Original Article

Evaluation of a new developed robotic system for head and neck surgery: a prospective study

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Background: Robotic surgery has been a revolution for head and neck tumor patients, with the da Vinci system predominating these procedures. This study aims to evaluate the feasibility, safety, and effectiveness of a newly developed robotic system (KangDuo Surgical Robot-1500, KD-SR-1500) for robotic-assisted parotidectomy and submandibular gland (SMG) resection.

Methods: This prospective, single-arm clinical study was conducted from November 2023 to January 2024 at the West China Hospital of Stomatology, Sichuan University. All operations were performed using the KD-SR-1500 via a trans-hairline approach by one experienced surgeon. Demographic, perioperative, and follow-up data were prospectively collected. To further assess the safety and feasibility of the KD-SR-1500 for parotidectomy, we included a historical control group of patients who underwent endoscopic parotidectomy (EP) at the same institution between 2021 and 2023.

Results: A total of 13 patients underwent parotidectomy and three underwent SMG resection in this prospective study. No cases were converted to endoscopic or open surgery. All robotic procedures were completed successfully, without significant complications observed. None of the 16 patients suffered from facial nerve injury. After propensity score matching, nine patients who underwent robotic parotidectomy (RP) and 28 patients who underwent EP were included. The operation time was not significantly different between the two groups. The RP group demonstrated excellent bleeding control, with an average blood loss of 10.00 mL compared to 47.86 mL in the EP group. Additionally, the robotic group showed superior facial nerve preservation, with no temporary nerve injuries reported, compared to 15 cases in the endoscopic group.

Conclusions: The KD-SR-1500 system has been proven to be a feasible, safe, and effective tool for performing parotidectomy and SMG resection, supporting its utility in robotic-assisted head and neck surgery.

Keywords: Robot; head and neck; parotidectomy; surgery

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Introduction

Traditional parotidectomy and submandibular gland (SMG) resection are performed through facial and cervical incisions (1,2). While these techniques are generally safe and effective, the resulting prominent scars can cause significant psychological and aesthetic concerns (3,4). Since Lin *et al.* pioneered endoscopic parotidectomy (EP) in 2000, salivary gland resection has evolved from endoscopic-assisted procedures with smaller incisions to fully endoscopic procedures, significant improving aesthetic outcomes (5-7). However, endoscopic surgery is not without its challenges. Ergonomic difficulties, such as awkward hand positions and prolonged standing, can lead to surgeon fatigue and musculoskeletal issues (8). The magnification of hand tremors by the endoscopic instruments can compromise surgical accuracy (9,10). Additionally, the steep learning curve associated with mastering endoscopic techniques further complicates the widespread adoption of this approach (11).

Robotic-assisted surgery represents a revolutionary advancement in modern medicine (12). The three-dimension (3D) magnified visualization, combined with robotic instruments that possess multiple degrees of freedom, enables surgeons to precisely identify and preserve critical structures (13). This is particularly advantageous in procedures like parotidectomy, where the flexible, highly articulated robotic instruments can easily access hard-to-reach areas, such as the preauricular region, which are challenging to approach with conventional tools. The da Vinci surgical system, developed by Intuitive Surgical, Inc., dominates the surgical robot market and has been proven effective in numerous fields (14-16). However, the high costs associated with research, development, and maintenance, resulting from da Vinci's dominant market position, significantly contribute to the elevated expenses of robotic surgeries. Nevertheless, several newly developed robotic systems, such as Senhance, Versius, Toumai, have entered the market in recent years, potentially offering more affordable alternatives (17-19).

The KangDuo Surgical Robot (KD-SR) system, a newly developed surgical robot featuring an open surgical console, multiple robotic arms, and a sophisticated 3D-video imaging system, has been developed in China (20,21). It has been proven effective in operations within natural cavities, including urology and gastrointestinal surgeries (10,22). However, its applicability and efficacy in head and neck surgery remain inadequately explored. Although we have previously reported the preliminary application of the KD-SR in robot-assisted head and neck surgery and compared its results with those of an endoscopic system in porcine models, there remains a gap in its clinical application (23). This study aims to assess the feasibility, safety, and effectiveness of the KD-SR system in a clinical practice to address this gap. Additionally, we conducted a historical comparison between robotic parotidectomy (RP) and EP to further explore its potential. We present this article in accordance with the STROBE reporting checklist (available at https://gs.amegroups.com/article/view/10.21037/gs-2025-149/rc).

Highlight box

Key findings

- This study demonstrated that the newly developed robotic platform, KD-SR-1500, is a feasible, safe, and effective tool for performing minimally invasive parotidectomy and submandibular gland (SMG) resection. These findings provide preliminary evidence supporting the use of this Chinese-manufactured robotic system in head and neck surgery.

What is known and what is new?

- Traditional parotidectomy and SMG resection are performed through facial and cervical incisions, leading to visible scars and psychological concerns. Endoscopic techniques improved aesthetics but present ergonomic challenges and steep learning curve.
- Robotic-assisted surgery enhances surgical precision by providing 3D visualization and flexible instruments. However, the da Vinci system, which dominates robotic-assisted surgery, entails substantial costs. Research on Chinese-manufactured robotic system for procedures such as parotidectomy and SMG resection remains limited.

What is the implication, and what should change now?

