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MOVEMENT DISORDERS (S FOX, SECTION EDITOR)

The Promise of Telemedicine for Movement Disorders: an Interdisciplinary Approach

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Abstract

Purpose of Review Advances in technology have expanded telemedicine opportunities covering medical practice, research, and education. This is of particular importance in movement disorders (MDs), where the combination of disease progression, mobility limitations, and the sparse distribution of MD specialists increase the difficulty to access. In this review, we discuss the prospects, challenges, and strategies for telemedicine in MDs.

Recent Findings Telemedicine for MDs has been mainly evaluated in Parkinson's disease (PD) and compared to in-office care is cost-effective with similar clinical care, despite the barriers to engagement. However, particular groups including pediatric patients, rare MDs, and the use of telemedicine in underserved areas need further research.

Summary Interdisciplinary telemedicine and tele-education for MDs are feasible, provide similar care, and reduce travel costs and travel time compared to in-person visits. These benefits have been mainly demonstrated for PD but serve as a model for further validation in other movement disorders.

Keywords Telemedicine · Movement disorders · Telehealth · Tele-education

Introduction

Technology advancements have expanded the application of information technology in the field of medicine, changing the landscape and enabling medical practice and education without the encumbrance of geographical barriers. Telemedicine (also referred to as telehealth in this article) is the use of electronic information and communication technology to provide and support healthcare when distance separates participants [1]. Over time, the utility of telemedicine has expanded beyond conventional clinical uses (e.g., diagnostic evaluation, patient monitoring, and preventive health) to non-clinical applications such as continuing medical education (e.g., through web-based conferencing), research, and health systems administration

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[2–4]. Uneven distribution and shortages of manpower and infrastructure hamper delivery of quality healthcare. The inherent attraction of telemedicine is its ability to bridge the major barriers that limit such access, including distance, disability, and distribution of qualified health providers [5••]. The typical outpatient visit to the clinic offers face to face contact, but is, at best, a very crude and often inaccurate perspective of the patient's real functioning at home.

Telemedicine allows physicians and other healthcare professionals to literally take healthcare back into the patient's own home and to reinstate within a modern context the cherished "house-call" of past centuries [6]. It offers the ability to judge patients in their own natural environment. Furthermore, telemedicine holds promise as a tool to help reduce mounting healthcare costs, by increasing efficiency of consultations and care delivery, not least for patients who no longer have to travel long distances or to wait in public waiting rooms. The variety of current (traditional) and emerging options for deploying telehealth (such as real-time communication, store and forward [asynchronous] connections, remote patient monitoring, and mobile health technologies, apps and web-based services) extend opportunities to include patients in urban, suburban, rural, and remote locations [1, 7].

Telemedicine is of particular importance in neurological disorders [8], and specifically movement disorders [9••], where the combination of disease progression, limitations in mobility, and the sparse distribution of movement disorder specialists globally add layers of difficulty to the challenges of access. Movement disorders are clinical syndromes manifested by slowness or poverty of movement (such as parkinsonian disorders), at one end of the spectrum, and abnormal involuntary movements (such as tremor, dystonia, chorea, tics, etc.), at the other. Over three million adults and children worldwide suffer from movement disorders. Many have poor access to subspecialists and a multidisciplinary approach to care. Current care models require travel to tertiary centers, increasing the burden on patients and caregivers [10]. Moreover, many patients with movement disorders have symptoms and signs that are difficult to assess in a clinical setting, either because they are intermittent (e.g., freezing in patients with PD), because they are rare and typically home-based (e.g., falls), or because they require longer observation periods to be assessed reliably (e.g., response fluctuations to dopaminergic medication).

In this article, the Telemedicine Task Force of the International Parkinson and Movement Disorders Society (IPMDS) discusses the current and future prospects, challenges, and strategies to overcome barriers for the practice of telemedicine in movement disorders from a global and interdisciplinary perspective. Overall, major advantages and limitations of different telemedicine applications are presented in Table 1. Extensive description of new technologies is beyond the scope of this review.

Telemedicine in Parkinson's Disease

Telemedicine is particularly suited to the evaluation of patients with PD, primarily because much of the physical exam findings are visual. Training and certification for many PD motor rating scales are completed via video, and those who serve as blinded raters for clinical trials often do so via asynchronous video evaluations. Synchronous telemedicine allows for face-to-face virtual interactions, enabling the provider to interact with the patient and request repetition or alternative tasks to better define the characteristics of both normal and abnormal movements. One of the first mentions of telemedicine for PD was by Hubble and colleagues (1992) [11], who used "interactive video conferencing" to assess its validity in evaluating PD patients. Numerous studies have confirmed the validity of remote assessments [9••, 12–15], but telemedicine does have limitations. There are portions of the exam, such as rigidity and pull testing, which cannot be adequately evaluated via telemedicine without the use of an on-site reliable assistant. Although rigidity and postural reflex testing and their response to dopaminergic drugs help with the initial diagnostic evaluation and management plan, these relative limitations do not detract from other significant benefits. Furthermore, a modified version of the Unified Parkinson's Disease Rating Scale (UPDRS) with rigidity and postural instability removed has been deemed reliable and valid [16].

As the global incidence and prevalence of PD are expected to rise, doubling between 2005 and 2030 [17,5••], the shortage of neurologists is predicted to increase as well, widening the gap between those in need of specialized PD care and those providing it [18]. Furthermore, evidence shows that PD patients who receive treatment from a movement disorders specialist show improved health outcomes, including greater adherence to quality indicators [19] and increased patient satisfaction [20]. In one US study, more than 40% of patients with PD did not receive any neurologist care [21]. Neurologist-treated patients were less likely to be placed in a skilled nursing facility, had a lower risk of hip fracture and lower likelihood of death [21]. Telemedicine offers the opportunity for enhanced access to specialty care, thus potentially reducing morbidity and mortality and improving quality of life (QoL) for patients with PD.

