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A I G E

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ABOUT COVER

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AIMS AND SCOPE

The primary aim of *Artificial Intelligence in Gastrointestinal Endoscopy* (*AIGE*, *Artif Intell Gastrointest Endosc*) is to provide scholars and readers from various fields of artificial intelligence in gastrointestinal endoscopy with a platform to publish high-quality basic and clinical research articles and communicate their research findings online.

AIGE mainly publishes articles reporting research results obtained in the field of artificial intelligence in gastrointestinal endoscopy and covering a wide range of topics, including artificial intelligence in capsule endoscopy, colonoscopy, double-balloon enteroscopy, duodenoscopy, endoscopic retrograde cholangiopancreatography, endosonography, esophagoscopy, gastrointestinal endoscopy, gastroscopy, laparoscopy, natural orifice endoscopic surgery, proctoscopy, and sigmoidoscopy.

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MINIREVIEWS

5G mobile communication applications for surgery: An overview of the latest literature

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Abstract

Fifth-generation wireless network, 5G, is expected to bring surgery to a next level. Remote surgery and telementoring could be enabled and be brought into routine medical care due to 5G characteristics, such as extreme high bandwidth, ultra-short latency, multiconnectivity, high mobility, high availability, and high reliability. This work explores the benefits, applications and demands of 5G for surgery. Therefore, the development of previous surgical procedures from using older networks to 5G is outlined. The current state of 5G in surgical research studies is discussed, as well as future aspects and requirements of 5G in surgery are presented.

Key Words: 5G; Wireless networks; Remote surgery; Telesurgery; Telementoring; Robotic surgery

Core Tip: Very few research studies have been conducted to prove efficacy and feasibility of 5G in surgery so far, with most of these studies being case studies. All of them reported a stable 5G network proving 5G to be feasible for surgery. However, detailed information about the data rate and latency are missing. More research efforts are demanded to explore questions like the combination with new technologies, *e.g.*, Virtual Reality, political regulations, or cyber-security if 5G becomes the backbone of next-generation surgery.

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INTRODUCTION

The use of the Internet in the medical field emerged over time. With the current global situation dealing with coronavirus disease 2019, it has become clear that the healthcare system is dependent on the Internet more than ever. The Internet presents a base to solve existing problems in our health care system. First, medicine being impersonal instead of individual. Second, healthcare being provider-centered instead of invalid-centered. Finally, medical treatment being unevenly available instead of accessible to any ethnicity, income, and geographic location[1].

Looking at the problems in the field of surgery, it has been reported that surgical procedures are not provided worldwide due to a lack of trained professionals[2,3], and besides the invention of laparoscopic surgery most surgeries are technically still performed as they were a hundred years ago[4]. In 1994, Simon[5] already forecasted that the future of surgery in the 21st century will be characterized by an increased distance between the patient and the surgeon.

One step in this trend was the introduction of robotic surgery. Though, it has not passed the threshold to standard use in clinic yet. To play a role in surgery where high precision and reliability are an unquestionable requirement, the evolution of the Internet to 5G - 5th generation mobile network - seems to be the promising and necessary surgical tool in the operating room that will ultimately avail the existing innovations of surgical technologies.

This review aims to clarify the potential benefits and applications of 5G in surgery. Therefore, a brief historical overview and the development of previous surgical procedures using the Internet are provided. Next, 5G and its characteristics are described, followed by a current state summarization of 5G in surgical research studies. Finally, future aspects and requirements of 5G in surgery are outlined.

LITERATURE REVIEW

A literature review was conducted by two researchers (Börner Valdez L, Fuchs HF) individually. The search terms of "5G", "5G network" or "wireless network" paired with "surgery", "remote surgery" or "telesurgery" applied to PubMed yielded a total of 6538 search results. An additional Internet search and reviewed references yielded an additional 20 records. After screening the abstracts for eligibility and removing duplicates, 137 articles were left. Research studies, case reports, reviews or book chapters in English were included for the purpose of this study. After full-text articles were read, 53 articles remained for this study.

