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Platinum Priority – Brief Correspondence

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Application of Improved Robot-assisted Laparoscopic Telesurgery with 5G Technology in Urology

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Abstract

The demand for telesurgery is rising rapidly, but robust evidence regarding the feasibility of its application in urology is still rare. From March to October 2021, a surgeon-controlled surgical robot in a tertiary hospital in Qingdao was used to remotely conduct robot-assisted laparoscopic radical nephrectomy (RN) in 29 patients located in eight primary hospitals. The median round-trip delay was 26 ms (interquartile range [IQR] 5) and the median distance between the primary hospital and the surgeon was 187 km (IQR 57). Both the master unit and the slave unit were guaranteed by network and mechanical engineers, and surgical assistants were well prepared on the patient side to prevent complications. The primary evaluation metric was the success rate, defined as the percentage of patients who underwent successful remote RN without conversion to other surgical procedures and no major intraoperative or postoperative complications. The results demonstrate that the combination of 5G technology and surgical robots is a novel potential telemedicine-based therapy choice for renal tumors.

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Patient summary: Our study shows that telesurgery using 5G technology is a safe and feasible treatment option for patients with kidney tumors. The total delay between the remote location and the operating rooms where surgery was being performed was just 200 ms. This approach could reduce health care costs and improve the quality of medical services accessed by patients.

Rapid advances in 5G network communication technologies and surgical robotic devices have boosted the development of telesurgery since the Lindbergh operation [1]. The telesurgery platform could provide high-quality medical services to surrounding areas and play an essential role in overcoming the obstacles underlying health care inequity [2]. Especially after the outbreak of COVID-19, the demand for telesurgery has risen significantly [3–5]. However, comprehensive exploration of telesurgery in the field of urology is lacking. We previously successfully verified the application value of 5G technology in urology via experimental animal telesurgery [2]. We performed the current study to explore the safety and feasibility of robot-assisted laparoscopic telesurgery in patients with renal tumors undergoing radical nephrectomy (RN).

A total of 29 patients with a preoperative diagnosis of renal tumor from eight primary hospitals underwent remote RN (Fig. 1A, Supplementary Fig. 1). Success was defined as successful remote RN without conversion to other surgical procedures and no major intraoperative or postoperative complications. All participating hospitals met the environmental and equipment requirements (Supplementary Fig. 2) and all medical staff received adequate training (Supplementary Fig. 3). The American Society of Anesthesiologists (ASA) physical status score and RENAL nephrometry score were used to assess the preoperative condition of patients and their tumor complexity, respectively [6,7]; key information is listed in Table 1 and Supplementary Table 1. All procedures were performed by the same surgeon, and there was a surgical assistant on the patient side for assistance during the entire process. The study was approved by the ethics committee of each site and was registered on ClinicalTrials.gov (NCT04804163). All patients were fully informed by an experienced surgeon preoperatively and voluntarily signed an informed consent form.

The Micro Hand S robotic system (Shangdong WEGO Surgical Robot Company, Weihai, China) used in this study consists of two physically separate subsystems on the surgeon side (master unit) and the patient side (slave unit). The network transmission devices were installed in two units to collect motion parameters and various control signals. The telesurgical process used a master-slave real-time control system to interact with the data transmitted through the network to achieve the connection between the master and slave units (Fig. 1B,C). 5G network slicing technology is widely used in robotic operation and video signal transmission, and can slice the physical network into multiple virtual end-to-end networks that provide independent bandwidth and guarantee the quality of the service. Deterministic networking techniques were applied to further reduce latency and network load while improving data security and privacy. A wired network-dedicated line was also set up between the two sides as an alternative plan. Network communication during surgery was maintained and guaranteed by the network operator (Fig. 1D). Various mechanical engineering algorithms were used to guarantee security protection and verification of the telesurgical robots and the consistency of the master-slave units.

During the procedure, the primary surgeon at the Affiliated Hospital of Qingdao University remotely controlled the slave unit in the primary hospital to transect renal blood vessels and remove the kidney. The success rate in the study was 100% and the median operation time was 67 min (interquartile range [IQR] 21). The vital signs of patients were stable during the entire procedure, and the 24-h Visual Analog Scale score and Comprehensive Complication Index showed that most patients had low levels of postoperative pain and no major postoperative comorbidities [8]. The improvement in surgical procedures also guaranteed the safety of patients during telesurgery (Supplementary Fig. 4). Only one elderly male patient was administered an intraoperative prophylactic transfusion of two units of red blood cells because of preoperative anemia. Two elderly female patients experienced delayed postoperative wound healing and mild intestinal obstruction, but their prognosis was not affected. At present, all patients have been followed for more than 6 mo and have good prognostic outcomes.