Telemedicine in Other Movement Disorders

The body of evidence for telehealth in PD is in stark contrast to the sparse investigation of telemedicine in the treatment of other movement disorders. For example, very little has been published on the use of telemedicine for Huntington disease (HD). As an illness that causes such severe motor, cognitive, and psychiatric disability, as well as psychosocial and financial burden, a more patient-centered approach would entail moving the multidisciplinary, subspecialty care from an

Table 1 Major advantages and limitations of telemedicine

	Advantages	Limitations
Parkinson's disease	Home-based gait assessment, particularly gait freezing	Rigidity and pull-tests are not assessed.
	Validated online-motor UPDRS assessment	
Other MDs	HD: validated online-UHDRS assessment	Limited data compared to Parkinson's disease
	Tics: VoIP comprehensive behavioral intervention for Tics (CBIT).	
	Tics are usually suppressed less frequently compared to in-clinic visits.	
Pediatric MDs	Familiarity with technology	Limited data compared to adult MDs
	Validated online UBDRS	
	Neurofunctional assessment (playing with toys, etc).	
Underserved areas	Feasibility studies available in Africa, China, and South America	Cultural, costs, and technology barriers
	Covering different targets: allied health professional, doctors, medical students	
	Reduce academic isolation	
Interdisciplinary approach	Speech pathology applications	Remains underutilized
	Physiotherapy programs	
	Multidisciplinary consulting	
	Palliative care	
	Psychological care	
MDs overview	Home environment assessment	Dearth of established telemedicine programs worldwide
	Decrease healthcare costs	Low reimbursement
	Access to remote areas	High cost of equipment
	Access to patients with limited mobility	Limited technology access and infrastructure
	Virtual research visits	Limited training in technology
	Wearables and other mobile applications can be used	Long-term adherence
		Cultural limitations on examining certain body areas

MDs movement disorders, *UPDRS* Unified Parkinson's Disease Rating Scale, *UBDRS* Unified Batten Disease Rating Scale, *HD* Huntington's disease

outpatient clinical setting to the home via telehealth. In a small pilot study, virtual home visits were found to be reliable for conducting motor assessments in HD [22]. Telemedicine for HD patients was also found to improve healthcare access while maintaining quality of care [23]. Unfortunately, the limited research on the use of telemedicine in HD leaves important questions unanswered. This includes the effect of telemedicine interventions on HD-specific symptoms, as well as on access to interdisciplinary care and palliative care. Disease-specific barriers to telemedicine and an analysis of the cost-effectiveness of telemedicine for HD are also important to explore.

Neuroleptic-induced movement disorders are common but a formalized screening method to identify related symptoms remains unavailable. The Abnormal Involuntary Movement Scale (AIMS) has been validated to monitor drug-induced movement disorders via synchronous videoconferencing [24]. However, research is required to formalize the procedures, assess the strengths and limitations of this method, and monitor response to treatment. Furthermore, advanced technology utilizing digital measures of abnormal movement could objectively assess hyperkinetic disorders, which is of relevance to other movement disorders such as HD.

Tics are a common childhood-onset movement disorder which are often associated with psychiatric co-morbidities, such as attention deficit disorder and obsessive compulsive disorder [25]. Tics are typically less pronounced when the patient is being examined face-to-face, so telemedicine and less obtrusive monitoring is attractive for this group [26]. The wide spectrum of primary chronic tic disorders can have significant effects on cognitive function and QoL. Currently, Comprehensive Behavioral Intervention for Tics (CBIT) is the most effective treatment for tic disorders [27, 28]. Unfortunately, access is limited due to a paucity of skilled

providers. Voice over Internet Protocol (VoIP) provides an online CBIT option with high patient satisfaction [29].. TicHelper.com ("TicHelper") [30] is another available tool providing an interactive module treatment program. Online modalities may increase compliance and adherence by creating alternative avenues for diagnosis, monitoring, and management of chronic tic disorders.

Telemedicine is an equally important tool for the treatment of pediatric movement disorders. With limited access to adequate care, many children remain under-treated with complications that could be averted by continuous care via telehealth instead of fragmented in-person follow ups. Young adults and children may feel more comfortable with video conferencing compared to adults; furthermore, young adult parents are more likely to be technologically aware than elderly adult patients, facilitating teleconsultations [31]. Likewise, working parents may prefer the convenience of teleclinics, which do not add travel burden and cost to strained schedules and budgets.

Batten disease, a juvenile neurodegenerative disorder caused by neuronal ceroid lipofuscinoses, is the only example in the literature of telemedicine being employed for the treatment of a pediatric movement disorder [32]. A recent pilot study suggested that remote cognitive assessment using the Unified Batten Disease Rating Scale (UBDRS) is feasible and reliable [33]. In our experience, pediatric movement disorder examinations with cooperative children are similar to those for adults. Limited cooperation due to age and/or cognitive impairment is addressed with the assistance of the caregiver or allied health professional, similarly to in-person visits, facilitating videography and examination. We recommend that the physician organizes the examination area to ensure that both the child and caregiver are seated in front of the screen, enabling the physician to maintain eye contact with both of them. Home telemedicine provides the opportunity to observe children in their natural environment, which may help reduce patient and caregiver anxiety. The neurological examination could include observing the child performing daily chores and playing in his/her natural environment, which might bring out symptoms or signs not apparent in clinic. It is important to appreciate that examining certain body areas may be very uncomfortably perceived by patients and families in a telemedicine setting. As such, we recommend that the healthcare provider consider the cultural and environmental issues when planning a telemedicine visit [34,35].

