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Review Article

# Comparison of emerging Chinese robot-assisted surgery systems and the da Vinci surgical system: A meta-analysis and systematic review

Zehao Yu [a], Jiawei Chen [a], Yarong Song [b], Qingliu He [c], Liang Chen [a], Kang Chen [a], Yifei Xing [d,*]

[a] Master of Medicine, Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, China
[b] Department of Urology, Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, China
[c] Master of Medicine, Department of Urology, The Second Affiliated Hospital of Fujian Medical University, Quanzhou, 362000, China
[d] Department of Urology, Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, No. 1277, Jiefang Avenue, Wuhan City, Hubei Province, China

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ABSTRACT

To synthesize and compare the intraoperative performance of the emerging Chinese surgical robot (CNR) and its postoperative impacts on patients with the Da Vinci surgical robot (DVR). A search of articles published before April 2024 was launched in Embase, Scopus, PubMed, Web of Science, and Cochrane Center for meta-analysis and systematic review. Intraoperative and postoperative outcomes were evaluated between CNRs and DVRs. The meta-analysis results, performed using Review Manager (RevMan) (Version 5.4), were reported as risk ratios (RR) for binary variables via the Mantel-Haenszel method and as mean difference (MD) for continuous variables via the inverse variance method. All effect estimates were accompanied by a 95 % confidence interval (CI) and statistical significance was established with a two-tailed p-value of less than 0.05 ($p < 0.05$). Eight studies, 541 individuals totally, were incorporated into the analysis. CNRs had a longer operating time than DVRs [MD 9.44, 95 %CI 3.33, 15.56, $p = 0.002$]. However, the conversion rate, intraoperative blood loss, postoperative hospital stay, complication rate, number of lymph nodes retrieved and robotic docking time failed to show noticeable differences. Subgroup analysis revealed Kangduo surgical robots took more operating time than Da Vinci robots [MD 15.37, 95 %CI 8.98, 21.76, $p < 0.00001$]. Despite the extended operating time associated with CNRs, the surgical outcomes showed no significant differences. Hence, we can assert CNRs are not inferior to DVRs in terms of intraoperative performance and postoperative patient recovery.

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## 1. Introduction

Minimally invasive surgery (MIS) is widely used for various surgical procedures. It involves making smaller incisions or percutaneous punctures to access the body, utilizing endoscopes and specialized surgical instruments, thereby avoiding the large incisions characteristic of traditional surgery. This technique typically offers several advantages, including reduced trauma, less bleeding, faster recovery, and less pain.[1] With the completion of the first cholecystectomy assisted by the Da Vinci robot in 1997.[2] The safety and advantages of DVRs have been repeatedly proven involving urology, gastroenterology, gynecology, and cardiovascular surgery in the following nearly three decades.[3,4] Despite ongoing advancements in MIS, DVRs remain irreplaceable due to their continuous upgrades.

However, a large number of new surgical robots have emerged in the past 10 years.[5–7] The first gastric perforation repair surgery performed by CNR was completed in 2014,[8] marking a new era of robotic-assisted surgery in China. The feasibility and safety of CNRs with definite advantages including motion stability, absence of pivot effects, reduced surgeon fatigue, three-dimensional high-definition field of vision, seven degrees of freedom, and ergonomic design improvements for the surgeon have been verified in major hospitals.[9–11] Although relevant comparative studies have been conducted between CNRs and DVRs,[12–19] the latter is still more reliant on many surgeons. Consequently, we gathered the most

* Corresponding author.
*E-mail address:* yfxing@hust.edu.cn (Y. Xing).

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extensive collection of comparative clinical studies available in the existing literature and performed a systematic review and meta-analysis to evaluate the distinction between CNRs and DVRs.

## 2. Materials and methods

### 2.1. Search strategy

According to *Goossen et al*[20] a thorough search was launched in Embase, Scopus, PubMed, Web of Science, and Cochrane Center for meta-analyses and systematic reviews. The PICO criteria were met following the updated guidance[21]:

- P (population): patients undergoing robot-assisted surgery.
- I (Intervention): Surgery assisted by robots made in China
- C (comparator): Using DVRs.
- O (Outcome): intraoperative and postoperative results
- S (study design): comparative studies

The search strategy was formulated to retrieve articles published up to April 2024. The detailed search strategy is described in additional document 1.

### 2.2. Article selection

The selection criteria for the articles were formulated with reference to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and Assessing of Methodological Quality of Systematic Reviews (AMSTAR) guidelines.[22,23] Two authors (Y.F.X. and Z.H.Y.) separately reviewed the articles for inclusion and exclusion criteria. The research protocol was registered in PROSPERO (registry number: CRD42024535582).

All studies that compared CNR and DVR surgery with surgical outcomes were included. Case reports, reviews, letters, animal experiments, and non-English articles were excluded from analysis.

Initially, the articles were categorized into absolute exclusion and possible inclusion categories by screening the title and abstract. Further full-text review of possible inclusion was performed to ensure that the inclusion criteria were satisfied. In instances where multiple articles from the same institution used the same database, only the most recent reports or those with the highest data density were selected.

### 2.3. Quality assessment

Two authors independently evaluated the quality of included studies. Quality assessment of comparative non-randomized studies was conducted using the Newcastle-Ottawa scale.[24] The Jadad scale was applied to evaluate inclusive randomized controlled trials (RCTs).[25]

### 2.4. Risk of bias evaluation

The revised Cochrane risk-of-bias tool for randomized trials (RoB 2) and The Risk of Bias in Non-Randomized Studies of Interventions (ROBINS-I) tool were employed to assess bias risks in RCTs and non-randomized studies, respectively.[26,27]

### 2.5. Statistical analysis

A quantitative meta-analysis was conducted using Review Manager (RevMan) (Version 5.4. The Cochrane Collaboration, 2020). General information of each inclusive study was described as summative figures. Outcomes of meta-analysis are reported as risk ratios (RR) for binary variable by Mantel-Haenszel method and as mean difference (MD) for continuous variables via inverse variance method. All effect estimates were accompanied by 95 % confidence interval (CI). Regarding continuous variables, prior to conversion from median, interquartile range (IQR), and range to mean and standard deviation (SD), skewness detection was conducted using the method proposed by *Shi et al*[28] while referencing the methodologies of *Wan* et al. *and Luo* et al.[20,29] Statistical significance was established with a two-tailed p-value of less than 0.05 ($p < 0.05$). Given the anticipated clinical heterogeneity across studies, random effects models were employed. Heterogeneities between studies were described by $I^2$,[30] and subgroup analyses stratified by the types of domestic robots were performed to further investigate the factors influencing heterogeneity. The publication bias of the included studies was evaluated through funnel plots, which are provided in additional document 2.

## 3. Results

### 3.1. Study composition and characteristics

An amount of 315 articles were retrieved through search strategies from the electronic database. Before the formal audit, 112 duplicate articles and 6 incomplete clinical trials were excluded. After reviewing the titles and abstracts, 165 studies without comparisons or CNRs were eliminated, and they were classified as absolute exclusion. Out of the potential 31 studies identified for possible inclusion, 24 were excluded during full-text screening due to non-compliance with the inclusion criteria. The screening process is outlined in the flow diagram in Fig. 1. Ultimately, the analysis included eight studies comprising a total of 541 individuals.[12–19] Of these five were comparative studies and three were randomized controlled trials. The MicroHand S surgical system and KangDuo surgical robot were reported in three and four studies, respectively. Only one study examined the Toumai® surgical robot. The baseline features of all studies are shown in Table 1.

### 3.2. Bias assessment and study quality

The quality of the five comparative studies, assessed by the Newcastle-Ottawa scale, ranged from moderate to high. Three RCTs showed acceptable quality for Jadad 2 and 3 (Table 2). All studies, except for two, received low-to-moderate risk assessment results. The assessment of the bias is summarized in Fig. 2.

### 3.3. Skewness test

In total, five of the eight outcomes involved a data transformation. Except for the estimated blood loss study, in which the skewness test failed, none showed significant evidence that the data were skewed. Therefore, a subgroup analysis was performed to estimate blood loss in cases with potential impact on the final results.

