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Telerehabilitation Technology Used for Remote Wrist/Finger Range of Motion Evaluation: A Scoping Review

Adrian Kuchtaruk, MSc*
Sammie Sam Yee Yu, BMSc†
Alla Iansavichene, BSc, MLIS‡
Jacob Davidson, MSc§
Claire A. Wilson, PhD§
Caitlin Symonette, BMSc, MSc, MD§

Background: Monitoring finger/wrist range of motion (ROM) is an important component of routine hand therapy after surgery. Telerehabilitation is a field that may potentially address various barriers of in-person hand therapy appointments. Therefore, the purpose of this scoping review is to identify telerehabilitation technologies that can be feasibly used in a patient's home to objectively measure finger/wrist ROM.

Methods: Following PRISMA-ScR guidelines for scoping reviews, we systematically searched MEDLINE and Embase electronic databases using alternative word spellings for the following core concepts: "wrist/hand," "rehabilitation," and "telemedicine." Studies were imported into Covidence, and systematic two-level screening was done by two independent reviewers. Patient demographics and telerehabilitation information were extracted from the selected articles, and a narrative synthesis of the findings was done.

Results: There were 28 studies included in this review, of which the telerehabilitation strategies included smartphone angle measurement applications, smartphone photography, videoconference, and wearable or external sensors. Most studies measured wrist ROM with the most accurate technologies being wearable and external sensors. For finger ROM, the smartphone angle application and photography had higher accuracy than sensor systems. The telerehabilitation strategies that had the highest level of usability in a remote setting were smartphone photographs and estimation during virtual appointments.

Conclusions: Telerehabilitation can be used as a reliable substitute to in-person goniometer measurements, particularly the smartphone photography and motion sensor ROM measurement technologies. Future research should investigate how to improve the accuracy of motion sensor applications that are available on easy-to-access devices. *(Plast Reconstr Surg Glob Open 2023; 11:e5147; doi: 10.1097/GOX.0000000000005147; Published online 23 August 2023.)*

INTRODUCTION

Telehealth is defined as the use of electronic or communication technologies to provide healthcare-related services to patients remotely.[1] Telehealth encompasses a variety of technologies that serve a range of purposes for patients, which include patient consultation via videoconferencing, remote patient monitoring, wireless health applications, and transmission of imaging and medical reports.[2] Telehealth use has expanded over the last several years due to the perceived healthcare cost savings, improved patient follow-up, and ability to care for patients living in rural areas.[3] The use of telehealth has especially gained attention during the COVID-19 pandemic as a method of reducing the spread of the virus, and health experts believe that telehealth will continue to be used widely in the postpandemic world.[4–7]

*From the *Schulich School of Medicine and Dentistry, Western University, London, Ontario, Canada; †Faculty of Science, Western University, London, Ontario, Canada; ‡Library Services, London Health Sciences Centre, London, Ontario, Canada; and §Department of Surgery, London Health Sciences Centre, London, Ontario, Canada.*

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Hand therapy is one area that can be positively impacted by using telehealth technologies, particularly in the form of telerehabilitation. Hand therapy is a key component of recovery after hand trauma, as consistent therapy has been linked to improved strength, range of motion (ROM), and overall functional ability.[8–12] Although the positive impact of hand therapy is well known, rates of patient nonadherence to home exercises and routine visits have been recorded as high as 25% and up to 73% of patients miss at least one physical therapy appointment for musculoskeletal conditions in general.[13–15] Several barriers that may be attributed to lack of compliance to traditional hand rehabilitation appointments include cost, lack of time and inconvenience of attending in-person appointments, and patients not educated on the importance of regular hand therapy assessment.[16–18] Additionally, access to trained hand therapists is sparse in remote and rural communities, making it difficult for these patients to receive consistent follow-up.[19–21]

Regular evaluation of patient progress during in-person appointments using a variety of metrics (eg, ROM, strength, dexterity) is important to ensure the rehab program is optimized to the phase of recovery. ROM has been shown to be a key objective measure of overall hand function and is evaluated using a goniometer.[22,23] However, due to the barriers to compliance of hand therapy, it can be difficult to regularly assess patient ROM using traditional hand therapy appointments. The application of telerehabilitation in hand therapy has the potential to overcome many of the barriers that negatively impact patient compliance rates.[24] Furthermore, remote ROM assessment may allow for better tracking of large amounts of patient data, which can be used to illustrate average time of recovery for various hand pathologies based on physiotherapy adherence.

