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CKJ REVIEW

Telemedicine in nephrology: future perspective and solutions

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ABSTRACT

Telemedicine is a medical practice that uses electronic information and communication technologies. It is not exclusive to face-to-face care but complements face-to-face care and other forms of medical care. It has advantages such as facilitating home therapy, reducing patient travel time and costs, and empowering patients. This makes equitable access to care feasible. Clinical studies have been conducted on telemedicine in nephrology outpatient care, inpatient consultations and hemodialysis, indicating that telemedicine can improve patient satisfaction, leading to enhanced treatment owing to increased adherence and frequency of visits. However, it has not been sufficiently used in the kidney field. The key to spreading "telenephrology" (telemedicine in nephrology) is how physical examinations and laboratory/imaging/physiological tests, currently challenging to perform without face-to-face contact, can be substituted with methods optimized for the telemedicine framework. This paper describes the current status of telemedicine and telenephrology, along with advanced methods for collecting data equivalent to laboratory, imaging and physiological tests outside of hospitals, including estimation of serum creatinine levels from saliva or tear fluid, estimation of blood hemoglobin levels by taking pictures of the eyelid conjunctiva or nails with a smartphone and ultrasound of the kidneys using motion capture technology. With an understanding of the strengths and weaknesses of current telemedicine, we should make full use of it for better treatment and patient care. However, further telenephrology research is required.

Keywords: advanced diagnostic techniques, equitable access to care, remote monitoring methods, telemedicine in nephrology, telenephrology

IMPORTANCE OF TELEMEDICINE

"Telemedicine" literally means "healing at a distance" and is defined as the use of electronic information and communications technologies to provide and support healthcare when distance separates the participants [1, 2]. This includes video/phone consultations with doctors, remote monitoring of patients' vital signs and online prescription services. Another similar term, "telehealth," covers all healthcare activities using digital technology; it is a broader concept than telemedicine and includes self-management digital applications (Fig. 1).

The clinical applications of telemedicine can be categorized as follows: (i) initial urgent evaluation of patients for triage, stabilization and transfer decisions; (ii) supervision of primary care by non-physician providers (e.g. nurses) when a physician is locally unavailable; (iii) one-time or continuing provision of specialty care when a specialist is locally unavailable; (iv) consultation, including a second opinion; (v) monitoring and tracking of patient status as part of follow-up care or management of chronic problems; and (vi) use of remote information and decision analysis resources to support or guide the care of patients.

Although telehealth services have been developed and are available in many areas, they were not commonly adopted before the coronavirus disease 2019 (COVID-19) pandemic [3],

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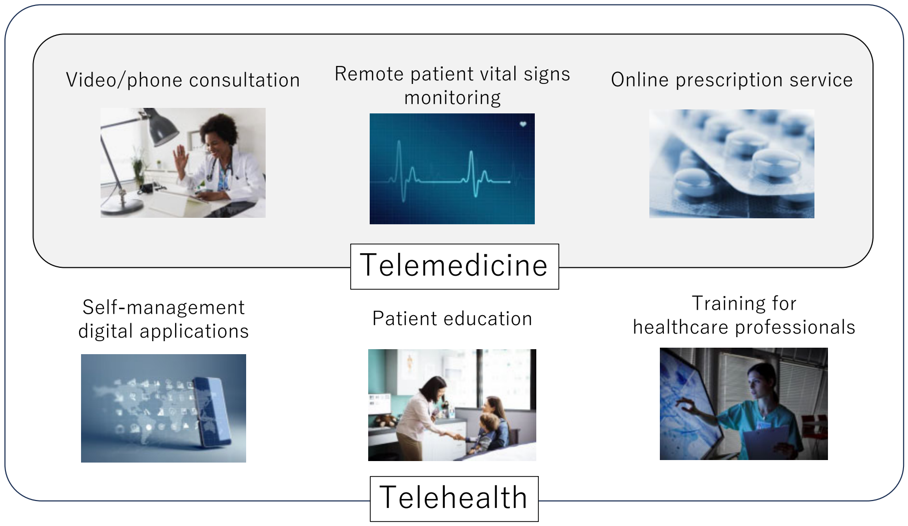

Figure 1: Telemedicine and telehealth. Telehealth is a broader concept than telemedicine. Telemedicine includes general medical practices, such as diagnosis and prescription. In contrast, telehealth includes additional activities, such as patient self-management, patient education and medical staff training.