### 3.4. Outcomes

#### 3.4.1. Estimated blood loss

Subgroup analysis indicated more estimated blood loss in the CNR of the skewed subgroup [MD 5.08, 95 %CI -7.50, 17.65, $p = 0.43$] and in the DVR of the subgroup with no skewness [MD -0.86, 95 %CI -14.05, 12.32, $p = 0.9$], although neither was significantly different (Fig. 4A), which was the same as those without subgroup analyses, indicating that inclusion of non-normally distributed data had no significant impact on the conclusions of

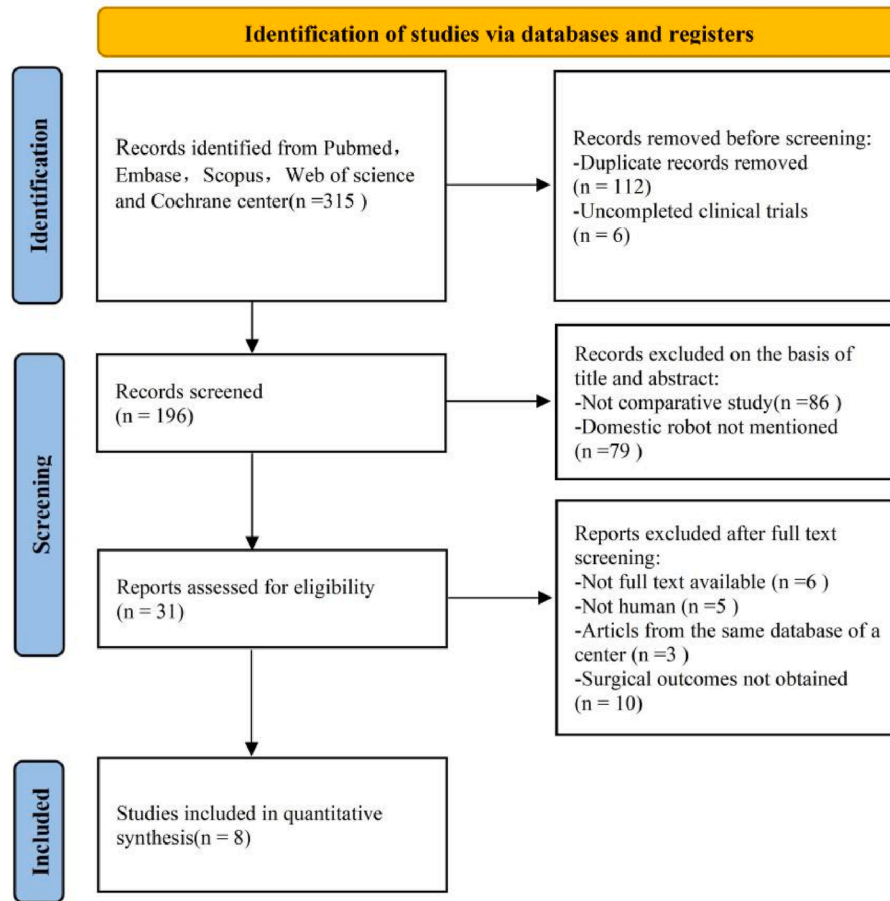



**Fig. 1.** Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

**Table 1**
General information for the studies included in the review.

| Study | Study period | DMR | DVR | Surgical approach | Patients (n) | | Age (yr) | | Body mass index (kg/m$^2$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | DMR | DVR | DMR | DVR | DMR | DVR |
| Luo 2020 | 2017–2019 | Micro Hand S | Da Vinci Si | Radical sigmoid colon cancer resection | 21 | 24 | 65.43 ± 9.38 | 59 ± 12.74 | 22.85 ± 3.14 | 22.43 ± 3.95 |
| Lei 2021 | 2017–2019 | Micro Hand S | | Mesorectal excision for rectal cancer | 43 | 45 | 59.51 ± 7.75 | 58.3 ± 9.05 | 24.71 ± 1.66 | 25.51 ± 1.71 |
| Fan 2022 | 2019–2021 | Kangduo | | Pyeloplasty | 16 | 16 | 31 ± 14 | 27 ± 10 | 23 ± 5 | 22 ± 4 |
| Wang 2022 | 2020–2021 | Micro Hand S | | Cholecystectomy | 84 | 84 | 45.18 ± 10.75 | 48.84 ± 10.65 | 23.87 ± 2.71 | 24.57 ± 2.58 |
| Li 2022 | 2020–2021 | KangDuo | | Partial Nephrectomy | 49 | 50 | 54.36 ± 10.25 | 52.14 ± 12.38 | 25.80 ± 2.84 | 25.63 ± 3.29 |
| Fan 2023 | 2021 | KangDuo | | Radical Prostatectomy | 16 | 16 | 66 (58–75) | 69 (57–78) | 23.62 (19.69–28.01) | 24.63 (20.96–31.22) |
| Huang 2023 | 2021 | Toumai® | | lobectomy | 9 | 10 | 62 [44.50–74.50] | 61.5 [55.75–66.75] | 22.58 [19.94–26.69] | 23.31 [21.17–26.92] |

this study [MD 2.87, 95 %CI -7.58, 13.33, p = 0.59] (Fig. 3A).

*3.4.2. Conversion rate*

Seven studies reported intraoperative conversion. The results revealed no statistically significant increase in the conversion rate in the CNR group [MD 0.74, 95 %CI, 0.12, 4.34, p = 0.74] (Fig. 3B).

*3.4.3. Operating time*

All studies included the duration of surgery. The meta-analysis demonstrated that the DVR group had a marginally shorter operating time than the CNR group, with the difference reaching statistical significance [MD 9.44, 95 %CI 3.33, 15.56, p = 0.002] (Fig. 3C).

*3.4.4. Robotic docking time*

Five inclusive studies additionally recorded the time spent docking the robot before the operation. The difference in CNRs cost more time to be ready for use than the DVR was not statistically significant [MD 0.27, 95 %CI -1.32, 1.86, p = 0.74] (Fig. 3D).

*3.4.5. Hospital stay*

Days in the hospital after surgery were reported in all studies,

**Table 2**
Quality assessment and for the studies included in the review.

| Study | Design | Surgical approach | Domestic surgical robot | Outcomes assessed | Study quality |
|---|---|---|---|---|---|
| Luo et al., 2020 | retrospective study | radical sigmoid colon cancer resection | MicroHand S | OT, number of lymph node harvested, EBL, intestinal exhaust time, time of oral feeding resumption, abdominal cavity 24-h drainage volume, removal time of drainage tube, removal time of catheter, HS, Visual Analogue Score, the time to get out of bed after surgery, hospitalization costs, complication, CR, PC | 6 |
| Lei et al., 2021 | retrospective study | mesorectal excision for rectal cancer | MicroHand S | circumferential and distal resection margin (CRM and DRM) involvement, number of retrieved lymph nodes, EBL, OT, time to first flatus, time to oral feeding, HS, postoperative function, PC | 8 |
| Fan et al., 2022 | retrospective study | Pyeloplasty | Kangduo | OT, EBL, suturing time, time per stitch, PC, CR, HS | 8 |
| Wang et al., 2022 | RCT | Cholecystectomy | MicroHand S | docking time, console time, OT, EBL, gallbladder breach rate, postoperative pain, time of first flatus, Comprehensive Complication Index (CCI), HS | Jadad 2 |
| Li et al., 2022 | RCT | Partial Nephrectomy | Kangduo | Primary outcomes (Conversions, Without renal artery clamping, warm ischemia time, positive surgical margin) Secondary outcomes (Preoperative eGFR, eGFR at POWs 4–12, Atrophy on B-scan ultrasonography at POWs), adverse events | Jadad 3 |
| Fan et al., 2023 | retrospective study | Radical Prostatectomy | Kangduo | EBL, CR, OT, HS, surgical margin, biochemical recurrence, and continence rate, PC | 7 |
| Huang et al., 2023 | retrospective study | Lobectomy | Toumai | CR, OT (docking time, console time and closure time), EBL, thoracic drainage, complication within 4 weeks of surgery, HS, the number of LNs and LN stations harvested,PC | 7 |
| Liu et al., 2024 | RCT | Radical colon cancer | Kangduo | OT, device docking time, robotic arm operation time, EBL, blood transfusion, CR blood index examination on the 1st day, the 3rd day, and the 4th week postoperatively, Clavien–Dindo grade, Number of harvested lymph nodes, Time to first flatus | Jadad 2 |

Operation time = OT; estimated blood loss = EBL; HS = hospital stay; PC = postoperative complications; CR = conversion rate; eGFR = estimated glomerular filtration rate; POW = postoperative week; Newcastle-Ottawa scale (total score: 5 = low quality; 6–7 = intermediate quality; 8–9 = high quality); Jadad scale (0 = very poor quality, 5 = rigorous quality).

except for one. It failed to find statistically significant difference in length of hospital stay [MD -0.10, 95 %CI, −0.43, 0.23, p = 0.55] (Fig. 3E).

### 3.4.6. Complication rate

Seven studies evaluated postoperative complications and reported the results based on the Clavien-Dindo classification system (grades I, II, III, and IV). We pooled all complication data and then analyzed postoperative complication rates with no statistical discrepancy [MD 0.98, 95 %CI 0.77, 1.26, p = 0.90] (Fig. 3F).

### 3.4.7. Number of lymph nodes retrieved

Six studies mentioned oncology surgery, but just four reported lymph nodes retrieval. The amount of retrieved lymph nodes showed no statistically significant disparity [MD -0.35, 95 %CI -1.72, 1.02, p = 0.62] (Fig. 3G) between the CNR group and DVR group.

