

Original Paper

# Telerehabilitation for Patients With Knee Osteoarthritis: A Focused Review of Technologies and Teleservices

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## Abstract

**Background:** Telerehabilitation programs are designed with the aim of improving the quality of services as well as overcoming existing limitations in terms of resource management and accessibility of services. This review will collect recent studies investigating telerehabilitation programs for patients with knee osteoarthritis while focusing on the technologies and services provided in the programs.

**Objective:** The main objective of this review is to identify and discuss the modes of service delivery and technologies in telerehabilitation programs for patients with knee osteoarthritis. The gaps, strengths, and weaknesses of programs will be discussed individually.

**Methods:** Studies published in English since 2000 were retrieved from the EMBASE, Scopus, Web of Science, Cumulative Index to Nursing and Allied Health Literature (CINAHL), PubMed, Physiotherapy Evidence Database (PEDro), and PsycINFO databases. The search words “telerehabilitation,” “telehealth,” “telemedicine,” “teletherapy,” and “ehealth” were combined with “knee” and “rehabilitation” to generate a data set of studies for screening and review. The final group of studies reviewed here includes those that implemented teletreatment for patients for at least 2 weeks of rehabilitation.

**Results:** In total, 1198 studies were screened, and the full text of 154 studies was reviewed. Of these, 38 studies were included, and data were extracted accordingly. Four modes of telerehabilitation service delivery were identified: phone-based, video-based, sensor-based, and expert system-based telerehabilitation. The intervention services provided in the studies included information, training, communication, monitoring, and tracking. Video-based telerehabilitation programs were frequently used. Among the identified services, information and educational material were introduced in only one-quarter of the studies.

**Conclusions:** Video-based telerehabilitation programs can be considered the best alternative solution to conventional treatment. This study shows that, in recent years, sensor-based solutions have also become more popular due to rapid developments in sensor technology. Nevertheless, communication and human-generated feedback remain as important as monitoring and intervention services.

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**KEYWORDS**

telemedicine; telerehabilitation; communication technologies; knee osteoarthritis; total knee replacement

**Introduction**

Osteoarthritis and chronic musculoskeletal disorders are considered the second most frequent medical condition and are the primary causes of physical disability and pain [1-4]. Knee osteoarthritis (KOA) among seniors is estimated at 10% and 13% in men and women, respectively [5]. Moreover, it has been reported that symptomatic KOA has doubled among women and tripled among men in the past 20 years [6]. Previous studies indicate that postsurgical physical rehabilitation is a crucial component of the recovery process [7] and that exercises and education are frequently recommended for patients with KOA [8].

Telecommunication technologies have been used to provide health care, monitoring, and rehabilitation services for patients who experience stroke [9], pulmonary disorders [10], COPD [11,12], dermatological disorders [13], oral diseases [14], and musculoskeletal conditions [15,16]. Such technologies have also been used for remote consultations [17]. Using internet access, early telehomecare programs were implemented as a substitute for home care visits, and user perception and satisfaction were assessed and reported to be high [18,19]. Russell [20] introduced telerehabilitation as a means of augmenting traditional rehabilitation by employing telecommunication technologies that would provide services such as assessment, education, intervention, and interview. Previous studies indicated that telerehabilitation programs can provide better clinical services in rural and remote communities compared with conventional therapy [21,22], as well as improve cost efficiency and resource management of the services [23-25] with high validity and reliability [26].

Previous studies have noted that a telerehabilitation program for KOA not only improves patients' quality of life [27] but also introduces a better functional recovery after arthroplasty in comparison to conventional therapy [28]. Sharareh et al [29] showed that providing a postoperative telerehabilitation program reduced the frequency of postoperative visits and increased patient satisfaction. Tousignant et al [30] and Chalupka et al [31] also indicated that home telerehabilitation enhanced accessibility to health care services and was as effective as conventional therapy.

Russell divided the technologies used for telerehabilitation into image-based, sensor-based, virtual environment, and virtual reality telerehabilitation [32]. Real-time video conferences were extensively used in physical telerehabilitation [33-36]. Giantomassi et al [37] indicated that current video game technologies could be used in physical rehabilitation. Several telerehabilitation programs have been developed using the Microsoft Kinect sensor [38-41] and the Nintendo Wii board [42-45]. Wearable sensors were also proposed as a means to facilitate a telerehabilitation program and monitor patient performance [46]. Moreover, Strecher [47] remarked that health care services could be delivered using decision-making algorithms and expert systems [48] over the internet. Rini et al

[49], using an expert system approach, adapted the face-to-face therapeutic intervention into an internet-based intervention. However, there is no clear vision of the strengths and weaknesses of each solution as well as the existing gaps and limitations of the presented solutions. In addition, there is a lack of focused reviews investigating the presented services as part of telerehabilitation programs.

Therefore, the main objective of this review was to identify and discuss the modes of service delivery and technologies used as a telerehabilitation program for patients with KOA in recent studies. The gaps, strengths, and weaknesses of programs were discussed individually.

