) PSA: 7.9 (5.8–10.7) GG≥3: 34% PV: 40 (32–55)	150 (145–175)	400 (250–575)	9 (8%)	3 (3–4)	PSM: 10 (9%) pT3: 31% pN+: 4% GG≥3: 43%	1-mo UCR: 36% 3-mo UCR: 81% 4-wk uPSA: 88%
Paciotti 2023 [35]	Belgium	Case series (NSS)	62	2b	Age: 65 yr (60–69) BMI: 26 (24–29) PSA: 6.5 (5.4–8.3) GG≥3: 11% PV: 39 (32–50)	120 (110–150)	400 (300–500)	3 (5%)	3 (3–4)	PSM: 3 (5%) pT3: 16% GG≥2: 87%	1-mo UCR: 59% 3-mo UCR: 82% 3-mo potency: 37%
Bravi 2023 [20]	Belgium	Comparative series	H: 164 D: 378	2b–3	**Age** H: 65 yr (60–70) D: 66 yr (61–71) **BMI** H: 26 (24–29) D: 27 (25–30) **PSA** H: 8 (5.7–11) D: 7.6 (5.1–11.3) **GG≥3** H: 53 (33%) D: 130 (34%) **PV** H: 42 (33–58) D: 40 (32–60)	H: 180 (150–200) D: 165 (130–200)	H: 400 (250–500) D: 350 (200–500)	H: 10 (6%) D: 15 (4%)	H: 3 (3–4) D: 3 (2–4)	**PSM rate** H: 2%; D: 15% **>pT2 rate** H: 33%; D:34% **GG≥3 rate** H: 37%;D: 41%	**1-mo UCR** H: 66%; D: 63% **3-mo UCR** H: 81%; D: 79%
Ou 2023 [36]	Taiwan	Case series	12	2a	Age: 71±13.2 yr BMI: 24.5±4.01 PSA: 9.6±7.9	145	193±226		7±3	PSM: 3 (25%) >pT2 (25%) ≥ GG3 (75%)	
Olsen 2023 [22]	Denmark	Comparative series	H: 19 D: 11	2a	Age: 66 yr (63–73) BMI: 25.5 (24–27) Biopsy GG≥2: 79% PV: 47 (30–75)	89	200 (100–350)	3 (15.7%)	1 (1–2)		3-mo UCR 61% 3-mo potency: 26% 3-mo uPSA: 100%
Territo 2023 [37]	Spain	Case series	17	2a	Age: 64 yr (59–69) BMI: 27 (24–27) PSA: 6.4 (5.1–9.4) PV: 35 (30–56)	185 (177–192)	200 (150–250)	3 (17.6%)	3 (2–4)	PSM: 5 (29.4%) >pT2 (17.6%) ≥ GG3 (41%)	

Table 2 (*continued*)

Study	Country	Design	Cases	IDEAL stage	Preoperative characteristics	ORT (min)	EBL (ml)	POPCs	LOS (d)	Pathology	Functional outcomes
Ragavan 2023 [23]	India	Comparative series	H: 17 D: 17	2a	**Age** H: 68 yr (66–72) D: 68 yr (65–73) **BMI** H: 24.6 (22.6–26.6) D: 25.1 (23.1–27) **PSA** H: 12.3 (8.8–27) D: 22 (7.3–42) **cT3** H: 6 (35%) D: 8 (47%)	H: 195 (180–240) D: 210 (210–240)			H: 1 (1–2) D: 1 (1–2)	PSM H: 4 (23.5%) D: 4 (23.5%)	3-mo UCR: H: 94.2% D: 94.2%
Marques-Monteiro 2023 [38]	Portugal	Case series	16	2a		152 (119–196)	200 (150–400)	1 (6.2%)	2 (2–2)		
Antonelli 2024 [21]	Italy	Comparative series	H: 50 D: 50	2b	**Age** H: 65.9±5.9 yr D: 66.4±5.5 yr **BMI** H: 25.4 (24.5–27.8) D: 27 (24.5–29.7) **PSA** H: 7.7 (5.9–11) D: 5.9 (4.8–8.7) **GG≥3** H: 23 (46%) D: 23 (46%) **PV** H: 40 (29–50) D: 43 (35–57)	H: 126 D: 97	H: 300 (150–400) D: 200 (150–300)				
Robot-assisted simple prostatectomy											
Ragavan 2022 [30]	India	Case report	1	1	Age: 66 yr PV. 94		150	0	1		
Motteran 2023 [39]	Belgium	Case report	1	1	Age: 72 yr PSA: 13.4 PV: 155	120	200	0	3		
Piro 2023 [40]	Belgium	Case series	20	2a	Age: 72 yr (67–76) PSA: 7.7 (5–13) PV: 120 (101–154)	125 (101–148)		3 (15%)	3 (3–4)		
Balestrazzi 2023 [24]	Belgium	Comparative series	H: 20 D: 20	2a	**Age** H: 72 yr (67–76) D: 76 yr (67–80) **BMI** H: 28.5 (30–35) D: 27 (25–31) **PSA** H: 7.7 (5–13.4) D: 10 (5.3–14.3) **PV** H: 206 (160–260) D: 198 (133–220)	H: 125 (101–148) D: 105 (100–125)	H: 400 (300–875) D: 400 (350–1125)	H: 3 (15%) D: 5 (20%)	H: 4 (3–4) D: 4 (3–5)		**CT (d)** H: 1 (1–2) D: 1 (1–2) **Qmax (ml/s)** H: 20.9 (14.7–28.3) D: 15.4 (9.9–22.4)

(*continued on next page*)

Table 2 (*continued*)