Table 1: Key advantages of telemedicine.

Patient related	Health economy related
Technology may facilitate home therapy and shorten the duration of home training	Reduction in staff travel time and costs for satellite clinics
Reduction in patient travel time and costs	Reduction in costs for outpatient clinics, clinic room usage and nursing support
Patient empowerment and engagement in self-care	Improved access to healthcare for remote areas
Less impact on work and employment	Scarce resources such as outpatient clinics focus on those most in need
	Less ambulance costs for transport and unscheduled visits

owing to insurance coverage, reimbursement and legal regulations. The COVID-19 pandemic forced people to avoid visiting clinics and receiving face-to-face medication. Therefore, telemedicine has emerged as a way to deliver care at a social distance [4]. However, the shift to telemedicine has impacted people interacting with the healthcare system, not only those related to COVID-19. Telemedicine was initially considered familiar to patients in rural areas because they spent more time visiting clinics. However, recent studies have revealed that patients in urban areas frequently underwent telemedicine [5–7]. Systematic causes, such as internet vulnerability, may interfere with the spread of telemedicine in rural areas.

The advantages of telemedicine include facilitating home therapy, reducing patient travel time and costs, empowering patients and engaging them in self-care, and having less impact on work and employment from a patient-related perspective (Table 1). From a health-economic perspective, telemedicine's advantages include a reduction in staff travel time and costs, lower costs for clinics, improved access to healthcare in remote areas, and decreased ambulance costs for transport and unscheduled visits. Telemedicine is also expected to be beneficial in disaster medicine for several reasons, including its potential to quickly link multiple specialties and local generalists and provide appropriate specialty care to disaster victims, thereby improving patient safety and reducing medical costs [8].

Furthermore, the world's population, especially the older population, is growing rapidly. It is predicted that the percentage of humans aged over 65 years will reach 16% by 2050 [9]. An increase in life expectancy presents healthcare challenges, resulting in substantial socioeconomic burdens. Elderly patients suffer from a progressive decline in their physical and cognitive abilities, and the increasing geriatric population, coupled with the decline in the caregiver workforce, is a major healthcare issue considering limited operational costs and resources [10]. Traditional face-to-face medical examinations contain healthcare risks of delayed diagnosis when patients' mobility is reduced, and caregiver workforces are limited. Therefore, telemedicine, including remote patient monitoring, has attracted attention as a solution to health issues in aging societies.

However, there are various barriers to the use of telemedicine (Table 2). Patient-related barriers include technological difficulties, problems with internet access and low eHealth literacy, collectively referred to as the "digital divide" [1]. When engaging patients using digital tools, we can only reach the population already fully engaged in digital tools. To eliminate the digital divide, it is important to consider the concept of universal design [11] while developing information and communication devices for telemedicine, taking into consideration the elderly and those who have difficulty using information technology. It is also important that the operation of such devices be intuitive and easy, such as connecting as soon as the user touches the device. The prevalence of smartphones is increasing worldwide

Table 2: Key barriers to the further spread of telemedicine.

Patient related	Physician related	Related to law, governance and infrastructure
Technological difficulty, especially for the elderly	Resistance to change	Regulations about telemedicine are preliminary and imperfect
Problems with internet connection	Limited availability of biological data (only information on sounds and images)	Technology may fail either spontaneously or during denial-of-service attacks
Care may be perceived as impersonal when compared with face-to-face	Additional workload due to technological issues	Cost and reimbursement
Anxiety when remote advice is not immediately available	Perceived loss of control when compared with face-to-face	
Feeling unnecessary because of easy accessibility to family doctors and hospitals	Data overload and user fatigue	

Figure 2: Relationship of telemedicine to other care. Just as outpatient care, inpatient care and home visits are not in opposition to each other, telemedicine (online care) is not opposed to face-to-face care but they should instead complement each other, aiming for better treatment and patient experience.

[12]. Other solutions include community-based education and the use of primary care to support patients with low eHealth literacy. Physician-related barriers include resistance to change, limited availability of biological data, additional workload attributed to technological issues, and user fatigue owing to data overload. Barriers related to law, governance and infrastructure also exist. Telemedicine regulations are still immature. Costs and reimbursement are also not optimized for telemedicine. Telemedicine can be disrupted spontaneously or through malicious attacks. However, these challenges should be overcome to popularize telemedicine. Most barriers are infrastructural, institutional or legal. In medical research, technological breakthroughs that enhance the availability of biological data from remote patients are required.

