Chapter

Toward a Design of a Telerehabilitation Program for the Functional Recovery in Post-Hip Arthroplasty Patients

Wilmer Esparza, Arian Ramón Aladro-Gonzalvo, Jonathan Baldeon and Sophia Ortiz

Abstract

Telerehabilitation uses new information and communication technologies as an instrument to ensure a distant rehabilitation service. Patients who underwent hip replacement surgery are an excellent case study for the application of this technology. Post-surgical rehabilitation guidelines for hip arthroplasty are well known, and the correct application has a positive effect on the patients' prognosis. However, there are no complementary guidelines for physical therapy that could be used at a distance by patients through a computer platform. This chapter presents a systematic review about conventional physical therapy programs for hip arthroplasty. Based on this review, we proposed therapeutic exercises adapted to a low cost web-platform. In order to reach this objective we will present a brief review of the total hip arthroplasty, telemedicine, telerehabilitation and conventional physical therapy approaches.

Keywords: systematic review, telerehabilitation, web-platform, hip arthroplasty, physical therapy, functional recovery

1. Introduction

The technological advances and the greater access to knowledge networks have generated new treatment prototypes in the health field. An ongoing technological possibility that could complement the conventional physical therapy treatment is the telerehabilitation (TR) application. TR uses new information and communication technologies as an instrument to ensure a distant rehabilitation service. In addition, this tool optimizes recovery time and saves expenses in health services, benefitting both users and healthcare professionals.

The implementation of this technology is supported by: (i) health personnel; (ii) the impact on the patient's budget and the health system (lessening the number of medical appointments and therapy sessions, decreasing the time of hospitalization, and trips to the hospital); (iii) the expansion of medical care to distant or low-income populations; and (iv) the empowerment of the patient in the rehabilitation process.

Patients who underwent hip replacement surgery are an excellent case study for the application of this technology. Total hip arthroplasty (THA) involves replacing the skeletal surfaces of the hip joint (femoral head and acetabulum).

The coxofemoral joint is one of the most important joints in the human body, because it is fundamental for walking. The rehabilitation of these patients after surgery seeks to relieve pain, restore normal function and improve quality of life. Specifically, functional recovery plays an important role to engaging patient in activities of daily living (ADL).

Post-surgical rehabilitation guidelines for hip arthroplasty are well known, and the correct application has a positive effect on the patients' prognosis. However, there are no complementary guidelines for physical therapy that could be used at a distance by patients through a computer platform. A recent systematic review shows that the TR application in real time combined with a conventional physiotherapy program is more favorable than isolated treatment of musculoskeletal dysfunctions. Thus, the objective of this chapter was to report the main results of a systematic review about conventional physiotherapy programs for hip arthroplasty and to propose some exercises adapted to a low-cost TR platform for the functional recovery. We will present a brief review of the THA, telemedicine/TR, conventional physical therapy approaches, the methodology used to design the therapeutic intervention program adapted to the low-cost TR platform from a systematic literature review, and present the initial results about the implementation of some exercises.

2. Hip arthroplasty

The coxofemoral joint is formed by two articulated surfaces—the acetabulum and the femoral head—that are related to the hipbone and the femur, respectively. The THA consists of replacing the femoral head and the acetabulum with prosthesis. The surgery purpose is to reduce pain, improve mobility and quality of life the people with hip osteoarthrosis [1]. The type of THA to be performed will depend on the patient needs. In case of people with limited physical activity, a cemented THA is performed, while an uncemented THA is performed in people with high activity demands [2]. THA and knee arthroplasty are the most frequent surgical interventions in the USA, representing a high economic burden for the public and private health system [3, 4].

One of the main intervention shortcomings is related to the prosthesis lifetime, which depends on the amount of activity carried out with it. That means if the person performs activities with greater load on the lower limbs, the replacement period will be shorter compared to a person who performs less activity. Overall, the patients' progress after joint replacement is satisfactory. Nonetheless, a significant number of patients may present functional and balance limitations, even 1 year after surgery [5].

These limitations may imply deficits in the proprioceptive system that lead to altered pattern of movements (e.g., gait difficulties and poor postural control). Likewise, these alterations would disturb basic daily activities performance and patients' quality of life [6]. Therefore, balance and proprioception are key factors in the treatment to an integral rehabilitation [7]; since there is a positive association between equilibrium capacities and functional capacities [8].