The paucity of data regarding the use of telemedicine in the evaluation and treatment of additional movement disorders is even more problematic. Ataxia, for example, causes progressive motor and cognitive disability, with over 150,000 individuals affected in the USA alone, and limited access to tertiary care centers for these patients. Creating online tools and dedicated telehealth research efforts should be encouraged to help expand subspecialty and interdisciplinary care to a population in need. This will also create a larger pool of patients that can potentially contribute to disease-modifying trials and genetic phenotyping.

Telemedicine Health Networks for Parkinson's Disease and Other Movement Disorders

Telemedicine programs are blossoming across the globe as virtual clinical visit becomes more readily accepted as an alternative to in-person clinic visits. In the USA, the Department of Veteran's Affairs (VA) Office of Connected Care leverages robust telemedicine infrastructure and advanced information technologies including telehealth and mobile applications, among others, to provide alternatives to in-person clinic visits [36]. This includes not only synchronous encounters for patients at remote VA clinics but home telehealth and e-consultations as well. Kaiser Permanente, an integrated managed care consortium, has widely adopted a telehealth model accounting for more than half of all health encounters in the system in 2016 [37]. Medicare, the United States' universal healthcare system for older (> 65 years of age) and disabled adults, currently reimburses telemedicine in only a subset of rural areas. However, recently proposed legislation aims to expand the scope and reach of telemedicine services allowed by Medicare [38]. Many other programs, such as those described by Dorsey, Biglan, and colleagues, have reported on the benefits of "virtual house calls" which provide equal clinical outcomes compared with office visits but are of greater efficiency and service to patients in residential care facilities, in terms of patient/provider satisfaction with comfort/convenience [14, 15, 39].

Canada is home to one of the most established telemedicine programs. The Ontario Telemedicine Network provided telehealth services to 785,986 patients, over 1200 patients with movement disorders in 2017, and continues to provide care for advanced PD patients, including those with deep brain stimulation (DBS) [40]. dB makers are also examining ways to remotely perform DBS programming for PD patients without requiring patients to leave their home [41].

Interdisciplinary Telemedicine Care for Patients with Movement Disorders

Research demonstrates that people with PD and other movement disorders benefit greatly from interdisciplinary medical care [42–44]. Telehealth technologies have the potential to increase the accessibility of care for patients, especially those with advanced disease living in underserved areas with difficulties accessing specialized centers [45]. Telemedicine in the field of pediatric psychology is still rather new but important to consider for clinical applications including individual and group therapies for depression, obesity, and other chronic illnesses [46]. In a survey conducted in Australia among allied health professionals to study the use of telehealth in research,

most studies evaluated speech pathology applications (64%) [47] and physiotherapy (22%) [48], with only one study in each of the following disciplines, respectively (occupational therapy, podiatry, and audiology). Only one study involved more than one allied health discipline [45,49]. The study outcomes indicated that interdisciplinary telehealth was comparable with traditional in-person care delivery [45]. Bloem et al. [50] analyzed therapeutic interventions for PD outside pharmacological and surgical therapies, and growing evidence has been found for the effectiveness of various types of non-pharmacological interventions. Physiotherapy is best studied [51], with several advances in recent years, and an interesting challenge for the next years is to evaluate whether some of the evidence-based treatments (such as cueing to improve gait) can now also be delivered remotely using telehealth, either entirely or—more likely—as part of an integrated approach that also involves occasional in-person consultations [50]. The effectiveness of aerobic training, gait training, and balance training has been further established, and several promising physiotherapy interventions administered via telehealth have been developed, including Balance Training on Postural Control in Patients with PD Using a Virtual Rehabilitation System [52], and PD-Webb approaches [53, 54]. Interesting new work suggests that emerging technologies, e.g., virtual reality dancing [51], may offer tools to accomplish a better long-term adherence to a physically active lifestyle. In addition, computer game-based exercise for different modalities (movement, speech, cognition) is a promising and rapidly growing field [55]. Dias et al. [56] used a synchronous tele-rehabilitation (videoconferences) approach to study the effectiveness and feasibility of vocal tele-rehabilitation by using the extended version of the Lee Silverman® method in PD patients. This is a particularly promising area, because current voice treatment programs are fairly intensive, requiring regular visits to the clinic, and in that regard, doing at least some of those treatments via telemedicine would be a great service to patients. Moreover, treatment effects may taper off after the intensive treatment period, so remote follow-up visits would be ideal to ascertain a sustained efficacy. A recent study provided integrative specialized care to PD patients and caregivers by using synchronous videoconferencing telehealth technology [42]. A movement disorder team composed of movement disorder specialists, psychologists, nurse practitioners, researchers, physical and speech therapists, nutritionists, and graduate students followed 36 PD patients for 6 months. In this study, PD patients, after being evaluated by this interdisciplinary approach [42], received recommendations to change their medication regimen or were referred to physical therapy, speech therapy, occupational therapy, and/or mental health care, as clinically indicated.

Beyond PD, there are little data about the use of interdisciplinary care delivery models using telemedicine for movement disorders. In a survey conducted to analyze the organization of clinical services for HD at 231 sites surveyed in Europe, North America, Latin America, and Oceania, multidisciplinary case reviews were offered in 54.5% of sites, and only videoconferencing and telemedicine were used by only 23.6% sites [57].