## 3.5. Subgroup analysis and publication bias

Owing to data scale limitations, subgroup analysis stratified by types of CNRs was only implemented for operating time, robotic docking time, intra-operative estimated blood loss, and hospital stay, which showed results consistent with the main analysis. It was revealed that Kangduo surgical robots took more operating time than DVR [MD 15.37, 95 %CI 8.98, 21.76, p < 0.00001] (Fig. 4BCDE). Furthermore, given the limited number of studies, visual assessment was likely inaccurate, and the funnel plots failed to demonstrate any evident signs of publication bias.

# 4. Discussion

The inevitable trend in the development of surgery is MIS. The application of the DVR has promoted the popularization of MIS. However, it has made surgeons stay in the console instead of standing beside the operating table, a concept that remains perplexing to laypeople. With core characteristics including seven degrees of freedom for wrist movement, with the capability of enlarging three-dimensional images by ten times with intuitive control, and several software functions including shake elimination and optional motion expansion up to 3:1, DVRs have been favored by surgeons around the world for nearly 30 years.[31]

As the utilization and demand for robotic surgical platforms continue to increase, new robotic surgical platforms are proliferating. *M. Boal et al*[32] formulated the DEAL Framework (an internationally recognized tool for evaluating novel surgical technology) assessing a total of 21 emerging robotic system platforms. A review identified the benefits and limitations of each surgical robot, including FDA-approved devices, as well as robots that are not yet FDA-approved.[33] Although Chinese surgical robots appear relatively late, they are developing rapidly. The inaugural surgical robot system was pioneered through a collaboration between Central South University and Tianjin University, named as "Micro Hand S" in 2013, to deliver more value to surgical development.[8] In the following decade, emerging Chinese surgical robots involving TIANVI orthopedic surgical robots, Chinese neurosurgery medical robots, Remebot, endoscopic Toumai® robotic system, Kangduo robotic system, endovascular interventional robotic system ETcath, and oral robots have arose in various surgical fields.[34–38]

Our study analyzed the emerging CNRs and DVRs in the field of general surgery. Three marketed laparoscopic surgical robots involving the Micro Hand S, Kangduo, and Toumai® robotic systems were included in the study. Intraoperative estimated blood loss and surgical conversion rate were indicators to assess the safety of surgery.[39] A gratifying result was that estimated blood loss [MD 2.87, 95 %CI -7.58, 13.33; p = 0.59] and conversion rate [MD 0.74, 95 %CI 0.12, 4.34; p = 0.74] showed no difference between CNRs and DVRs, which indicated that CNRs were reliable on safety. The duration of hospital stay and long-term complications were factors associated with postoperative evaluation.[40] Similarly, there was no significant disparity in postoperative recovery [MD -0.1, 95 %CI -0.43, 0.23, p = 0.55] [MD 0.98, 95 %CI 0.77, 1.26, p = 0.90], regardless of the use of CNRs or DVRs. Regarding

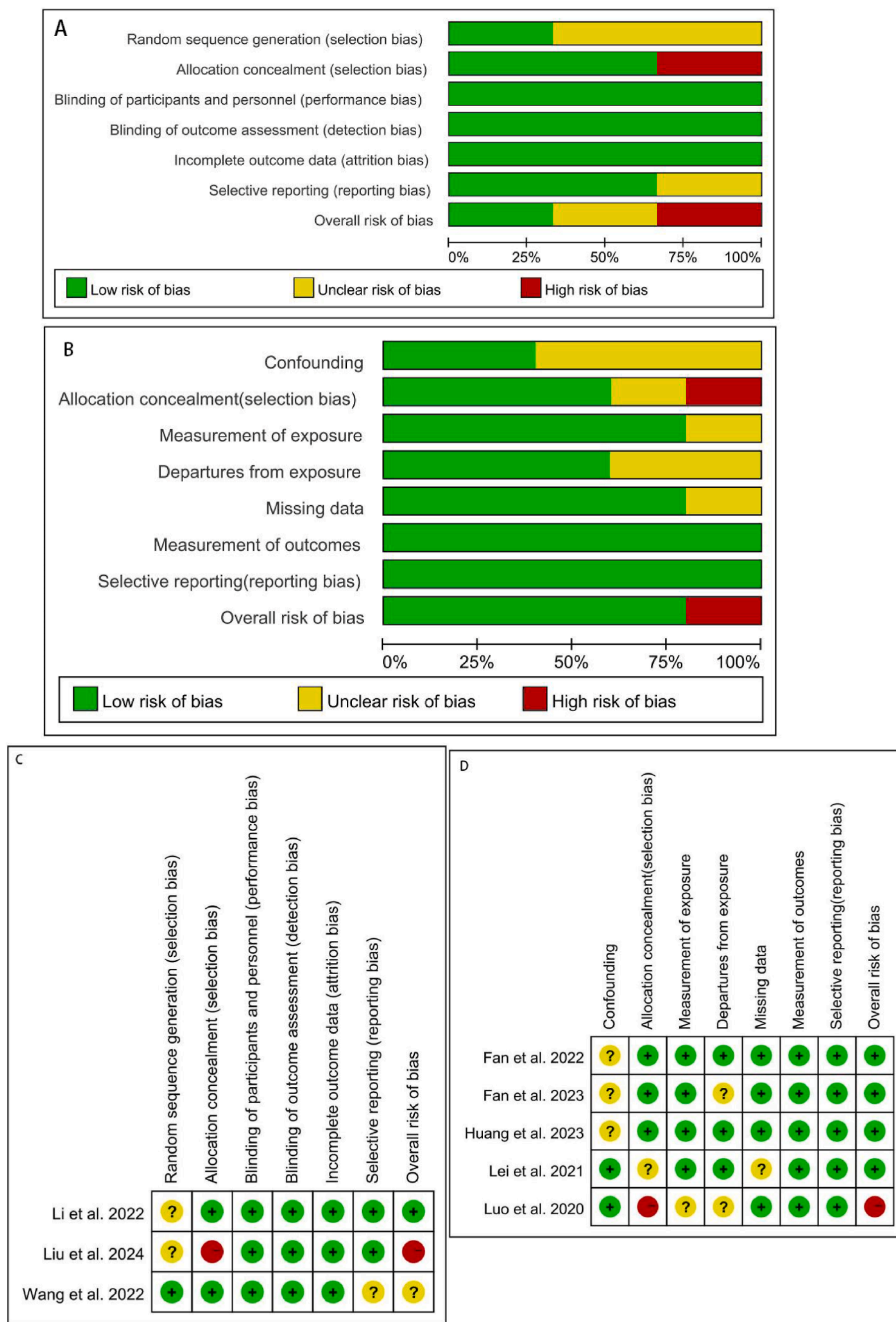
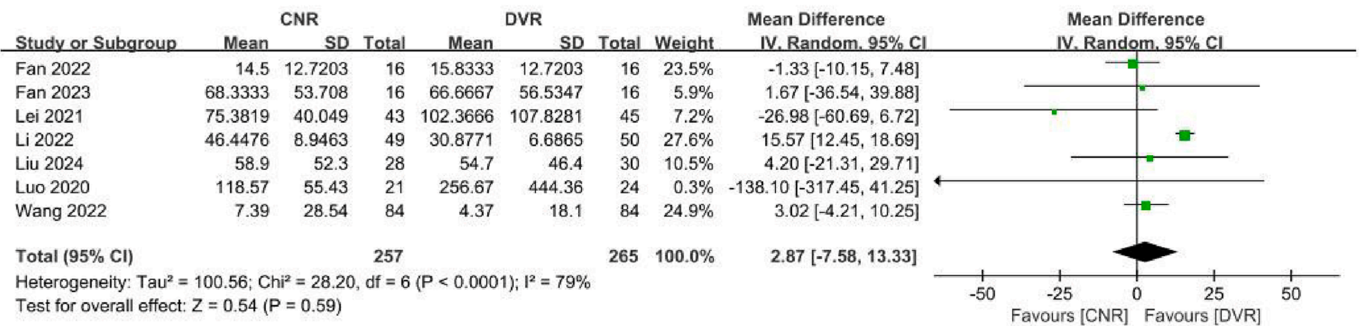
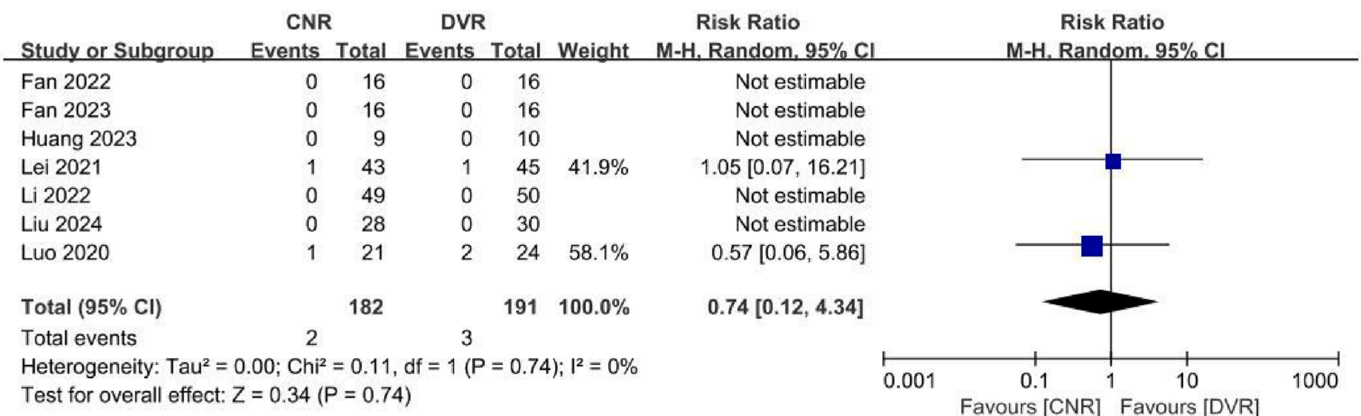