INTERNET – BACKBONE FOR MODERN SURGERY

History of the Internet in surgery

Two studies are frequently cited in the related research and constitute noteworthy enablers for a next step in modern surgery. One is the "Lindbergh Operation" conducted by Marescaux *et al*[6] in 2001. Marescaux *et al*[6] performed a safe and uneventful cholecystectomy on a woman in Strasbourg, France, using the ZEUS robotic system. The extraordinary feature of this case was that the procedure was performed from New York City, United States, 6.000 km away from the patient's bedside. To do so, a transatlantic fiberoptic connection (referred to as ATM) was established. This connection enabled the use of a guaranteed bandwidth of 10 Mbit/s for both the robot motion and video data. A latency of 155 ms was measured, thereby ranging under the previously stated safe latency threshold of 300 ms[7,8]. The costs for the medical and technical staff, the robot and the Internet connection exceeded 1 million US dollars[6].

In 2003, Anvari[9] aimed to show that remote surgery is advantageous, especially for countries with a greater portion of rural areas. Therefore, 22 abdominal surgeries were performed remotely between two locations in Canada, 400 km away from each other, using the ZEUS robotic system without any intra- or postoperative complications. Compared to the Marescaux's operation, a commercial Internet Protocol/Virtual

Private Network (*i.e.* IP/VPN) was used at a bandwidth of 15 Mbit/s. The latency was comparable, between 135 and 140 ms[10]. The costs reached 2.5 million US dollars, including the costs for exploring the Internet requirements and solutions for this operation[11].

Both studies were conducted successfully and uneventfully, proving that the technical requirements to separate the surgeon from the patient side already existed 20 years ago. These studies also show that, in remote surgeries, the Internet plays a fundamental role in the operating room, even if some fine touch adjustments were needed in matters of bandwidth, latency, and costs at that time.

Advantages of the Internet in surgery

Taking the idea of using the Internet in surgery one step further, possibilities open up which are not new as an idea but have not been fully reached nor transferred into daily practice yet. As mentioned before, remote surgery could serve areas which are geographically difficult accessible, or by simply saving long-distance travel and costs. Hence, the expertise of specialized surgeons could still be experienced from far away[10,11].

Minimizing the transmission of infectious diseases or avoiding dangerous environments in general is more relevant than ever[12,13]. Both the patients and the medical staff could minimize these risks if remote surgery would become more applicable[14,15]. To provide surgical care in risky surroundings or battlefields has always been of interest to the military and naval sectors. Therefore, it is not surprising that a lot of research in telesurgery has been initiated by the military[16,17].

However, not only extreme situations have to be thought of in regards to how the Internet could improve surgical care. Specialized surgeons could either collaborate on a national or international level, or unexperienced surgeons could be trained and mentored through remote surgery[18,19]. Surgical education could therefore expand in both directions — in width and depth.

Problems and requirements of the Internet in surgery

Already in 1996, Smithwick[20] defined the network requirements for surgery, as follows: "reliability; an acceptable end-to-end delay; the ability to transfer data from sources with widely different data rates; low data error rate." Furthermore, availability needs to be added to this listing, especially if remote surgery or telementoring shall be utilized at any time, from any place[14,16].

Previous studies exposed the flaws and examined the necessary requirements for networks in surgery, mainly bandwidth and latency. The bandwidth describes the possible data volume transmitted per time unit[21]. Rayman *et al*[22] explored the minimum bandwidth for safe remote surgery and found that a bandwidth above 5 Mbit/s should be achieved, whereas Anvari[11] stated that 7 Mbit/s would be needed for remote surgery. Bandwidths used in previous studies for remote surgery - mainly for the video and the robotic signals – have ranged from 10[6] and 15[10] to 23[23,24] and 40[25] Mbit/s.