Study	Country	Design	Cases	IDEAL stage	Preoperative characteristics	ORT (min)	EBL (ml)	POPCs	LOS (d)	Pathology	Functional outcomes
Robot-assisted partial nephrectomy											
Gallioli 2023 [41]	Spain	Case series	10	1–2a	Age: 65.8 yr (42–87) TS: 3 cm (2.2–3.7) PADUA: 9 (8–9)	138 (124–162) WIT: 13 min (10–14)	90 (75–100) OC: 1 (10%)	1 (10%)	5 (3–13)	PSM: 0%	
Prata 2024 [42]	Italy	Case series (off-clamp)	7	1	Age: 69 yr (60–72) M/F: 3/4 BMI: 27 (25–28) TS: 2.6 cm (2.3–3.1) RENAL: 5 (5–6)	83 (68–115) WIT: 0 min	200 (50–400) OC: 100%	0	2 (2–3)	PSM: 0% pT1: 100%	PO-eGFR: 90.2 (65–95)
Prata 2024 [43]	Italy	Case series (off-clamp)	18	2a	Age: 69 yr (60–72) M/F: 13/5 BMI: 27 (25–28) TS: 3.1 cm (2.6–3.4) RENAL: 5 (5–7)	100 (68–125) WIT: 0 min	250 (90–400) OC 100%	2 (11%)	3 (2–4)	PSM: 0%	PO-eGFR: 84 (63.9–93.1)
Prata 2023 [44]	Italy	Case series (off-clamp)	25	2a	Age 69 yr (60–73) M/F 19/6 BMI 27.3 (25.7–28) TS: 3.2 (2.6–4.3) RENAL: 6 (5–7)	90 (68–135) WIT: 0 min	175 (100–400) OC: 100%	4 (16%)	3 (3-4)	PSM: 0% pT1a: 84% pT1b: 8% pT2: 8%	PO-eGFR: 81.9 (60.6–89.5)
Robot-assisted sacrocolpopexy											
Motteran 2023 [45]	Belgium	Case series	5	1	Age: 73 yr (56–76) BMI: 25 (22–28) POP grade III–IV: 100%	130 (115–165)	20 (10–35)	0	2 (1–2)	5 (100%)	Success 100%
Collà Ruvolo 2023 [25]	Belgium	Comparative series	H: 15 D: 23	2a	Age: 73 yr (60–76) BMI: 26 (24–30)	H: 120 D: 123		H: 1 (6.7%) D: 0	H: 2 (1–2.5) D: 2 (2–2)	H: 13 (86.7%) D: 18 (78.3%)	
Robot-assisted radical cystectomy											
Rocco 2023 [46]	Italy	Case reports Neobladder CUS	 1 1	1	Age: 61 yr 70 yr	 150 140					
Gaya 2023 [47]	Spain	Case reports	2	1	Age: 71 yr 64 yr	 360 420	 200 400	 Ileus			
Other procedures											
Ragavan 2022 [30]	India	Case reports Nephrectomy	 2	1	F: 54 yr M: 45 yr		100 150	0 0	2 1		
Elioreta 2023 [48]	Chile	Case reports ULT URI Pyeloplasty Nephrectomy	 1 2 1 1	1	Age: 50 yr BMI: 27.7						
Raffaelli 2023 [49]	Italy	Case series Adrenalectomy	 5	1	Age: 60.6 yr (30–78) BMI: 24.6 (19.2–30) TS: 51 (30–90)	61.4 (29–108)		1 (20%)	3.2 (2–8)	3 adenomas 1 pseudocyst 1 PCC	

ORT = operative room time; EBL =estimated blood loss (ml); POPCs = postoperative complications; LOS = length of stay; GS = Gleason score; BMI = body mass index (kg/m^2); PSA = prostate-specific antigen (ng/ml); PV = prostate volume (cm^3); GG = grade group; PSM = positive surgical margin; H = Hugo RAS system; D = da Vinci system; WIT = warm ischemia time; OC = off-clamp technique; POP = pelvic organ prolapse; CUS = cutaneous ureterostomy; NSS = nerve-sparing surgery; PCC = pheochromocytoma ; CT = catheter time; Qmax = maximum urinary flow rate; UCR = urinary continence rate; ULT = ureterolithotripsy; uPSA = undetectable PSA; URI = ureteral reimplantation TS = tumour size (mm) PO-eGFR = postoperative estimated glomerular filtration rate (ml/min/1.73 m^2).

Table 3 – Studies evaluating robotic procedures performed using the Versius robotic system

Study LOS (d)	Country	Design	Procedure (cases) Pathology	IDEAL stage	Preoperative	Functional outcomes		characteristics	ORT (min)	EBL (ml)	POPCs
Reeves 2022 [50]	UK	CS	RARP (4) RARN (2) Pyeloplasty (3) Adrenalectomy (1)	1	**Age** **BMI** 66 yr 28 41 yr 26 32 yr 22 73 yr 28	272 110 110 110					
Rocco 2023 [51]	Italy	CR	RARP (1)	1	Age: 72 yr BMI: 25 PSA: 6 GS: 3+4	130			3	PSM: 0	
De Maria 2023 [52]	Italy	CS	RARP (18)	2a	Age: 70 yr PSA: 15 (7–25) GG≥2: 89%	201	140 (100–500)	2 (11%)	4 (3-5)	PSM: 83% pT3: 61%	1-mo UCR: 55.5% 2-mo UCR: 72.2% uPSA: 94%
Gaia 2023 [53]	Italy	CR	Sacrocolpopexy (1)	1		75	0	0	2		
Soumpasis 2023 [54]	UK	Registry	Mixed urological procedures (177)	2b	Age: 55.7±14.7 yr BMI: 26.6±5 M/F: 58.4%/31.6%		>500: 7.4%	Major: 1.7% 3-mo mortality: 3.4% Conversion: 16.6%	5.5±2.9		
Hussein 2023 [55]	Pakistan USA	MCS	Adrenalectomy (4) Pyeloplasty (20) RARN (10) Renal cysts (3) SN (42) RARC (1) RASP (9) URI (2) Varicocelectomy (3) Stones (17)	2a–b		150	123	Major: 8% Conversion: 5.6% TIs: 1.8%	3		
Sighinolfi 2024 [56]	Italy	CS	RARP (22)	2a		201 (130–242)	140 (100–550)	3/22 (13.6%) 2 TIs	4 (3.5–7)		
Meneghetti 2024 [57]	Italy	MCS	RAPN (15)	2a	TS: 4 cm (2.3–5) PADUA: 8 (7–9)	75 (66–80) WIT: 10 min (9–11)	200 (100–250)	Conversion: 13%	4 (3.5-4)	PSM: 7.6%	