- The KD-SR-1500 has demonstrated efficacy in minimally invasive parotidectomy and SMG resection, showcasing the potential of Chinese-manufactured robotic systems in head and neck surgery. Compared to endoscopic-assisted parotidectomy, the KD-SR-1500 offers improved facial nerve preservation and enhanced intraoperative bleeding control. To further validate these findings, large-scale clinical trials are warranted.

Methods

Study design and participants

This prospective, single-arm study was conducted from November 2023 to January 2024 at the Department of Head and Neck Oncology, West China Hospital of Stomatology, Sichuan University. Patients aged 18 to 80 years, preoperatively diagnosed with benign salivary

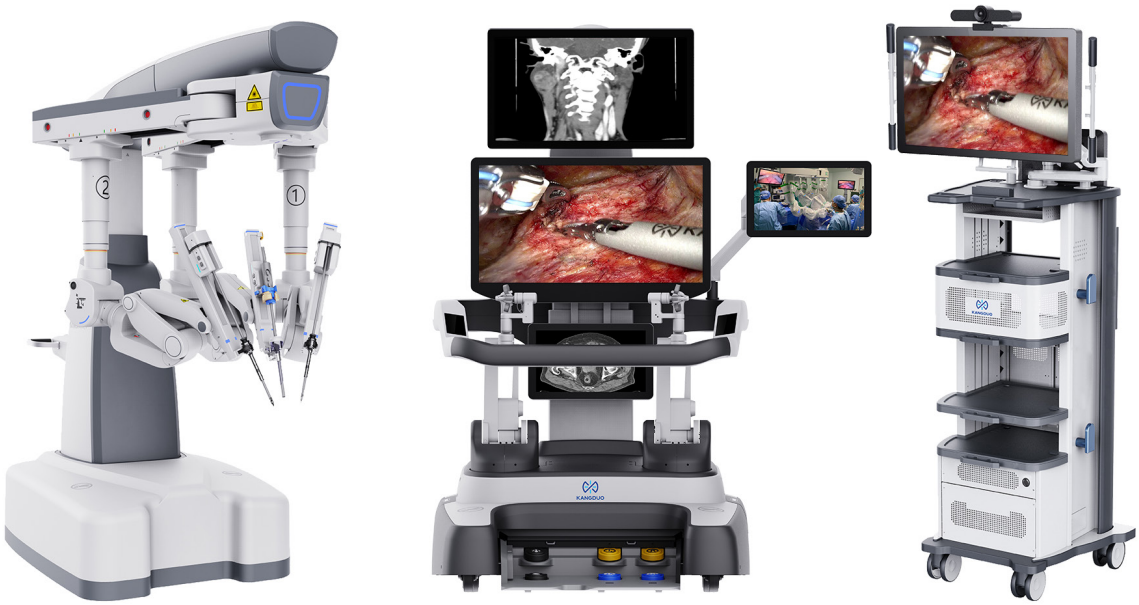

Figure 1 KD-SR-1500 system. This surgical robot consists of a patient cart (left), a surgeon control console (middle), and a vision cart (right). The figure is published with permission granted by Harbin Sagebot Intelligent Medical Equipment Co., Ltd.

gland tumors and requiring surgical resection, were enrolled. Patients requiring reoperation in the same operative area or with tumors exceeding 4 cm in diameter were excluded (detailed in Table S1). This study received ethics approval from the Ethics Committee of the West China Hospital of Stomatology, Sichuan University (No. WSCHSIRB-CT-2023-196), and the study was registered at www.chictr.org.cn (ChiCTR2300076776). All participants were fully informed about the surgical risks and provided written informed consent prior to undergoing robotic surgery with the KD-SR-1500 system (*Figure 1*). The study was conducted in strict compliance with the Declaration of Helsinki and its subsequent amendments.

Historical control

To further access the effectiveness, safety and feasibility of this newly developed robot, we compared it with a cohort of patients who underwent EP in a separated clinical trial conducted at the same institution between 2021 and 2023. This trial, which aimed to compare surgical outcomes between endoscopic and traditional open parotidectomy, also received ethical approval (WCHSIRB-D-2020-311-R1). Both studies shared similar inclusion and exclusion criteria (detailed in Table S2), facilitating a direct comparison. Propensity score matching (PSM) was employed to ensure comparability between the RP and EP groups. Using a logistic regression model, propensity scores were calculated, and patients were matched in a 1:4 ratio using a caliper width of 0.2. Six factors were matched: age, sex, body mass index (BMI), hypertension, diabetes, and tumor diameter.

Data collection

The demographic, operative, and postoperative data were collected. Each patient had a follow-up period of at least six months. Cavity construction time was defined as the time from the initial skin incision to the placement of the specialized surgical retractor. Docking time was interval from the robotic cart's approach to the operating table to the final attachment of the cannula to the robotic arm. Console time spanned from robot docking to undocking. All sutures were performed manually. Intraoperative facial nerve monitoring (IFNM) was used to detect potential facial nerve damage during procedures. The National Aeronautics and Space Administration Task Load Index (NASA-TLX) was applied to evaluate the subjective workload assessment