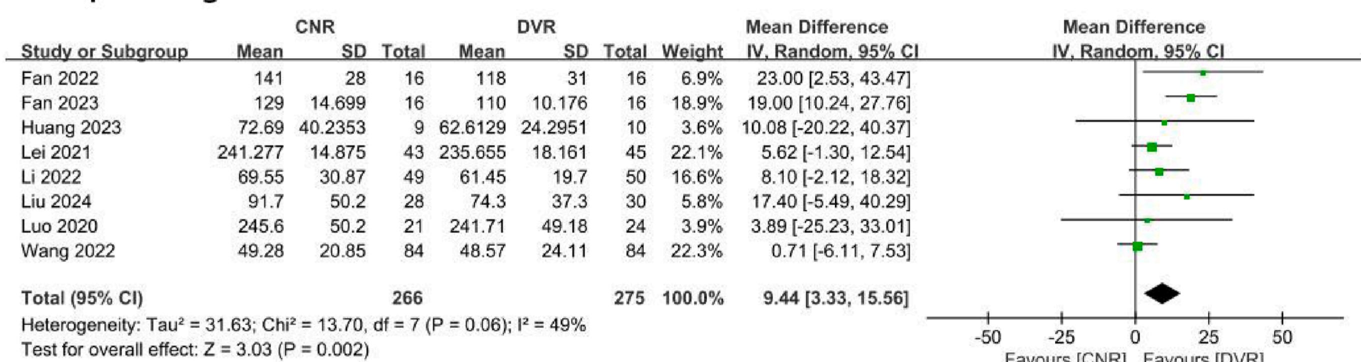

**Fig. 2.** Risk-of-bias assessment for comparative studies using (A and C) the revised Cochrane risk-of-bias tool (RoB 2) for randomized trials and (B and D) the ROBINS-I tool for nonrandomized studies.

oncological outcomes, the number of intraoperative lymph nodes dissected [MD -0.35, 95 %CI -1.72, 1.02, p = 0.62] had little to do with the type of robot. However, owing to the differences in the structure and assembly technology of the robots, CNRs required a longer operation time than DVRs [MD 9.44, 95 %CI 3.33, 15.56, p = 0.002].

Major emerging surgical robots have been invented based on DVRs, such as CNRs. Within the current technological framework, innovation incurs a greater cost. The three laparoscopic surgical systems included in this study were all master–slave robots, akin to DVRs, leading to an acceptable learning curve (Table 3). Micro Hand S is the earliest surgical robot on the market in China, whose miniaturization achieved by the polar layout design allows various body position changes for different surgeries.[41] Apart from the typical features of the robotic surgical platform, the distinction of Micro Hand S is mainly on slave operators and surgical instruments.[8] Three slave manipulators are engineered with two passive joints featuring orthogonal axes, allowing the robot to conform to the incision point constraints of MIS by automatically adapting to the incision point during movement. Compared with the dynamic fixed-point structure of DVRs, the passive fixed-point structure of Micro Hand S is designed to reduce the number of joints, shrink the size of the mechanism, and shorten the preoperative adjustment time. However, there was no significant



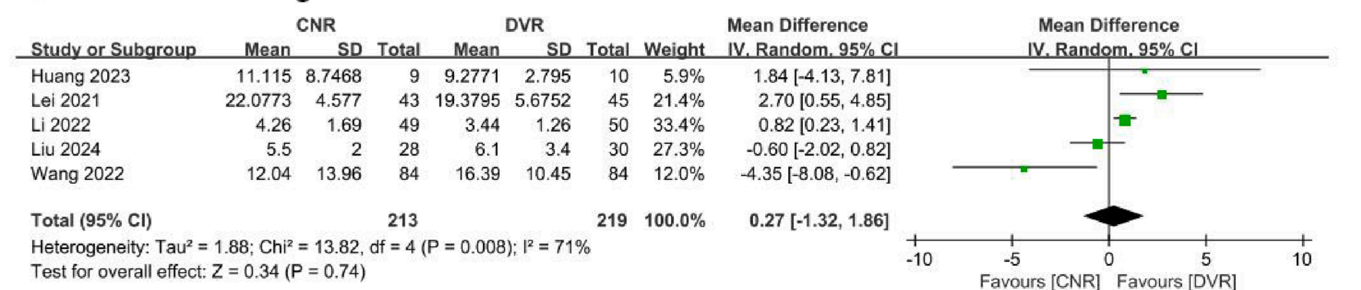
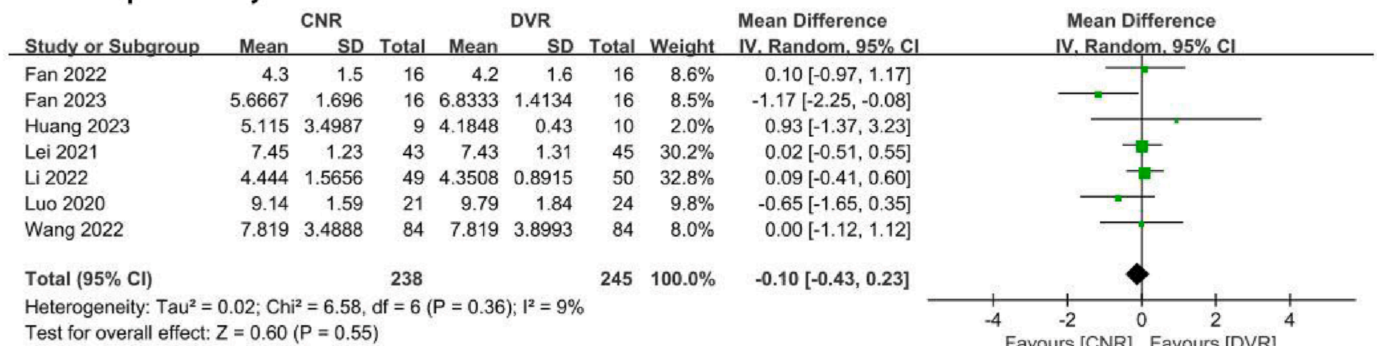
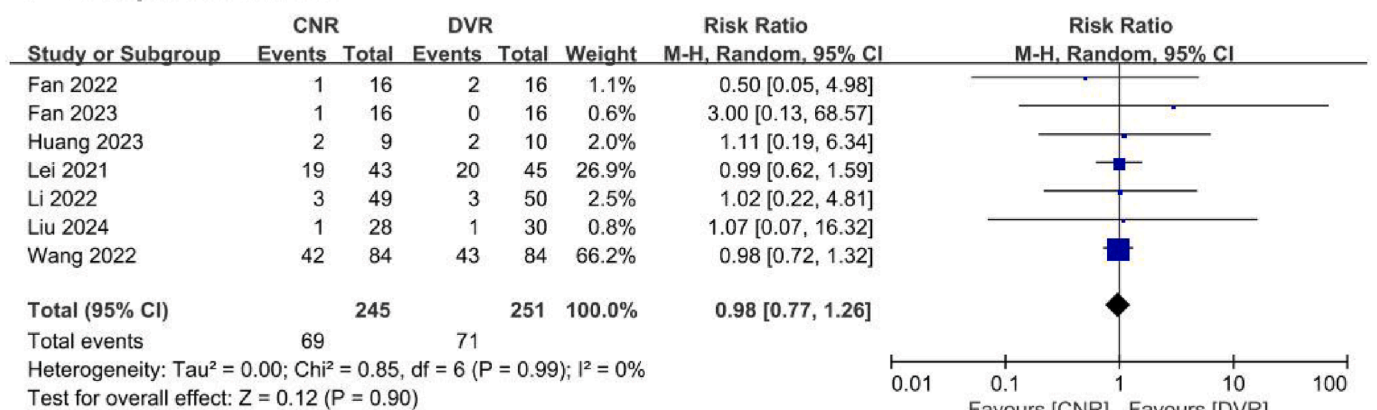