A different setting where telemedicine can be used involves palliative care, which is aimed at optimizing QoL and relieving suffering for people with life-threatening illnesses or advanced chronic diseases, as well as that of their caregivers. In many cases, the treating neurologist/clinician remains the principal physician for these patients, even in late-stage disease. With the expansion of palliative care needs and a relative lack of access to palliative care specialists, an interdisciplinary approach involving nurses, allied health therapists, social workers, chaplains, and hospice workers is important for holistic care coordination [58]. In this regard, the Telemedicine Task Force of the IPMDS is currently conducting a research study analyzing the feasibility of providing an interdisciplinary palliative care via telemedicine to patients with atypical parkinsonian syndromes. Results of this study are forthcoming.

Telemedicine Programs in Underserved Areas

Access to specialty care remains poor for certain subpopulations even among nations with developed healthcare systems and is even more limited in nations with limited resources for healthcare. Telemedicine is particularly needed in remote areas that are currently facing a shortage of general practitioners and specialists. Telemedicine may be also considered to be an effective strategy to aid in the recruitment and retention of physicians in underserved areas by breaking their professional isolation and reducing the stress related to this, facilitating their distance learning and, in doing so, improve access to healthcare [59].

Over the last 5 years, the IPMDS has been sponsoring several telemedicine programs in underserved areas, including South America, Africa, and China. The Asynchronous Consultation in Movement Disorders (ACMD) is a specialized program conducted in Africa. The use of this store-and-forward technology has enabled referring sites with slower internet speeds and variable electrical power to participate in ACMD. In addition, our referring sites in Africa are able to access the simple equipment required (PC and digital camera or smartphone) to request a consult, eliminating the challenges of scheduling virtual clinic visits in different time zones. The ACMD program is structured such that the consultant solely provides advice to the local provider, who continues to be the treating physician. The consultant's report may include a differential diagnosis, a list of follow-up questions for consideration, and/or an empiric plan of care. The consultant can also attach other documents, such as relevant academic literature. The feedback from consultants and referrers has been

overwhelmingly positive. In particular, the referrers have identified that the program has been especially useful as a professional development tool.

Using a different approach, a tele-education PD program for health providers was conducted at Hospital Laquintinie in Douala (Cameroon) (see picture presenting a tele-education classroom; Fig. 1) [60•]. Twenty lectures over the course of a year that connected participants with movement disorder experts using live, synchronous video conferences and teaching materials were given. Thirty-three health professionals (52.4% women) including 16 doctors and 17 allied health professionals and 18 speakers participated. Videoconferences were successfully completed in 80%, participation ranged from 20 to 70%, and satisfaction was at least above average in 70% of participants. Whereas medical knowledge was dramatically improved, post-course patient access was not changed in the short-term. On the other hand, using a different audience target, a movement disorders tele-education project for medical students was conducted in 2016 in a low-middle-income (Cameroon) and a middle-high-income (Argentina) country lacking access to movement disorders education [3]. Six real-time videoconferences covering hyperkinetic and hypokinetic movement disorders were included. This study included 151 undergraduate medical students (79.4% from Argentina, 20.6% from Cameroon). Feasibility was acceptable with 100 and 85.7% of the videoconferences completed in Argentina and Cameroon, respectively, and medical knowledge improved similarly in both countries. Attendance was higher in Argentina compared to Cameroon (75 vs. 33.1%).

In China, a pilot project supported by the IPMDS Telemedicine Task force used telemedicine to provide care to PD patients through a network of neighborhood clinics and to train primary care neurologists in neighborhood clinics in the diagnosis and management of PD with specialist support. The community neurologists were satisfied with the use of telemedicine to obtain expert advice. Contrary to our expectation, PD performance was similar in the intervention and non-intervention group. However, a non-significant reduction in fractures, emergency visits, and hospitalizations was observed in the intervention group. The use of telemedicine facilitated consultations between community neurologists and movement disorders experts providing a step forward in access to high-quality care in remote provinces of China. PD patients saved hundreds of hours of traveling time, and serious adverse outcomes such as fractures and hospitalizations appeared to be reduced.

Quality of Life, Cost-Effectiveness, and Barriers

Telemedicine for movement disorders has been evaluated mainly in PD and has been shown to deliver similar QoL outcomes and is cost-effective compared to in-office care, despite barriers to engagement. Five randomized controlled trials conducted to date compared telemedicine versus usual care for persons with PD [14, 15, 61–63]. QoL was similar [14, 15, 62, 63] or improved [14, 64] for those receiving telemedicine care. In a separate non-controlled study, there was no improvement in QoL after 6 months [65••]. Cost reduction is one of several benefits of applying telemedicine to chronic movement disorders such as PD [9••]. Firstly, telemedicine is cost-effective for patients by reducing direct out-of-pocket travel costs and travel time compared to in-person visits [15, 61, 62, 66, 67]. For example, telemedicine saved up to US$100 [15] or CA$200, travel time up to 209 min, and travel distance up to 160 km, per visit [67]. One study calculated savings for 34 patients with PD over 3 years as approximately 1500 attendant travel hours, 100,000 km of distance, and US$37,000 [66]. Secondly, it is cost-effective for healthcare delivery, with similar clinical outcomes and motor and non-motor assessments, for telemedicine versus in-office visits [61, 63]. Lastly, it is cost-effective for physicians who practice in well-established telemedicine systems (e.g., Canada; Veterans Affairs [federal], Kaiser Permanente [private] in the USA), where telemedicine visits have similar or higher reimbursement to in-office care [68].