CS = case series; CR = case report; MCS = multicentre case series; ORT = operative room time; WIT = warm ischaemia time; EBL = estimated blood loss; POPCa = postoperative complications; LOS = length of stay; RARP = robot-assisted radical prostatectomy; RARN = robot-assisted radical nephrectomy; BMI = body mass index (kg/m^2); PSA = prostate-specific antigen (ng/ml); uPSA = undetectable PSA; GS = Gleason score; PSM = positive surgical margin; GG = grade group; M = male; F = female; RARC = robot-assisted radical cystectomy; SN = simple nephrectomy; RASP = robot-assisted simple prostatectomy; URI = ureteral reimplantation; RAPN = robot-assisted partial nephrectomy UCR = urinary continence rate; TIs = technical issues; TS = tumour size.

Table 4 – Studies evaluating robotic procedures performed using the KangDuo surgical robot

Study	Country	Design	Procedure (cases)	IDEAL stage	Preoperative characteristics	ORT/WIT (min)/ OC	EBL (ml)	POPCs	LOS (d)	Pathology	Functional outcomes
Fan 2021 [58]	China	Case series	PYP (16)	2a	Age: 27 yr (21–75) BMI: 23 (15–33) M/F: 44%/56%	151 (110-190	50	Major: 0	4 (3–9)		
Fan 2022 [26]	China	Comparative series	PYP K: 16 D: 16	2a	**Age** K: 31±14 D: 27± 10 **BMI** K: 23±5 D: 22±4	K: 141±28 D: 118±31	K: 8 (5–50) D: 10 (5–50)	K: 1 (6.3%) D: 2 (12.5%)	K: 4.3±1.5 D: 4.2±1.6		Success rate K: 15 (93.7%) D: 16 (100%)
Li 2023 [59]	China	Case report	Bilateral PYP (1)	1	Age: 36 yr	298	50				
Wang 2022 [60]	China	Case series	Retroperitoneal RAPN (11)	2a	Age: 52 yr (44–64) BMI: 25.8 (24–27) M/F: 63.6%/36.4% TS: 2 cm (1.3–2.2) **RENAL risk** Low: 72.7% Intermediate: 27.3%	50 (38–60) WIT: 18.5 (13.7–21)	10 (5–20)	0	4 (4–4)	PSM: 0	6-mo eGFR 90.7 (83.7–97.7)
Fan 2022 [61]	China	Case series	RARP (16)	2a	Age: 66 yr (58–75) BMI: 23.6 (19.6–28) PSA: 6.67 (0.8–18) GG>2: 18% PV: 39±18.8	87 (70–120)	50 (10–200)	Major: 0%	5 (4–10)	PSM: 4 (25%)	1-mo UCR 14 (87.5%)
Li 2023 [15]	China	RCT	RAPN K: 49 D: 50	3	**Age** K: 54.3±10.2 yr D: 52.1±12.38 yr **BMI** K: 25.8±2.8 D: 25.6±3.2	**OC** K: 3 (6%) D: 0 (0%) **WIT** K 18.3 D: 17		K: 3 (6.12%) D: 3 (6%)		PSM K: 0% D: 0%	eGFR K: 94 (63–118) D: 93 (25–120)
Chen 2023 [62]	China	Case report	RAPN (1)	1a		OR: 127 WIT 19	0			PSM: 0	
Fan 2023 [27]	China	Comparative series	RARP K: 16 D: 16	2a	**Age** K: 66 yr (58–75) D: 69 yr (57–78) **BMI** K: 23.6 (19.6–28) D: 24.6 (20.9–31.2) **PSA** K: 6.67 (0.88–27.9) D: 6.28 (0.03–26.1) **GS≥3** K: 2 (12.6%) D: 0 **PV** K: 39 (18-86) D: 28.5 (19-74)	K: 127 (107–159) D: 70.5 (54–90)	K: 50 (10–200) D: 50 (0–200)	Major K: 0 D: 0	K: 5 (4–10) D:6.5 (5–10)	**PSM** K: 4 (25%) D: 2 (12.5%) **pT3** K: 8 (50%) D: 8 (50%)	3-mo UCR K: 15 (93.8%) D: 14 (87.5%)
Fan 2023 [63]	China	Case report	PYPT (1)	1	Age: 32 yr	98	15	0			
Xiong 2023 [64]	China	Case series	RAPN (28) PYP (26) URT (3) UCS (12) RARP (41)	2b		112 157 151 142 138	10 10 30 30 50	0 0 0 0 0		PSM: 38%	Success: 96% Success. 92%

Table 4 (*continued*)