**Methods****Search Strategy**

The search strategy was designed to identify relevant literature regarding telerehabilitation solutions for KOA while focusing on the technologies and services of the programs [15,26,28,50]. The literature search used here investigated studies that had implemented and evaluated a telerehabilitation program for patients with KOA using an experimental study design. The EMBASE, Scopus, Web of Science, CINAHL, PubMed, Physiotherapy Evidence Database (PEDro), and PsycINFO databases were searched. Searches were undertaken in March 2020, and comprised medical subject heading (MeSH) [51] terms and keyword search terms. The MeSH terms "telemedicine," "rehabilitation," and "knee" and keyword terms "telehealth," "ehealth," "teletherapy," "telecare," and "knee" were used. Moreover, both *Telemedicine and e-Health* and the *Journal of Telemedicine and Telecare* were searched independently using knee rehabilitation key search terms.

**Research Question**

The research questions of this review are the following: (1) Which modes of service delivery were used to establish a telerehabilitation program for patients with KOA? (2) What services were introduced by these programs? (3) What are the strengths and weaknesses of each solution?

**Inclusion Criteria**

Original English-language studies published from January 2000 to January 2020 were included if they fit the eligibility criteria, which were based on the PICOS framework [52].

**Participants**

Studies with adult participants (aged 18 years and above) with KOA were included. The studies in which participants' primary medical condition was not related to KOA (eg, stroke, upper limb disability, pulmonary disorders) were excluded.

**Intervention**

Only studies where telecommunication technology was employed as an interventional rehabilitation method in an experimental or observational study were included. The study intervention had to focus on knee pain management or knee

rehabilitation for a period of at least two weeks via synchronous or asynchronous telerehabilitation (eg, phone, email, website report, videoconference, multimedia messages). Studies with insufficient technical explanations were excluded.

### Comparison

All trials were included, whether they did or did not employ a control group.

### Study Design

Any randomized controlled trial (RCT), quasi-RCT, non-RCT, controlled clinical trial, and pilot study designs, regardless of the blinding of the assessor, were included. Protocol manuscripts, review studies, abstracts, and guidelines were excluded.

### Data Collection

According to the inclusion and exclusion criteria, a two-step study identification and data extraction process was used. Two authors (MRN and HF) independently screened the electronic search results. First, the retrieved studies were screened for eligibility based on their title and abstract. The full text of studies selected in the first stage was then reviewed and analyzed as a candidate for final inclusion. Any disagreement between the two authors was resolved through discussion between the

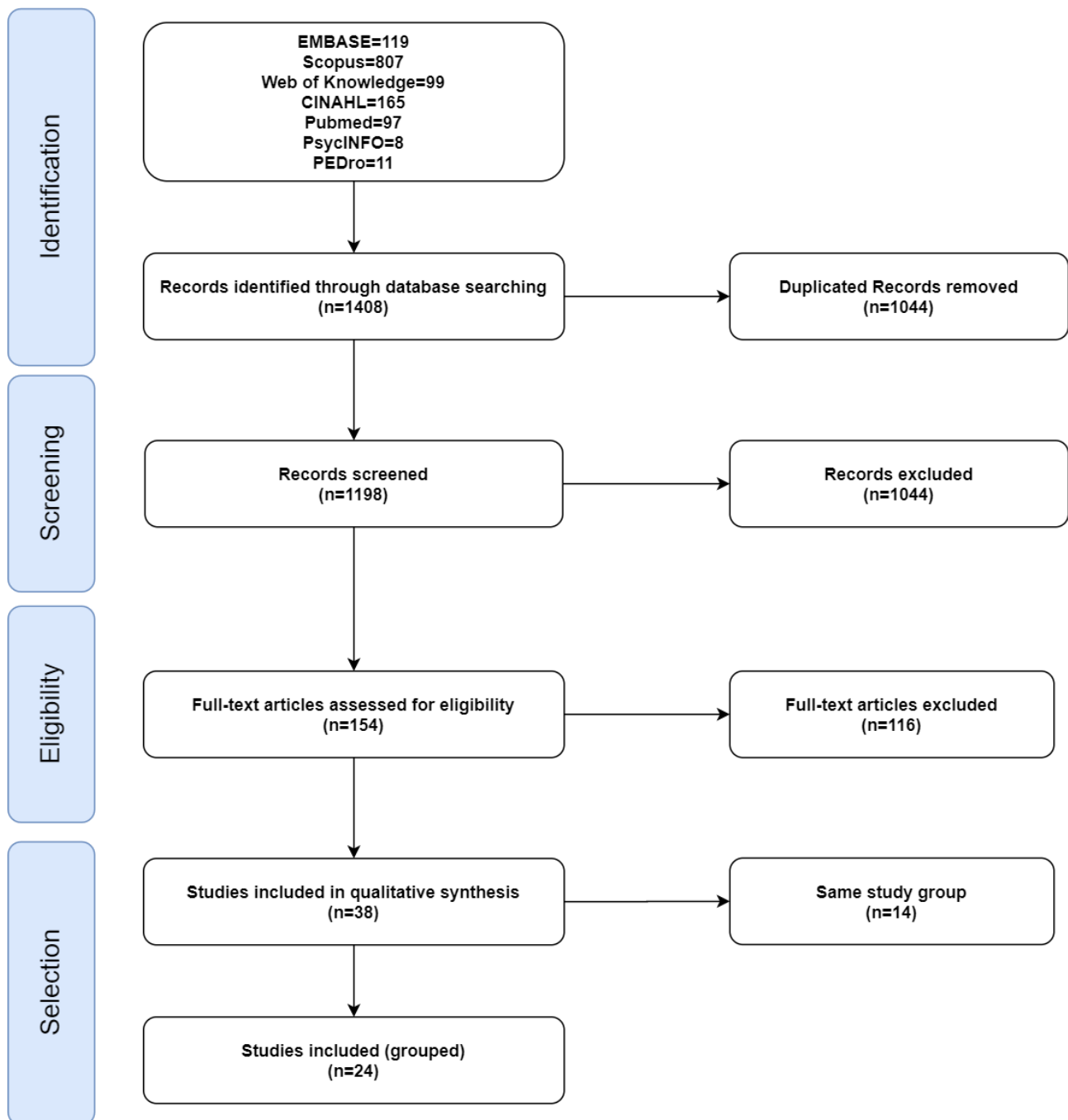
authors; if necessary, a third author (JH) was referred to for arbitration. Two authors (MRN and SN) were responsible for data extraction from the included articles. The extracted items were study design, study population, medicinal condition (population), outcomes, modes of telerehabilitation program (intervention) delivery, and rehabilitation duration.