**Fig. 3.** Overall intraoperative and postoperative findings: comparison of Chinese robot-assisted surgery system (CNR) and Da Vinci surgical system (DVR). CI = confidence interval; MH = Mantel-Haenszel method; RCT = randomized controlled trial; df = degrees of freedom; IV = inverse variance; SD = standard deviation.

difference between DVRs and CNRs in docking time [MD 0.27, 95 % CI -1.32, 1.86, p = 0.74], as did the results of subgroup analysis [MD -0.65, 95 %CI -7.55, 6.24, p = 0.85] [MD 0.26, 95 %CI -1.09, 1.62, p = 0.70]. Theoretically, Micro Hand S and KD-SR-01 system, with only two operative arms, should dock more efficiently than DVRs. However, among the five studies discussing docking time, three reported faster docking with DVRs. This discrepancy is attributed to the distinct transformation interface at the distal end of each subordinate arm,[42] differing in structure and operation from the Da Vinci system adater, necessitating an adaptation period for the assistant. In practice, as the assistant gains experience within the same surgical procedure, this unfamiliarity will gradually diminish. The surgical instruments of Micro Hand S are different from DVRs, mainly in the layout of the degrees of freedom. Instead of roll-pitch-yaw in DVRs, Micro Hand S is equipped with a roll-pitch-roll arrangement for the instrument's degrees of freedom. Actually, for easier stiching, it is a compromise to make the end of the instrument to “roll” rather than “yaw” on the poor accuracy of motion caused by the elasticity of fixed points, which means possible failure of high-precision operation.[8] KD-SR-01 system features an open surgeon console designed to optimize hand-eye synchronization and permit a natural, modifiable neck posture. The configuration liberates the neck from a static position, allowing the neck muscles to relax and significantly reducing fatigue compared to immersive surgeon consoles. This advantage has been validated by the National Aeronautics and Space Administration Task Load Index (NASA-TLX).[43,44] Compared with DVRs, the slave surgical arms of Kangduo are suspended on a beam engineered to accommodate different patient positions and conserve space, but the latest generation Da Vinci Xi has also



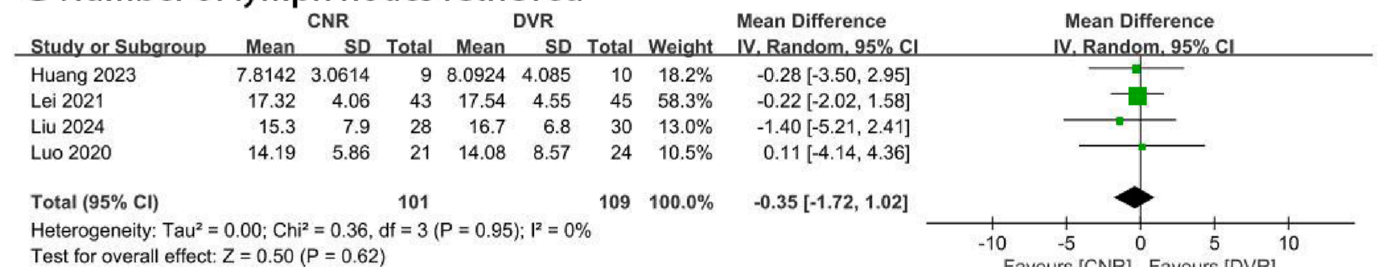
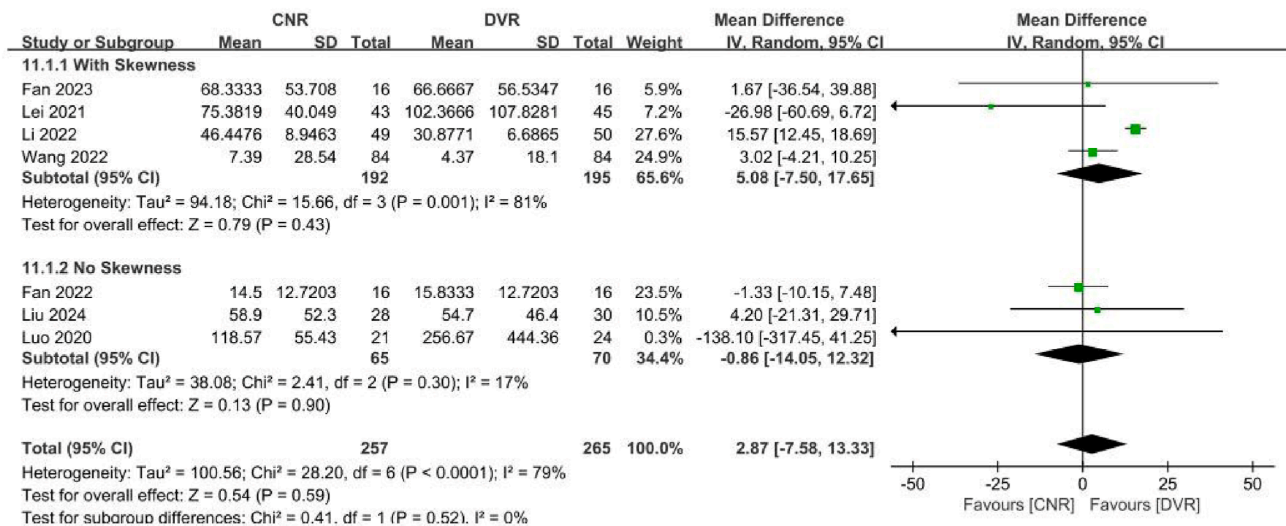
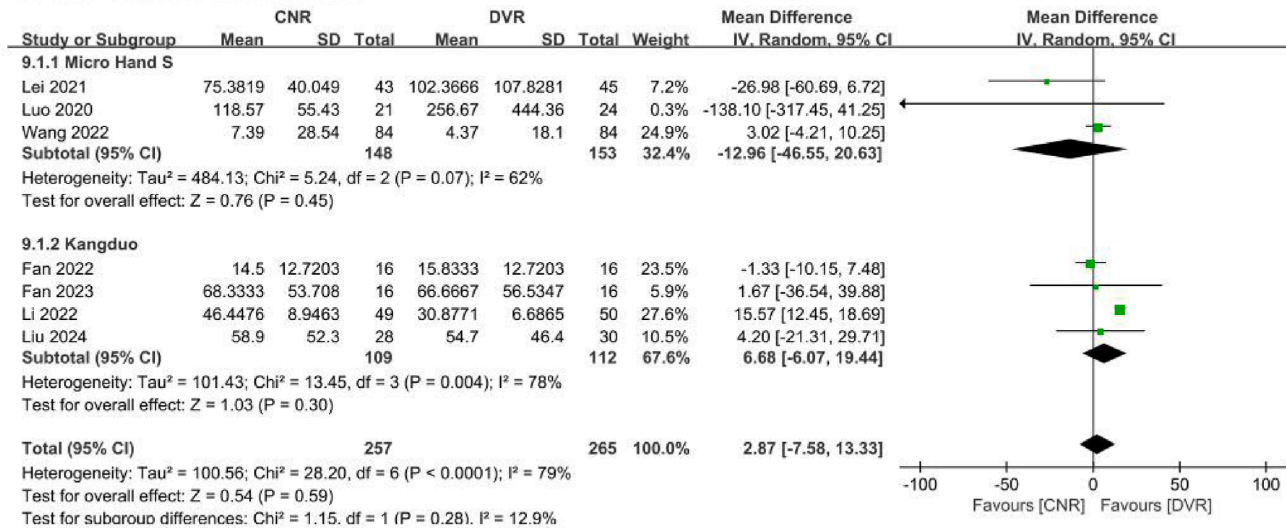