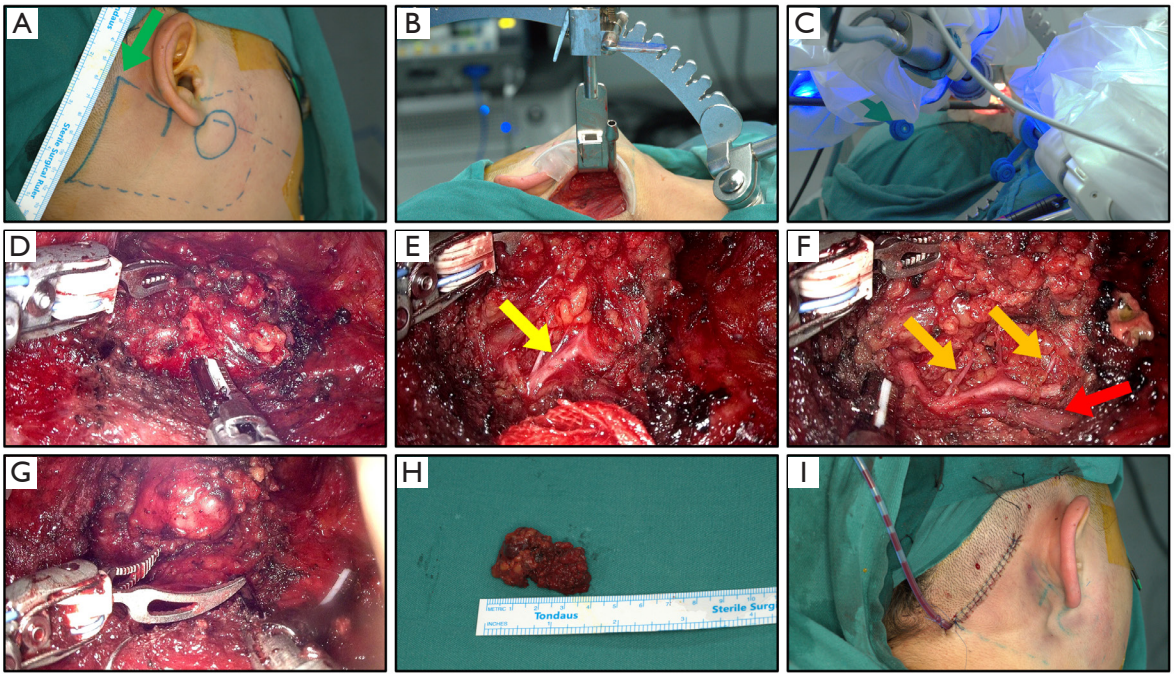

Figure 2 Surgical technique of robot-assisted parotidectomy with the KD-SR-1500 system. (A) Design of the surgical incision (green arrows). (B) Placement of the specialized surgical retractor. (C) Docking of the robotic system. (D) Dissection of the posterior and inferior boundaries of the parotid gland. (E) The main trunk of the facial nerve (yellow arrow) was identified at the inferior border of the parotid gland. (F) The posterior mandibular vein (red arrow) is visualized during the dissection of inferior boundary, and the branches of the facial nerve (orange arrow) become visible as the dissection advanced anteriorly. (G) Complete mobilization of the tumor and the surrounding parotid tissue from adjacent structures. (H) Excised specimen of the tumor and surrounding tissues. (I) Placement of a drainage tube followed by closure of the incision.

of the surgeon.

Surgical procedures

All robotic surgeries were performed by a single experienced surgeon. All robotic surgeries were conducted using the KD-SR-1500 system.

For RP, the procedure commenced under general anesthesia, with patients positioned supine and their hand turned toward the side opposite the lesion. The searching units of IFNM were inserted into the orbicularis oculi and orbicularis oris muscles, respectively. An incision was drawn from the earlobe to the trans-hairline over the mastoid process, establishing the superior end. This incision extends downward along the hairline, with the inferior end defined by a horizontal line drawn from the mandibular angle to the hairline (*Figure 2A*). Following the incision, careful dissection of the subcutaneous and muscular tissues was performed to access the parotid gland. Once the posterior lower boundary of the parotid gland was visually confirmed, further dissection was carried out toward the anterior boundary to finalized cavity construction. At this point, a specialized surgical retractor designed by Dr. Zhu was placed (*Figure 2B*). The KD-SR-1500 system was then accurately positioned using laser guidance, equipped with a 0-degree angled endoscopic camera, a Maryland dissector, and an ultrasonic scalpel (*Figure 2C*). The procedure began with the incision of the posterior fascia at the anterior border of the sternocleidomastoid muscle, followed by meticulous dissection to preserve the great auricular nerve. The fascia over the parotid masseteric region was then dissected at the superior margin, allowing access to the superficial lobe of the parotid gland. The superficial lobe was carefully separated using an ultrasonic scalpel, with gentle anterior traction applied to the tumor and adjacent glandular tissue (*Figure 2D*). During the dissection of the tumor's base, special attention was given to the meticulous separation and preservation of the facial nerve and its