## Results

### Study Identification

Figure 1 shows an overview of the relevant study identification process using a four-step PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [53] flow diagram. A total of 1198 studies were identified through the literature search: 119 in EMBASE, 807 in Scopus, 99 in Web of Knowledge, 165 in CINAHL, 97 in PubMed, 8 in PsycINFO, and 11 in the PEDro database. In total, 210 duplicated studies were found in the identified documents, and 909 articles were excluded by screening the titles and abstracts of the identified articles based on the defined inclusion criteria. The full text of 154 papers was reviewed by the authors in the eligibility stage, and 38 of the studies were included in this review. The eligible studies were reviewed, and studies using the same experimental setup and population were grouped together. Eventually, 24 group studies were chosen (Table 1).

**Figure 1.** Flowchart of the results from the literature search. CINAHL: Cumulative Index to Nursing and Allied Health Literature; PEDro: Physiotherapy Evidence Database.



**Table 1.** Study characteristics.

Group	Author(s), year	Study design <sup>a</sup>	Population <sup>b</sup>	Patients (control, target)	Duration (weeks)	Intervention type <sup>c</sup> and detail	Finding
1	Kramer et al, 2003 [54]	RCT	TKA	80, 80	12	P; Patients got the exercise plan in a booklet and received at least two phone calls within the rehabilitation period	No statistically difference between the groups. A phone call by a physiotherapist can effectively treat patients after TKA.
2	Han et al, 2015 [55]	RCT	TKA	196, 194	6	P; Patients got a daily exercise program and were asked to perform exercises 3 times per day. They received a phone call every week.	The intervention group achieved noninferior outcomes (pain and function) compared with usual care physiotherapy.
3	Chen et al, 2016 [56]	RCT	TKA	101, 101	12	P; The patients received the standard rehabilitation program and were asked to perform exercises for 1 hour per day. They also received 3 phone calls.	A structured telephone follow-up may improve patient adherence as well as enhance patient mental health and range of motion.
4	Azma et al, 2017 [57]	RCT	KOA	27, 27	6	P; Home training with a weekly phone call and logbook	The telerehabilitation was as effective as regular rehabilitation, and no significant difference was observed between the study groups.
5	Wong et al, 2005 [58]	PiS	KnP	— <sup>d</sup> , 20	12	V; Video call at the secondary center with a group of patients and unsupervised home training.	Videoconferencing was accepted as a mode of health care service delivery among the users. Significant reductions were observed in pain level and stiffness, and there was an improvement in physical function and the Berg Balance Scale score.
6	Tousignant et al, 2009 [59]	PiS	TKA	— <sup>d</sup> , 5	8	V; Over 8 weeks, there were 16 video calls, which included the prescribing of an individualized training program.	A high level of participant satisfaction was achieved, and positive patient-therapist relationships were established.
6 <sup>e</sup>	Tousignant et al, 2011 [30]	RCT	TKA	24, 24	8	V; Over 8 weeks, there were 16 video calls, which included the prescribing of an individualized training program.	The home telerehabilitation was as effective as conventional home visits in terms of reducing disability and improving function in the short term.
6	Tousignant et al, 2011 [35]	RCT	TKA	20, 22	8	V; Over 8 weeks, there were 16 video calls, which included the prescribing of an individualized training program.	Patient and therapist satisfaction were high and comparable to that of conventional therapy.
7 <sup>e</sup>	Moffet et al, 2015 [60]	RCT	TKA	101, 104	8	V; In-home training using 16 video calls over 8 weeks. Treatment, assessment, and recommendations were considered in the video sessions.	The telerehabilitation was as effective as conventional face-to-face rehabilitation in terms of functional recovery and quality of life.
7	Tousignant et al, 2015 [23]	RCT	TKA	100, 97	8	V; In-home training using 16 video calls over 8 weeks. Treatment, assessment, and recommendations were considered in the video sessions.	The telerehabilitation program was less expensive compared to conventional home visits when the distance between the health care center and patients was more than 30 km.
7	Moffet et al, 2017 [36]	RCT	TKA	98, 84	8	V; In-home training using 16 video calls over 8 weeks. Treatment, assessment, and recommendations were considered in the video sessions.	Patient satisfaction was reported high for both control and intervention groups. No strong correlation was found between reported satisfaction and measurements.
7	Boissy et al, 2015 [61]	Mix	TKA	— <sup>d</sup> , 97	8	V; In-home training using 16 video calls over 8 weeks. Treatment, assessment, and recommendations were considered in the video sessions.	The telerehabilitation program was reliable; however, the program required technical maintenance, support, and initial installation.