**Fig. 3.** (*continued*).



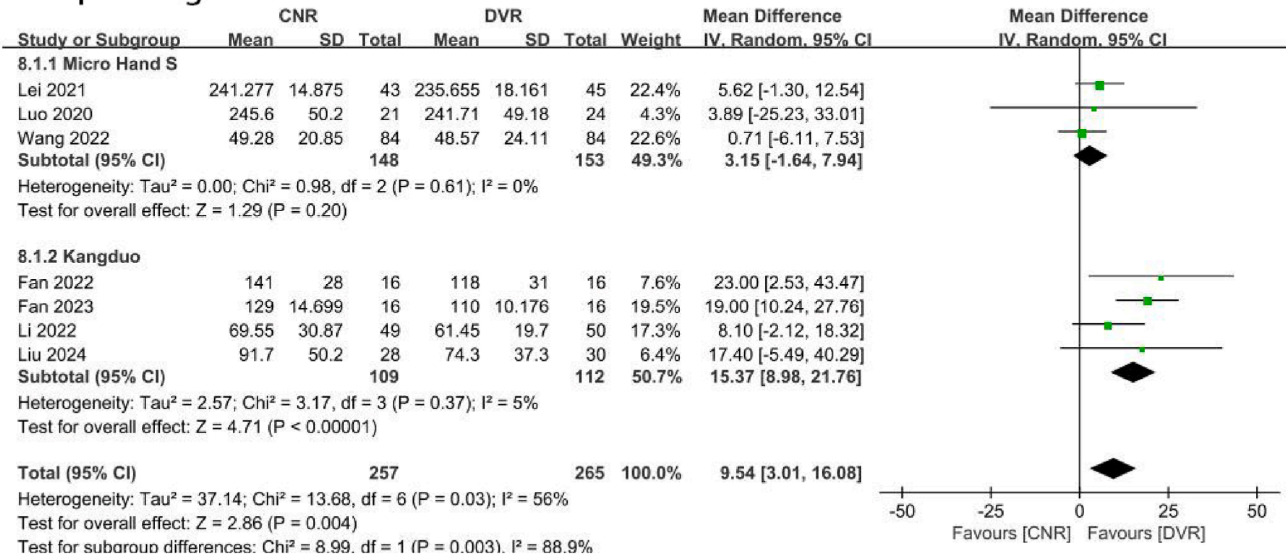
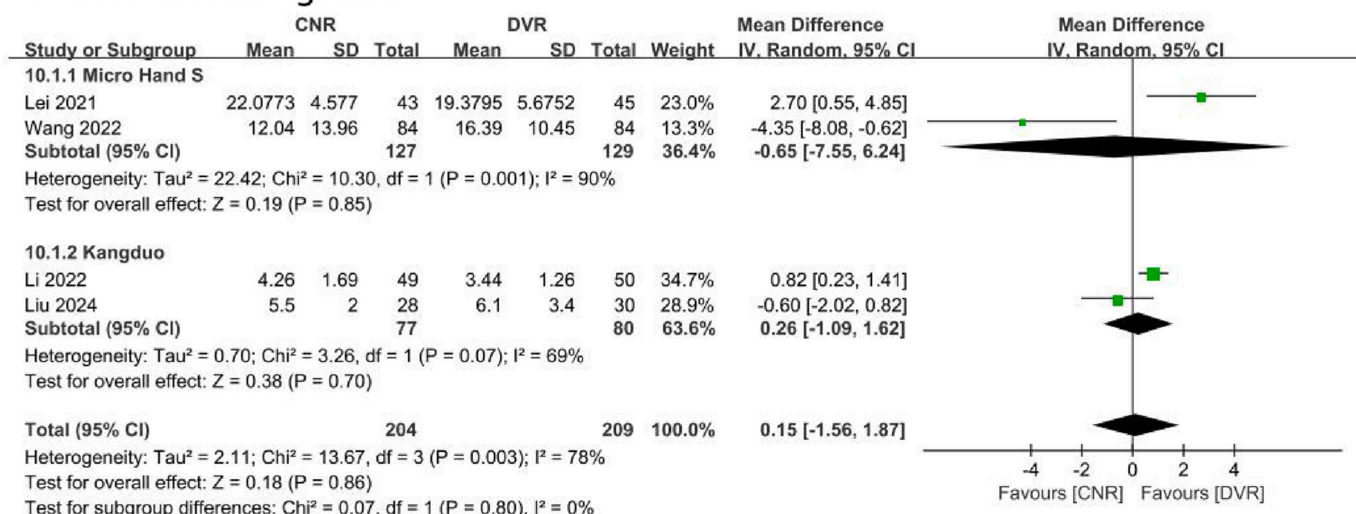




**Fig. 4.** Estimated blood loss stratified according to presence of skewness (A). Outcomes stratified according to types of CNRs (BCDE).

adopted this design.[9] Regrettably, except for the Toumai® robotic system, Micro Hand S and Kangduo surgical robots are only equipped with three robotic arms so that CNRs take longer time to surgery [MD 9.44, 95 %CI 3.33, 15.56, p = 0.002]. Additionally, the KD-SR-01 system designed a foot clutch that required more training from surgeons accustomed to the DVR system's manual clutch to re-adapt.[9] Therefore, a significantly longer operation time was observed in the Kangduo subgroup [MD 15.37, 95 %CI 8.98, 21.76, p < 0.00001]. However, the new-generation KD-SR-2000 was outfitted with four robotic arms and desired more clinical evidence for verification of viability. Toumai® has the highest degree of compatibility with Da Vinci Si. It inherited the virtues of Da Vinci. In the meantime it was facilitated with an independently developed DFVision® 3D endoscope system (Shanghai Minimally Invasive Medical Robot Co. Ltd.) offering a steady and realistic 3D surgical field vision.[35] Up to now, there have been few clinical comparative studies of Toumai. Therefore, subgroup analyses were not performed to obtain additional information. Furthermore, two studies mentioned the surgical costs of CNRs and DVRs. Obviously, the cost of surgery with CNRs was lower.[18,45] Given the limited number of studies investigating the cost of surgery, our study did not prioritize it despite its undeniable advantage.

Surgical robot technology has continuously advanced through technological innovations aimed at addressing the challenges of traditional tremors, limited instrument maneuverability, non-intuitive hand-eye coordination, and long-term ergonomic issues.[46] Correspondingly, the fourth-generation Da Vinci surgical platform, Da Vinci Xi, improves the cross-laser positioning mechanism for a more precise, standardized placement, patient cart undergoing a complete redesign of its kinematic chain, resulting in improved accuracy, and the robotic arms are made thinner and longer with revised joints, enabling a broader range of movement.[47] The lack of a haptic feedback system, a common problem with laparoscopic robots currently on the market, leads to



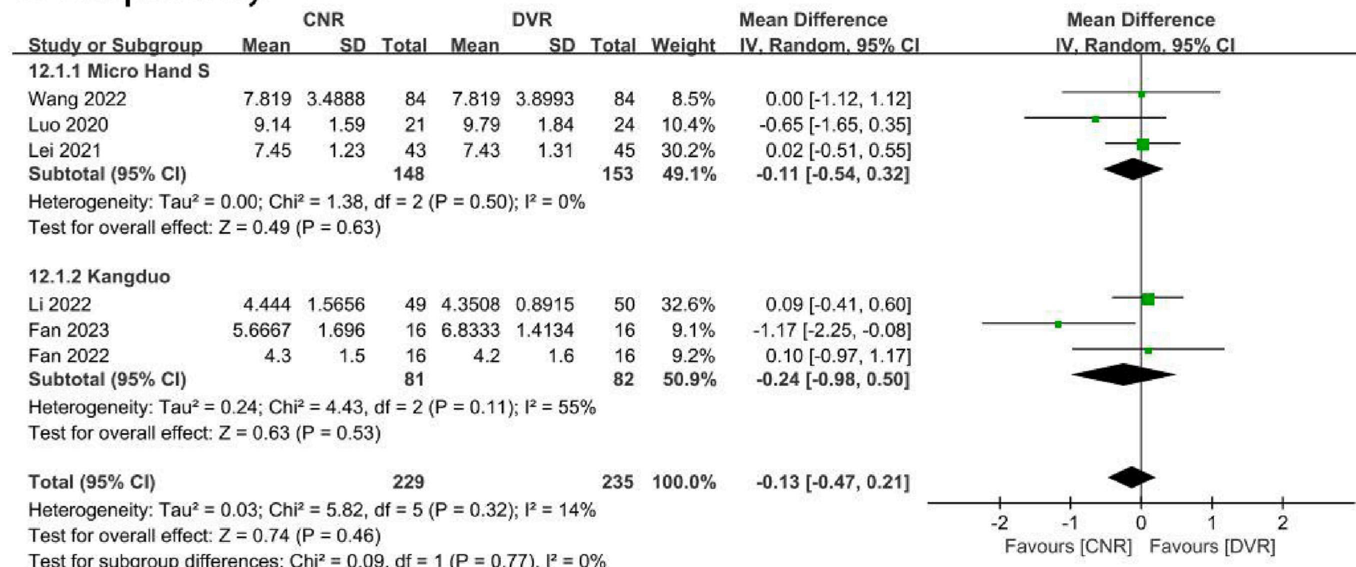




**Fig. 4.** (*continued*).

**Table 3**
Comparison of surgical robot properties.

| Specifications | KD-SR-01 | Da Vinci Si surgical system | Micro Hand S | Toumai® |
|---|---|---|---|---|
| Movement mode | Master-slave | Master-slave | Master-slave | Master-slave |
| Master console | Open (wear 3D glasses) | Immersive | Immersive | Immersive |
| Robotic arm construction | Suspended | Si autonomous/Xi Suspended | autonomous | Suspended |
| Robotic arm numbers | 3 arms (1 camera and 2 working) | 4 arms (1 camera and 3 working) | 3 arms (1 camera and 2 working) | 4 arms (1 camera and 3 working) |
| Vision system | 3D high-definition | 3D high-definition | 3D high-definition | 3D high-definition |
| Laparoscopy | Compatible with marketed laparoscopy | Dedicated laparoscopy | Compatible with marketed laparoscopy | Compatible with marketed laparoscopy |
| Device freedom degrees | 7 | 7 | 7 | 7 |
| Instrument service life | 10 | 10 | 10 | 10 |
| Laser-assisted docking | Yes | Si no/Xi Yes | Yes | Yes |