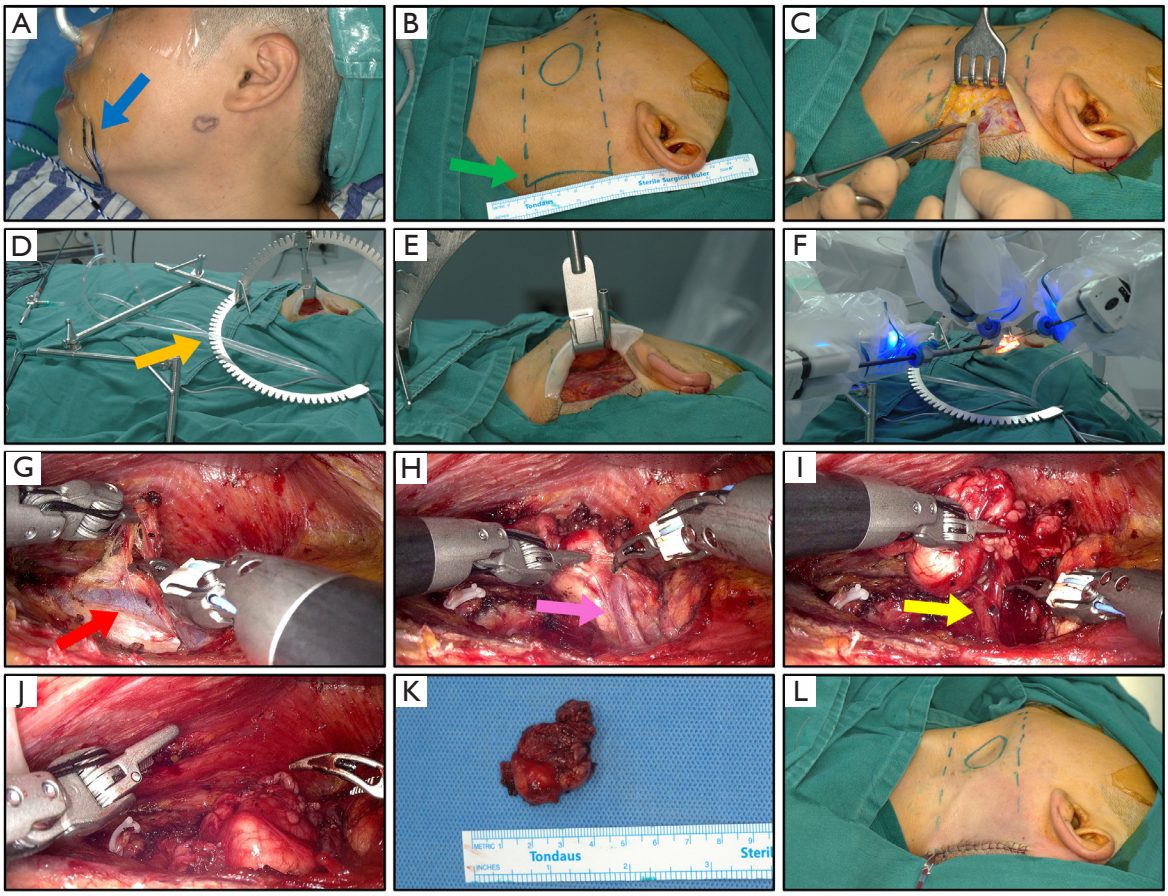

Figure 3 Surgical technique of robot-assisted SMG with the KD-SR-1500 system. (A) Placement of the positive terminals and searching units of the IFNM (blue arrow). (B) Design of the surgical incision (green arrow). (C) Creation of the surgical cavity under direct visualization. (D,E) Placement of the specialized surgical retractor (orange arrow). (F) Docking of the surgical robot. (G) Visualization of the facial vein (red arrow) prior to SMG exposure. (H,I) Dissection of basal boundary of SMG, revealing the facial artery (pink arrow) and Wharton's duct (yellow arrow). (J) Complete mobilization of the SMG from adjacent structures. (K) Excised specimen of the SMG and surrounding tissues. (L) Placement of a drainage tube followed by closure of the incision. IFNM, intraoperative facial nerve monitoring; SMG, submandibular gland.

major branches (*Figure 2E,2F*). The tumor was carefully dissected from its base, extending through the superficial lobe anteriorly, and was excised along with a portion of the superficial lobe (*Figure 2G,2H*). Finally, a drainage tube was inserted, and the incision was manually sutured (*Figure 2I*). Upon emergence from general anesthesia, the pressure dressings were applied.

For robotic SMG resection, the searching units of IFNM were inserted into the orbicularis oris muscle (*Figure 3A*). The surgical incision was meticulously made along the hairline, followed by dissection of the subcutaneous and muscular tissues from the incision toward the SMG through the subplatysmal space using direct visualization (*Figure 3B,3C*). A specialized surgical retractor was utilized to assist in creating the working space (*Figure 3D,3E*). Subsequently, the KD-SR-1500 was docked (*Figure 3F*). After establishing the initial surgical cavity, the robot was active to expand the surgical space, facilitating the identification of the SMG through endoscopic visualization. This trans-hairline approach reduced the risk of injury to the marginal mandibular nerve. The facial vein is typically located on the surface of the SMG (*Figure 3G*). The vein was carefully cut to enhance exposure of the gland. During the dissection of deep surface, facial artery and Wharton's duct were exposed (*Figure 3H,3I*). To facilitate better access to the deep surface, the proximal end of the facial artery was clamped, coagulated, and then cut. The SMG specimen was then extracted through the surgical tunnel, followed

Table 1 Baseline, intraoperative and postoperative characteristics in patient underwent robotic surgery