Although telemedicine is often discussed in comparison with face-to-face care, it should be noted that these are not opposing concepts. Many forms of medical care, including inpatient and outpatient care, home visits, house calls, routine visits and emergency visits, should complement each other to improve the content of medical care and patient experience, and telemedicine should be considered part of this process (Fig. 2). Currently, few diseases can be definitively diagnosed with only online medical care (medical interviews and videos over the screen). However, patients and healthcare providers would benefit from telemedicine for many diseases. It is appropriate to sufficiently understand both the benefits and limitations of telemedicine and to use ease of access as an advantage.

CLINICAL RESEARCH ON TELENEPHROLOGY SO FAR

Telemedicine for kidney issues, namely "telenephrology," can also potentially improve kidney treatment. Patients who visit nephrologists, whether their disease is chronic kidney disease (CKD) or end-stage kidney disease (ESKD) requiring kidney replacement therapy, such as hemodialysis, peritoneal dialysis or renal transplantation, will require long-term or semi-permanent visits. Since this significantly affects the patient's quality of life, it is important for nephrologists to seek a form of medical care that does not impair the patient's quality of life. This will ultimately lead to higher retention rates and more frequent contact with medical facilities, which in turn will lead to better medical care. In this sense, the spread of telenephrology is desirable. Furthermore, a major aspect of nephrology practice is the management of lifestyle-related diseases such as hypertension and diabetes mellitus, for which knowing the lifestyle background of each individual is beneficial to the practice. By using telemedicine, physicians can easily ascertain how the patient lives or works outside clinic. Therefore, telemedicine should provide this benefit.

In addition, though measurement of estimated glomerular filtration rate, or creatinine, which is almost indispensable in renal care, is difficult to perform at home at this time (see below for details), urianalysis at the clinic can be substituted by urine dipstick test at home, showing affinity with telemedicine. Blood pressure, which is also an important physiological parameter in patients with kidney disease, can be measured at home. Home blood pressure monitoring (HBPM) is considered important for its control [13], which alone can result in successful blood pressure treatment [14]. Furthermore, while we do conventional ambulatory blood pressure monitoring (ABPM) for approximately 24 h at hospitals and clinics to determine diurnal variation in blood pressure, advances in wearable devices allow us continuous blood pressure monitoring for more than 24 h. Development of a small, wearable, non-invasive continuous blood pressure monitoring system that exceeds HBPM and conventional ABPM in terms of accuracy and duration is important for the success of blood pressure control by telemedicine [15]. Currently available devices such as smartwatches can be useful for continuous blood pressure monitoring [16]. A flexible and wearable sensor can accurately measure blood pressure and replace the existing sensors of blood pressure devices [17]. Furthermore, not only peritoneal dialysis but also hemodialysis can be performed at home [18], which is also highly compatible with online medical care. However, it has not been sufficiently used in the kidney field and there are few objective data available on telenephrology at this time. This study presents several examples.

First, hybrid inpatient doctor-to-doctor nephrology consultation, combining face-to-face and online examinations, was non-inferior to standard nephrology consultation, employing only face-to-face examination [19]. In this study, the nephrologists preferred video consultations and spent less time using telenephrology. This result indicates that telenephrology could reduce the nephrologist workforce without compromising examination quality. Inpatient nephrology consultation is a good indication for telenephrology because data from physical examinations and laboratory tests are available at the hospital where patients are admitted.

Subsequently, we address outpatient care using online medical services in nephrology. When 234 patients with CKD received telemedicine via video conferences and were compared with 817 patients with CKD who received standard care (face-to-face) [20], there were significantly fewer dialysis inductions in the telemedicine group (5.1% vs 9.9%; $P = .02$) and significantly lower mortality (11.1% vs 18.9%; $P = .02$). In a comparison of 112 CKD patients who received telenephrology and 116 who received standard care, cancellations of scheduled visits and "no-shows" in the telenephrology group were reduced by nearly half (53.1% vs 28.5%; $P < .001$), and the frequency of attending appointments was greater in the telenephrology group compared with the standard care group (71.9% vs 61.0%; $P < .001$) [21], although outcomes such as death, ESKD and doubling of creatinine did not differ between the two groups.