Study	Country	Design	Procedure (cases)	IDEAL stage	Preoperative characteristics	ORT/WIT (min)/ OC	EBL (ml)	POPCs	LOS (d)	Pathology	Functional outcomes
Dong 2023 [65]	China	Case series	Adrenalectomy (23)	2a	Age: 49 yr (22–67) M/F: 10/13 BMI: 23.8 (20.8–27) TS: 2.8 cm (1.5–3.5)	86 (60–112.5)	50 (20–400)	Minor 3 (21.7%)		PSM: 0	

RCT = randomised controlled trial; ORT = operative room time; WIT = warm ischaemia time; OC = off-clamp technique; EBL = estimated blood loss; LOS = length of stay; BMI = body mass index (kg/m^2); M = male; F = female; K = KangDuo robot; D = da Vinci robot; RAPN =robot-assisted partial nephrectomy; PSM = positive surgical margin; PV = prostate volume (cm^3); RARP = robot-assisted radical prostatectomy; PSA = prostate-specific antigen (ng/ml); GG = grade group; GS = Gleason score; PYP = pyeloplasty; PYPT = PYP telesurgery; URT = ureterectomy; UCS = ureterocystoneostomy; TS = tumour size; eGFR = estimated glomerular filtration rate (ml/min/1.73 m^2); UCR = urinary continence rate.

Fifteen studies reporting clinical data for the Senhance surgical robotic system were included in our review [17,18,28,66–76] (Table 5). Most studies evaluating the Senhance robot in urology have been focused on RARP. The initial clinical experiences (stage 2a) were in Croatia and Lithuania and were published in 2019 [66,67]. Developmental and explorative studies were subsequently published by the same teams with extensive experience, including a series of 200 cases published in 2023 (stage 2b) [71]. In 2022, Kulis et al [28] described a prospective nonrandomised study comparing 107 extraperitoneal RARPs performed with a Senhance robot to 61 laparoscopic radical prostatectomy cases. The study demonstrated equivalent ORT, EBL, and PSM results for the two techniques [28]. A 2023 matched pair analysis (stage 3) by Lin et al [17] in Taiwan compared 63 RARPs performed with the Senhance robot to 63 da Vinci RARPs, which revealed no differences in EBL, postoperative complications, PSM rate, 3-mo undetectable PSA rate, or 3-mo urinary incontinence rate. Kulis et al [72] recently reported data for 375 RARPs performed in the context of a multicentre study. The authors reported a conversion rate of 5.3% and a postoperative complication rate of 3.4% for this larger series.

Three studies evaluated use of the Senhance robot for sacrocolpopexy [18,73,74]. A 2023 A matched pair analysis by Glass Clark et al [18] compared 25 sacrocolpopexy procedures performed using the Senhance system to 50 da Vinci cases (stage 3). The authors reported longer ORT but lower costs for the Senhance group. An initial clinical experience with robot-assisted radical nephrectomy (RARN) using the Senhance system was published in 2021 (stage 1) [75]. In 2022, Knežević et al [76] reported the first surgical series of 12 patients who underwent robot-assisted adrenalectomy.

3.5. *REVO-I robot platform*

Use of the REVO-I robot platform (model MSR-5000; Meere Company Inc., Yongin, Korea) for human surgery was approved in Korea in 2016. Only two studies reporting clinical data for the REVO-I system were included in our review [16,77] (Table 6). In 2018, Chang et al [77] reported results for 17 consecutive Retzius-sparing RARP (RS-RARP) cases (stage 2a). A 2022 propensity score analysis by Alip et al [16] compared 33 RS-RARPs performed with the REVO-I platform to 33 da Vinci RS-RARP cases (stage 3). The authors observed overlapping results in terms of EBL, complications, and early oncological outcomes. The REVO-I system was associated with shorter length of stay and the da Vinci robot with shorter ORT.

3.6. *Hinotori surgical robot*

The Hinotori robotic system (Medicaroid, Kobe, Japan) was approved for use in Japan in 2020.

Eight studies reporting clinical data on Hinotori surgical system were included in our review [19,29,78–83] (Table 6). The first clinical experience with RAPN was published in 2023 and involved 30 consecutive cases with a median tumour size of 28 mm and a median RENAL nephrometry score of 8 (stage 2b) [78]. The same team published an

Table 5 – Studies evaluating robotic procedures performed using the Senhance robot