The purpose of this scoping review is to review the literature and identify telerehabilitation technologies that can be feasibly used in a patient's home to objectively measure finger/wrist ROM without having to be assessed in-person by a healthcare provider. Furthermore, this review will assess the advantages and limitations of each technology and make recommendations on future clinical uses of these technologies. A scoping review was used for this study because the goal of this study was to identify the types of available technologies in the field of hand therapy and to identify and analyze gaps in the use of these technologies in clinical practice.

Takeaways

Question: What telerehabilitation technologies are currently available for hand therapy after surgery, and which technologies have the highest accuracy and ease of use? Additionally, what technologies are recommended for clinical practice?

Findings: Our results identified several technologies that can accurately measure finger and wrist ROM in a remote setting; however, some methods are prone to patient error and require significant patient education to provide accurate measurements.

Meaning: This study provides useful information for hand surgeons to determine which telerehabilitation technologies may be the most useful in clinical practice and what elements are most important when evaluating these technologies.

METHODS

This scoping review utilized the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Extension for Scoping Review (PRISMA-ScR) framework and checklist for scoping reviews.[25,26] [**See table, Supplemental Digital Content 1,** which displays the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA ScR) Checklist adapted from Tricco et al. (2018). **http://links.lww.com/PRSGO/C677**.] The inclusion criteria were developed using the participant-concept-context framework.[27]

Participants

This review included participants that required hand rehabilitation due to traumatic or nontraumatic injury to the finger/wrist bones, joints, muscles, or ligaments. We also included patients with rheumatological conditions as well as studies that examined healthy patients. There were no restrictions placed on age, sex, severity of the underlying pathology or length of rehabilitation required. Participants were excluded if they were receiving telerehabilitation for hand/wrist pathologies affecting the central nervous system or neuromuscular disorders due to differences in rehabilitation options and treatment goals. Studies were excluded if they included fewer than five participants.

Concept

Studies that examined specific technologies used for telerehabilitation ROM assessments for hand/wrist pathologies were considered. Technologies were included if they allowed the participant to self-measure their hand/wrist ROM in their own home or in a clinic setting. Studies that did not include objective ROM assessment and that were not compared with a gold-standard ROM assessment were excluded. Systematic and scoping reviews, conference abstracts, opinion pieces, and news articles were also excluded.

Context

This review considered studies that provided telerehabilitation ROM accuracy rates, acceptance, and recommendations for implementing technologies for hand/wrist ROM pathologies in a healthcare context.

Search Strategy

A systematic database search was performed using MEDLINE and Embase (both via Ovid platform) electronic databases from January 2000 to November 2021, because technologies before 2000 were assumed to be obsolete. (**See table, Supplemental Digital Content 2,** which displays search strategies created for Embase and MEDLINE. **http://links.lww.com/PRSGO/C678**.) A gray literature search was also conducted using Google Scholar and IEEE Xplore to locate additional research studies not indexed in bibliographic databases. The references of relevant retrieved studies were also reviewed. Sensitive search strategies were constructed, by the clinical librarian (A.I.) with experience in conducting electronic literature searches in collaboration with the review authors (A.K. and C.S.), based on a combination of synonymous searches comprised of database specific subject headings, such as MeSH in MEDLINE and EMTree descriptors in Embase, and keywords using alternative word spellings and endings for the following core concepts: "wrist/hand," "rehabilitation," and "telemedicine." Each strategy was modified to complement the specific database and platform.

Study Selection

After the database search, all studies were imported into Covidence (Covidence systematic review software, Veritas Health Innovation). Duplicates were removed and systematic two-level screening was done by two independent reviewers (A.K. and S.Y.). KAPPA statistics were calculated after the title and abstract screen, and again after the full-text screen. Conflicts at each level of screening were resolved by consensus. If consensus could not be reached, a third reviewer was required to make the final decision.