Fig. 1 Tele-education for medical students in Cameroon. Courtesy of Dr. Jacques Doumbe, Cameroon

However, a number of major barriers limit universal adoption of telemedicine and are generally more prohibitive for physicians than for patients. The most common barriers perceived by physicians include the inability to perform a full neurological exam, technological difficulties, and reimbursement issues [69, 70]. Although providers are typically not trained in the use of telehealth technologies in their respective medical specialty and subspecialty training programs, new telemedicine rotation programs are emerging for neurology residents in a few US centers. From a patient perspective, a significant barrier is accessing telemedicine due to the digital divide. Persons with PD who participate in telemedicine studies are overwhelmingly white, well-educated, and more familiar with technology than the general PD population [62]. Additionally, older and less educated individuals with chronic diseases are less likely to have internet access. While research trials may provide cameras and even smart phones to research participants, this is not currently feasible for standard practice [71]. Patients who have participated in telemedicine have also reported difficulties establishing rapport with medical providers in this clinical setting [9••, 69].

Although video camera technology and smartphones are almost ubiquitous and becoming more affordable over time, a major challenge is the lack of reimbursement for providers' time and expertise in some health systems. It is difficult to properly assess the value of telehealth considering the rapid rate of change in both technologies and healthcare reimbursement. It is likely that an entirely new role, perhaps called "telehealth technologist," may need to be developed to track and organize the plethora of novel and emerging technologies applied in healthcare. Funding for this new role may pose a challenge for smaller medical facilities.

New Technologies and Other Research Opportunities

Novel technologies that constantly track our activities, sleep, motor performance, location, and a variety of other daily functions are evolving at an unprecedented rate. These technologies are swiftly penetrating the commercial fitness and health industry, and we also foresee their increasing applications in telemedicine.

Some of the most exciting novel technologies being applied or tested in the context of telemedicine include [1] proprietary wearables; [2] self-sensing and adjusting "closed loop" systems for optimizing DBS programming; [3] robotic technologies to enhance remote physical exams; [4] applications for commercial smart devices to detect movement, background keyboard use, or standardized motor tasks; [5••] programs that improve medication adherence; [6] "smart home" integration with ADL assistance; [7] triangulated cloud-based networks for enhanced family/care partner engagement; and [8] more recently, machine-learning/AI-based systems.

These technologies [1] aid treatments (DBS "closed loop" system, medication reminders), [2] facilitate care delivery (virtual visits, triangulated cloud-based networks), and [3] help assess therapeutic response (wearables, most app-based technologies). Complex multi-element technologies, especially with the use of machine-learning, may represent multiple or all three of these categories. In this regard, another major development is the use of wearables as surrogate—and occasionally primary—outcomes in clinical trials [72].

Expansion of the role of telemedicine for movement disorders necessitates more objective methods to measure neurological signs as well. To this goal, numerous mobile applications and wearables have been developed. While in-depth evaluation of these is beyond the scope of this review, some of the largest studies warrant mention. The Mobile Parkinson's Observatory for Worldwide, Evidence-based Research (mPOWER) is a clinical observational study that obtains data via surveys and frequents sensor-based recordings purely through an iPhone app interface [73]. In a different study, the Parkinson@home study, the feasibility of using multiple wearable sensors in PD during daily life in a large cohort was studied, providing promising results [71]. The Michael J. Fox Foundation has also launched a virtual research study using a wearable device to monitor a patient's movements and activity level during daily activity as well as collecting data via surveys [74]. Lastly, other private companies such as Great Lakes Neurotechnologies, Inc., have performed validation studies using finger- and wrist-worn motion sensors to objectively measure motion in PD patients [75–78].

While the rapidly improving ability to objectively and accurately measure every major aspect of movement and daily function is of tremendous interest to movement disorder neurologists and clinical trialists, it also brings novel challenges. One such problem is the appropriate interpretation of massive amounts of data and extraction of actionable and clinically meaningful information, to aid patient management decisions on the one hand and to establish dependable clinical outcomes on the other. The validation of wearable sensor, smartphone app, and smartwatch data as "gold standard" outcomes remain largely unresolved.

While many of these novel technologies have showed positive preliminary results in aiding clinical decision-making and capturing a specific aspect of disease, they do not yet offer validated global measures of motor function or well-being as do standard scales and traditional exams. As a result, they are not yet being used as mainstream research instruments to measure primary or secondary outcomes in clinical trials.

Conclusions

Telemedicine and tele-education using synchronous and asynchronous technology has been shown to be feasible, reduce direct out-of-pocket travel costs and travel time compared to in-person visits, and provide similar care to in-person visits. These benefits

have been mainly demonstrated for PD and will require validation for many other movement disorders. Recognizing the potential of telemedicine and overcoming current barriers will translate to much greater adoption of this modality in the future. In the decades ahead, the IPMDS and its telemedicine and technology task forces, and other medical associations, will continue to provide authority and guidance in these rapidly developing areas.

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Compliance with Ethics Standards

Conflict of Interest Browne P, Chan P, Cubo E, Guttman M, Hassan A, Hatcher JM, Moukheiber E, Okubadejo NU, Shalash A, Bajwa J, Bloem BR, Galifianakis N, Gatto E, Goetz CG, Katz M, Mari Z, Pantelyat A, Tanner C, and Spindler M declare that they have no conflict of interest.

Ben-Pazi H is the founder of NeuroCan LTD, providing accessible neurological services including teleNeurology clinics.