Latency describes the time amount for data to be transmitted from the sending source to the receiver[21]. For remote surgery, latency must be kept as low as possible. The higher the latency, the more surgical performance deteriorates[8,25-27], even though adaption occurs[28,29]. Acceptable latency in remote surgery has been determined as below 300 ms, in various studies[6,9,30-32]. Both ideal bandwidth and latency are crucial determinants for the Internet to be sufficient in modern surgery.

5G - FIFTH-GENERATION WIRELESS NETWORKS

Properties of 5G

Networks used for surgery evolved over time from satellite[22,24,28,29], Integrated Services Digital Network[8,33-35], ATM[6,7] and IP/VPN[10,27] to the current wireless networks[36]. 5G could meet the previously outlined demands for surgery which were not reached by its predecessor, the 4G/Long-term evolution (LTE) mobile communication standard[1,37,38]. To have a better understanding of the improvements compared to LTE, the properties of 5G are described herein (Figure 1, Table 1).

5G is characterized by its extremely high data rate, up to 10 Gbit/s, thus being 100 times faster than LTE[39-42]. The high data transmission is explained by high frequencies, up to 30 GHz[40,43]. However, the high frequencies of 5G explain two disadvantages compared to LTE. With higher frequencies, wavelengths become smaller and therefore have worse penetration of objects. Consequently, LTE is less susceptible to blockage by

Table 1 Comparison between long-term evolution and 5G[40]

Characteristic	4G/LTE	5G
Data rate	0.01-1 Gbit/s	0.1-20 Gbit/s
Latency	10 ms	1 ms
Mobility	~ 360 km/h	~ 500 km/h
Energy efficiency	0.1 mJ per 100 bits	0.1 μJ per 100 bits

LTE: Long-term evolution.

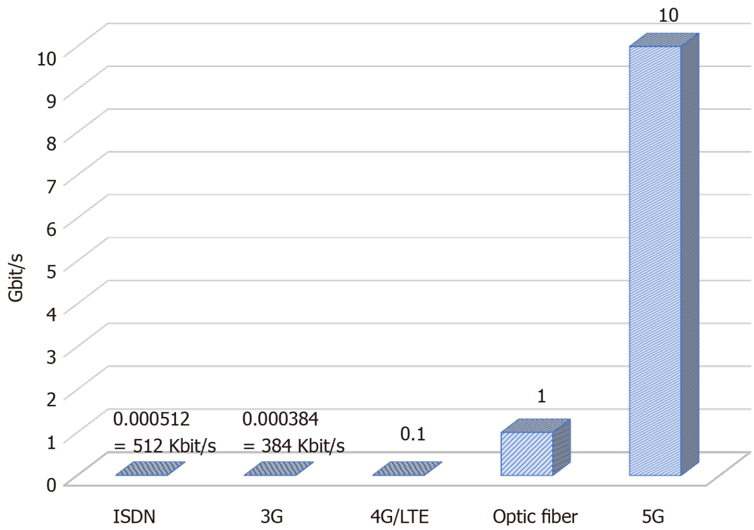

Figure 1 Data rate of distinct networks in Gbit/s[59]. ISDN: Integrated services digital network; LTE: Long-term evolution.

objects in a room than 5G[44,45]. Second, 60 times less distance can be overcome by the high bands of 5G[44].

The latency of 5G is about 1 -2 ms, which represents a 10-fold decrease in latency of LTE[38-42]. 5G is less energy-consuming than LTE (0.1 μJ per 100 bits *vs* 0.1 mJ per 100 bits)[39,41]. With 5G, simultaneous mobile use and device connectivity (massive multiple-input multiple-output; *i.e.* MMIMO) increase by a 100-fold compared to 4G/LTE. Further key features of 5G are high availability and stable reliability[41,42].

Benefits and applications of 5G in surgery

Knowledge of the 5G characteristics makes its use as a platform for new-generation surgery seem possible.