Data Extraction

The data extraction was performed by two independent reviewers (A.K. and S.Y.). Data were recorded using a customized Excel spreadsheet. The data extracted included patient demographics and telerehabilitation technology information. Technologies were divided by low/high, with the low technology classifier given to technologies that most participants would already have access to (smartphone, camera, etc.) or technologies that cost less than $100. Technologies were also classified based on patient usability in a home setting as either low, moderate, or high. Technologies were scored as either poor, moderate, or excellent relative to each other by considering four criteria, which is shown in Supplemental Digital Content 3. (See table, **Supplemental Digital Content 3**, which displays usability scores among the included studies based on four criteria. Each section is given a score from 1 to 3, with 1 being poor, 2 being moderate, and 3 being excellent. **http://links.lww.com/PRSGO/C679**.)

1) Device availability and access in a home setting
2) Patient time required
3) Training required and user error rate
4) Patient satisfaction

Any disagreements between reviewers were resolved by discussion and bringing in a third reviewer if necessary.

Data Synthesis

We conducted a narrative synthesis of the findings from the included studies that was structured according to our review objectives.

RESULTS

Article Selection

The initial database search yielded 2520 articles, and the gray literature search yielded an additional 84 articles after duplicates were removed. Based on eligibility criteria, a total of 28 studies were included in this review.[28–56] Figure 1 illustrates the PRISMA flow chart describing the article selection process. The KAPPA statistics for agreement between the two reviewers were between moderate and substantial at 0.47 and 0.66 for the title and abstract screen and the full-length text screening, respectively.

Characteristics of Included Studies

The characteristics of the included studies can be found in Supplemental Digital Content 4. (See table, **Supplemental Digital Content 4,** which displays demographic information for each included study. **http://links.lww.com/PRSGO/C680**.)

The 28 included studies were conducted across 14 different countries with the majority taking place in the United States (n = 10).[28,31–35,40,41,43,54] All study designs were observational cross-sectional studies with sample sizes ranging from five to 171. Although most participants in the included studies were healthy (n = 721), there were several studies that examined participants with specific hand pathologies.

Characteristics of Telerehabilitation Technologies

The characteristics of the included telerehabilitation technologies can be found in Supplemental Digital Content 5. (**See table, Supplemental Digital Content 5**, which displays summary of telerehabilitation technologies. **http://links.lww.com/PRSGO/C681**.)

In this review, we found seven different types of telerehabilitation technologies used to measure finger/wrist ROM (Fig. 2). Most studies were compared with universal goniometers as the gold standard (n = 25), with three being compared with optoelectronic motion capture system, which has been shown to be highly accurate compared with goniometer when used in office. When categorizing studies based on whether the device used was high or low technology, we found that most studies utilized low technological telerehabilitation solutions (n = 23).[28–36,38–43,45,47,49–52,54–56]

Accuracy of Telerehabilitation Technologies Compared with Gold-Standard Measurement Devices

Overall, most of the telerehabilitation devices used in the study had good to excellent correlations with the gold standard devices used. (See table, **Supplemental Digital Content 6** which displays accuracy of telerehabilitation technologies compared with gold-standard assessments. **http://links.lww.com/PRSGO/C682.**) For wrist ROM, the most accurate technologies included sensor gloves[37,50] and external motion sensor systems.[35,44,45,47,48,51] For finger flexion and extension, the smartphone angle application and smartphone photography had higher accuracy than the motion capture systems on average. The motion sensor systems generally had a wide variation of accuracy between fingers, which ranged from an intraclass