Study	Country	Design	Procedure (cases)	IDEAL stage	Preoperative characteristics	ORT (min)	EBL (ml)	POPCs	LOS/CT (d)	Pathology	Functional outcomes
Kaštelan 2019 [66]	Croatia	Case series	eRARP (9)	1–2a	Age 64 (48–72)	217 (150–300)					
Samalavicius 2019 [67]	Lithuania	Case series	Varicocelectomy (1) Pyeloplasty (1) Pyelolithotomy (1) Nephrectomy (1) RARP (27)	1 1 1 1 2a							
Kaštelan 2020 [68]	Croatia	Case series	eRARP (40)	2b	Age: 65.7 yr (45–74) PSA: 6.3 (4–14) PV: 50 (28–101)	200 (120–305)	300 (100–700)	Minor 5 (12.5%)	**LOS** 6 (4–7) **CT** 10 (9–15)	pT3: 3 (22.5%) PSM: 11 (27.5%)	
Kaštelan 2021 [69]	Croatia	Case series	eRARP (70)	2b	Age: 65 yr (61–72) PSA: 7.1 (5–10) PV: 40 (33–55)	200 (180–230)	200 (150–400)	Minor 6 (8.4%)	**LOS** 5 (4–7) **CT** 8 (7–11)	pT3: 14 (20%) PSM: 18 (25.7%)	Continence (2–15 mo): 62 (88.6%)
Kaštelan 2021 [69]	Croatia	Case series	Adrenalectomy (9) Nephrectomy (6) Kidney cyst (19) Pyeloplasty (4)	2a 2a 2a 1							
Kulis 2022 [28]	Croatia	Comparative series	eRARP (107) LRP (61)	2b	Age: 65 yr (60–68) S PSA: 6.8 (5.13–8.8) S PV 40 (30–50) S	195 (180–218) S	300 (200–500) S	Major 1 (0.9%) S:	**LOS** 5 (4–7) S **CT 13** (12–15)	>pT2: 18% S PSM: 28% S	20-mo UCR: 79% S
Venckus, 2021 [70]	Lithuania	Case series	RARP (127)	2b	Age: 61 yr (37–73) BMI: 26.2 (19–40) PSA: 5.5 (2–26.8)	180 (150–215)	250 (175–400)	**Minor** 12 (9.5%) **Major** 3 (2.4%)		>pT2: 19 (15%) PSM: 43 (33.9%)	
Hudolin, 2023 [71]	Croatia	Case series	eRARP (200)	2b	Age: 65 yr (41–79) BMI: 27 PSA: 6.9 (1–29.8)	190 (120–135)	250 (15–1200)	**Minor** 14 (7%) **Major** 1 (0.5%)	**LOS** 5 (3–12) **CT** 13 (5–25)	**>pT2** 43 (21.5%) **PSM** 55 (27.5%)	UCR at follow-up: 93.3%
Lin, 2023 [17]	Taiwan	Comparative (MPA)	RARP S: 63 D: 63	3	**Age** S: 66 yr (64–71) D: 66 yr (62–68.5) **BMI** S: 25.4 (23–28) D: 25.3 (22–27) **PSA** S: 11.3 (7.4–19) D: 11.9 (7.4–19) **High risk** S: 34 (54%) D: 34 (54%)	S: 231 (198–272) D: 265 (234–306)	S:: 180 (100–285) D:: 180 (92–285)	S: 16 (25.3%) D: 14 (22.2%)		**PSM** S: 23 (36.5%) D: 26 (41.3%) **>pT2** S: 24 (38%) D: 25 (39.6%)	**3-mo uPSA** S: 68.3% D: 66.7% **3-mo UCR** S: 85.7% D: 84.1% Costs S: $4170 D: $7675
Kulis 2024 [72]	Croatia Lithuania	MCS	RARP (375)	2b		190 (167–215)		Conversion: 5.3% POPC: 3.4%			
Panico 2020 [73]	Italy	Case report	Sacrocolpopexy (1)	1	Age: 60 yr BMI: 28.7	186	30				
Sassani 2022 [74]	USA	Case series	Sacrocolpopexy (25)	2b	Age: 62.3±9.2 yr BMI: 26.5±3.8 POP III–IV: 84%	210±48.6	35 (25–50)	Major: 2 (8%)			Failure: 2 (8%)

Table 5 (*continued*)

Study	Country	Design	Procedure (cases)	IDEAL stage	Preoperative characteristics	ORT (min)	EBL (ml)	POPCs	LOS/CT (d)	Pathology	Functional outcomes
Glass Clark 2023 [18]	USA	Comparative (MPA)	Sacrocolpopexy S: 25 D: 50	3	**Age** S: 62±9 yr D: 59.7±9.9 yr **BMI** S: 26.6±3.8 D: 28.6±5 **POP grade III–IV** S: 72% D: 67.3%	S: 210±48 D: 178±36	S: 56±69.6 D: 51±45.6	S: 4 (16%) D: 14 (28%)			Costs S: $5368 D: $5741
Kaneko 2021 [75]	Japan	Case report	RARN (2)	1	Age: 52 yr, 67 yr BMI: 21.4, 27.6 TS: 52, 75	143 122	3 50			PSM: 0	
Knežević 2022 [76]	Croatia	Case series	Adrenalectomy (12)	2a	Age: 48 yr (42–51) M/F: 6/6 TS: 1.7 cm (1.3–2)	98.6 (85–112.5)	47 (8.7-62.5)		LOS: 4.5 (4–5)		

MCS = multicentre case series; MPA = matched pair analysis; ORT = operative room time; EBL = estimated blood loss; POPCs = postoperative complications; LOS = length of stay; CT = catheter time; RARP = robot-assisted radical prostatectomy; eRARP = extraperitoneal RARP; PSA = prostate-specific antigen (ng/ml); uPSA = undetectable PSA; PSM = positive surgical margin; LRP = laparoscopic radical prostatectomy; BMI = body mass index (kg/m^2); S = Senhance robot; D = da Vinci robotic system; POP = pelvic organ prolapse; RARN = robot-assisted radical nephrectomy; M = male; F = female; MPA = matched pair analysis; TS = tumour size (mm); UCR = urinary continence rate.

assessment study (stage 3) comparing 37 RAPNs performed with the Hinotori robot to a propensity score–matched group of 74 da Vinci RAPN cases [19]. The study demonstrated equivalent results between the groups in terms of ORT, EBL, warm ischaemia time, complication rates, PSM rates, and renal functional outcomes. The same institution published the first developmental studies on RARN [79], robot-assisted nephroureterectomy [80], robot-assisted adrenalectomy [81], RARN and inferior vena cava thrombectomy [82], and RARC and intracorporeal urinary diversion [83] with the Hinotori robot. Finally, in 2024 Nakayama et al [29] reported on a nonrandomised study comparing 97 RARPs performed with the Hinotori robot to 40 da Vinci RARP cases that showed overlapping perioperative outcomes.

3.7. *Dexter robotic system*

The Dexter robotic system (Distalmotion SA, Épalinges, Switzerland) is currently approved in Europe. Two studies reporting clinical data for the Dexter robot were included in our review [84,85] (Table 7).