As outlined before, key requirements for remote surgery are a high bandwidth with a fast data transfer and without delays. 5G mobile networks meet these requirements. With a data rate in the gigabit range, previously stated necessary bandwidths of 7 Mbit/s[11] are easily met. The same applies to the necessary latency for remote surgery, which has been defined as below 300 ms[6,9,30-32]. 5G offers a 1 ms latency and therefore represents a huge improvement for this crucial aspect in surgery.

With its high speed, low latency and wireless transfer, multi-connectivity between multiple devices or users is possible[41,42]. This opens the door for real-time telementoring with the option to participate and interfere from a distant location. This does not only mean a gain in surgical quality. It can mean a cost and time reduction in the microcosmos of a hospital under increasing economic pressure of the health system, *e.g.*, a surgeon can operate from their office, with less staff in the operating theater and saving of materials. Globally, long-distance travel can be decreased, even though real-time exchange would still be possible.

Not only videos or pictures could be transferred in high definition (*e.g.*, 4K and 8K)[38]. The sensual experience in robotic surgery could be extended in matters of tactile sensation. Not only can the executive device adapt the movements of the surgeon but also the surgeon can experience haptic feedback when the patient is connected to a sensing device[46,47]. This equates to a great data load, which could be transmitted through 5G. Especially in surgery, the sense for tissue is of great importance. The transfer of this information represents an innovative possibility.

Robotic surgery could furthermore be combined with virtual reality (referred to as VR) and augmented reality (referred to as AR) technology. With 5G, this technology can expand and be refined for surgery. It could be used for surgical education as well as for safer and more accurate surgery[38,41]. Collected data during robotic surgery could be processed for either machine learning (referred to as ML) or artificial intelligence (referred to as AI)[1]. Furthermore, it could be shared and transferred at another speed and size for research purposes[41].

With 5G, it is expected that the Internet of Things (referred to as IoT) technology will become possible. IoT means that any physical object and its use could be connected to each other virtually, creating a whole new data cloud[45]. At best, these data will facilitate processes in daily life. An already existing IoT-technology in the medical sector is the monitoring of blood sugar levels of patients with diabetes *via* an integrated sensing device and smartphones. This technology could be extended, meaning that other human measurable parameters could be directly transmitted from an integrated sensing device to a monitor wirelessly and remotely[1].

In surgery, these health devices could monitor patients before and after the operation to filter and prevent complications early or simply to come to an early diagnosis. Monitoring and extracting medical information through these devices could offer a new perspective about diseases on an individual basis and therefore bring about new aspects of treatment[1,47].

CURRENT STATUS OF RESEARCH: 5G IN SURGERY

Some of these possible features and applications still sound far away. However, the global implementation of 5G has already begun. Obviously, experiments with only machines or devices are easier to conduct and have less risks. Therefore, it is not surprising that medicine lags with the incorporation of new technologies. Very few clinical studies have been conducted so far to prove the benefit of 5G for surgery, most likely due to the lack of a standard 5G network and the expense to establish a technical setup.

It is of note that the first telesurgical procedures with 5G network were reported from China. One was a porcine liver resection and the other was a human brain surgery in 2019. Both procedures were supported by Huawei, the biggest network provider of 5G[48,49]. Although, it is hard to find any detailed information about these two procedures outside of the Huawei online page and Chinese media. No related scientific research papers have been published for these two cases, to the best of our knowledge. Therefore, only published research papers on 5G in surgery will be considered herein (Table 2).