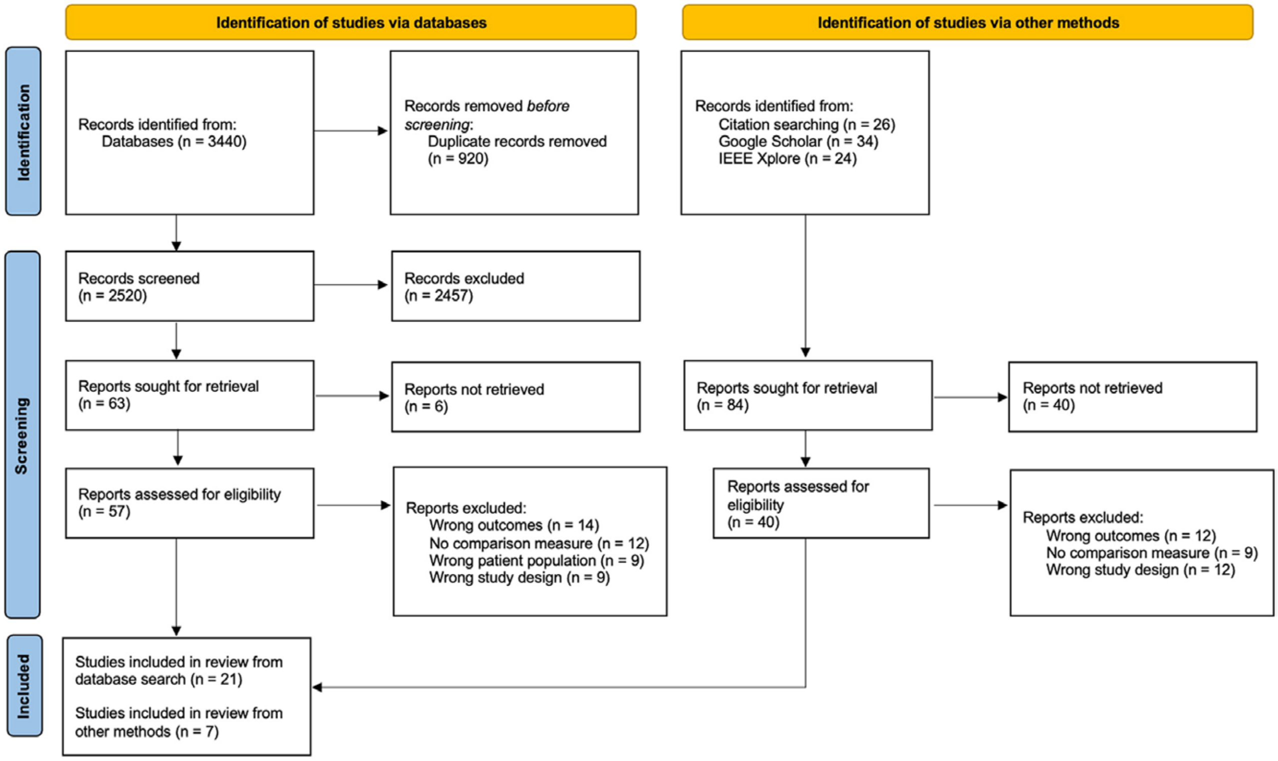

Fig. 1. PRISMA flow diagram for systematic reviews illustrating search results.

