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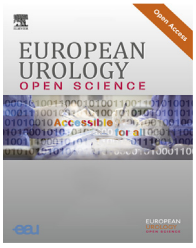

European Association of Urology

Brief Correspondence

Feasibility and Safety of Dual-console Telesurgery with the KangDuo Surgical Robot-01 System Using Fifth-generation and Wired Networks: An Animal Experiment and Clinical Study

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Abstract

The coronavirus disease 2019 pandemic has drawn attention to telesurgery. Important advances in fifth-generation (5G) mobile telecommunication technology have facilitated the rapid evolution of telesurgery. Previously, only a single console was used in telesurgery; thus, there was the possibility of open or laparoscopic conversion. Furthermore, the 5G network has not been available for regional hospitals in China. From October 2021 to April 2022, dual-console telesurgeries with the KangDuo Surgical Robot-01 (KD-SR-01) system were performed using 5G and wired networks in an animal experiment and clinical study. A partial nephrectomy in a porcine model was performed successfully using a wired network. The console time, warm ischemia time, and control swap time were 69 min, 27 min, and 3 s, respectively. The mean latency time was 130 (range, 60–200) ms. A 32-yr-old male patient successfully underwent a remote pyeloplasty using a series connection of 5G wireless and wired networks. The console time and control swap time were 98 min and 3 s, respectively. The mean latency time was 271 (range, 206–307) ms. In the two studies, data pocket loss was <1%. The results demonstrated that dual-console telesurgery with the KD-SR-01 system is feasible and safe using 5G and wired networks.

Patient summary: Advances in fifth-generation (5G) mobile telecommunication technology helped in the rapid evolution of telesurgery. Dual-console telesurgery performed with the KD-SR-01 system using 5G and wired networks was shown to be feasible and safe in an animal experiment and clinical study.

The first remote surgery was conducted in 2001 and was termed the "Lindbergh operation" [1]. Although further development was limited by time delays and safety concerns, important advances in fifth-generation (5G) mobile telecommunication technology provided a reliable and instantaneous transmission that facilitated the rapid evolution of telesurgery [2,3]. A single console was used in those telesurgery procedures previously [2,3]. However, there