Jell *et al*[37] evaluated whether 5G technology is suitable for surgery, in 2019. The study design contained a theoretical and a technical part. First, a structured questionnaire (Delphi study) was conducted to explore the benefits and demands for surgery by 12 professionals; nine of the participants were from the industry. Second, two case studies examined the technical feasibility and parameters of 5G in the operation room. Therefore, tracking and tracing of static (n = 4) and moving (n = 4) objects was investigated in the operating theater by 5G locators. The second case study simulated the remote robotic camera control (SoloAssist; AKTORmed GmbH) in a phantom, by both inexperienced and advanced medical staff (n = 15). Only camera positioning was performed without any surgical tasks. The Delphi study showed that the majority agreed in the general, useful capability of 5G for the health care sector but more research efforts, especially in daily clinical routine, and global standards are requested. More than a half of the respondents expected benefits for rural areas through telemedicine and advocated for state-funded support. The participants were neutral about industrial funding but recommended early participation of the industry for the realization of 5G in medicine. No statement about the additional effort and justified costs to establish 5G in hospitals was possible. The tracking and tracing of static and moving objects in the operating room was possible; though, the tracking of objects revealed some inaccuracies. The robotic test case showed data rates of the video and robotic signals together around 8 Mbit/s. The latency ranged between 2-60 ms, with most data (75%) being transferred after 30 ms. No disruption of the network was noted.

Lacy *et al*[50] performed the first telementored surgery using 5G network to prove feasibility and benefits. Two procedures (laparoscopic high or low anterior resection)

Table 2 Research studies using 5G for surgery

Ref.	Yr	Study type	Robot system	Location - remote distance	Data rate	Latency
Jell *et al*[37]	2019	(1) Delphi study; and (2) 2 use cases: (a) Track and tracing; and (b) Remote robotic camera control on phantom	SoloAssist (AKTORmed)	Munich (Germany): Not indicated	~ 8 Mbit/s	2-60 ms
Lacy *et al*[50]	2019	Telementoring with telestration: (1) Laparoscopic ant. high resection; and (2) Laparoscopic ant. low resection	-	(1) Barcelona (Spain): 4 km; and (2) Shanghai (China): 6 km	(1) 95-102 Mbit/s; and (2) 99-106 Mbit/s	(1) 202 ms; and (2) 146 ms
Acemoglu *et al*[51]	2010	Brief research report: Remote microsurgical cordectomy on a cadaver	Panda robot (Franka Emika); 3D-microscop (Karl Storz)	Milan (Italy): 15 km	-	One-way video latency: 102 ± 2 ms (max. ≤ 140 ms); Round-trip latency: 280 ms
Tian *et al*[52]	2020	Remote spinal surgery on human (*n* = 12)	TiRobot system (Tinavi)	Beijing (China): 120 km; 280 km; 750 km; 1200 km; 3000 km	-	28 ms
Zheng *et al*[53]	2020	Remote laparoscopic surgery on porcine model (*n* = 4)	MicroHand (WEGO Group)	Quingdolo (China): 3000 km	-	Mean round trip latency: 264 ms (258-278 ms)

were safely performed in Spain and China. The distance between the mentoring surgeon and the operation side was 4 and 6.2 km respectively. The remote surgeon carried out his mentoring function through verbal communication and telestration, so that the surgeon to drew on the laparoscopic image which was received by the operating team at the same time. Both surgeries were performed without signal interruption. Image and transmission quality were highly rated by both surgeons. A data rate of 98 and 101 Mbit/s and a latency of 202 and 146 ms were recorded respectively.

In 2020, Acemoglu *et al*[51] presented a case report where a remote microsurgical cordectomy was performed effectively on a human cadaver from a distance of 15 km using 5G network. The robot used for surgery was the Panda robot (Franka Emika) and visualization was established by 3D-microscopy (Vitom 3D; Karl Storz). Neither information about the data rate nor about the latency of the robotic effector movement solely was indicated by the authors. The maximum video-transmission latency was below 140 ms. The maximum round-trip latency was 280 ms.

Tian *et al*[52] performed 12 cases of remote spinal surgeries on humans with lumbar spinal disorders using a surgical robot (TiRobot system) and 5G network. The aim was also to test the reliability and therefore applicability of 5G for surgery. The remote surgeon, located in Beijing, conducted the pedicle screw planning and robot arm positioning for five different patient sides, with distances ranging from 120 to 3000 km. The surgeons on the patient side performed the screw placement. No detailed data about the number of surgeries or technical parameters of the network at each location was provided. Additionally, the remote surgeon guided the following two operations at different locations at one time, called “one-to-many-remote-surgery”: A one-to-two operation sides (Beijing to Shangdong and Zhejiang) and a one-to-three operation sides (Beijing to Xianjiang, Hebei and Tianjin). There was no network disruption in any case. The mean network latency was reported to be 28 ms but was not explained further. No data was provided about the data rate. The pedicle screw implantation was rated acceptable in all cases and there were no intraoperative complications.