The entire telesurgical process is achieved via real-time communication using network transmission. The median total delay was 176 ms (IQR 5), and intraoperative transmission of 3D images and audio signals was timely during surgery. The cumulative round-trip distance in this study was >14 700 km and the furthest surgical distance was approximately 1775 km. Our study proves that a total delay of <200 ms facilitates the conduction of telesurgery, and we successfully performed telesurgeries for three patients located in different primary hospitals on the same day by the same surgeon via network switching, which highlights the advantages of telesurgery in solving the unequal distribution of medical resources.

We distributed a questionnaire on telesurgery services to members of the Chinese Urological Association Youth Committee Section to assess current recognition of the development of telesurgery in China. Approximately 66% of the 50 urologists in this study reported positive feedback and expressed enthusiasm for continued follow-up. The major concerns for telesurgery were the cost and legal requirements. The special cost involved in performing telesurgery is for network equipment [9]. In this study, the major Internet equipment we used included customer premises, base station, and transmission equipment. The cost of this equipment is less than $70 000, and its use for subsequent

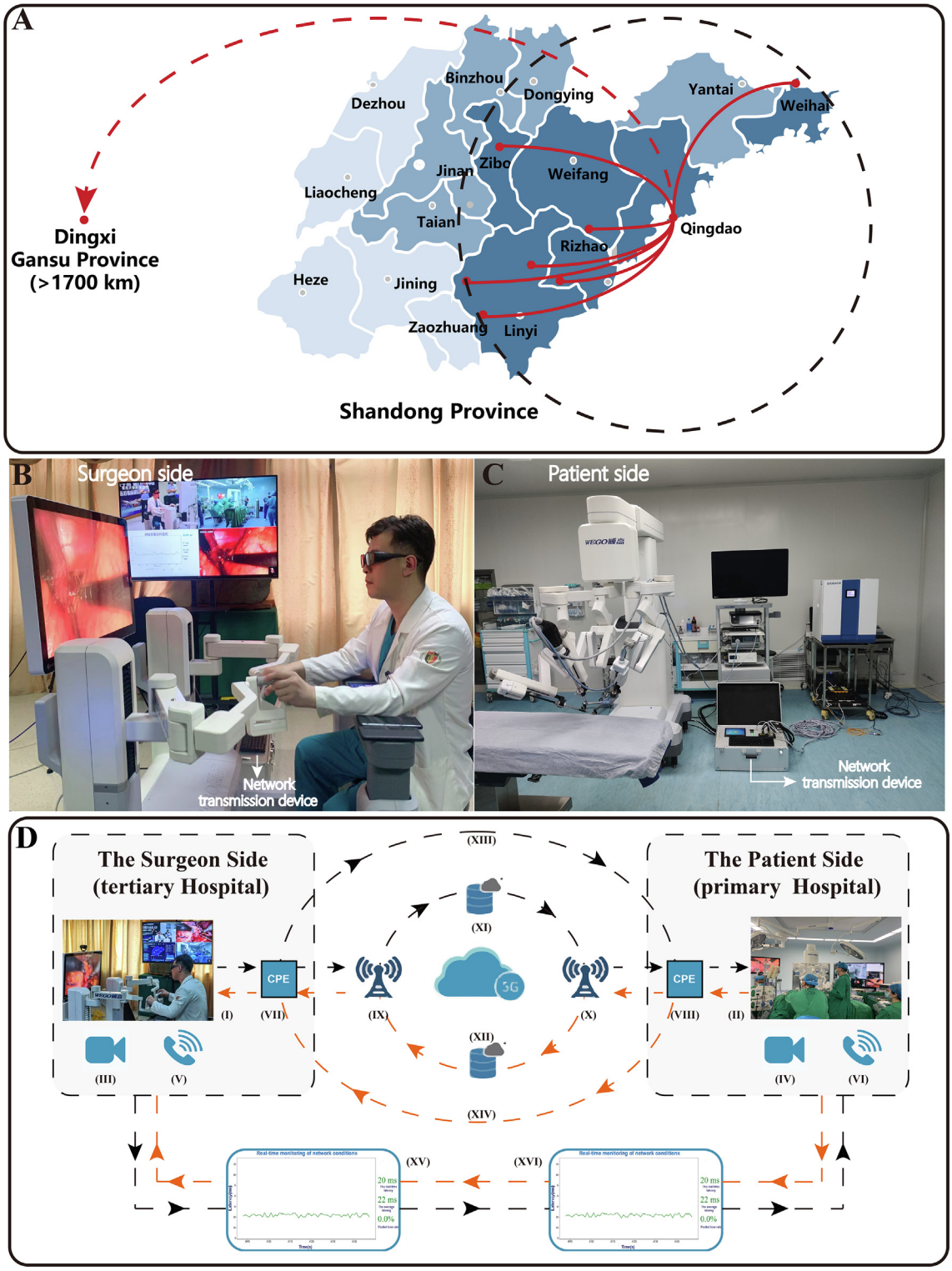

Fig. 1 – Map of the area surrounding Qingdao, the telesurgical robotic system, and the network configuration for the urological telesurgery platform. (A) Area covered by the telesurgical platform. The master unit was located in Qingdao and the slave units were in other hospitals. The black curve denotes the coverage area, taking Qingdao as the center of a circle and the distance between Qingdao and the farthest location in Shandong Province that participated in the telesurgery as the radius. Dark blue denotes cities participating in the telesurgery study, light blue, cities within the coverage area, and lightest blue, cities without coverage. The red curve denotes telesurgery between Qingdao and Dingxi City, Gansu Province, with a distance of >1700 km. (B) The surgeon console, display system, and network transmission device on the master unit. (C) The patient-side cart, display system, and network transmission device on the slave unit. (D) The process for transmission of multimodal data between the surgeon and patient sides. I. The surgeon side in Qingdao. II. The patient side in other hospitals. III–IV. The video device on the two sides. V–VI. The wireless headphones device on the two sides. VII–VIII. The customer premises equipment (CPE) on the two sides. IX–X. The base station on the two sides. XI–XII. The equipment for deterministic networking transmission of data. XIII–XIV. The equipment for a wired network for dedicated connection. XV–XVI. Network real-time latency monitoring on the two sides using the professional Ping Delay software we developed. The black dotted line represents data transfer from the surgeon side and the orange dotted line represents data coming back from the patient side.