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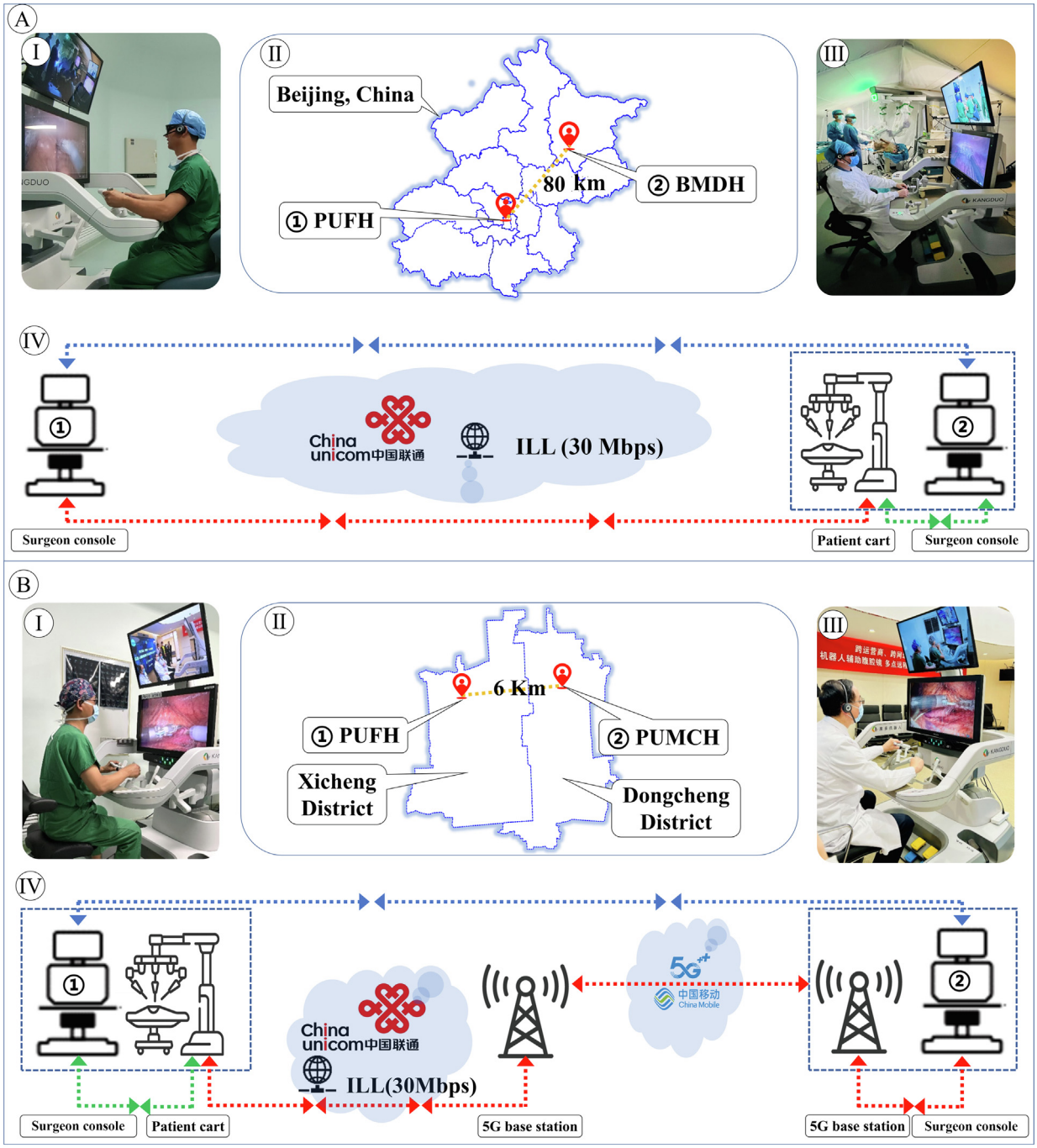

Fig. 1 – The protocol for dual-console telesurgery of the KangDuo Surgical Robot-01 system using 5G and wired networks in the animal experiment and a clinical study. (A) The protocol for dual-console telesurgery of the KangDuo Surgical Robot-01 system using a wired network in the animal experiment: I—The surgeon performed the surgery remotely at PUFH. II—Telesurgery was performed between PUFH and BMDH with a distance of 80 km in Beijing, China. III—The patient cart, second surgeon console, and porcine model were located at Beijing Miyun District Hospital. The other surgeon performed local surgery at Beijing Miyun District Hospital. IV—The network configuration was based on a wired network. The Internet Leased Line is a premium dedicated wired network service. The blue line represents the real-time two-way video telecommunication between the two surgeons. The red line represents two-way information transmission of the telesurgery. The surgical operation signals departed from the console at PUFH to the patient cart at BMDH. The captured image went from the patient cart at BMDH back to the console monitor at PUFH. Similarly, the green line represents two-way information transmission of the local surgery at BMDH. (B) The protocol for dual-console telesurgery of the KangDuo Surgical Robot-01 system using a series connection of 5G wireless and wired networks in the clinical study: I—The surgeon performed the surgery locally. The patient cart, console, and patient were located at PUFH. II—The telesurgery was performed between PUFH and PUMCH with a distance of 6 km between Xicheng District and Dongcheng District (Beijing, China). III—The other surgeon performed the surgery remotely at PUMCH. IV—The network configuration was based on 5G wireless and wired networks. Similarly, the blue line represents the real-time two-way video telecommunication between the two surgeons. The red line represents two-way information transmission of the telesurgery. The surgical operation signals departed from the console at PUMCH, went to the 5G base station and then to the next 5G base station. Afterward, the surgical operation signals went along the wired network to the patient cart at PUFH. Then, the captured image went from the patient cart at PUFH back to the console monitor at PUMCH. The green line represents two-way information transmission of the local surgery at PUFH. BMDH = Beijing Miyun District Hospital; 5G = fifth generation; ILL = Internet leased line'; PUFH = Peking University First Hospital; PUMCH = Peking Union Medical College Hospital.

was a possibility of an open or a laparoscopic conversion. Owing to this concern, a dual console is a possible solution [4]. The KangDuo Surgical Robot-01 (KD-SR-01) system, which was developed in China, has been used successfully in single-console telesurgery in animal experiments using the 5G network and clinical surgeries, including a pyeloplasty, partial nephrectomy, and radical prostatectomy [2,5–8]. The aim of this study was to evaluate the feasibility and safety of dual-console telesurgery with the KD-SR-01 system using 5G and wired networks in an animal experiment and clinical study.