3. Telemedicine and telerehabilitation

3.1 Telemedicine

The term telemedicine is used to describe the delivery of health care services, clinical information and patient education in all specialties. Telemedicine uses a wide variety of technologies (internet, mobile phones, electronic medical records…) to provide healthcare from distance [9]. It provides clinical information, allows consultations and helps communication between health professionals and patients, regardless the location of the patient. Therefore, telemedicine allows increasing access to specialized medical care. Remote patient monitoring happens regularly and certain interventions can be performed in real time rapidly and effectively [10]. Telemedicine can also be an instrument that helps patients and their caregivers get involved in their own care.

A large number of studies in a wide range of disciplines have bid to document the telemedicine effectiveness. It has been found that telemedicine is effective in the management of adult malnutrition [11]; asthma [12]; heart disease [13], diabetes—especially type 2 [14]; arterial hypertension [15] and multiple sclerosis [16]. In addition, positive clinical results have been presented for the patient follow-up and treatment in different situations such as: (1) burned [17]; (2) in palliative care [18]; (3) with acute cerebrovascular accident [19]; (4) with mental disorders [20]; (5) geriatric [21]; and (6) newborns, children and adolescents [22, 23].

Regardless the area in which telemedicine has been applied; different authors state general findings about its potential application. For instance, (1) It is a safe and feasible way to provide care and monitor certain groups of patients; (2) It leads to a decline in the number of visits to the hospital and decreases the length of stay in the hospital, therefore there is a reduction of costs in the health system; (3) Professionals and patients seem to follow and be satisfied when using the programs; and (4) It promotes self-management of the disease and adherence to treatment [24, 25]. Certainly, the increase usage of telemedicine could: (i) provide greater access to health services; (ii) offer the opportunity to carry out early interventions and even work on prevention; (iii) provide a constant follow-up, and (iv) involve the patient in the self-management of the disease.

3.2 Telerehabilitation

TR is a telemedicine form that provides remote support (temporary or permanent), evaluation and intervention to disabled people who need rehabilitation [26]. In the last decade TR has evolved due to the great reduction of costs in health services [27]. TR development has been pushed by several factors. Firstly, there is better access to specialized services and improved capacity for remote monitoring [28]. A second factor was the mobilization difficulties that people who require the service may face [26]. It has been shown that less than a third of patients discontinue outpatient rehabilitation 3 months after discharge [29]. In rural areas, transportation can be a burden due to less availability of public transportation or climatic factors. Thirdly, TR could defeat financial barriers for families with less purchasing power, since financing or using insurance in post-acute care is usually limited and expensive [26]. This reduces expenses for both, the user and the provider, because several patients can be treated by a single program at any time [27, 30]. Lastly, a key factor for TR progress is the connection between the healthcare provider and the patient, family members and the community which results in training improvement, which indirectly expands the health workforce [30].

The implementation of this technology is held by: (i) health personnel; (ii) the influence on the economy of the patients and the health system (decreased visits to the hospital and decreases the time of hospitalization); (iii) the ability of medical care to reach distant or low-income populations; and (iv) the autonomy of the patient in his rehabilitation process [26]. TR has been appropriate to: (i) complete pre-operative evaluations; (ii) analyze patterns of movement, gait; and (iii) prescribe orthopedic material [31]. These study trials showed favorable results, by not only improving physical health, reduction of fatigue, but also recovering mental health by the lessening of depressive symptoms. In addition, high levels of satisfaction and comfort were reported, as well as significant savings in time and travel costs of users [26, 31]. A recent study has aimed to develop a low-cost, online TR platform intended to evaluate and monitor patients after a total hip arthroplasty [32].

Despite all favorable aspects of the TR program implementation; there are still many challenges to face. The first challenge is to build a good relationship between the health provider and the patient. Many patients prefer to receive personalized and face-to-face care, lessening the possibilities of adopting this new form of approach. Elderly patients tend to have doubts about this kind of treatment method whereas it is extremely easy in young patients [30]. Developing an online application in smartphones could be one way to establish a relationship through TR [33]. These applications would allow a more direct, regular and personalized interaction with the patient.

There may also be safety problems, if the patient was alone during the session the patient could have an accident or when performing the movements wrongly increases the chances to get hurt [33, 34]. In order to avoid these situations, TR platforms should include links providing the necessary therapeutic information to prevent an accident or detect a wrong execution of the exercises. Likewise, the platform should be equipped with a control system able to allow the session to the patient, as well as disable it if necessary [32].