Group	Author(s), year	Study design <sup>a</sup>	Population <sup>b</sup>	Patients (control, target)	Duration (weeks)	Intervention type <sup>c</sup> and detail	Finding
8	Bini et al, 2017 [62]	RCT	TKA	15, 13	12	V; Asynchronous video communication using a mobile app.	No significant difference was observed between study groups in any of the outcomes. A high level of patient acceptance and satisfaction was achieved. Asynchronous communication may overcome the limitations of real-time telerehabilitation.
9	Doiron-Cadrin et al, 2018 [63]	RCT	HKA	12, 22	12	V; Video telerehabilitation sessions were performed twice per week, and patients were asked to repeat the exercises unsupervised.	High level of patient satisfaction and adherence to the intervention program were achieved. No significant differences were observed between groups for all measurements. Telerehabilitation seems feasible and safe.
10	Eisermann et al, 2004 [64]	RCT	HKA	142, 154	3-4	S; Home training using a computer (software) 3-5 times per week	The provided solution was feasible and as effective as conventional therapy.
11	Piqueras et al, 2013 [65]	RCT	TKA	70, 72	2	S; Included 1 week of on-site rehabilitation and 1 week of home training using a PC and sensors.	The proposed telerehabilitation program was at least as effective as conventional therapy. Significant improvement was observed in active extension range and quadriceps muscle strength.
12	Ayoade and Baillie, 2014 [66]	RCT	TKA	7, 8	6	S; Home training using a computer (software) and a video call (Week 3)	The system was acceptable among the seniors. However; it did not improve their adherence.
13 <sup>e</sup>	Correia et al, 2018 [67]	RCT	TKA	30, 29	8	S; Training at home using 3 wearable sensors and a tablet 5-7 days per week.	Performance tests, range of motion, and patient-reported outcomes were significantly higher in the intervention group.
13	Correia et al, 2019 [68]	RCT	TKA	30, 29	8	S; Training at home using 3 wearable sensors and a tablet 5-7 days per week.	High levels of adherence to the program and satisfaction were reported. All the outcomes were significantly higher in the intervention group at 3 months and primary outcomes at 6 months.
14	Argent et al, 2019 [69]	Mix	TKA	— <sup>d</sup> , 15	2	S; Training at home using a wearable sensor and customized Android application.	High level of adherence to the intervention was reported, and overall positive user-experience achieved. Technical issues caused some negative experiences.
15	Ramkumar et al, 2019 [70]	FiS	TKA	— <sup>d</sup> , 25	12	S; Training at home using a leg sleeve equipped with two wearable sensors communicating with an iPhone. Daily activities were measured based on the internal pedometer of the phone.	Patients found the telerehabilitation program engaging, motivating, and easy to use.
16	Eichler et al, 2019 [71]	RCT	HKA	55, 56	12	S; Microsoft Kinect was used and therapist could actively modify the exercises. Real-time video communication was used to establish the communication.	The effect of the telerehabilitation therapy was equivalent to the usual aftercare in terms of functional testing, quality of life, and pain.
17	Bettger et al, 2019 [72]	RCT	TKA	144, 143	12	S; An interactive training program was presented, and Microsoft Kinect was used to track the exercises. The therapist could track patient performance and modify the training program. The system provided real-time video communication as well.	The program was as effective as traditional treatment (function and disability) and as safe as traditional treatment (pain and rehospitalization).



Group	Author(s), year	Study design <sup>a</sup>	Population <sup>b</sup>	Patients (control, target)	Duration (weeks)	Intervention type <sup>c</sup> and detail	Finding
18	Kuether et al, 2019 [73]	PiS	HKA	— <sup>d</sup> , 40	≈ 8	S; An interactive training program was presented and Microsoft Kinect was used to track the exercises. The therapist could track patient performance and modify the training program. The system provided real-time video communication as well.	High satisfaction rate was observed among the patients, and comparable improvement in the patient-reported outcomes were achieved.
19	Chughtai et al, 2019 [74]	FiS	KA	— <sup>d</sup> , 157	≈ 4	S; An interactive training program was presented and Microsoft Kinect was used to track the exercises. The therapist could track patient performance and modify the training program. The system provided real-time video communication as well.	The intervention was cost-effective, convenient, and improved patient adherence and overall satisfaction.
20	Bossen et al, 2013 [75]	PiS	HKO	— <sup>d</sup> , 20	9	E; Web-based exercise management gradually increases the activity level over 9 weeks without physiotherapist involvement.	The intervention was feasible and accepted among the patients. Patient satisfaction was reported high.
20	Bossen et al, 2013 [76]	Mix	HKO	— <sup>d</sup> , 100	9	E; Web-based exercise management gradually increases the activity level over 9 weeks without physiotherapist involvement.	Higher age, presence of comorbidity, lack of self-discipline, and physical activity baseline have a negative impact on the intervention adherence rate.
20 <sup>e</sup>	Bossen et al, 2013 [77]	RCT	HKO	99, 100	9	E; Web-based exercise management gradually increases the activity level over 9 weeks without physiotherapist involvement.	In the intervention group, physical function status improved in the short term; in the long term, higher levels of subjective and objective physical activity were observed.
21	Rini et al, 2015 [78]	RCT	HKO	55, 58	8-10	E; Automatically generated training program and management based on feedback without therapist participation.	The intervention group reported significantly lower pain compared with the control group and a very high level of adherence to the intervention program was observed. The acceptability of the program was demonstrated based on the strong evidence.
22	Kim et al, 2016 [79]	RCT	KnP	20, 50	6	E; Training program generated and updated automatically with therapist involvement.	No statistical difference was observed between the control and intervention groups. Only 8% of the participants completed the program.
23	Hinman et al, 2017 [33]	Mix	KnP/KOA	— <sup>d</sup> , 12	12	E/V; Home training (3 times per week) and 7 video calls during the treatment period.	Patients were satisfied with the provided solution due to the time efficiency, flexibility of service, and ease of access. The solution also improved users' confidence and sense of self-efficacy.
23 <sup>e</sup>	Bennell et al, 2017 [80]	RCT	KnP	74, 74	12	E/V; Home training (3 times per week) and 7 video calls during the treatment period.	Short-term and long-term effectiveness of the intervention was achieved. A significant short-term improvement was observed in the primary outcomes.
23	Lawford et al, 2018 [81]	RCT	KnP	74, 74	12	E/V; Home training (3 times per week) and 7 video calls during the treatment period.	Employed participants with a higher self-efficacy had better improvement in their health condition compared to the rest of the study group.