Variables	Parotidectomy (n=13)	SMG resection (n=3)
Age, years	49.23 (14.91)	32.00 (14.00)
Sex		
Male	6 (46.15)	0 (0.00)
Female	7 (53.85)	3 (100.00)
Height, m	1.61 (0.09)	1.56 (0.05)
Weight, kg	62.08 (9.87)	47.67 (10.97)
BMI, kg/m^2	23.87 (2.89)	19.52 (3.43)
Systemic diseases		
Hypertension	3 (23.08)	0 (0.00)
Diabetes	1 (7.69)	0 (0.00)
Both	1 (7.69)	0 (0.00)
Tumor diameter, cm	2.46 (0.60)	1.87 (0.29)
Conversion	0 (0.00)	0 (0.00)
Length of incision, cm	5.96 (0.72)	5.67 (0.58)
Procedure time, min		
Cavity construction	18.15 (9.77)	20.33 (4.04)
Docking	11.69 (4.78)	11.33 (1.53)
Console	71.15 (24.68)	65.68 (5.13)
Total operation time	170.31 (33.26)	164.33 (14.36)
Estimated blood loss, mL	8.69 (2.53)	7.33 (1.54)
Pathological diagnosis		
Pleomorphic adenoma	8 (61.54)	3 (100.00)
Warthin tumor	4 (30.77)	0 (0.00)
Lymphoepithelial cyst	1 (7.69)	0 (0.00)
Tumor rupture and spillage	0 (0.00)	0 (0.00)
Total drainage volume, mL	59.23 (23.91)	64.00 (25.51)
Drainage tube time, day	2.23 (0.44)	2.33 (0.58)
Discharge after surgery, day	2.62 (0.96)	2.67 (0.58)
Temporary FNI	0 (0.00)	0 (0.00)

Data are presented as mean (SD) or number (percentage). BMI, body mass index; FNI, facial nerve injury; SD, standard deviation; SMG, submandibular gland.

by undocking of the robot (*Figure 3J*,*3K*). A drainage tube was inserted, and the surgical wound was closed manually (*Figure 3L*). Pressure dressings were applied immediately upon patient emergence from general anesthesia.

Outcomes

In this prospective study, the primary outcome measure was the intraoperative conversion rate, defined as the necessity to switch from robotic surgery to endoscopic or open surgery during operation. Secondary outcome measures included postoperative pain scores, subjective workload.

Statistical analysis

All statistical analyses were conducted using SPSS Statistics software version 22.0 (IBM Corp, Armonk, New York, USA). Continuous variables were presented as either means with standard deviations (SD) or median with interquartile ranges (IQR), depending on distribution normality. Categorical variables were expressed as frequencies and percentages. A P value of <0.05 was considered statistically significant.

Results

Surgical outcomes of robotic procedures

As shown in *Table 1*, a total of 16 participants, comprised of six male and 10 female, were included. Thirteen patients with parotid gland tumor and three patients with SMG tumor. Four patients were diagnosed with hypertension and one with diabetes, all of which were effectively managed. No case was converted to endoscopic surgery or traditional open surgery. All robotic surgeries utilized a trans-hairline approach, with the average incision lengths being 5.96 cm in parotidectomy and 5.67 cm in SMG resection, respectively. The mean maximum diameters of parotid gland and SMG tumors were 2.46 and 1.87 cm. For RP, the mean time for cavity construction, docking, and consoling were 18.15, 11.69, and 71.15 min. In contrast, robotic SMG resection recorded mean times of 20.33, 11.33, and 65.68 min for the same procedures. The average estimated blood loss was 8.69 mL for parotidectomy

and 7.33 mL for SMG resection, with no instances of intraoperative transfusions. Throughout these procedures, no instances of tumor capsule rupture or spillage were observed. Pathological examination revealed that all three SMG tumors and eight parotid gland tumors were pleomorphic adenomas, four parotid gland tumors were Warthin tumors, and one was a lymphoepithelial cyst. All robotic procedures were completed successfully, with no significant intraoperative or postoperative complications observed. None of the 16 patients suffered temporary or permanent nerve injury. At 24 hours postoperatively, the majority of patients reported mild pain (Table S3) and no significant abnormalities were observed in any patients during postoperative laboratory evaluations (Table S4). Patients were discharged from hospital for an average of 2.62 days after RP and 2.67 days after robotic SMG resection. According to the NASA-TLX, the surgeon experienced a low workload for both RP and SMG resection (*Table 2*). Postoperative scars from the robotic surgery were concealed within the hairline, resulting in favorable aesthetic outcomes (*Figure 4*).

Table 2 NASA-TLX scores of surgeons performing robotic head and neck surgery

Variables	PG tumor (n=13)	SMG tumor (n=3)
NASA-TLX		
Mental demand	2.46 (0.97)	2.67 (1.55)
Physical demand	2.08 (0.49)	2.33 (0.58)
Temporal demand	2.69 (1.11)	3.00 (1.73)
Performance	1.85 (0.55)	2.00 (1.00)
Effort	1.92 (0.28)	1.67 (0.58)
Frustration	1.85 (0.55)	1.67 (0.58)

Data are presented as mean (SD). PG, parotid gland; SD, standard deviation; SMG, submandibular gland.