a lack of perception of the organization. Actually, visual-tactile feedback can correct each other during operation.[48] Presently, several surgical robots with force feedback have been reported such as MiroSurge,[49] Versius,[50,51] and Senhance.[52] The current surgical instrument arm characterized by its large structural footprint, poses a risk of damaging the lesion and adjacent critical tissues due to manipulation mistakes. Therefore, the future development trend is focused on the miniaturization and reduction in weight of surgical instrument arms.[53] Da Vinci single-port (SP) console was first reported with clinical data by *Kaouk et al*[54] in 2014. The EDGE SP1000, designed and developed by Shanghai Jiao Tong University, was applied in gynecology and urology,[55] which addressed the issue of substantial space occupied by the surgical instrument arm, thereby maximizing the minimally invasive benefits of robotic surgery. However, sufficient space is required initially to extend the arms before articulation, necessitating a longer working distance.[56] The advent of 5G information technology will usher in widespread use of telemedicine utilizing master-slave operation robots. Remote surgery has increased the mobility of surgeons, enabled surgical capabilities to overcome their own limitations, and achieved the globalization of surgeries, markedly boosting the efficiency of medical operations.[57,58] In addition to the surgical robot, its supporting instruments are also indispensable for completing the operation. The da Vinci Bipolar Vascular Closure System is launched to greatly reduce intraoperative bleeding, reduce thermal damage and protect surrounding tissues on the basis of stable robotic arm operation provided by the surgical robot. The safety and efficacy of China's integrated energy devices have been validated in animal experiments, showing no significant difference in tissue temperature between the CNRs' interconnected bipolar electrocoagulation system and that of the DVRs when applied to liver tissue.[59] Additionally, DVRs combined with the Linear Incision Stapler, facilitates gastrointestinal reconstruction by enabling precise anastomosis in limited space, enhancing minimally invasive surgery success rates. Though Chinese scholars have proven that the curative effect of curved cutter stapler in the ultra low anterior resection for low rectal cancer,[60] it has not yet been reported in the CNRs. In general, the emergence of surgical robots has significantly accelerated the advancement of surgery. The ongoing progress in clinical medicine, artificial Intelligence, biomechanics, remote interaction technology, electronic communication and adjacent disciplines will enhance the intelligence, exactitude, security, and efficiency of MIS robots.

This is the first study to compare the overall intraoperative performance of the current emerging Chinese laparoscopic surgical robotic systems and DVRs, as well as the effect on postoperative patient recovery using meta-analysis. However, our analysis failed to avoid several limitations. First, the studies encompassed in this review demonstrated substantial heterogeneity, largely owing to the limited number of randomized controlled trials included and the intrinsic nature of retrospective studies, and partly due to different surgical robots, different surgical skills of different surgeons, and regional differences. Subgroup analysis classified by the type of surgical robot reduced this heterogeneity to some extent. In addition, due to great differences in the types of diseases and surgical methods, intraoperative results such as time per stitch, suturing time, and postoperative outcomes including intestinal exhaust time and abdominal cavity 24-h drainage volume were not analyzed owing to a shortage of data. Furthermore, surgical procedures in the included literature are concentrated in general surgery and urology, and robotic systems appear to be more advantageous for complex surgeries, so more randomized controlled trials are needed to verify the surgical performance of CNRs. Finally, since the fourth-generation Da Vinci surgical platform, Da Vinci Xi, has not yet widely available in China, all comparative studies have used Da Vinci Si, the third-generation Da Vinci surgical platform. Therefore, CNRs should be benchmarked against the latest technologies and proven in practice for surgical performance in the future.

## 5. Conclusion

Our research revealed no significant disparity in surgical outcomes between CNRs and DVRs, even though CNRs cost more time than DVRs on operation. We are confident of the safety and feasibility of emerging surgical robots. Additionally, multicenter, multi-sample clinical studies are needed to verify the effectiveness of surgical robots in China.

## Ethical approval

Not applicable.

## Consent

Not applicable.

## Author contribution

Z.Y. and Y.X.: conceptualization, methodology, and software; Q. H. and K.C.: data curation; Z.Y. and J.C.: writing – original draft preparation; Y.X. and Y.S.: supervision; Y.X. and L.C.: writing – review and editing.

### Research registration unique identifying number (UIN)

1. Name of the registry: PROSPERO.
2. Unique identifying number or registration ID: CRD42024535582.
3. Hyperlink to your specific registration (must be publicly accessible and will be checked):https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42023433310.

### Guarantor

Zehao Yu and Prof. Yifei Xing.

### Data availability statement

The critical raw data was provided. Other datasets used and/or analyzed in the current study are available from the corresponding author upon reasonable request.

### Provenance and peer review

Not commissioned, externally peer-reviewed.

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### Conflicts of interest disclosure

The authors declare that they have no financial conflicts of interest regarding the content of this report.