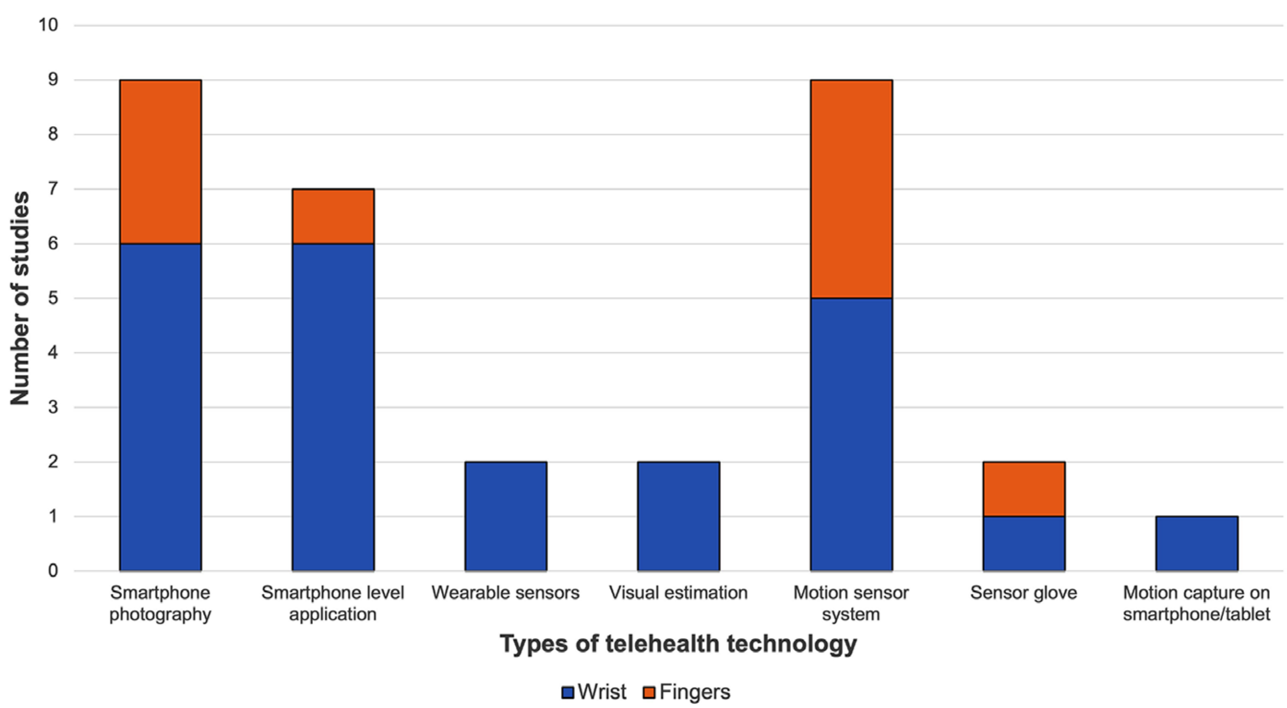

Fig. 2. A stacked bar graph illustrating the number of studies based on telerehabilitation technology used and the joint ROM examined.

correlation coefficient (ICC) between 0.09 and 0.88[47] (Fig. 3). There were 12 studies that assessed intraobserver reliability among the telerehabilitation devices (43%) (**Supplemental Digital Content 6, http://links.lww.com/PRSGO/C682.**).

Among the studies that measured wrist ROM, intraobserver reliability was excellent in wrist flexion and extension in all studies. There were three studies overall that looked at intraobserver reliability among finger joint ROM, all of which were motion capture systems.[44,45,51]