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References

Papers of particular interest, published recently, have been highlighted as:

- • Of importance
- •• Of major importance

1. Institute of Medicine (US) Committee on Evaluating Clinical Applications of Telemedicine; Field MJ, editor. Telemedicine: a guide to assessing telecommunications in health care. Washington (DC): National Academies Press (US); 1996.
2. World Health Organization. Telemedicine: opportunities and developments in member states: report on the second global survey on eHealth 2009. Global Observatory for eHealth Series; 2010. pp. 2.
3. Cubo E, Doumbe J, Lopez E, et al. Telemedicine enables broader access to movement disorders curricula for medical students. Tremor Other Hyperkinet Mov (N Y). 2017;7:501.
4. Evolution and Current Applications of Telemedicine. Available from https://www.ncbi.nlm.nih.gov/books/NBK45445/).
5.•• Achey M, Aldred JL, Aljehani N, et al. The past, present, and future of telemedicine for Parkinson's disease. Mov Disord. 2014;29:871–83. **This article reports the past, present, and likely future applications of telemedicine to Parkinson's disease**.
6. Dorsey ER, Vlaanderen FP, Engelen LJ, et al. Moving Parkinson care to the home. Mov Disord. 2016;31:1258–62.
7. Speedie SM, Ferguson AS, Sanders J, Doarn CR. Telehealth: the promise of new care delivery models. Telemed J E Health. 2008;14:964–7.
8. Wechsler LR, Tsao JW, Levine SR, et al. Teleneurology applications: report of the telemedicine work Group of the American Academy of Neurology. Neurology. 2013;80:670–6.
9.•• Schneider RB, Biglan KM. The promise of telemedicine for chronic neurological disorders: the example of Parkinson's disease. Lancet Neurol. 2017;16:541–51. **This article describes the benefits of telemedicine for Parkinson's disease and limitations and barriers to widespread implementation of telemedicine services remain to be addressed, including reimbursement, legal considerations, and technological issues**.
10. Velasquez SE, Chaves-Carballo E, Nelson EL. Pediatric Teleneurology: a model of epilepsy care for rural populations. Pediatr Neurol. 2016;64:32–7.
11. Hubble JP. Interactive video conferencing and Parkinson's disease. Kans Med. 1992;93:351–2.
12. Goetz CG, Stebbins GT, Wolff D, DeLeeuw W, Bronte-Stewart H, Elble R, et al. Testing objective measures of motor impairment in early Parkinson's disease: feasibility study of an at-home testing device. Mov Disord. 2009;24:551–6.
13. Cubo E, Gabriel-Galan JM, Martinez JS, et al. Comparison of office-based versus home web-based clinical assessments for Parkinson's disease. Mov Disord. 2012;27:308–11.
14. Dorsey ER, Deuel LM, Voss TS, Finnigan K, George BP, Eason S, et al. Increasing access to specialty care: a pilot, randomized controlled trial of telemedicine for Parkinson's disease. Mov Disord. 2010;25:1652–9.
15. Dorsey ER, Venkataraman V, Grana MJ, Bull MT, George BP, Boyd CM, et al. Randomized controlled clinical trial of "virtual house calls" for Parkinson disease. JAMA Neurol. 2013;70:565–70.
16. Abdolahi A, Scoglio N, Killoran A, Dorsey ER, Biglan KM. Potential reliability and validity of a modified version of the unified Parkinson's disease rating scale that could be administered remotely. Parkinsonism Relat Disord. 2013;19:218–21.
17. Dorsey ER, Bloem BR. The Parkinson pandemic-a call to action. JAMA Neurol. 2018;75:9–10.
18. Dall TM, Storm MV, Chakrabarti R, Drogan O, Keran CM, Donofrio PD, et al. Supply and demand analysis of the current and future US neurology workforce. Neurology. 2013;81:470–8.
19. Cheng EM, Swarztrauber K, Siderowf AD, Eisa MS, Lee M, Vassar S, et al. Association of specialist involvement and quality of care for Parkinson's disease. Mov Disord. 2007;22:515–22.
20. Dorsey ER, Voss TS, Shprecher DR, Deuel LM, Beck CA, Gardiner IF, et al. A U.S. survey of patients with Parkinson's disease: satisfaction with medical care and support groups. Mov Disord. 2010;25:2128–35.
21. Burke JF, Albin RL. Do neurologists make a difference in Parkinson disease care? Neurology. 2011;77:e52–3.