Table 1 – Patient characteristics, clinical outcomes, and network index parameters

Parameter	Result
Preoperative	
Median age, yr (interquartile range)	63 (18)
Gender, *n* (%)	
Male	15 (52)
Female	14 (48)
American Society of Anesthesiologists score, *n* (%)	
I	2 (7)
II	14 (48)
III	13 (45)
Tumor side, *n* (%)	
Left	14 (48)
Right	15 (52)
Medial RENAL nephrometry score (interquartile range)	8 (3)
Clinical stage, *n* (%)	
T1a N0 M0	8 (28)
T1b N0 M0	17 (59)
T2a N0 M0	1 (3)
T2b N0 M0	1 (3)
T1b N1 M0	1 (3)
T3 N1 M0	1 (3)
Median distance, km (interquartile range) [a]	187 (57)
Intraoperative	
Median total delay, ms (interquartile range)	176 (5)
Median round-trip delay, ms (interquartile range)	26 (5)
Median operating time, min (interquartile range)	67 (21)
Postoperative	
Pathological stage, *n* (%)	
T1a N0 M0	13 (45)
T1b N0 M0	13 (45)
T2a N0 M0	1 (3)
T2b N0 M0	2 (7)
Median postoperative hospital stay, d (interquartile range)	8 (2)

[a] Distance between the primary hospital and the surgeon in The Affiliated Hospital of Qingdao University.

telesurgery is sustainable. To make telesurgery more effective, improvements in ethical and legal requirements are necessary [10], especially strong national or international policies, which are essential to surmount the limitations of telesurgery across geographic regions and countries.

Our study has some limitations. Several stage cT1 renal tumors were selected for treatment with RN instead of partial nephrectomy because of complex masses, differences in the level of medical infrastructure and medical personnel experience between different hospitals, and patient choice. Owing to the small sample size, exploration of possible complications associated with this new treatment option is limited. Variations in medical expertise in the primary hospitals and the limitation of patients' awareness of their disease explain the prolonged hospital stays. Our technique needs to be applied to more patients, hospitals, and surgical procedures for further verification. Our aim is to further improve network security for telesurgery and overcome the network delay involved in high-definition video transmission to expand access to telesurgery. This study could be important for the development of telemedicine.

Author contributions: Haitao Niu had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Li, Yang, Chu.
Acquisition of data: W. Feng, Ding, Yin.
Analysis and interpretation of data: L. Zhang, Lv, Ma, Sun.
Drafting of the manuscript: Li, Yang, Chu.
Critical revision of the manuscript for important intellectual content: R. Feng, Qin, X. Zhang, Gou, S. Wang, Yu, Wei.
Statistical analysis: Jiao, Y. Wang, Luo, Yuan, Chang.
Obtaining funding: Niu, Li.
Administrative, technical, or material support: Niu, Li.
Supervision: Cai, Giulianotti, Dong, Niu.
Other: W. Feng, Ding.

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Data sharing statement: The data sets generated and/or analyzed during the current study are available from the corresponding author on reasonable request. All the people shown in the photographs published here consented to the taking and use of these images.

Peer Review Summary

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