The incompatibility of systems and platforms between different operating system providers should also be taken care of. This issue has showed conflicts in the past when integrating the contents of clinical databases [34]. On the other hand, TR is limited when it comes to detecting fine movements or tremors, movements in certain planes [33], and emotional states of patients. However, recent studies show advances in the development of computer programming for facial gestures recognition that could be used in TR platforms [35].

4. Conventional physiotherapy

Physical therapy after a THA is essentially performed to improve patient's functionality through posture and gait training. Some of the main focuses during treatment are the hip range of motion (ROM), muscle strength, pain and edema. The control and improvement of these parameters allows the patient reintegration to the activities of daily life (ADL). This reintegration to the ADLs is accelerated when the rehabilitation process has an early start. Prompt physical therapy intervention helps reduce hospital stay, as well as costs to the health system [36].

Commonly the therapeutic intervention is classified as early, standard or late. The early intervention begins immediately after the surgery, and can be carried out on the same day or the next day. The standard phase begins either 1 or 2 days postoperative, while the late intervention begins after the second week post-surgery [36].

Depending on the patient activity, postoperative physical therapy can last between 8 to 24 weeks, divided into three or four phases. Stage I (peri-operative) lasts for 2 weeks where the focus is the education of the patient about their current condition (recommendations when doing certain movements, changes of position, training the walk with technical aids, etc.) and performing active mobility exercises in the appropriate ROM [37].

Stage II and III focus on muscle strengthening, load tissue adaptation and ROM recovery of the hip. This phase is usually distributed in two stages: the first lasts two to 8 weeks and the second between two and seven. Manual techniques can be used in this stage, but the progressive load with therapeutic exercise should be prioritized, in open and/or closed kinetic chain exercises, resistance exercises with elastic bands or different weights. In addition, stability and proprioception work should be included, with an emphasis on lumbopelvic and hip stability [37].

Stage IV concentrates on the ADL reintegration, it can last 2 weeks up to 2 months. The objective of this stage is to reinsert the patient to their normal setting (educational, work and/or sports activities). The approach is done through imitation of motor gestures accompanied by exercises of cardiovascular resistance and progressive strength. Cheatman and colleagues [37] estimate that after 4 months of intervention, the patient can return to his medium impact activities, such as the recreational walk. Six months after surgery, the patient can return to high impact activities or sports.

In general, physical therapy concentrates on muscle strength, patient education, gait retraining, and improvement of hip mobility. It is recommended to perform two sessions a day, since it has been demonstrated that in early stages function recovery occurs quicker [38]. Evidence also proves that rehabilitation programs, with at least three phases, have more beneficial effects for postoperative THA patients [37]. Finally, the fulfillment of the health team recommendations and complementary work at home are important in the rehabilitation process, accelerating the patient reintegration to their setting.

As we have shown, post-surgical rehabilitation guidelines for THA are well known, and their correct application has benefits on the patients´ prognosis. However, there are no complementary guidelines for physical therapy that could be used at a distance by patients through a computer platform. A recent systematic review shows that the TR application in real time combined with a conventional physiotherapy program is more favorable than isolated treatment of musculoskeletal dysfunctions [39].

5. Systematic review methodology

5.1 Data sources and searches

An electronic search was performed to identify relevant articles in: PubMed Meta-search (1950 to March, 2017), ScienceDirect (1990 to March, 2017), PEDro (1950 to March 2017), and Cochrane Database (2000 to March 2017). Key words relating to the domains was used: (1) type of exercise: "Join mobility exercise OR Functional exercise OR Therapeutic exercise OR Rehabilitation exercise OR Post-hospital Home Exercise"; (2) clinical term: "Total OR partial hip replacement, Total OR partial hip arthroplasty"; (3) type of document: "Position stand OR Clinical guide OR Systematic review OR Literature review OR Randomised controlled trials [RCTs];" (4) their combination.

5.2 Study selection

The reviewers followed a selection protocol, developed prior to the beginning of the review that included a checklist for inclusion and exclusion criterion (**Figure 1**). Articles were eligible for inclusion if they: (a) included passive or active specific exercises to strengthen the hip, enhance the static balance and/or restore whole joint movement; (b) were carried out on individuals of all age groups and sex with total or partial hip replacement; (c) consisted of self-administered home exercise programs or a program supervised by a physical therapist; (d) reported that a criterion for entry was total or partial hip replacement of 1 day after surgery and within 12 weeks to 8 months following surgery; (e) reported one of the following outcome