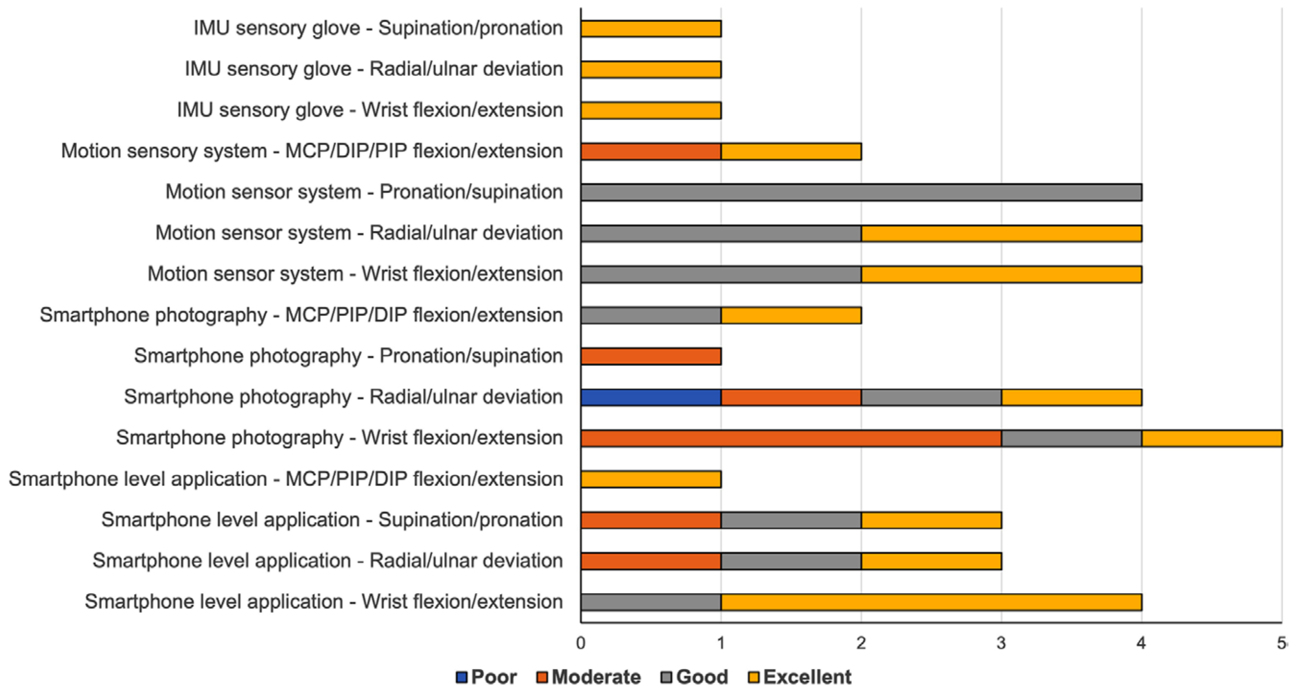

Fig. 3. A bar graph illustrating the number of studies that had poor, moderate, good, or excellent ICC comparing technologies with gold standard goniometer measurements, based on technology and jointly measured for each study. Poor ICC values are considered values below 0.5, moderate is between 0.5 and 0.75, good reliability is between 0.75 and 0.9, and excellent reliability is above 0.9.

All three studies found good to excellent intraobserver reliability with ICC values more than 0.80 for MCP, PIP, and DIP joint measurements in all fingers. There were eight studies that looked at interobserver reliability among the telerehabilitation technologies[33,38,42,48,49,54–56] with only one study reporting ICC values less than 0.75.[48]

Synthesis and Review of Findings Summarizing the Usability of Telerehabilitation Technologies

The usability, training required, advantages, and limitations of each telerehabilitation technology can be found in Supplemental Digital Content 7. (**See table, Supplemental Digital Content 7**, which displays telerehabilitation technology advantages, limitations, and recommendations for future use. **http://links.lww.com/PRSGO/C683**.) Many of the studies included did not report on patient satisfaction and ease of use of the technology; thus, the usability scores were decided based on criteria discussed in the methods and extrapolated from other studies that utilized similar technologies. Overall, the telerehabilitation technologies that had the highest usability in remote settings without assistance were smartphone photographs that were subsequently analyzed by the physician using digital software[29,32,33,41–43,49,52,54] as well as visual estimation during virtual appointments.[34,36] The advantages of smartphone photography include its accessibility, the patient time required, and limited training needed. However, this device can be limiting for healthcare providers if they do not have a software that measures the angles or if the photographs are poorly taken. Additionally, like many of these technologies, smartphone photography utilizes patient data sharing over electronic devices, which poses a risk to patient confidentiality.

Virtual visual estimation was also scored as a highly usable telerehabilitation technology for remote joint angle evaluation, as it only requires basic technology and little to no patient training. However, it does require the healthcare provider to virtually estimate each joint over the camera, which can take a substantial amount of time and may not be a reliable measure.

Most of the studies that evaluated the smartphone angle application technology and motion capture systems achieved a moderate usability rating. The advantages of the smartphone angle application include the accessibility and low cost of the technology. Where the application falls short is the large degree of user error that can occur when measurements are taken incorrectly. The advantages of the motion sensor technologies are the ease of taking measurements and limited training required from participants. These measurements can be taken within seconds and sent to the healthcare provider without any posttest analysis required. The limitations with motion sensor systems are the additional cost to the healthcare system as most require third-party technology to be loaned out to the patients.

DISCUSSION

Telehealth has been increasingly used in the field of hand surgery, particularly for virtual consults, accessing radiographs remotely, and ROM assessments.[57]

Telehealth is associated with reducing cost for both patients and health systems, reducing travel burden for patients, and can even increase healthcare provider efficiency.[58–60] Patients have also been shown to prefer telehealth encounters compared with in-clinic consultations in most hand surgery and other orthopedic settings.[57,61] The positive patient perceptions, in addition to the benefits of telehealth in hand surgery, reinforces the need for careful consideration of how telehealth can be further utilized in this field.

Two technologies that were commonly found in the literature for remote finger/wrist joint ROM assessment were the use of smartphones to take photographs and to measure joint angles. The major benefit of these devices is the accessibility of smartphones in patient populations. Surveys have shown that within orthopedic surgery practices, over 88% of patients own a computer or smartphone and have WiFi access at home.[57,61] In our review, we found that these technologies had very high ICC values on average for most joints measured with values greater than 0.90. Generally, it is recommended that ICC values be greater than 0.70 to be considered acceptable as a comparison to gold standard technologies.[62]

However, one drawback to these two joint assessment options is the time it takes to measure joint angles. The smartphone photography method requires the healthcare provider to manually measure the joint angles on the photograph using an online software. The angle measurement application requires the patient to manually measure each affected joint by placing the phone along the joint line and recording the measured angle. The time required is comparable to in-person goniometry, which limits the potential for efficiency that is highly valued in telehealth.[57] The other significant disadvantage with these technologies is the dependency on the patient for accurate recording. Both technologies require the patient to position the phone in a certain way to take optimal photographs or angle measurements. This can lead to inaccurate measurements being sent to the healthcare provider which can impact the rehabilitation process.