Another survey assessed the satisfaction of patients who received face-to-face, video or telephone care in an outpatient nephrology division [22]. The primary diagnoses of the surveyed patients included CKD stage 1–5, hypertension, kidney parenchymal disease, nephrolithiasis and cystic kidney disease. Patient satisfaction was rated on a 5-point scale, and the frequencies of the top four (good) and five (very good) responses regarding overall assessment were 98.9% in the video/telephone care group and 98.3% in the face-to-face care group, indicating that patients who received video/telephone care were as satisfied as those who received face-to-face care. Another study reported on telemedicine use in 55 patients with difficult-to-manage hypertension associated with CKD [23]. Patients were provided with a home blood pressure monitor and education regarding its use. After obtaining the home blood measurements, a nephrologist or pharmacist conducted a telemedicine session (doctor-to-patient or pharmacist-to-patient). Blood pressure improved significantly [mean reduction in systolic blood pressure, 16 mmHg (SD 14)] without deterioration of kidney function or electrolyte abnormalities. Blood pressure can be easily measured at home, making telemedicine likely to become widespread in this area.

Based on these reports on telenephrology in outpatient care, online medical care can help increase patient satisfaction, adherence and the frequency of medical visits, leading to better continuation rates and frequent prescription adjustments. This can provide better treatment details while preserving life prognosis and kidney outcomes.

Another report with 156 patients with CKD investigated the association between experience with online medical care (telephone or video care) and "trust" and "confidence" in online medical care [24]. Patients with previous experience in video/telephone medical care had significantly higher "trust" scores for online medical care compared with those without previous experiences. Patients with previous experience with telephone care had significantly higher "confidence" scores. Exposure to online medical care may change these indicators, and "experiencing online medical care once" may reduce patients' reluctance to receive it.

Reports exist on the use of telemedicine in dialysis. In a study of assisted home dialysis (home dialysis supported by visiting nurses), a telemedicine session of approximately 20 min once a week via Zoom® was introduced, and the experiences of 17 patients and 12 nurses were surveyed [25]. Although they answered that telemedicine was not a complete replacement for face-to-face care, most patients responded that telemedicine increased communication and their sense of being cared for, and helped them understand medical instructions. In addition, all nurses reported that "The experience with telemonitoring was positive," "The telemonitoring service met my expectations" and "I am satisfied with the telemonitoring service."

In another study involving 44 hemodialysis patients who received monthly in-person visits and 40 who received monthly telemedicine visits (one in-person visit every 6 months), dialysis adequacy, vascular access complications and mortality were compared. No significant differences were found between the two groups, and the authors concluded that telemedicine was a valuable opportunity for patients with dialysis [26].

Finally, though it is more in the area of telehealth rather than telemedicine, there are several types of smartphone-based applications for the self-management of patients with type 2 diabetes mellitus ("Dialbetics," "DialBetesPlus" and "Gluconote") [27–31]. Biological data (blood glucose, body weight, blood pressure, exercise, etc.) measured at home by the patients were automatically transmitted to the server, where it was automatically interpreted and judged by a computer and stratified according to medical risk. Data determined to be high-risk and requiring confirmation by a physician are reported to a medical professional through a doctor's call. The remaining data were handled automatically by the system. In addition, when a patient registers their diet and exercise, the system sends feedback to improve their lifestyle based on the registered information. This application has significantly improved HbA1c after a 3-month intervention [27]. It has also been indicated that it may prevent interruption of medical visits [29].

Though there have been some pioneering studies in this area, as described before, it is unclear how to evaluate whether telenephrology is appropriately working in the first place. While assessing patient satisfaction is valuable, evaluating treatment effectiveness, frequency of emergency visits and readmissions, patient dropout rates, and frequency of regular visits are also important. As mentioned earlier, we should keep in mind that telemedicine is not in opposition to face-to-face medical care but rather is used in combination with face-to-face and other types of care to improve patient experience and treatment, when evaluating telemedicine.

Management of kidney disease requires a physical examination and laboratory tests. It is challenging to imagine kidney care without a physical examination and laboratory testing, such as the measurement of blood pressure, blood hemoglobin, serum urea nitrogen, serum creatinine and serum electrolytes. When conducting outpatient telenephrology, another healthcare provider close to the patient, such as a general doctor or a nurse, could perform a physical examination in place of the nephrologist. Having only blood/urine or imaging tests at a clinic before receiving online medical care is also possible, reducing the time required to see a doctor. However, the need for medical personnel other than nephrologists to provide telenephrology raises the question of whether the limited medical resources are being used effectively. Additionally, if a patient needs to go to a hospital for laboratory tests, they think they should receive face-to-face medical care simultaneously. Therefore, to expand telenephrology, novel technologies are needed to collect parameters substituting for physical examinations and laboratory tests at home or in the office.