### Appendix A. Supplementary data

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### References

1. Speth J. Guidelines in practice: minimally invasive surgery. *AORN J*. 2023;118(4):250–257.
2. Himpens J, Leman G, Cadiere GB. Telesurgical laparoscopic cholecystectomy. *Surg Endosc*. 1998;12(8):1091.
3. Soliman BG, Nguyen DT, Chan EY, et al. Impact of da Vinci Xi robot in pulmonary resection. *J Thorac Dis*. 2020;12(7):3561–3572.
4. Agarwal DK, Sharma V, Toussi A, et al. Initial Experience with da Vinci Single-port Robot-assisted Radical Prostatectomies. *Eur Urol*. 2020;77(3):373–379.
5. Bozzini G, Gidaro S, Taverna G. Robot-assisted laparoscopic partial nephrectomy with the ALF-X robot on pig models. *Eur Urol*. 2016;69(2):376–377.
6. Dai X, Fan S, Hao H, et al. Comparison of KD-SR-01 robotic partial nephrectomy and 3D-laparoscopic partial nephrectomy from an operative and ergonomic perspective: a prospective randomized controlled study in porcine models. *Int J Med Robot + Comput Assist Surg : MRCAS*. 2021;17(2):e2187.
7. Kim DK, Park DW, Rha KH. Robot-assisted partial nephrectomy with the REVO-I robot platform in porcine models. *Eur Urol*. 2016;69(3):541–542.
8. Yi B, Wang G, Li J, et al. Domestically produced Chinese minimally invasive surgical robot system "Micro Hand S" is applied to clinical surgery preliminarily in China. *Surg Endosc*. 2017;31(1):487–493.
9. Fan S, Zhang Z, Wang J, et al. Robot-assisted radical prostatectomy using the KangDuo surgical robot-01 system: a prospective, single-center, single-arm clinical study. *J Urol*. 2022;208(1):119–127.
10. Han HJ, Kang CM. Reduced port minimally invasive distal pancreatectomy: single-port laparoscopic versus robotic single-site plus one-port distal pancreatectomy. *Surg Endosc*. 2019;33(4):1091–1099.
11. Yao Y, Liu Y, Li Z, Yi B, Wang G, Zhu S. Chinese surgical robot micro hand S: a consecutive case series in general surgery. *Int J Surg*. 2020;75:55–59.
12. Fan S, Hao H, Chen S, et al. Robot-Assisted Laparoscopic Radical Prostatectomy Using the KangDuo Surgical Robot System vs the da Vinci Si Robotic System. *J Endourol*. 2023;37(5):568–574.
13. Fan S, Xiong S, Li Z, et al. Pyeloplasty with the Kangduo Surgical Robot vs the da Vinci Si Robotic System: Preliminary Results. *J Endourol*. 2022;36(12):1538–1544.
14. Huang J, Zhu H, Lu P, et al. Comparison of lobectomy performed through Toumai® surgical robot and da Vinci surgical robot in early-stage non-small cell lung cancer: a retrospective study of early perioperative results. *Transl Lung Cancer Res*. 2023;12(11):2219–2228.
15. Lei Y, Jiang J, Zhu S, Yi B, Li J. Comparison of the short-term efficacy of two types of robotic total mesorectal excision for rectal cancer. *Tech Coloproctol*. 2021;26(1):19–28.
16. Li X, Xu W, Fan S, et al. Robot-assisted Partial Nephrectomy with the Newly Developed KangDuo Surgical Robot Versus the da Vinci Si Surgical System: A Double-center Prospective Randomized Controlled Noninferiority Trial. *Europ Urol Focus*. 2023;9(1):133–140.
17. Liu Y, Wang Y, Wang C, et al. Comparison of short-term outcomes of robotic-assisted radical colon cancer surgery using the Kangduo Surgical Robotic System and the Da Vinci Si Robotic System: a prospective cohort study. *Int J Surg*. 2024;110(3):1511–1518.
18. Luo D, Liu Y, Zhu H, et al. The MicroHand S robotic-assisted versus Da Vinci robotic-assisted radical resection for patients with sigmoid colon cancer: a single-center retrospective study. *Surg Endosc*. 2019;34(8):3368–3374.
19. Wang G, Yi B, Li Z, et al. Micro-Hand Robot-Assisted Versus da Vinci Robot-Assisted Cholecystectomy: A Multi-centre, Randomized Controlled Trial. *World J Surg*. 2022;46(11):2632–2641.
20. Goossen K, Tenckhoff S, Probst P, et al. Optimal literature search for systematic reviews in surgery. *Langenbecks Arch Surg*. 2017;403(1):119–129.
21. Cumpston M, Li T, Page MJ, et al. Updated guidance for trusted systematic reviews: a new edition of the Cochrane Handbook for Systematic Reviews of Interventions. *Cochrane Database Syst Rev*. 2019.
22. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Br Med J*. 2021;372:n71.
23. Shea BJ, Hamel C, Wells GA, et al. AMSTAR is a reliable and valid measurement tool to assess the methodological quality of systematic reviews. *J Clin Epidemiol*. 2009;62(10):1013–1020.
24. Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. *Eur J Epidemiol*. 2010;25(9):603–605.
25. Jadad AR, Moore RA, Carroll D, et al. Assessing the quality of reports of randomized clinical trials: is blinding necessary? *Control Clin Trials*. 1996;17(1):1–12.
26. Sterne JA, Hernán MA, Reeves BC, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. *Br Med J*. 2016;355:i4919.
27. Sterne JAC, Savović J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. *Br Med J*. 2019.
28. Shi J, Luo D, Wan X, et al. Detecting the skewness of data from the five-number summary and its application in meta-analysis. *Stat Methods Med Res*. 2023;32(7):1338–1360.
29. Wan X, Wang W, Liu J, Tong T. Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. *BMC Med Res Methodol*. 2014;14:135.
30. Higgins JPT, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med*. 2002;21(11):1539–1558.
31. Bann S, Khan M, Hernandez J, et al. Robotics in surgery. *J Am Coll Surg*. 2003;196(5):784–795.
32. Boal M, Di Girasole CG, Tesfai F, et al. Evaluation status of current and emerging minimally invasive robotic surgical platforms. *Surg Endosc*. 2024;38(2):554–585.
33. Peters BS, Armijo PR, Krause C, Choudhury SA, Oleynikov D. Review of emerging surgical robotic technology. *Surg Endosc*. 2018;32(4):1636–1655.
34. Liu HG, Liu YY, Zhang H, et al. A bulk retrospective study of robot-assisted stereotactic biopsies of intracranial lesions guided by videometric tracker. *Front Neurol*. 2021;12:682733.
35. Pokhrel G, Zheng H, Tao J, et al. Assessing the feasibility and safety of the Toumai® robotic system in urologic surgery: initial experience. *J Endourol*. 2024.
36. Song C, Xia S, Zhang L, et al. A novel endovascular robotic-assisted system for endovascular aortic repair: first-in-human evaluation of practicability and safety. *Eur Radiol*. 2023;33(11):7408–7418.
37. Wang X, Zhang Y, Lou L, et al. Robotic-assisted systems for the safe and reliable treatment of femoral neck fractures: retrospective cohort study. *J Orthop Surg Res*. 2023;18(1):633.
38. Wu Q, Zhao YM, Bai SZ, Li X. Application of robotics in stomatology. *Int J Comput Dent*. 2019;22(3):251–260.
39. Slagter JS, Outmani L, Tran K, Ijzermans JNM, Minnee RC. Robot-assisted kidney transplantation as a minimally invasive approach for kidney transplant recipients: a systematic review and meta-analyses. *Int J Surg*. 2022;99:106264.
40. Moglia A, Georgiou K, Georgiou E, Satava RM, Cuschieri A. A systematic review on artificial intelligence in robot-assisted surgery. *Int J Surg*. 2021;95:106151.
41. Jiang J, Zhu S, Yi B, Li J. Comparison of the short-term operative, Oncological, and Functional Outcomes between two types of robot-assisted total mesorectal excision for rectal cancer: da Vinci versus Micro Hand S surgical robot. *Int J Med Robot + Comput Assist Surg : MRCAS*. 2021;17(4):e2260.
42. Wang W, Li J, Wang S, Su H, Jiang X. System design and animal experiment study of a novel minimally invasive surgical robot. *Int J Med Robot + Comput Assist Surg : MRCAS*. 2016;12(1):73–84.
43. Lee GI, Lee MR, Clanton T, Sutton E, Park AE, Marohn MR. Comparative

assessment of physical and cognitive ergonomics associated with robotic and traditional laparoscopic surgeries. *Surg Endosc*. 2014;28(2):456–465.
44. Xu L, Li X, Fan S, et al. Analysis of KangDuo-SR-1500 and KangDuo-SR-2000 robotic partial nephrectomy from an operative and ergonomic perspective: a prospective controlled study in porcine models. *J Robot Surg*. 2024;18(1):26.
45. Zeng Y, Wang G, Li Z, Lin H, Zhu S, Yi B. The Micro Hand S vs. da Vinci Surgical Robot-Assisted Surgery on Total Mesorectal Excision: Short-Term Outcomes Using Propensity Score Matching Analysis. *Front Surg*. 2021;8:656270.
46. Kinross JM, Mason SE, Mylonas G, Darzi A. Next-generation robotics in gastrointestinal surgery. *Nat Rev Gastroenterol Hepatol*. 2020;17(7):430–440.
47. Bravi CA, Mottaran A, Sarchi L, et al. Transitioning from Da Vinci Si to Xi: assessing surgical outcomes at a high-volume robotic center. *World J Urol*. 2023;41(12):3737–3744.
48. Adams WJ, Kerrigan IS, Graf EW. Efficient visual recalibration from either visual or haptic feedback: the importance of being wrong. *J Neurosci : Off J Soc Neurosci*. 2010;30(44):14745–14749.
49. Hagn U, Konietschke R, Tobergte A, et al. DLR MiroSurge: a versatile system for research in endoscopic telesurgery. *Int J Comput Assist Radiol Surg*. 2010;5(2): 183–193.
50. Morton J, Hardwick RH, Tilney HS, et al. Preclinical evaluation of the versius surgical system, a new robot-assisted surgical device for use in minimal access general and colorectal procedures. *Surg Endosc*. 2021;35(5):2169–2177.
51. Thomas BC, Slack M, Hussain M, et al. Preclinical evaluation of the versius surgical system, a new robot-assisted surgical device for use in minimal access renal and prostate surgery. *Europ Urol Focus*. 2021;7(2):444–452.
52. Schmitz R, Willeke F, Barr J, et al. Robotic inguinal hernia repair (TAPP) first experience with the new senhance robotic system. *Surg Technol Int*. 2019;34: 243–249.
53. Liu K, Jiang L. Multifunctional integration: from biological to bio-inspired materials. *ACS Nano*. 2011;5(9):6786–6790.
54. Kaouk JH, Haber GP, Autorino R, et al. A novel robotic system for single-port urologic surgery: first clinical investigation. *Eur Urol*. 2014;66(6):1033–1043.
55. Chen Y, Zheng Y, Wang P, Wang Q, Yang F, Zhou S. Single-port robotic surgery using the EDGE SP1000 surgical system in gynaecology: initial experience of a single institution. *Int J Med Robot + Comput Assist Surg : MRCAS*. 2023:e2578.
56. Covas Moschovas M, Bhat S, Rogers T, et al. Technical Modifications Necessary to Implement the da Vinci Single-port Robotic System. *Eur Urol*. 2020;78(3): 415–423.
57. Anwar S, Prasad R. Framework for future telemedicine planning and infrastructure using 5G technology. *Wirel Pers Commun*. 2018;100(1):193–208.
58. Zheng J, Wang Y, Zhang J, et al. 5G ultra-remote robot-assisted laparoscopic surgery in China. *Surg Endosc*. 2020;34(11):5172–5180.
59. Song Z, Wang G, Zhu L, et al. Basic performance of domestic surgical robot and the safety and effectiveness of integrated energy equipment. *Zhong nan da xue xue bao Yi xue ban = J Central South Univ Med Sci*. 2023;48(2):221–230.
60. Han FH, Zhang ZD, Zhou ZG, et al. [Effect of curved cutter stapler in the ultra low anterior resection for low rectal cancer]. *Zhonghua wei chang wai ke za zhi = Chin J Gastrointest Surg*. 2007;10(1):60–63.