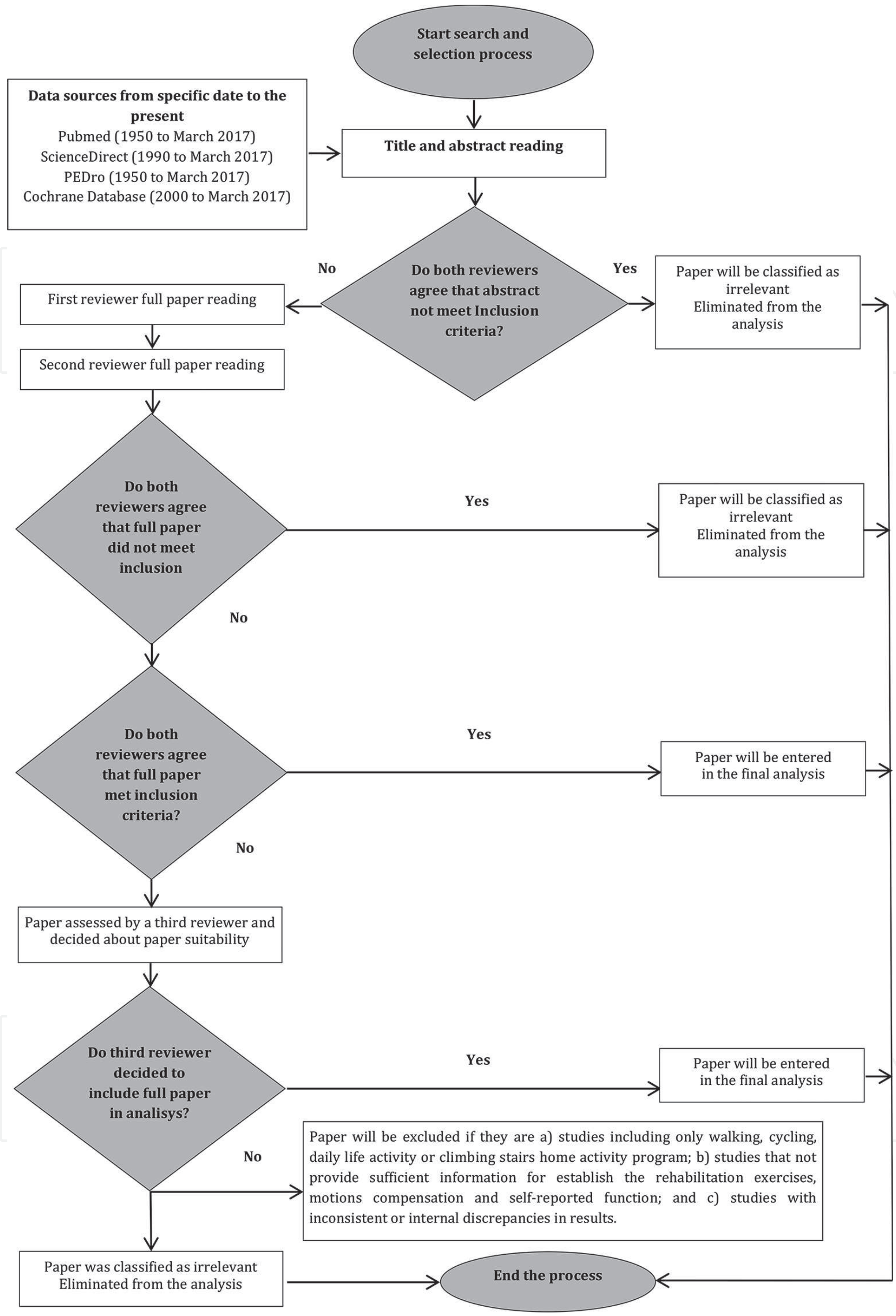

Figure 1.
Protocol used for studies selection.

measures: motions compensation and self-reported function; (f) were unpublished documents such as thesis, dissertations, and presentations in congresses; (g) peer-reviewed articles; and (h) were not restricted to any specific language.

Articles was excluded if they (a) included only walking, cycling, daily life activity or climbing stairs home activity program; (b) did not provide sufficient information for establish the rehabilitation exercises, motions compensation and self-reported function; and (c) showed inconsistent or internal discrepancies in results.

5.3 Data synthesis

The results were grouped under three characteristics: (1) specific passive or active exercises; (2) compensation of movements; and (3) self-report function. For specific exercises, the search focused on frequency (sets per hour); duration (time or repetitions per set); rest (recovery time); as well as the direction and speed of movement execution. Motion compensation analyzed the patient's position and the difficulties in performing the exercise. Finally, the function was related to the assessment of: (1) pain, (2) functional disability, (3) activities of daily life, and (4) perceived effort.