22. Bull MT, Darwin K, Venkataraman V, Wagner J, Beck CA, Dorsey ER, et al. A pilot study of virtual visits in Huntington disease. J Huntingtons Dis. 2014;3:189–95.
23. Hawkins AK, Creighton S, Ho A, McManus B, Hayden MR. Providing predictive testing for Huntington disease via telehealth: results of a pilot study in British Columbia, Canada. Clin Genet. 2013;84:60–4.
24. Amarendran V, George A, Gersappe V, Krishnaswamy S, Warren C. The reliability of telepsychiatry for a neuropsychiatric assessment. Telemed J E Health. 2011;17:223–5.
25. Martino D, Ganos C, Pringsheim TM. Tourette syndrome and chronic tic disorders: the clinical spectrum beyond tics. Int Rev Neurobiol. 2017;134:1461–90.
26. Goetz CG, Leurgans S, Chmura TA. Home alone: methods to maximize tic expression for objective videotape assessments in Gilles de la Tourette syndrome. Mov Disord. 2001;16:693–7.
27. Piacentini J, Woods DW, Scahill L, Wilhelm S, Peterson AL, Chang S, et al. Behavior therapy for children with Tourette disorder: a randomized controlled trial. JAMA. 2010;303:1929–37.
28. Wilhelm S, Peterson AL, Piacentini J, Woods DW, Deckersbach T, Sukhodolsky DG, et al. Randomized trial of behavior therapy for adults with Tourette syndrome. Arch Gen Psychiatry. 2012;69:795–803.
29. Ricketts EJ, Goetz AR, Capriotti MR, Bauer CC, Brei NG, Himle MB, et al. A randomized waitlist-controlled pilot trial of voice over internet protocol-delivered behavior therapy for youth with chronic tic disorders. J Telemed Telecare. 2016;22:153–62.
30. Conelea CA, Wellen BCM. Tic treatment goes tech: a review of TicHelper.com. Cogn Behav Pract. 2017;24:374–81.
31. Foster MV, Sethares KA. Facilitators and barriers to the adoption of telehealth in older adults: an integrative review. Comput Inform Nurs. 2014;32:523–33. quiz 534-525
32. Cialone J, Augustine EF, Newhouse N, Vierhile A, Marshall FJ, Mink JW. Quantitative telemedicine ratings in batten disease: implications for rare disease research. Neurology. 2011;77:1808–11.
33. Ragbeer SN, Augustine EF, Mink JW, Thatcher AR, Vierhile AE, Adams HR. Remote assessment of cognitive function in juvenile neuronal ceroid lipofuscinosis (batten disease): a pilot study of feasibility and reliability. J Child Neurol. 2016;31:481–7.
34. Padela AI, Gunter K, Killawi A, Heisler M. Religious values and healthcare accommodations: voices from the American Muslim community. J Gen Intern Med. 2012;27:708–15.
35. Alajlani M, Clarke M. Effect of culture on acceptance of telemedicine in middle eastern countries: case study of Jordan and Syria. Telemed J E Health. 2013;19:305–11.
36. U.S. Department of Veterans Affairs. FY 2018 / FY 2016: Annual performance plan and report [online]. Available at: https://www.va.gov/budget/docs/VAapprFY2018.pdf. Accessed 15 Nov 2017.
37. https://mhealthintelligence.com/news/kaiser-ceo-telehealth-outpaced-in-person-visits-last-year. Visited at January 10th 2018.
38. Congress.gov. Medicare Telehealth Parity Act of 2017. Available at: https://www.congress.gov/bill/115th-congress/house-bill/2550/titles. Accessed 4 Dec 2017.
39. Schneider R, Dorsey ER, Biglan K. Telemedicine Care for Nursing Home Residents with parkinsonism. J Am Geriatr Soc. 2016;64:218–20.
40. https://otn.ca/wp-content/uploads/2017/11/otn-annual-report.pdf. Visited at January, 10th 2018.
41. Li D, Zhang C, Gault J, Wang W, Liu J, Shao M, et al. Remotely programmed deep brain stimulation of the bilateral subthalamic nucleus for the treatment of primary Parkinson disease: a randomized controlled trial investigating the safety and efficacy of a novel deep brain stimulation system. Stereotact Funct Neurosurg. 2017;95:174–82.
42. Pretzer-Aboff I, Prettyman A. Implementation of an integrative holistic healthcare model for people living with Parkinson's disease. Gerontologist. 2015;55(Suppl 1):S146–53.
43. Veenhuizen RB, Kootstra B, Vink W, Posthumus J, van Bekkum P, Zijlstra M, et al. Coordinated multidisciplinary care for ambulatory Huntington's disease patients. Evaluation of 18 months of implementation. Orphanet J Rare Dis. 2011;6:77.
44. Veenhuizen RB, Tibben A. Coordinated multidisciplinary care for Huntington's disease. An outpatient department. Brain Res Bull. 2009;80:192–5.
45. Iacono T, Stagg K, Pearce N, Hulme Chambers A. A scoping review of Australian allied health research in ehealth. BMC Health Serv Res. 2016;16:543.
46. Van Allen J, Davis AM, Lassen S. The use of telemedicine in pediatric psychology: research review and current applications. Child Adolesc Psychiatr Clin N Am. 2011;20:55–66.
47. Wilson L, Onslow M, Lincoln M. Telehealth adaptation of the Lidcombe program of early stuttering intervention: five case studies. Am J Speech Lang Pathol. 2004;13:81–93.
48. Lade H, McKenzie S, Steele L, Russell TG. Validity and reliability of the assessment and diagnosis of musculoskeletal elbow disorders using telerehabilitation. J Telemed Telecare. 2012;18:413–8.
49. Crotty M, Killington M, van den Berg M, Morris C, Taylor A, Carati C. Telerehabilitation for older people using off-the-shelf applications: acceptability and feasibility. J Telemed Telecare. 2014;20:370–6.
50. Bloem BR, de Vries NM, Ebersbach G. Nonpharmacological treatments for patients with Parkinson's disease. Mov Disord. 2015;30:1504–20.
51. Lee NY, Lee DK, Song HS. Effect of virtual reality dance exercise on the balance, activities of daily living, and depressive disorder status of Parkinson's disease patients. J Phys Ther Sci. 2015;27:145–7.
52. Albiol-Perez S, Gil-Gomez JA, Munoz-Tomas MT, Gil-Gomez H, Vial-Escolano R, Lozano-Quilis JA. The effect of balance training on postural control in patients with Parkinson's disease using a virtual rehabilitation system. Methods Inf Med. 2017;56:138–44.
53. Canning CG, Sherrington C, Lord SR, Close JCT, Heritier S, Heller GZ, et al. Exercise for falls prevention in Parkinson disease: a randomized controlled trial. Neurology. 2015;84:304–12.
54. Siderowf A, Ravina B, Glick HA. Preference-based quality-of-life in patients with Parkinson's disease. Neurology. 2002;59:103–8.
55. Zimmermann R, Gschwandtner U, Benz N, Hatz F, Schindler C, Taub E, et al. Cognitive training in Parkinson disease: cognition-specific vs nonspecific computer training. Neurology. 2014;82:1219–26.
56. Dias AE, Limongi JC, Barbosa ER, Hsing WT. Voice telerehabilitation in Parkinson's disease. Codas. 2016;28:176–81.
57. Frich JC, Rae D, Roxburgh R, Miedzybrodzka ZH, Edmondson M, Pope EB, et al. Health care delivery practices in Huntington's disease specialty clinics: an international survey. J Huntingtons Dis. 2016;5:207–13.
58. Borasio GD. The role of palliative care in patients with neurological diseases. Nat Rev Neurol. 2013;9:292–5.
59. Ly BA, Bourgeault IL, Labonte R, Niang MN. Physicians' perceptions on the impact of telemedicine on recruitment and retention in underserved areas: a descriptive study in Senegal. Hum Resour Health. 2017;15:67.
60.• Cubo E, Doumbe J, Njiengwe E, et al. A Parkinson's disease tele-education program for health care providers in Cameroon. J Neurol Sci. 2015;357:285–7. **This article describes the feasibility of a tele-education program for Parkinson's disease in Cameroon**.
61. Wilkinson JR, Spindler M, Wood SM, Marcus SC, Weintraub D, Morley JF, et al. High patient satisfaction with telehealth in Parkinson disease: a randomized controlled study. Neurol Clin Pract. 2016;6:241–51.