Comparison of robotic and EP

After PSM, nine patients from the RP group and 28 patients from the EP group were included (*Figure 5*). The operation time was not significantly different between the two groups. Although there was no difference in total drainage volume, the duration of drainage tube retention was shorter in RP

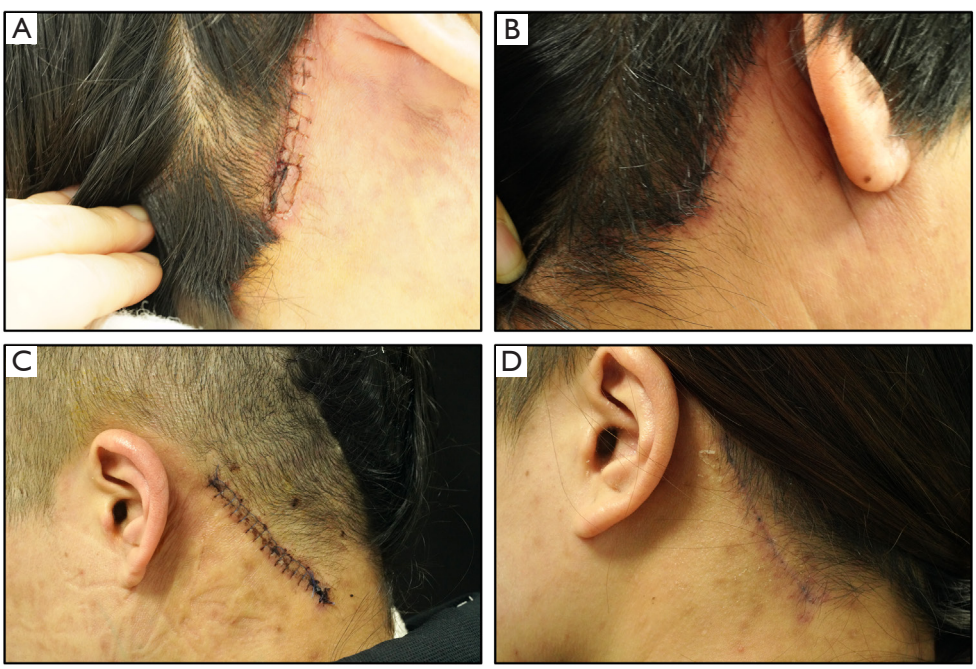

Figure 4 Postoperative images of patient who underwent robotic surgery. (A) Scar appearance 1 week after robotic parotidectomy. (B) Scar from robotic parotidectomy was hidden in the postauricular hairline at 1 month postoperatively. (C) Scar appearance 1 week after robotic SMG resection. (D) Scar from robotic SMG resection was hidden in the postauricular hairline at 1 month postoperatively. SMG, submandibular gland.

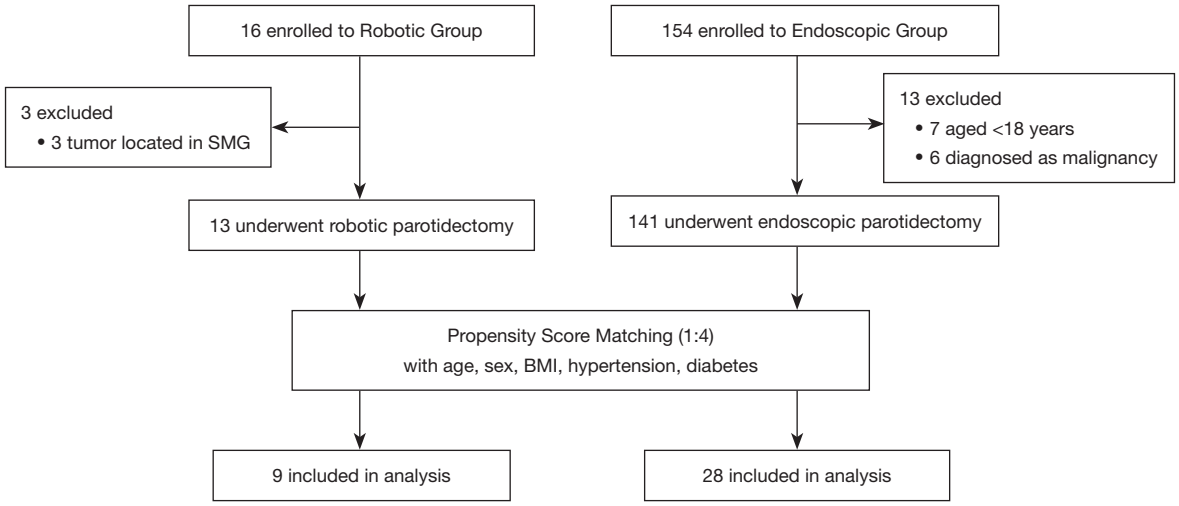

Figure 5 Flowchart of study inclusion for historical control study. BMI, body mass index; SMG, submandibular gland.

group. The RP group demonstrated excellent bleeding control, with an average blood loss of 8.00 mL compared to 47.86 mL in the EP group. Additionally, the surgical robot provided superior facial nerve protection, with no cases of temporary facial nerve injury reported (*Table 3*).

Discussion

In this study, all surgeries were completed using the KD-SR system without conversion to open or endoscopic surgery, underscoring the feasibility of this system. The intraoperative bleeding was effectively managed in all cases, and there were no instances of nerve injury, whether temporary or permanent.

In this study, we employed the hairline incision for minimally invasive parotidectomy. Although concealed incisions, such as periauricular incision (24), have been explored in open parotidectomy, these methods still result in visible scarring anterior to the ear, which remains a concern for cosmetically sensitive patients. Conversely, the hairline incision places the surgical scar within the hair-bearing scalp, concealing it and resulting in a "scarless" appearance in the facial region. Nevertheless, in patients with limited hair coverage, such as those who are bald, the hairline incision may not provide the same cosmetic advantage. In such cases, the retroauricular incision serves as a viable alternative, positioning the scar behind the ear—an area less conspicuous even in the absence of hair (25).