Group	Author(s), year	Study design <sup>a</sup>	Population <sup>b</sup>	Patients (control, target)	Duration (weeks)	Intervention type <sup>c</sup> and detail	Finding
24	Bossen et al, 2016 [82]	Mix	HKO	— <sup>d</sup> , 8	9	E; Web-based exercise management with gradual increases in the activity level over 12 weeks; the therapist could update the program, which included 5 face-to-face visits.	The proposed treatment seems to be feasible, and a good level of usability was reported. Lack of possibility to monitor patients between sessions was considered a limitation.
24	Vries et al, 2017 [83]	Mix	HKO	— <sup>d</sup> , 90	12	E; Web-based exercise management with gradual increases in the activity level over 12 weeks; the therapist could update the program, which included 5 face-to-face visits.	Internet skills, self-discipline, usability of the intervention, added value, time required, flexibility, and execution of the exercise plan and participating in research identified as determinants of patients' adherence.
24	Kloek et al, 2018 [84]	RCT	HKO	99, 109	12	E; Web-based exercise management with gradual increases in the activity level over 12 weeks; the therapist could update the program, which included 5 face-to-face visits.	The intervention cost was significantly lower in the intervention group. However; the total societal and healthcare costs were not statistically significant between groups.
24	Kloek et al, 2018 [85]	Mix	HKO	— <sup>f</sup> , — <sup>f</sup>	12	E; Web-based exercise management with gradual increases in the activity level over 12 weeks; the therapist could update the program, which included 5 face-to-face visits.	Appropriateness, required time, workload, added value, environmental factors, professional autonomy, and financial consequences were identified as determinants for physiotherapists' usage of the proposed intervention
24 <sup>e</sup>	Kloek et al, 2018 [86]	RCT	HKO	99, 109	12	E; Web-based exercise management with gradual increases in the activity level over 12 weeks; the therapist could update the program, which included 5 face-to-face visits.	No statistical differences were found between control and intervention groups in physical functioning and free-living physical activity.

<sup>a</sup>The study designs are randomized controlled trial (RCT), mixed method study (Mix), quasi-experimental study (QeS), pilot study (PiS), feasibility study (FiS), and cross-sectional study (CrS).

<sup>b</sup>The population groups are total hip/knee arthroplasty (HKA), knee osteoarthritis (KOA), total knee arthroplasty (TKA), knee pain (KnP), and hip/knee osteoarthritis (HKO).

<sup>c</sup>For the intervention type, the designations P, V, S, and E stand for phone-based, video-based, sensor-based, and expert system-based telerehabilitation, respectively.

<sup>d</sup>Not available.

<sup>e</sup>These studies are considered the reference study of their group.

<sup>f</sup>There were 123 physiotherapists that participated in the study.

## Technologies and Mode of Rehabilitation Service Delivery

We identified four modes of telerehabilitation programs: phone-based, video-based, sensor-based, and expert system-based; we focused on the given training solution.

### Phone-Based Telerehabilitation

Azma et al [57] and Han et al [55] used weekly phone communication initiated by a health care professional who would instruct patients and track their progress over the rehabilitation period. Kramer et al [54] and Chen et al [56] performed less frequent phone calls during the rehabilitation period. In the studies, training instructions were provided using a guidebook of the exercises. Information about adherence to the exercise programs was collected by filling out a logbook of activities [57] or during the phone calls [55].

### Video-Based Telerehabilitation

In previous studies, real-time video streaming communication was frequently used to deliver rehabilitation services to patients. Wong et al [58] established a weekly supervised training session with a group of patients using video conference communication at a secondary center. Patients were asked to perform the prescribed exercises 3 times per week for 12 weeks using a booklet of exercise instructions; patient activity/adherence was reported using a logbook. Tousignant et al [30] provided a home telerehabilitation service by setting up a video conferencing system in the patient's home, and rehabilitation sessions were carried out twice per week for 8 weeks. Moffet et al [60] developed the telerehabilitation solution by employing a hardware/software video communication platform (TelAge), which was the treatment program for the target group. In the TelAge system, custom computer software (TeRa) was developed to control the streaming video with a user-friendly



graphical interface [61]. Doiron-Cadrin et al [63] employed a medical teleconsultation application (REACTS Lite, Innovative Imaging Technologies) to establish real-time video communication.