6. Results

6.1 Systematic review

The flow diagram using PRISMA statement depicts the different phases of systematic review [40]. It maps out the number of records identified, papers included/excluded, and the reasons for exclusions (**Figure 2**).

6.2 Program design

After inclusion and exclusion criteria application, only 19 studies were included for to design the program. These studies provided information about the elaboration of the program stages, as well as to establish the components and rehabilitation program objectives. The program stages are shown in **Figure 3**. For the instant, some exercises of the program have been validated in healthy people and patients with THA [32, 41].

6.2.1 Stage 1: acute rehabilitation

This stage starts immediately after the intervention. During this stage the main objectives are: (i) pain management; (ii) reduce postoperative edema; (iii) teach the patient the correct position and transfer changes; and (iv) activate and maintain lower limbs musculature (**Figure 4**).

Pain management: It has been agreed that the local application of cryotherapy yields to vasoconstriction and decay in the conduction speed of type C fibers. These properties help regulate pain, decrease postoperative edema and internal blood loss caused by osteosynthesis material attachment in the bone [46].

Activation and maintenance of the lower limb musculature: After a hip replacement surgery, isometric contraction decreases, leading to stability and functional complications. In order to maintain proper gait speed and prevent falls it is important to activate hip musculature (quadriceps, abductors and extensors). An effective muscular control helps restore patient function and independence [47].

Teaching positional changes and transfer of the patient: One of the goals to reach immediately after THA is the patient autonomy on the ADL, during the stay in the hospital and later at home. Training on positional and transfer changes is an education form, which decreases the stay length in the hospital and improves the patient recovery prognosis after the intervention [45].