In this study, bleeding control during robotic surgery was more effective than during endoscopic surgery. This improvement can be attributed to several factors. First, in EP, the surgical field is accessed through a hairline incision, which presents unique challenges compared to endoscopic abdominal surgeries. Unlike abdominal procedures, where the endoscope can be stabilized using fixed ports, the parotidectomy lacks such anchoring points. Consequently, the assistant must manually hold the endoscope without a stable support, requiring both hands to maintain the camera's position. This setup can lead to inadvertent movements and less stable visualization, potentially complicating the identification and control of small blood vessels. In contrast, the robotic system provides high-definition, 3D visualization through a camera mounted on a stable robotic arm. This configuration allows the surgeon to camera directly, ensuring a steady and precise view of the surgical field. The enhanced stability and superior visualization facilitate the identification of small vessels. Second, in robotic surgery, the surgeon operates two energy instruments simultaneously, facilitating efficient tissue dissection and hemostasis. In contrast, during endoscopic procedures, the surgeon often manages an energy instrument in one hand while the other hand is occupied with suction, which may limit the ability to control bleeding promptly. Third, although all procedures were performed by the same surgeon, the endoscopic group included cases from the early phase of adopting endoscopic techniques. During this period, both the surgeon and the assistant were adjusting to the challenges of endoscopic surgery, which may have contributed to increased bleeding.

To date, literature on the safety and efficacy of RP via

Table 3 Baseline, intraoperative and postoperative characteristics in EP and RP groups after propensity score matching

Variables	EP (n=28)	RP (n=9)	P value
Age, years	37.68 (11.65)	42.11 (9.99)	0.31
Sex			0.69
Male	18 (64.29)	7 (77.78)	
Female	10 (35.71)	2 (22.22)	
Height, m	1.64 (0.07)	1.61 (0.11)	0.31
Weight, kg	62.21 (10.40)	62.00 (11.26)	0.93
BMI, kg/m^2	22.98 (3.09)	23.83 (3.29)	0.49
Hypertension			>0.99
Yes	2 (7.14)	1 (11.11)	
No	26 (92.86)	8 (88.89)	
Tumor diameter, cm	2.24 (0.75)	2.33 (0.57)	0.74
Conversion	0 (0.00)	0 (0.00)	–
Total operation time, min	136.68 (50.17)	162.11 (34.86)	0.14
Estimated blood loss, mL	47.86 (27.80)	8.00 (1.94)	<0.001
Total drainage volume, mL	71.43 (45.69)	51.33 (18.71)	0.07
Drainage tube time, days	3.32 (1.12)	2.11 (0.33)	<0.001
Discharge after surgery, days	3.21 (1.57)	2.44 (0.73)	0.17
Temporary FNI	15 (53.57)	0 (0.00)	0.005
FNI at the 6-month follow-up	0 (0.00)	0 (0.00)	–

Data are presented as mean (SD) or number (percentage). BMI, body mass index; EP, endoscopic parotidectomy; FNI, facial nerve injury; RP, robotic parotidectomy; SD, standard deviation.

a trans-hairline incision is limited. Park *et al.* conducted this procedure through a retroauricular-hairline incision extending behind the ear, and reported a console time of 98 min, which is longer than the 71 min recorded in our study (26). Their approach, although effective, did not entirely conceal the incision within the hairline, thus offering only partial aesthetic benefits. In contrast, we made a deliberate modification by positioning the incision 1 cm posterior to the hairline, achieving concealment of the postoperative scar. Our incisions averaged 5.96 cm in length, and notably, none of the patients who underwent RP experienced facial nerve symptoms or tumor recurrence during the six-month postoperative follow-up. To further evaluate the safety and effectiveness of this newly developed robotic system for parotidectomy, we conducted a historical comparison between RP in this study and those who underwent EP. The results demonstrated that the surgical robot provided superior control of intraoperative bleeding and excellent preservation of the facial nerve, largely due to the 3D visualization, enhanced dexterity, and wider range of motion offered by KD-SR-1500. These features confer significant advantages in managing complex anatomical structures, supporting the efficacy and safety of RP using the KD-SR-1500 system.

For robot-assisted SMG resection, various approaches have been explored to improve aesthetic outcomes. In 2013, Lee *et al.* first reported robot-assisted SMG resection through a retroauricular incision (27). However, the aesthetic results of this method needed improvement because the incision in the retroauricular region was still visible. Although Prosser *et al.* reported several cases of robotic SMG resection through a transoral approach, which achieved no incisions on the body surface and significantly improved aesthetic outcomes, this method has rarely been adopted (28). The small operative space at the floor of the mouth and the obstruction by the hypoglossal nerve and the

mylohyoid muscle significantly increase the complexity of the procedure, requiring a high level of skill and experience from the surgeon. Beyond these technique challenges, the potential for neurological damage also makes the transoral approach controversial. It has been reported that all patients undergoing transoral approach robotic SMG surgery experienced symptoms of lingual nerve damage postoperatively, with one patient suffering persistent pain at the tip of the tongue (29,30). Yang *et al.* pioneered the trans-hairline approach in robotic SMG surgery, demonstrating its feasibility for benign SMG tumors through a preliminary comparison with traditional open surgery (31). They subsequently conducted an expanded study on robotic SMG resection using this approach, which included 11 cases of pleomorphic adenoma, 12 of sialolithiasis, and one of adenoid carcinoma (32). After surgery, none of the patients suffered from the lingual or facial nerve injury, and no instances of tumor recurrence were reported during the 28-month follow-up period. Similarly, in our study, no patients experienced temporary or permanent lingual or facial nerve injury. While complete invisibility of surgical scars is unattainable, the trans-hairline approach enables comprehensive lesion exposure while placing the incision in a less visible area, thus harmonizing aesthetic and functional outcomes. Hence, we have preliminarily demonstrated the feasibility and effectiveness of KD-SR-1500 in SMG resection using this minimally invasive and concealed approach.