The animal experiment was approved by the Experimental Animal Center. The clinical study was approved by the Ethics Committee of Peking University First Hospital and Peking Union Medical College Hospital. The patient provided signed informed consent. Latency time was defined as the interval between the surgical operation signals from the console and transfer of the captured image back to the console monitor. The console time was defined as the time required to complete the surgery with the console. The swap mode of the dual-console system was used, which allows the two surgeons to actively swap control of the robot arms [9]. Control swap time was defined as the time from the stop of the instrument arm to the restart of the instrument arm controlled by the other console.

In October 2021, a partial nephrectomy in a porcine model was performed remotely using the dual-console KD-SR-01 system through a wired network (Internet Leased Line, 30 MB/s; China United Network Communications Group Co., Ltd., Beijing, China; Fig. 1A). A female pig (60 kg) underwent surgery at Beijing Miyun District Hospital (Beijing, China). After general anesthesia, the experienced assistants performed trocar placement, docking, and clamping of the renal artery. Based on a three-dimensional image displayed on the monitor captured by the endoscopic camera at Beijing Miyun District Hospital, an experienced robotic surgeon (>100 cases) excised the renal parenchyma and performed suturing in front of the surgeon console at Peking University First Hospital. Then, the control was swapped to the other surgeon at Beijing Miyun District Hospital, who excised the second renal parenchyma and performed suturing.

As shown in Table 1, the telesurgery was successfully performed with no severe intraoperative complications or significant technical malfunctions. The volume of each resected renal parenchyma was 3 cm^3. The console time, warm ischemia time, and control swap time were 69 min, 27 min, and 3 s, respectively. The mean latency time was 130 (range, 60–200) ms. The data pocket loss was <1%.

Given that 5G wireless and wired networks coexist and there were multiple telecom operators in China, cross-network and interoperator telesurgery were inevitable according to current national conditions. Thus, a series connection of 5G wireless (China Mobile Limited, Beijing, China) and wired networks (China United Network Communications Group Co., Ltd.) was finally selected for a clinical remote pyeloplasty (Fig. 1B). As far as we know, this is the first report of clinical dual-console telesurgery all over the world.

In April 2022, a 32-yr-old male patient underwent a remote pyeloplasty at Peking University First Hospital using the dual-console KD-SR-01 system. The identification and incision of the ureteropelvic junction were performed by a surgeon at Peking University First Hospital. Then, the control was swapped to the other experienced robotic surgeon at Peking Union Medical College Hospital, who inserted the double-J stent. This was the only step of the surgery performed remotely in this human surgical procedure. The control was then swapped to the surgeon at Peking University First Hospital to perform an anastomosis of the ureteropelvic junction.

As shown in Table 1, the telesurgery was performed successfully, with no severe intraoperative complications or significant technical malfunctions. The console time and control swap time were 98 min and 3 s, respectively. The mean latency time was 271 (range, 206–307) ms. The data pocket loss was <1%.