62. Beck CA, Beran DB, Biglan KM, Boyd CM, Dorsey ER, Schmidt PN, et al. National randomized controlled trial of virtual house calls for Parkinson disease. Neurology. 2017;89:1152–61.
63. Cubo E, Mariscal N, Solano B, Becerra V, Armesto D, Calvo S, et al. Prospective study on cost-effectiveness of home-based motor assessment in Parkinson's disease. J Telemed Telecare. 2017;23: 328–38.
64. Group GNDC. Global, regional, and national burden of neurological disorders during 1990-2015: a systematic analysis for the global burden of disease study 2015. Lancet Neurol. 2017;16:877–97.
65.•• Korn RE, Shukla AW, Katz M, et al. Virtual visits for Parkinson disease: a multicenter noncontrolled cohort. Neurol Clin Pract. 2017;7:283–95. **This article reports that Providing specialty care remotely into the homes of individuals with PD is feasible, but a one-time visit did not improve quality of life. Satisfaction with the visits was high among physicians and patients, who were interested in receiving such care in the future**.
66. Samii A, Ryan-Dykes P, Tsukuda RA, Zink C, Franks R, Nichol WP. Telemedicine for delivery of health care in Parkinson's disease. J Telemed Telecare. 2006;12:16–8.
67. Qiang JK, Marras C. Telemedicine in Parkinson's disease: a patient perspective at a tertiary care Centre. Parkinsonism Relat Disord. 2015;21:525–8.
68. Dorsey ER, Topol EJ. State of telehealth. N Engl J Med. 2016;375: 1400.
69. Mammen JR, Elson MJ, Java JJ, Beck CA, Beran DB, Biglan KM, Boyd CM, Schmidt PN, Simone R, Willis AW, Dorsey ER Patient and physician perceptions of virtual visits for Parkinson's disease: a qualitative study. Telemed J E Health. 2017.
70. Hassan A, Dorsey ER, Goetz CG, et al. Telemedicine task force. Telemedicine for Movement Disorders: A Global Perspective (in submission).
71. Silva de Lima AL, Hahn T, Evers LJW, de Vries NM, Cohen E, Afek M, et al. Feasibility of large-scale deployment of multiple wearable sensors in Parkinson's disease. PLoS One. 2017;12: e0189161.
72. Henderson EJ, Lord SR, Brodie MA, Gaunt DM, Lawrence AD, Close JCT, et al. Rivastigmine for gait stability in patients with Parkinson's disease (ReSPonD): a randomised, double-blind, placebo-controlled, phase 2 trial. Lancet Neurol. 2016;15:249–58.
73. Bot BM, Suver C, Neto EC, Kellen M, Klein A, Bare C, et al. The mPower study, Parkinson disease mobile data collected using ResearchKit. Sci Data. 2016;3:160011.
74. Michael J Fox Foundation (MJFF). Fox Insight Wearables: a virtual research study [online]. Available at: https://www.michaeljfox.org/fox-insight-form.html. Accessed November 8.
75. Mera TO, Burack MA, Giuffrida JP. Objective motion sensor assessment highly correlated with scores of global levodopa-induced dyskinesia in Parkinson's disease. J Parkinson's Dis. 2013;3:399–407.
76. Heldman DA, Espay AJ, LeWitt PA, Giuffrida JP. Clinician versus machine: reliability and responsiveness of motor endpoints in Parkinson's disease. Parkinsonism Relat Disord. 2014;20:590–5.
77. Heldman DA, Giuffrida JP, Cubo E. Wearable sensors for advanced therapy referral in Parkinson's disease. J Parkinson's Dis. 2016;6:631–8.
78. Heldman DA, Urrea-Mendoza E, Lovera LC, Schmerler DA, Garcia X, Mohammad ME, et al. App-based bradykinesia tasks for clinic and home assessment in Parkinson's disease: reliability and responsiveness. J Parkinson's Dis. 2017;7:741–7.