NEEDED BREAKTHROUGH FOR TELENEPHROLOGY

One technical breakthrough in telemedicine is smartwatch-based atrial fibrillation detection [32], though the disease mainly affects the cardiovascular system rather than nephrology. In this study by Perez *et al.*, a telemedicine visit was initiated if a smartwatch identified possible atrial fibrillation, and an electrocardiography patch was installed. Using this application, 34% of the participants had atrial fibrillation, and 84% of the smartphone-based notifications were concordant with atrial fibrillation. The yield of atrial fibrillation can be greater in smartphone-based, siteless detection than in conventional electrocardiography, including Holter electrocardiography, because a common pattern in early fibrillation can be paroxysmal and infrequent. In this study, smartphone-based detection of atrial fibrillation can be used as a new diagnostic tool, not a substitute for conventional tests, and this is an ideal example of a technological breakthrough in telemedicine. Another outstanding point of this study was that only telemedicine visits were planned unless serious arrhythmias occurred. In this field, advancements in the mechanical compatibility of skin sensors have enabled long-term, non-invasive electrocardiography. Skin-attached and wearable sensors are now in development [33, 34]. The future may be that patients can perform electrocardiography independently, and physicians can check the results from clouds.

Another example is the assessment of wounds. Because wound measurement is important for predicting wound healing, exact wound measurement is vital for wound management. A conventional technique for wound measurement is the ruler-based method, which measures the longest head-to-toe and side-to-side lengths. However, this method can overestimate wound size [35]. The combination of wound care applications and infrared cameras yielded an exact and reliable assessment. Although this technique requires an infrared camera, the image can be shared by a physician or dermatologist, enabling proper remote monitoring.

Aside from this outstanding example, breakthroughs needed for better-quality telemedicine are substitutes for conventional physical examinations and laboratory tests.

The basic and essential components of physical examinations are vital signs, but obtaining even vital signs in telemedicine is challenging for patients at home. The main reason is the absence of instruments such as pulse oximetry in patients' homes. Smartphone-based measurement techniques for hemoglobin saturation and pulse rate are now under development, and soon patients' smartphones will be able to be substituted for a pulse oximeter [36]. In this field, advancements in material technology have enabled the simultaneous acquisition of pulse waves and fingerprints for personal authentication [37].

A challenge to substituting physical examinations for patient motion includes 3D hologram-based telemedicine [38]. A report applying camera sensors and a head-mounted display revealed sufficient assessment of movement in Parkinson's via the head-mounted display. Another report indicated that the position data of the head-mounted display itself could be used to quantify walking speed, step length and cadence, indicating the possibility of auto-quantification [39].

The acquisition of data as substitutes for laboratory tests is a major issue in the development of telemedicine. One solution is patient self-testing. Self-monitoring of blood glucose and continuous glucose monitoring are two representative self-tests [40]. The results of these tests can be shared with physicians, and the physicians' decisions should not change during face-to-face consultations or telemedicine. Urine dipstick tests can be used in nephrology; however, their usefulness may be limited to patients with nephrotic syndrome in remission. Therefore, the substitution of blood tests other than glucose monitoring is required. One major barrier is blood sampling and centrifugation at the patient's home. One success was in the measurement of glycoalbumin for glucose monitoring. Tears and saliva reflect the ingredients of blood, especially albumin, and are candidates for biological samples substituted for blood. It has been reported that the measurement of glycoalbumin in tears is feasible and that glycoalbumin in tears reflects serum glycoalbumin [41], indicating its usefulness in telemedicine. The crux of this study is that glycoalbumin is always interpreted as a proportion rather than an absolute concentration. The ingredients of tears and saliva usually reflect those of blood but do not have the same absolute concentration.