Zheng *et al*[53] evaluated the efficacy, availability, reliability, and safety of 5G in four remote laparoscopic surgeries on a porcine model using the MicroHand robot system (*n* = 4; nephrectomy, hepatectomy, cholecystectomy and cystectomy). The remote surgeon was located 3000 km away from the patient side in China, connected *via* 5G network with a bandwidth of 1 Gb/s. A wired Internet connection served as reference with a bandwidth of 100 Mbit/s. The procedures were conducted safely without any adverse effects. No network errors were noted. The mean total latency of 5G was 264 ms (258-278 ms), whereas the mean latency of the wired Internet connection was shorter, with 206 ms (204-210 ms). The parts of the total latency consisted of the mean round-trip delay, the servo period of the surgical robot (< 1 ms), the mechanical response delay of the robot (40 ms), the endoscope imaging and image processing delay (50 ms), and the video codec delay (60 ms). Mentioned times were the same in both network setups but the mean round-trip delay was 114 ms (108-124 ms) for 5G and 56 ms (54-60 ms) for the wired network setup. The data rate was not mentioned in this study.

DISCUSSION, FUTURE ASPECTS AND DEMANDS FOR 5G IN SURGERY

The described studies evaluating 5G for surgery comprise a technical report using a use case on a phantom[37], one remote telementoring study with two use cases on humans[50], one brief research report about remote microsurgery on a cadaver[51] and a remote laparoscopic surgery on four pigs[53] but only one interventional study with 12 patients undergoing remote robotic neurosurgery[52]. This *status quo* demonstrates that surgery using 5G has not passed the threshold of a first-line approach. As a matter of fact, only very few randomized studies on telesurgery and telementoring using older networks have been published so far[54,55]. Though, randomized studies must follow.

However, case studies are a good start to develop an understanding about the technical details of the network and to detect first obstacles. Jell *et al*[37] and Lacy *et al*[50] provided the first data about the particular data rate and latency of the video and robotic camera movement signals. Both studies, though, did not use 5G technology to directly perform surgical tasks. Only the work of Tian *et al*[52] included robotic movement control for spinal surgery on humans but they did not provide any data about the particular data rate. However, it would be of great interest to know how a higher data size of robotic control would be transmitted through 5G.

Only Zhen *et al*[53] provided detailed information about their results regarding latency. The measured total latency using the 5G network (264 ms), though, was longer than the reference setup using a wired connection (206 ms). When looking closer at the parts causing the latency, it is noticeable that the 5G and wired connection setup only differ in the time of the mean round trip delay. A detailed explanation for the longer mean round trip delay of the 5G network was not provided by the authors. A lack of enough 5G antennas between the patient and surgeon side might be an explanation. The authors pleaded for 5G, due to such benefits as its multimodal data transmission, higher bandwidth and being wireless, which therefore provide great mobility, even in rural areas which are difficult to access.

Lacy *et al*[50] argued that recorded latencies could have been faster in their setup if 5G would have been the connecting network of any device in the whole study setup, and not only two 5G antennas between the patient and mentor side. Furthermore, adequate image processing software for coding and decoding video signals would lead to shortened latencies. Jell *et al*[37] explained measured inaccuracies in their tracking setup due to other, intermediate objects interrupting the signals to the 5G receiver. Both examples show that further software innovations for the use of 5G is demanded. Overall, published data using 5G in surgery lacks technical details and needs to provide more information about the composition of data rate and latency for further improvements.