Telesurgery combines robotic surgery and communication technology. Telesurgery involves a lack of tactile feedback and also latency of visual feedback, which make telesurgery more challenging. Generally, latency time $\leq$200 ms is ideal for telesurgery, 300 ms is also suitable, and 400–500 ms may be acceptable but tiring [10]. The

Table 1 – Perioperative parameters of dual-console telesurgery of the KangDuo Surgical Robot-01 system using 5G and wired networks in the animal experiment and clinical study

	Animal experiment	Clinical study
Surgery	Partial nephrectomy	Pyeloplasty
Number	1	1
Network	Wired	Series connection of 5G wireless network and wired network
Distance (km)	80	6
Remote steps	Excision of the renal parenchyma and suturing	Insertion of the double-J stent
Latency time (ms), mean (range)	130 (60–200)	271 (206–307)
Control swap time (s)	3	3
Data pocket loss (%)	<1	<1
Conversion	None	None
Docking time (min)	4.5	2.8
Console time (min)	69	98
Operative time (min)	94	106
Estimated blood loss (ml)	10	15
Complication (*n*)	None	None

5G = fifth generation.

mean latency time in the animal experiment and the clinical study was <300 ms, which was totally acceptable. The time delay should be improved further in telesurgery cases with longer distances or in time-critical telesurgery.

On the one hand, telesurgery allows real-time interaction with the operating surgeon from any location eliminating long-distance travel. On the other hand, there are several advantages to dual-console telesurgery compared with single-console telesurgery. First, in case of telecommunication or console dysfunction, no conversion is required and the surgery can continue without interruption, which ensures surgical safety. Second, the system could remotely assist in training of junior surgeons and minimize errors during the learning curve [9]. Third, time and location barriers are eliminated, thereby enabling collaboration across distances for challenging cases and delivery of realistic assistance in real time.

Nowadays, all prefecture-level cities have got access to 5G in China. The cost of the network equipment was <$70 000 [3]. In our experience, to perform the telesurgery, the cost for updating the infrastructure was $430, which was sustainable for subsequent telesurgeries. Furthermore, the fixed network charge was about $300/mo and the 5G network fee was about $24 for a 2-h operation. Further studies are required to illustrate the cost-benefit relationship of telesurgery. The main limitation of the current study was the small sample size.

Dual-console telesurgery with the KD-SR-01 system was shown to be feasible and safe using 5G and wired networks.

***Author contributions*:** Xuesong Li 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: Fan, Xu, Diao, Yang, Ji, Shen, Zhou, Li.
Acquisition of data: Fan, Yang.
Analysis and interpretation of data: Fan, Xu, Diao, Yang.
Drafting of the manuscript: Fan, Xu, Diao, Yang.
Critical revision of the manuscript for important intellectual content: Ji, Shen, Zhou, Li.
Statistical analysis: Fan, Xu, Diao, Yang.
Obtaining funding: Ji, Shen, Zhou, Li.
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References

[1] Marescaux J, Leroy J, Gagner M, et al. Transatlantic robot-assisted telesurgery. Nature 2001;413:379–80.
[2] Rong L, Guodong Z, Yuning S, et al. Animal experiment for 5G remote robotic surgery. Chin J Laparosc Surg 2019;12:45–8.
[3] Li J, Yang X, Chu G, et al. Application of improved robot-assisted laparoscopic telesurgery with 5G technology in urology. Eur Urol 2023;83:41–4.
[4] De Pastena M, Salvia R, Paiella S, et al. Robotic dual-console distal pancreatectomy: could it be considered a safe approach and surgical teaching even in pancreatic surgery? A retrospective observational study cohort. World J Surg 2021;45:3191–7.
[5] 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 2021;17:e2187.
[6] Fan S, Dai X, Yang K, et al. Robot-assisted pyeloplasty using a new robotic system, the KangDuo-Surgical Robot-01: a prospective, single-centre, single-arm clinical study. BJU Int 2021;128:162–5.
[7] 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;208:119–27.
[8] Wang J, Fan S, Shen C, et al. Partial nephrectomy through retroperitoneal approach with a new surgical robot system, KD-SR-01. Int J Med Robot Comput Assist Surg 2022;18:e2352.
[9] Morgan MS, Shakir NA, Garcia-Gil M, et al. Single- versus dual-console robot-assisted radical prostatectomy: impact on intraoperative and postoperative outcomes in a teaching institution. World J Urol 2015;33:781–6.
[10] Xu S, Perez M, Yang K, Perrenot C, Felblinger J, Hubert J. Determination of the latency effects on surgical performance and the acceptable latency levels in telesurgery using the dV-Trainer(®) simulator. Surg Endosc 2014;28:2569–76.

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