Sensor-based technologies, including wearable inertial sensors and motion sensors, have also been studied as a way to measure wrist/finger joint ROM remotely.[63] Single camera motion capture systems in particular have the ability to overcome the challenges presented with smartphone photography and smartphone angle measurement applications. Motion capture systems utilize augmented reality to track bony landmarks of the joints using a camera to provide the joint ROM. These systems can measure joint angles significantly faster than goniometers and do not require any posttest analysis, thereby saving time for both the patient and the healthcare provider.[51] Furthermore, motion capture systems require very little training from the patient, are significantly less prone to user error, and have the highest inter/intraobserver reliability among the various technologies included in the review. Where the motion capture systems fall short is the added cost associated with purchasing the external sensors and implementing them in patient's homes as well as the accuracy of the technologies.[44]

Study Limitations

Despite the strengths of this study, there are several limitations that should be addressed. First, most of the studies included were conducted in a clinic setting where researchers could monitor patients to ensure they were using the technologies appropriately. Patients also received instructions immediately before using the technology and could repeat the measurements if done incorrectly. Therefore, the results in a remote setting may not be as accurate as the studies included in this review. Furthermore, most participants were healthy, which does not generalize to the clinical practice. However, we should note that there were no significant differences in joint ROM assessment accuracy between healthy and injured fingers/wrists among the included studies, and this is specifically highlighted in the study by Modest et al., where they compared these two groups.[31] Additionally, there was significant heterogeneity in the technologies, and the results are limited when certain technologies were represented only by a small subset of studies. Additional studies evaluating specific technologies with larger sample sizes are required to make clinical recommendations for future practice. Finally, several studies found that the goniometer used to compare telerehabilitation technologies had large intrarater and interrater variability, which would have affected the relative accuracy of the telerehabilitation devices.

Recommendations for Clinical Practice and Future Research

This study highlights that there are several technologies that can be implemented in clinical practice to remotely assess finger and wrist ROM. Smartphone photography is one that can be accurately utilized for both finger and wrist joint ROM assessment, as there are several studies validating its usability and accuracy. Clinicians who utilize this method should provide an instructional booklet for patients that describes how to take the photographs and the specific lighting conditions required.

There are two future research priorities that should be highlighted in this review. First is the need for studies that are more representative of the clinical environment where these technologies will be used. Most of these studies utilized the telerehabilitation technologies within the clinic with researchers monitoring the participants to ensure accurate use. This limits the generalizability of the results, as the accuracy may be significantly lower if participant use is not monitored. Furthermore, 19 of the 28 included studies involved healthy participants or did not disclose if the participants had any hand/wrist pathology. Patients with hand/wrist pathology may have a more difficult time utilizing the technology, which would not have been identified in these studies.

The second research priority is the need for a more robust and cost-effective motion sensor technology. Although smartphone photography and the smartphone angle measurement application are both effective and affordable methods of remote ROM assessment, they both require extensive time from the patient or healthcare provider to measure each angle. Most motion sensor technologies included in this review required third-party technology such as the Leap Motion Sensor or the VICON MX3 Optoelectronic system. This would add an extensive cost to healthcare providers if they were given out to patients for regular remote assessment. The ideal solution would be to create a motion sensor application on the phone/computer that can track joint angles while the patient performs the desired ROM exercises. This system has the potential to allow both the healthcare provider and patient to clearly see how the ROM is progressing throughout the rehabilitation process in a cost-effective and time efficient manner.

Caitlin Symonette, BMSc, MSc, MD
London Health Sciences Centre
800 Commissioners Rd E
London, ON N6A 5W9
Canada
E-mail: caitlin.symonette@lhsc.on.ca

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