None of the cited studies used the Da Vinci robot system (Intuitive Surgical Inc.). However, the Da Vinci surgical system is the most used surgical robot worldwide[56]. To evaluate whether 5G works for remote robotic surgery in a broad spectrum of surgical fields, research efforts need assess the technical feasibility with the Da Vinci system. Furthermore, new technologies such as AI, ML, VR or AR that are being claimed to contribute to surgery have not been studied with 5G and surgery scientifically, to our knowledge.

All authors of the studies using 5G for surgery agreed in the benefit of telesurgery for remote areas. This is in accordance with previous literature as outlined before. However, none of the described studies mentioned the costs to establish 5G-based surgery. Van Wynsberghe *et al*[15] justifiably raised the objection that aforementioned, remote areas - usually rural and low-income areas – will not have the means to afford highly advanced technology.

It is estimated that the network expansion of 5G in a country of size and economic status similar to Germany's would cost tens of billions of Euros[57]. Therefore, a depiction of the costs establishing such a technical system like robotic surgery with 5G is important. It could elucidate to what extent financial support or funding by the government or a Union of States is needed. This has also been demanded in the Delphi study of Jell *et al*[37].

Three of the five described studies used a 5G network provided by Huawei[37,52,53]. Huawei – a Chinese company - is the biggest 5G technology provider worldwide, far beyond other providers. In times of the predominance of virtual technologies, Huawei has been in the spotlight of geopolitical interests between China and the United States[58]. The matters of security and reliability are crucial in surgery. Not only does the network itself have to be stable enough to perform safe surgery, which has been proven by the outlined studies[37,50-53], but also cybersecurity now needs to be an issue of interest if the 5G wireless network will be the basis of modern surgery. Patient data and data transmission must be protected against cyber-attack.

Although the 5G technology already exists, the biggest technical issue is simply its pending implementation in daily life. In Germany, the expansion of the 5G network was subjected to a politically regulated and costly tender. Now, four providers have started to offer 5G in Germany, but it is far from being universally available[57]. Due to its high frequencies, more antennas are needed to create a stable 5G network. Therefore, more radio masts need to be constructed in urban as well as in natural areas. However, this might interfere with citizen movement and nature conservation organization interests.

From an ethical point of view, the topic of dehumanizing can become a greater issue when remote surgery becomes reality with 5G. The surgeon will not physically interact with his patient and therefore may be more likely to comprehend his patient just as a data set[15]. The sense of responsibility can be lost, and the criticized mechanization of medicine could be enhanced instead of resolved by 5G.

Consequently, 5G in surgery is not just a topic of medicine. It is a global, political issue which needs to be discussed from a political point of view as well. Recommendations and laws regarding how to handle this new technology in a practical but safe manner in medicine need to be addressed. These laws cannot just follow the geographical boundaries of states. One of the major advancements of the Internet is global networking. Practicing the advancement that surgery could be possible with 5G regardless of boundaries, legal and ethical agreements must be established on an international level.

CONCLUSION

Introduction of the fifth-generation wireless network, 5G, is forecasted to finally enable long-awaited establishment of telesurgery and telementoring in routine medical care. The first trials to prove the feasibility of remote surgery using the Internet were conducted decades ago and identified important network parameters for safe surgery, such as bandwidth, data rate and latency. 5G is supposed to meet these requirements with its enormous bandwidth, very short latency, multi-connectivity, high mobility, high availability, and high reliability.

Very few research studies are present in the literature to prove efficacy and feasibility of 5G in surgery so far and most of these studies are case studies. Nevertheless, all of them have reported safe surgery without connection disruption of the 5G network. However, these studies lack detailed information about the data rate and latency. More in-depth studies as well as finally randomized studies need to follow.

Combination of surgery with new technologies such as AI, ML, VR and AR using 5G as the providing network remains an issue of interest. Furthermore, questions like costs, political regulations on a national as well as international level, and data security need to be taken in consideration if 5G becomes an integral part in next-generation surgery.

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