Bini et al [62] introduced asynchronous video communication by employing smart devices (iPod Touch, Apple Inc) and media file-sharing applications (CaptureProof). The system established a two-way asynchronous communication between the physiotherapist and patient. It also enabled the physiotherapist to instruct the patient using prerecorded exercise introductions and provide supplementary media.

### **Sensor-Based Telerehabilitation**

Eisermann et al [64] provided a telerehabilitation program using custom computer software and several sensors to track the patient's performance. Patients were asked to perform individualized exercises based on the training program prescribed by the therapist; the program could be modified based on the patient's feedback. Accelerometers, webcams, chest sensors, and wristbands were employed in the study to monitor training performance and generate relevant reports and online feedback.

Ayoade et al [66] and Piqueras et al [65] developed a telerehabilitation program by using two wireless sensors equipped with 9 degrees of freedom (9DOF) inertial measurement units to track the knee angle. Participants were asked to wear the sensors on their operated leg (shin and thigh) using elastic bands while performing the recommended exercises. Argent et al [69] used a classic Bluetooth 9DOF sensor (Shimmer3, Shimmer Sensing) fixed on the patient's shin, and Correia et al [67] increased the number of Bluetooth Low Energy 9DOF sensors to three; these were placed on the chest, thigh, and shin. Ramkumar et al [70,87] employed Focus Motion (Focus Ventures) sleeves to track the operated knee's range of motion. The sleeve was designed for the lower limb and equipped with two classic Bluetooth 9DOF sensors. In addition, the user's cellphone was used to track daily activities based on the internal pedometer.

Eichler et al [71,88] used Microsoft Kinect (Version 2, Microsoft Corp) in the training program to track the patient's performance. The VERA (Reflexion Health) system also used Microsoft Kinect to track the exercises and it has been used in several clinical studies [72-74]. The Microsoft Kinect software development kit (Version 2.0) [89] can provide an estimation of 25 joints (including the knee) in space. Therefore, the telerehabilitation program could produce an avatar of the user performing the exercises.

All the introduced telerehabilitation programs were able to track the number of performed exercises and to provide real-time visual feedback on user performance.

### **Expert System-Based Telerehabilitation**

Bossen et al [77] provided a web-based training program (Join2Move). The training program was automatically generated based on reported baseline measurements. The intensity of the exercises was increased over time, based on the behavioral graded activity concept [90]. The expert system collected weekly

patient adherence reports and provided autogenerated messages and reports without any intervention by the physiotherapist. The telerehabilitation program was improved and developed using a participatory design method [82,91]. In the improved program (E-exercise), online information and 5 face-to-face visits were included in the internet-based intervention [86]. Moreover, in E-exercise, it was observed that the therapist could deviate from the suggested training program.

Kim et al [79] used a decision-making system that introduced an adaptive training program based on the patient's adherence, pain level, and difficulty reports. However, the physiotherapists were not involved in adjusting the training program; they were able to monitor the patient's reports and respond to the patient's questions via a text messaging service embedded in the program.

Rini et al [78] employed an expert system to provide internet-based pain coping skills training (PainCoach). An individualized training program was automatically generated based on the patient's baseline without physiotherapist participation. In addition, the program enabled the patients to access the appropriate instructions and a history of their performance; they could also ask other patients about their experiences and share experiences. Bennell et al [80] extended the PainCoach program by including 7 videoconference sessions with a physiotherapist over 12 weeks.

### **Intervention and Services**

In total, five different services were identified in the included papers. Table 2 shows the introduced services as part of the telerehabilitation program. The details regarding services were provided as follows.

#### **Information**

The information service provided relevant educational material for the target group and was accessible on a 24/7 basis without any interruption. The information provided could cover a wide variety of instructions and answer questions; in addition, it could introduce critical challenges that the patient might encounter. Only four of the studies introduced education materials via an online service as a part of the rehabilitation program.

#### **Communication**

The two-way communication between the patient and health care professionals can be used for consultation, recommendation, and interview purposes. The majority of the studies provided this service (19 studies). Real-time communication (using the phone or a video call) was used more than asynchronous communication (asynchronous SMS text messaging or video messaging). In the phone-based and video-based solutions, the communication platform was also used to deliver the training services. It should be mentioned that two of the studies [67,86] chose to include regular in-person visits. Eichler et al [71] used both real-time videoconferencing and asynchronous messaging approaches in the program.

#### **Training**

The training service includes exercise instructions, daily/weekly rehabilitation plans (number of repetitions and sets for each exercise) and relevant interactive materials for each exercise. All the studies provided training services using an interactive

training program with visual feedback, video rehabilitation sessions, or a printed booklet of instructions.

### ***Intervention***

Intervention in a telerehabilitation program can be carried out based on the patient's reports and is done individually by either a physiotherapist or a decision-making algorithm (as part of an expert system). Making adjustments and modifications to the training program (ie, repetitions, intensity, number of exercises) and providing relevant feedback are considered as interventions in the treatment.