In 2023, Böhlen et al [84] reported on the first ever RARP performed with the Dexter robotic system (stage 1), which was in a 71-yr-old patient with organ-confined prostate cancer. In the same year, Thillou et al [85] described the first case series of ten RARP procedures performed with the Dexter robot (stage 2a). In this developmental study, the median ORT for RARP was 230 min, with median EBL of 655 ml. Only one major postoperative complication was reported. Patients were discharged after a median of 3 d and catheters were removed after 10 d [85].

3.8. *Avatera robotic surgical system*

The Avatera (Avateramedical, Jena, Germany) was introduced into clinical practice in Germany in 2022.

Two studies reporting clinical data on the Avatera robotic system were included in our review [86,87] (Table 7). In 2023, Kallidonis et al [86] published results from the first human clinical study and reported on the surgical technique and clinical data for nine patients who underwent robot-assisted pyeloplasty (stage 1–2a). Gkeka et al [87] described perioperative outcomes for 14 consecutive RARP cases performed with the Avatera system (stage 1–2a).

3.9. *Toumai robot*

The Toumai surgical robot was independently developed in China by the Shanghai Minimally Invasive Medical Robot Company.

Only one study reporting clinical data for the Toumai robot was included in our review [88] (Table 7). The first-in-man RARP with the Toumai surgical robot was successfully completed at Shanghai Oriental Hospital in November 2019. Pokhrel et al [88] recently reported their initial experience in assessing the feasibility and safety of the Toumai robotic system for some urological procedures. In detail, 17 consecutive patients underwent various nephrectomy procedures and three RARPs. The median ORT was 120

Table 6 – Studies evaluating robotic procedures performed using the REVO-I robotic platform or the Hinotori robot

Study	Country	Study design	Procedure (cases)	IDEAL stage	Preoperative characteristics	ORT/WIT (min)	EBL (ml)	POPCs	LOS (d)	Pathology	Functional outcomes
REVO-I robotic platform											
Chang 2018 [77]	Korea	Case series	RS-RARP (17)	1-2a	Age: 72 (62.5–75) BMI: 24.9 (23–27) PSA: 6.6 (3.1–10.7) PV: 25 (23–32)	ORT 92 (85.5–133)	200 (200–300)	Major: 0	4 (4.7)	pT2: 16 (94.1%) pT3: 1 (5.9%) PSM: 4 (23.5%)	Continence 1 wk: 9 (58.8%) 1 mo: 14 (82.4%) 3 mo: 3 (17.6%)
Alip 2022 [16]	Korea/ Philippines	Comparative series (MPSA)	RS-RARP R: 33 D: 33	3	**Age** R: 71±6 yr D: 72±9 yr **BMI** R: 24.8 ± 3.6 D: 25.4 ± 4.8 **PSA** R: 6.64 ± 6.35 D: 6 ± 3.2 **GG>3** R: 6 (18.2%) D: 6 (18.2%) **cT3** R: 8 (24.2%) D: 10 (30.3%)	R: 89.4 ± 31.3 D: 49.5 ± 14.2	R: 284 ± 262 D: 206 ± 165	**Overall** R: 3 (9%) D: 3 (9%) **Major** R: 0 D: 1 (3%)	(R) 5.8 ± 2.1 D: 5 ± 1.8	**PSM** R: 16 (48%) D: 15 (45%) GG>3 R: 7 (21%) D: 6 (18%) ≥**pT3** R: 6 (18%) D: 8 (24%)	6-mo BCR R: 4 (12%) D: 0
Hinotori robot											
Miyake 2023 [78]	Japan	Case series	RAPN (30)	2b	Age: 62 yr (46–84) BMI: 23 (20–49) TS: 28 mm (8–53) RENAL: 8 (5–10) cT1a: 23 (76.7%) cT1b: 3 (23.3%)	ORT 179 (122–268) WIT 13 (5–20)	39 (5–312)	Major: 0	7 (4–23)	PSM: 0	MIC 29 (96.7%)
Motoyama 2023 [19]	Japan	Comparative (MPSA)	RAPN H: 37 D: 74	3	**Age** H: 62 yr (37–84) D: 68 yr (18–86) **BMI** H: 23.7 (15.3–49) D: 23.8 (18–35.2) **TS** H: 27 mm (8–53) D: 24 mm (5–50) **RENAL score** H: 7 (4–10) D: 8 (4–10)	**ORT** H: 108 (53–191) D: 107 (50–194) **WIT** H: 12 (5-20) D: 12 (4–21)	H: 34 (1–312) D: 52 (0–262)	Major H: 0 D: 0	H: 7 (4–23) D: 7 (4–28)	PSM H: 0 D: 0	**MIC** H: 97.3% D: 94.6% **1-mo ΔeGFR** H: −9.2 D: −8.9
Motoyama 2023 [79]	Japan	Case series	RARN (13)	2a	Age: 65 yr (46–85) BMI: 23 (16–33) TS: 50 mm (14–84)	ORT 157 (129–232)	11 (5–66)	Major: 0	6 (4–10)	PSM 0	
Motoyama 2023 [80]	Japan	Case series	RANUT (8)	1–2a	Age: 76 yr BMI: 29 TS: 13 mm	230	23		8	PSM 1 (12.5%)	
Motoyama 2023 [81]	Japan	Case series	Adrenalectomy (6)	1–2a	Age: 64 yr BMI: 27.5 M/F: 3/3 TS: 36 mm	119	8		7		
Motoyama 2024 [82]	Japan	Case report	RARN + IVCT (2)	1	Age 66 yr (M) 76 yr (M)	ORT 158 156	 535 200	 No No	 8 10		

Table 6 (*continued*)