Beyond its application in transcutaneous approaches for oral and maxillofacial surgery, this robotic platform has also demonstrated preliminary trials in transoral robotic surgery (TORS). Sun *et al.* conducted a preliminary study involving 13 patients undergoing TORS for lesions in the base of tongue, soft palate, and tonsillar regions (33). The study included nine extended resections for malignance and four biopsies. All patient experienced favorable postoperative recoveries without unplanned surgeries, and no positive margins were reported. One patient did experience a temporomandibular joint displacement. The clinical feasibility and safety of this robotic system for TORS remain limited, necessitating further exploration.

The KD-SR-1500 system has several differences compared to the da Vinci systems. Its open-console design allows surgeons to maintain a more natural posture during prolonged procedures, potentially reducing neck strain, and also facilitates more effective communication with the surgical team (34). In addition, the patient cart is equipped with a laser-guided positioning system, which helps expedite and enhance the accuracy of docking. Another advantage is its compatibility with most commercially available laparoscopes, which reduces equipment costs and promotes wider clinical adoption. Notably, the KD-SR system has seen accelerated commercialization in China since receiving regulatory approval, with a commercial price approximately 40–50% lower than that of the da Vinci Xi system, making it a cost-effective alternative (35). However, there also some disadvantages. The KD-SR system does not support naked-eye 3D viewing, requiring surgeons to wear specialized glasses. Furthermore, the da Vinci system has a smaller size, which allows for easier movement and positioning in the operating room. Despite these differences, several studies have reported comparable surgical outcomes between the KD-SR and da Vinci systems (21,36,37). It is important to note that the KD-SR system has not yet been widely applied in head and neck surgery, and more clinical evidence is needed to be support its use in this specific field.

Despite significant progress in robotic surgery over the past two decades, current surgical robots still face several technical limitations. First, their multi-armed and cumbersome design can extend preparation time and compromise surgical efficiency. Second, the lack of haptic feedback impacts the precision of operations, as surgeons rely on tactile sensation to gauge the force and pressure applied to tissues during surgery (38,39). Additionally, current master-slave systems require constant input from the surgeon for every movement and decision, limiting their capacity to perform complex or repetitive tasks independently. That being said, promising advancements have been made. For example, Ge *et al.* developed an innovative autonomous system for tumor resection (ASTR) and successfully performed six consecutive supervised autonomous midline partial glossectomies on porcine specimens (40). Although the ASTR was not tested in realistic and challenging scenarios, such as autonomous tongue base tumor resection with blood obfuscation and spatial constraints, this attempt indicates a promising direction for the future development of robotic head and neck surgery. In addition, we recently completed animal experiments on parotidectomy using a domestically developed single-port surgical robot, which has laid a solid foundation for the subsequent clinical trials of this technology (41). With ongoing technological evolution, surgical robots are advancing towards miniaturization, non-invasiveness, telesurgery, digitalization, and intelligence (42). Furthermore, as robotic surgery, which emerged as a novel treatment approach rooted in endoscopic technology, must overcome

challenges associated with the development and promotion of endoscopic techniques in oral and maxillofacial surgery. In recent years, our team has made significant strides in developing minimally invasive surgical techniques for oral and maxillofacial procedures. We introduced the "endoscopic parotidectomy: a seven-step procedure" and the "endoscopic SMG excision: a seven-step procedure" (43,44). These methodologies have helped standardize endoscopic procedures, laying a strong foundation for the wider adoption of surgical robots in oral and maxillofacial surgery.

There are several limitations in this study. Firstly, while this study provides initial insights, the single-center, small-sample design limits the generalization of these findings. Nevertheless, a multi-center study with a larger sample size is currently being planned, which will be essential to confirm and expand upon these results. Secondly, our follow-up period was short. For a comprehensive understanding of the benefits and drawbacks of this newly developed surgical robot in head and neck surgery, studies with longer follow-up focusing on patient outcomes are crucial. Thirdly, although a randomized clinical trial would be ideal for evaluating robotic head and neck surgery, due to budget constraints and medical insurance coverage limitations, we conducted this study as a prospective, single-arm, single-center study. Furthermore, we performed a historical control analysis comparing RP to EP using PSM to reduce selection bias and maximize patient benefits. This analysis provided further evidence supporting the safety and effectiveness of the newly developed robotic platform in parotidectomy.

Conclusions

This study demonstrates that all procedures using the newly developed robotic system, KD-SR-1500, were completed without conversion to open or endoscopic surgery, providing preliminary evidence of its feasibility, safety, and effectiveness in robotic-assisted head and neck surgery. To further assess its performance, we conducted a historical control study comparing it with EP. Despite similar operative times, the robotic system achieved superior bleeding control and enhanced facial nerve protection.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki and its subsequent amendments. This study received ethics approval from the Ethics Committee of the West China Hospital of Stomatology, Sichuan University (No. WSCHSIRB-CT-2023-196). All participants were fully informed about the surgical risks and provided written informed consent prior to undergoing robotic surgery.

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