### ***Monitoring and Tracking***

Monitoring and tracking services enable physiotherapists or an expert system to perform a predefined assessment or diagnosis remotely. In addition, this service may provide a history of the patient's performance. The data can be recorded manually by a physiotherapist, self-reported by the patient (such as adherence or pain level), or collected automatically using motion tracking sensors.

**Table 2.** Details of the services provided in the included telerehabilitation programs.

Group	Main study	Information	Communication	Training	Intervention	Tracking
1	Kramer et al, 2003 [54]	Booklet	Phone call	Instruction booklet of the exercises	Phone call	N/A <sup>a</sup>
2	Han et al, 2015 [55]	N/A	Phone call	A hard copy of the instructions	Phone call	Adherence (by phone call)
3	Chen et al, 2016 [56]	N/A	Phone call	A hard copy of the instructions	Phone call	Unclear
4	Azma et al, 2017 [57]	N/A	Phone call	Instruction booklet of the exercises	Phone call	Adherence logbook
5	Wong et al, 2005 [58]	N/A	Real-time video communication	Instruction booklet of the exercises	Unclear	Real-time video communication
6	Tousignant et al, 2011 [30]	N/A	Real-time video communication	Real-time video communication	A therapist can modify the training program	Real-time video communication
7	Moffet et al, 2015 [60]	N/A	Real-time video communication	Real-time video communication	A therapist can modify the training program	Real-time video communication
8	Bini et al, 2017 [62]	N/A	Asynchronous video communication	Video instruction of the training program	A therapist can modify the training program	Video reports
9	Doiron-Cadrin et al, 2018 [63]	N/A	Real-time video communication	Real-time video communication	Real-time video communication	Adherence using logbook
10	Eisermann et al, 2004 [64]	N/A	Asynchronous text messaging	An interactive training program with real-time feedback using motion sensors	A therapist can modify the training program	Patient performance collected by sensors and reported
11	Piqueras et al, 2013 [65]	N/A	Unclear	An interactive training program with real-time feedback using motion sensors	A therapist can modify the training program	Patient performance collected by sensors and reported
12	Ayoade and Baillie, 2014 [66]	N/A	Real-time video communication	An interactive training program with real-time feedback using motion sensors	Real-time video communication	Unclear
13	Correia et al, 2018 [67]	N/A	Face-to-face, phone call	Visual real-time feedback and audio instructions using motion sensors	A therapist can modify the training program	System generated performance
14	Argent et al, 2019 [69]	Provided by the application	Unclear	An interactive training program with real-time feedback using motion sensors	Unclear	Adherence (performance) collected by the system and patient reports (pain, difficulty)
15	Ramkumar et al, 2019 [70]	Unclear	Unclear	An interactive training program with real-time feedback using motion sensors	Unclear	Adherence and daily steps were collected automatically, and patient-reported outcome data were reported every week electronically.
16	Eichler et al, 2019 [71]	N/A	Asynchronous SMS text and voice messaging as well as real-time video communication	An interactive training program with real-time feedback using Microsoft Kinect	A therapist can modify the training program.	Patient adherence and performance collected and reported
17	Bettger et al, 2019 [72]	N/A	Real-time video communication	An interactive training program with real-time feedback using Microsoft Kinect	A therapist can modify the training program.	Patient adherence and performance collected and reported

Group	Main study	Information	Communication	Training	Intervention	Tracking
18	Kuether et al, 2019 [73]	N/A	Real-time video communication	An interactive training program with real-time feedback using Microsoft Kinect	A therapist can modify the training program.	Adherence to the program reported automatically.
19	Chughtai et al, 2019 [74]	N/A	Real-time video communication	An interactive training program with real-time feedback using Microsoft Kinect	A therapist can modify the training program.	Adherence to the program reported automatically.
20	Bossen et al, 2013 [77]	Online education materials	N/A	Interactive training program	The expert system modifies the training program	Adherence report
21	Rini et al, 2015 [78]	Online education materials	N/A	Interactive training program	The expert system modifies the training program	Patient reports
22	Kim et al, 2016 [79]	Unclear	Asynchronous text messaging	Interactive training program	The expert system modifies the training program	Patient reports
23	Bennell et al, 2017 [80]	Online education materials	Real-time video communication	Interactive training program	The expert system modifies the training program	Unclear
24	Kloek et al, 2018 [86]	Online education materials	Face-to-face	Interactive training program	The expert system and therapist modify the training program	Adherence report
Overall	N/A	6	19	24	21	20

<sup>a</sup>N/A: not applicable.

## Discussion

This focused review had two purposes: to investigate the technologies used in telerehabilitation programs for patients with KOA and to identify the services that were introduced for the target group. The review identified 24 group studies. The majority of studies (87.5%) were conducted in the second decade of the investigation period (2010-2020) and half of the studies published in the last 4 years. Four different modes of service delivery and five groups of services were identified. The findings showed that video-based communication was the most well-established mode of service delivery, and the studies primarily emphasized establishing training and intervention services rather than providing online education materials.