Study	Country	Study design	Procedure (cases)	IDEAL stage	Preoperative characteristics	ORT/WIT (min)	EBL (ml)	POPCs	LOS (d)	Pathology	Functional outcomes
Hayashi 2024 [83]	Japan	Cases report	RARC + iUD	1	Age: 79 yr	OR: 476	562	Ileus			
Nakayama 2024 [29]	Japan	Comparative series	RARP H: 97 D: 246	2b	**Age** H: 69 (63-73) D: 69 (65-72) **BMI** H: 24 (22.3-27) D: 23.7 (22-26) **PSA** H: 7.2 (5.4-10.8) D: 7.4 (5.4-11.3) **PV** H: 33 (26-40) D: 32 (25-40)	ORT H: 173 D: 144	H: 20 D: 25	Major H: 0 D: 4 (1.6%)		**PSM** H: 36% D: 39% **pT2** H: 59.8% D: 74.4%	

ORT = operative room time; WIT = warm ischaemia time; EBL = estimated blood loss; LOS = length of stay; BMI = body mass index (kg/m^2); PSA = prostate-specific antigen (ng/ml); PSM = positive surgical margin; R = REVO-I robot; D = da Vinci system; GG = grade group; RAPN = robot-assisted partial nephrectomy; MIC = composite margin/ischaemia time/complication achievement; H = Hinotori robot; RARN = robot-assisted radical nephrectomy; IVCT = inferior vena cava thrombectomy; RANUT = robot-assisted nephroureterectomy; M = male; F = female; RARC - robot-assisted radical cystectomy; iUD = intracorporeal urinary diversion; RARP = robot-assisted radical prostatectomy; RS-RARP = Retzius-sparing RARP; MPSA = matched propensity score analysis; PV = prostate volume (cm^3); TS = tumour size; BCR = biochemical recurrence; ΔeGFR = change in estimated glomerular filtration rate (ml/min/1.73 m^2).

min for RAPN, 140 min for RARN, and 210 min for RARP. Only one major complication was observed [88].

4. Discussion

To the best of our knowledge, this is the first systematic review to examine the evolution of clinical research on the novel robotic platforms currently available worldwide and licensed for urological surgery according to the IDEAL framework [9] and to assess clinical outcomes. The literature search for our systematic review identified a considerable number of single-arm explorative studies, and only a few comparative studies. These comparative studies demonstrated comparable clinical outcomes between the novel platforms and the fourth-generation da Vinci system. However, they should be considered preliminary because they were mostly nonrandomised trials, included small sample sizes, and were performed in centres involved in the development and/or training programmes for the novel platforms. Moreover, no study has performed a head-to-head comparison between the novel robotic platforms (Supplementary Table 1).

The past two decades have been characterised by an Intuitive Surgical monopoly in robotic surgery. Several surgeons were trained on da Vinci robotic platforms, and robotic procedures have subsequently been increasingly performed on a worldwide basis, with a progressive decrease in the number of surgical procedures performed via open surgery or traditional laparoscopy in several high-volume referral centres. However, the high costs for purchase and maintenance of da Vinci robotic systems are a significant barrier for many hospitals, especially in countries with limited economic resources. Several experts have claimed that the Intuitive Surgical monopoly is responsible for the persistence of high costs for robotic procedures worldwide, and have called for the introduction of novel robotic platforms on the market.

As demonstrated by our systematic review, several novel robotic systems have been approved for clinical use in recent years, although none of them is yet available on a worldwide scale, in contrast to da Vinci systems. Moreover, most of the clinical studies carried out demonstrated the safety and feasibility of a variety of urological procedures performed by pioneers working in a few centres directly involved in the development of these new platforms and/or in the training programmes. Therefore, with increasing implementation of new robotic platforms, we await explorative and assessment studies performed by second-generation surgeons working in other centres. External validation of currently available clinical data is an essential step to increase the acceptance of these robots across the diverse urology community.

The Hugo RAS system, which was approved for clinical use in Europe in 2022, is currently the novel platform for which the most clinical studies in urology are available; the greatest number of evaluations have been for RARP. However, most clinical studies were conducted in the same centre directly involved in the manufacturer's training programme. Nevertheless, this platform seems to be the most promising and developed alternative to the da

Table 7 – Studies evaluating robotic procedures performed using a Dexter, Avatera, or Toumai robotic system

Study	Country	Design	Procedure (cases)	IDEAL stage	Preoperative characteristics	ORT (min)	EBL (ml)	POPCs	LOS (d)	Pathology	Functional outcomes
Dexter robot											
Böhlen 2023 [84]	Switzerland	CR	RARP (1)	1	Age 71 yr PSA 6	300		No		pT2a, GS 7 No PSM	
Thillou 2023 [85]	France	CS	RARP (10)	2a	Age 67 yr (62–71) BMI 27 (25–30) PSA: 8.5 (5–12.9) PV 42 (26–50)	230 (226–235)	655 (425–788)	Major: 1 (10%)	3 (3–4) Catheter: 10		
Avatera robot											
Kallidonis 2023 [86]	Greece	CS	Pyeloplasty (9)	1–2a		88 (76–116)		0			
Gkeka 2023 [87]	Greece	CS	RARP (14)	1–2a		103 (90–121)		0		PSM 2 (14%)	3-mo UCR 78.6% 3-mo potency 77.7%
Toumai robot											
Pokhrel 2024 [88]	China	CS	RAPN/RARN (17) RARP (3)	2a 1		120 (RAPN) 140 (RARN) 210 (RARP)		Major: 1/20 (5%)			

CR = case report; CS = case series; ORT = operative room time; EBL = estimated blood loss; LOS = length of stay; RARP = robot-assisted radical prostatectomy; PSA = prostate-specific antigen (ng/ml); PV = prostate volume (cm^3); POPCs = postoperative complications; PSM = positive surgical margin; GS = Gleason score; BMI = body mass index; RAPN = robot-assisted partial nephrectomy; RARN = robot-assisted radical nephrectomy; UCR = urinary continence rate.