For telenephrology, remote monitoring of urea nitrogen and creatinine is required, and tears and saliva are candidates for measurement. Recent progress in sensing devices has enabled the development of tear and saliva measurements. Regarding the measurement of tear creatinine, a goggle-type sensor can selectively measure tear creatinine concentration. However, the accuracy of serum creatinine prediction from tear creatinine in three classifications, 0–50, 50–100 and 100–150 μM, reached only 83.3% [42]. Another report revealed that cotton swabs for saliva collection were sufficient to measure salivary creatinine concentration, but the correlation between serum creatinine and salivary creatinine was weak ($r = 0.72$) [43]. Another study demonstrated that wearable skin sensors and their remote evaluation were sufficient to monitor creatinine concentrations in sweat [44]. Based on these results, measuring creatinine concentration in biological samples other than blood is technically feasible. However, estimating serum creatinine concentration in other samples is a major barrier. Regarding future development, measuring creatinine concentration in tear or saliva samples is insufficient, and a novel estimation or evaluation method for serum creatinine concentration is needed.

Since anemia frequently occurs in patients with CKD, measuring blood hemoglobin is essential for diagnosing anemia and titrating the prescription of erythropoiesis-stimulating agents or hypoxia-inducible factor prolyl hydroxylase inhibitors. Physicians observe the eye conjunctiva to detect anemia qualitatively; therefore, quantitatively assessing the conjunctiva is an option for hemoglobin measurement. One report revealed that conjunctival images taken by volunteers using cameras in Apple iPhone 6s were sufficient to assess volunteers' hemoglobin levels between 9 and 18 g/dL [45].

Another potential target for hemoglobin monitoring is the nail. Analyzing nail images taken with a smartphone yielded hemoglobin estimations of sufficient quality [46, 47]. Because smartphones are popular electronic devices, their use in self-monitoring is promising.

The remote acquisition of biological images, especially kidney images, helps spread telenephrology. If a caregiver unfamiliar with kidney image acquisition can obtain ultrasound kidney images, it would be useful for an accurate diagnosis. However, this is challenging because optimal cross-sectional images are easily lost with slight deviations in the scanning location or angle of the probe. Motion capture technique may be a solution. The motion capture of professional operators enabled amateur operators to perform ultrasound coinciding with the probe position and angle of the professional [48]. Although this study only replicated ultrasonography in the same patient, future developments will make it possible to assist caregivers in performing ultrasonography.

A new measurement target is volatile molecules, namely gases. Recent progress in materials science has enabled highly sensitive and comprehensive volatile organic component analysis [49]. Evidence has proven that the detection or measurement of volatile organic molecules can be used for disease diagnosis; therefore, the application of volatile organic molecule measurements in kidney disease is anticipated [50]. One advantage of measuring volatile organic molecules in patients is that complicated or invasive sampling techniques are not required. The attachment of the passive flux sampler to the patient's skin was sufficient for gas sampling. It is known that patients with ESKD emit a peculiar odor, characteristic of volatile organic compounds. Therefore, gas analysis is a new diagnostic tool for kidney disease and is suitable for telenephrology.

Finally, we would like to mention artificial intelligence (AI), as it is one of the key technologies today that uses electronic information, while telemedicine is the use of electronic information and communication technology in medicine. The field of AI has evolved rapidly in recent years. The famous AI ChatGPT achieved a correct response rate of over 60% in a US medical license examination, equivalent to a third-year student [51]. Even in non-English language Japanese, there are reports of GPT-4 scores above the passing standard for medical questions in the National Medical Licensing Examination in Japan [52]. However, these reports indicate that the AI sometimes selects prohibited answers. It is impossible to say that there will never be a day when AI will intervene in the management of telemedicine, both in its operational management (e.g. adjusting patient appointment times, predicting the number of medical personnel working, loading large amounts of information to resolve data fatigue, etc.) and in the management of the disease itself (e.g. diagnosis, prognosis prediction, prescription content suggestions) to reduce workload pressures. Such a day is probably still a long way off in the field of medicine, where nearly 100% safety is required.

CONCLUSIONS

Telemedicine is an emerging technique for providing medical care using electronic information and communication technologies, and its importance in kidney disease is increasing. Although telemedicine has significant advantages, several problems remain. Therefore, to minimize these problems, novel remote monitoring methods have been developed to replace physical examinations and various tests. The expansion of telemedicine is urgently required to adapt to an aging society; therefore, research that enhances the quality of telemedicine is needed.

DATA AVAILABILITY STATEMENT

No new data were generated or analysed in support of this research.

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CONFLICT OF INTEREST STATEMENT

None declared.

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