It is believed that limited services can be provided using a phone-based telerehabilitation program such as phone consultations, recommendations, and interviews [57,92,93], while real-time video communication can be seen as an alternative implementation of an in-person physiotherapy session. Real-time video can be employed not only for consultation purposes but also for training, intervention, and assessment services [30,94,95]. Video conferencing enables the physiotherapist to provide individualized instructions, feedback, and training programs for each patient in real time [59]. Cottrell et al [15] also concluded that real-time video telerehabilitation might be as effective as conventional therapy. Furthermore, the clinical assessment can be carried out by a physiotherapist via the visual observation of a patient's performance while performing a clinical test [59]. Capturing high-quality still images to assess the range of motion of a patient's knee is also

recommended [96,97]. In addition, it has been shown that video conferencing can be carried out using a low-bandwidth internet connection [94,98].

Bini et al [62] remarked that real-time video communication might involve several limitations when compared to asynchronous video communication, such as time restrictions and limited or no access to the previous records. The video conference session is usually conducted according to predefined schedules (for example, twice per week in [30,60]), and patients were asked to repeat the exercises without any supervision [63]. Consequently, the patient cannot initiate on-demand communication. Moreover, storing the real-time video stream for later use requires more complicated infrastructure; therefore, neither the physiotherapist nor patients would have access to the previous sessions to track treatment progress. Russell et al [99] recommended a store and forward method to provide video instructions with higher quality. Perez-Manchon et al [100] stated that asynchronous telemedicine could be an efficient method for providing health care services at a distance. However, this method still requires the active engagement of the therapists to review the recorded video session.

Sensor-based telerehabilitation programs are a more independent service than video communication as they use one or more sensors to record the patient's physical activity and collect movement information using software running on a computer device (PC, smartphone, tablet). Ayoade and Baillie [66] showed that a sensor-based telerehabilitation program can offer increased time flexibility and independence for patients by using semi supervised training sessions. Interactive telerehabilitation can be provided by presenting real-time graphical feedback of the

patient's performance using the software. In addition, interactive telerehabilitation enables users to review their performance over time. Moreover, several services can also be provided by software such as asynchronous or synchronous communication, educational materials, and patient reports. The program can be divided into wearable sensor-based and Microsoft Kinect-based programs. Earlier studies remarked that wearable sensors can provide accurate and precise details of movement [101-103]. However, several limitations were observed in the studies. Ayoade and Baillie [66] evaluated the system on only five patients, and Piqueras et al [65] reported that patients used the program for five days. Argent et al [69] reported that patients had a negative experience due to inconsistencies in the automatic measuring system. Ramkumar et al [70] remarked that the users did not appreciate the frequent charging of sensors. In addition, Naeemabadi et al [104] showed that Bluetooth Low Energy-based motion sensors might have a less accurate estimation of the sensor orientation due to a low sampling rate. Moreover, the sampling rate will also decline when the number of sensors is increased. Therefore, further investigation might be required to assess the real-time responsiveness of telerehabilitation programs like those introduced by Correia et al [67,68]. In general, wearable sensors can only represent the orientation of the limb to which they are attached. Therefore, the depicted avatar cannot represent the movement of the whole body. However, Microsoft Kinect-based solutions can track the whole body without the need to wear sensors. In addition, no calibration process is required, and users can immediately start the exercises. The portability of these solutions are debatable due to the computational requirement for Kinect. Eichler et al [71] used a small form factor PC attached to the user's TV; for the VERA solution, the PC, display, and Kinect sensor were placed in a case. Conversely, cellphones and tablets were used in the wearable sensor-based solutions. It was also shown that Microsoft Kinect might impose practical limitations on particular exercises [105]. Microsoft Kinect requires a large space to track the body and Eichler et al [71] consider this in

the inclusion criteria. Hence, using Microsoft Kinect to track the exercises might be controversial. It is believed that we still lack a robust solution for the sensor-based telerehabilitation program. Hence, further studies are needed to provide a better understanding of these challenges.

The recent investigations showed that the expert system could partly or entirely interact with the patient and take the therapist's responsibilities. In only 2 out of the 5 identified studies, the expert system was entirely responsible for managing and supervising the treatment procedure, and the patient-to-therapist connection was disrupted [77,78]. Later on, both studies saw improvements, with physiotherapists being more involved in the treatment process via face-to-face visits [86] and video conference communication [80]. Kim et al [79] also used an asynchronous communication with a physiotherapist in the expert system that they introduced. We conclude that the expert system can be effectively used as an assistant system that allows the physiotherapist to have responsibility and maintain physiotherapist-patient telecommunication.

Russell [32] also recognized virtual reality-based telerehabilitation programs as a mode of telerehabilitation. However, we were not able to identify any studies that employed this mode based on the taxonomy of virtual reality displays [106].

In summary, video conference-based programs can be considered the well-established alternative solution to the conventional rehabilitation program for the target group; however, there remain several limitations, such as flexibility and resource management. The recent studies justified the effectiveness of this approach. Although sensor-based solutions might offer higher flexibility and better resource management. The investigations indicated, more studies are being conducted utilizing the sensor technology as a telerehabilitation in the last two years thanks to the existing demand for a more flexible and portable telerehabilitation with better human resource management.

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## Conflicts of Interest

None declared.

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## Abbreviations

**9DOF:** 9 degrees of freedom

**CINAHL:** Cumulative Index to Nursing and Allied Health Literature

**PEDro:** Physiotherapy Evidence Database

**PRISMA:** Preferred Reporting Items for Systematic Reviews and Meta-Analyses

**MeSH:** medical subject heading

**RCT:** randomized controlled trial



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