Vinci system in Europe for renal and prostate robotic surgery. The largest series published to date involves comparison of 164 Hugo RAS RARPs to 378 da Vinci RARPs. This study represents the highest stage of clinical research for the Hugo RAS platform so far and demonstrated comparable perioperative and functional results between the two systems [20]. Clinical research on other surgical procedures performed with Hugo RAS system is still at the developmental stage, although two small nonrandomised studies have compared Hugo and da Vinci systems in performing RASP and sacrocolpopexy [24,25]. We believe that well-conducted, multicentre studies comparing Hugo RAS procedures with the current technological standard (represented by da Vinci systems) are needed.

Although approved both in Europe in 2014 and in the USA in 2017, the Senhance robotic system has not been widely tested or used since then. The studies available were performed in Croatia and Lithuania, mainly for RARP; the larger explorative study included 375 cases [72]. A matched-pair analysis performed in Taiwan assessed Senhance RARP versus da Vinci RARP and demonstrated overlapping perioperative outcomes [17]. This system seems to be interesting from both economic and technical perspectives, as it allows incorporation of traditional laparoscopic instruments. Similarly, the Dexter robotic system allows surgeons to switch easily between laparoscopy and robotic surgery. However, the Dexter system has only been tested in ten RARP cases to date and remains in a developmental stage of clinical research [85].

Versius is another novel robotic surgical system developed in the UK and available in Europe. A few development studies in urology that involved small numbers of patients have been published, in addition to a series of 177 urological procedures included in the Versius Surgical Registry, a prospective, multicentre data registry with ongoing collection across numerous surgical indications that was developed to accompany the Versius robotic surgical system in clinical practice [54].

Other robotic platforms included in our systematic review have mainly been adopted in the countries where they were developed: the KangDuo surgical robot and Toumai robotic system in China; the REVO-I robot in Korea; and the Hinotori robot in Japan. Notably, an RCT comparing RAPN procedures demonstrated equivalent results between the novel robotic KangDuo platform and a da Vinci system [15].

The few studies with a cost analysis demonstrated that the novel robotic systems offer lower costs in comparison to da Vinci systems, and may therefore be suitable for health systems looking for a cheaper alternative or to significantly increase the number of surgical procedures performed robotically while limiting costs.

Although costs may represent an advantage of novel robotic platforms in comparison to da Vinci systems, the need for specific training for each novel robotic system and differences in surgeon comfort and skill could represent potential barriers to their widespread adoption of in health systems already equipped with da Vinci system.

The literature is lacking in comprehensive comparative studies evaluating distinct differences between robotic plat-

forms, such as the advantages and limitations of modular systems versus single carts and the benefits of open versus immersive consoles. As a result, any discussion regarding the superiority of these features is largely speculative and based on the personal preferences and experiences of individual operators. Given the early stages of evaluation for many new robotic systems, it is crucial to conduct detailed comparative studies to establish a clearer understanding of their performance, usability, and impact on surgical outcomes. Such studies would provide valuable insights into the practical benefits and potential drawbacks of different system designs and could thereby inform the decision-making processes of surgical teams and health care providers.

There are several limitations to our systematic review, mainly related to the low quality of the literature given the early stages of development of novel robotic systems. Most studies were small case series demonstrating the feasibility and/or describing the technique used to perform each surgical procedure according to the technological characteristics of new robots. Only a few good-quality studies compared novel platforms with da Vinci systems. Moreover, all these studies must be considered underpowered and strongly limited by the small sample sizes. Notably, most comparative studies tested first-generation novel platforms against the fourth-generation multiarm da Vinci system. The data available are not appropriate for a meta-analysis considering the heterogeneity across studies. Further exploration (stage 2b) and well-conducted assessment studies (stage 3) are still needed before attempting to discern the additional or alternative role of novel platforms in comparison to evidence-based data for the da Vinci systems. Finally, our systematic review focused on multiport robotic systems and excluded single-port robotic platforms. In 2018 the FDA granted approval for use of a da Vinci single-port robotic system, which could represent a new frontier in the evolution of robotic surgery.

5. Conclusions

The introduction of novel robotic surgical systems to the market has halted the monopoly of Intuitive Surgical in many countries. Although none of these systems is available on a worldwide scale yet, some platforms such as the Hugo RAS and Versius CMR have spread mainly in Europe, while other platforms such as the KangDuo surgical robot, Toumai, REVO-I, and Hinotori are used in China, Korea, and Japan.

Most studies focused on demonstrating the feasibility and safety of novel platforms for different surgical procedures. Only a few studies reached IDEAL stage 3 of clinical research, and most studies can be classified as developmental or explorative. Most of the comparative studies demonstrated comparable outcomes to those with a da Vinci robotic system. The novel platforms introduce new features and may reduce the costs of robotic surgery in urology. However, further well-conducted, multicentre, comparative studies are required to confirm the promising results reported mainly by the few centres involved in the development and training program of these new platforms and to understand whether novel robots could offer some advantages over da Vinci systems beyond cost savings.

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Study concept and design: Ficarra.
Acquisition of data: Rossanese, Russo, Viganò.
Analysis and interpretation of data: Ficarra, Rossanese, Di Trapani, Sorce.
Drafting of the manuscript: Ficarra.
Critical revision of the manuscript for important intellectual content: Ficarra, Rossanese, Giannarini, Sorce, Di Trapani.
Statistical analysis: Ficarra.
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Appendix A. Supplementary data

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