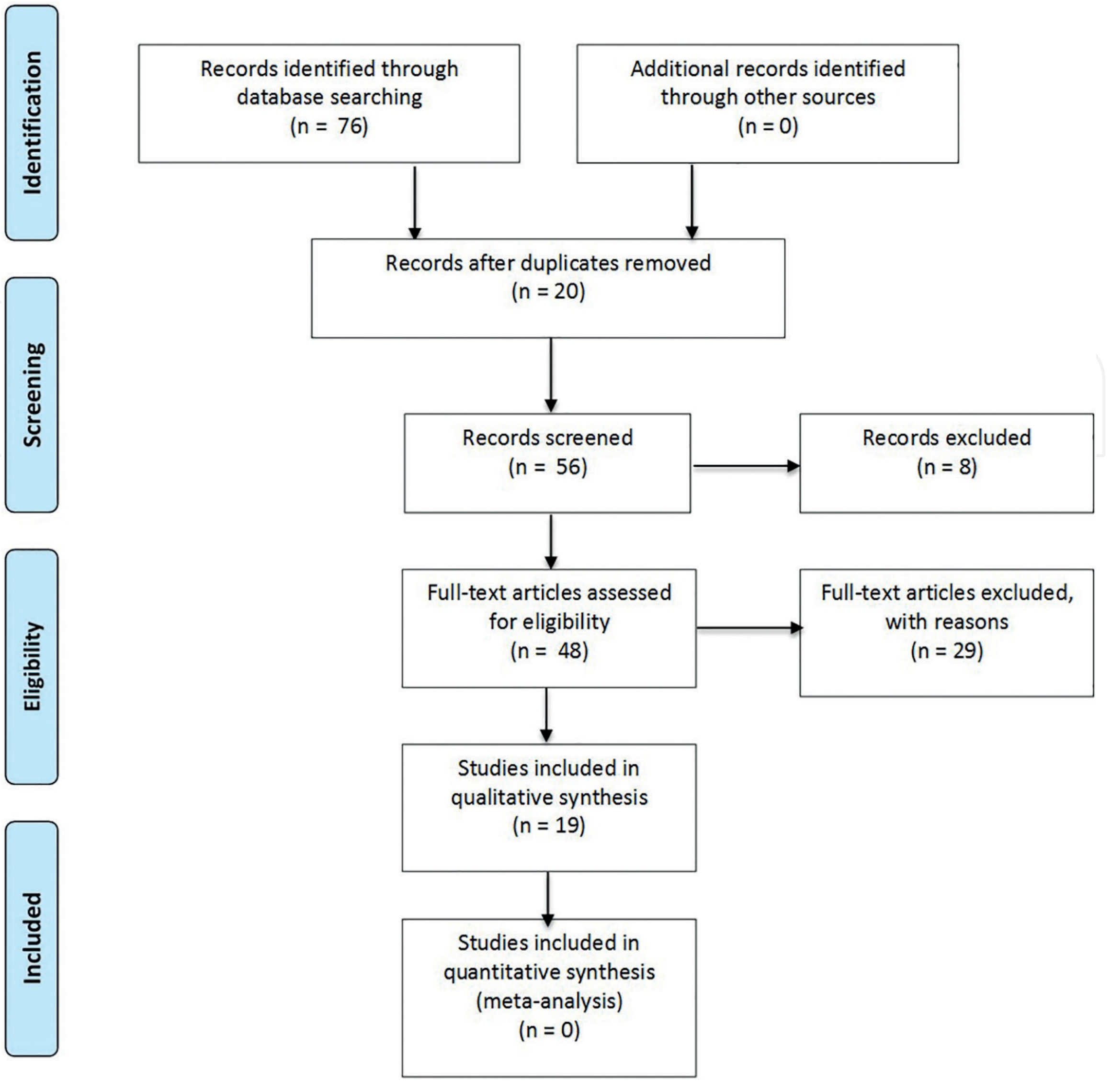

Figure 2.
Flow chart of systematic review process.

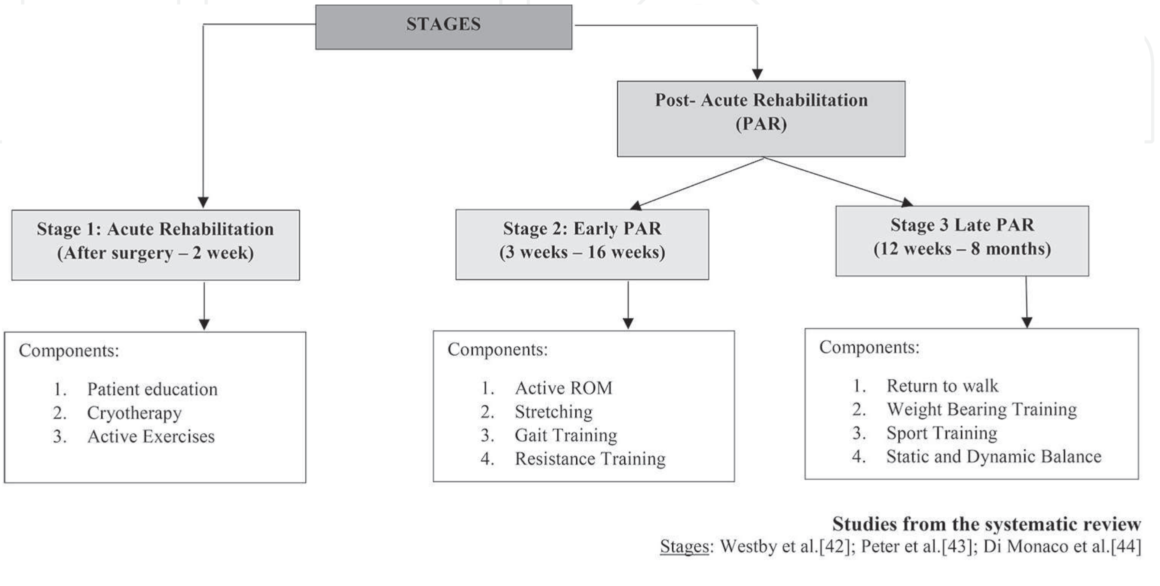

Figure 3.
Stages for acute and post-acute rehabilitation after total hip and knee arthroplasty [42–44].

6.2.2 Stage 2: early post-acute rehabilitation

This stage starts 3 weeks after surgery and lasts for 16 weeks. It focuses on recovering ROM and flexibility, as well as muscle and gait competence. This stage aims to prepare the lower limbs for the next stage of rehabilitation (**Figure 5**).

Active ROM mobility: After THA surgery the hip ROM decreases, caused by different factors such as post-surgical edema, protective muscular contraction, pain, capsular retractions, immobilization and patient's fear. This leads to gait deficits, static and dynamic postural instability, and limitation to perform ADL [49]. Consequently, patient function and independence are diminished.

Gait reeducation: Generally, gait patterns after THA surgery remain altered. For instance, there is Trendelemburg sign with a pelvis tilt towards the limb where the load is. This alteration is especially due to the gluteus medius dysfunction, which is severely affected during surgery [54]. The gait reeducation aims to recover the normal movement pattern. Visual, sensory and auditory feedback give information about the movement before it is automatized. It has been shown that reeducation with visual feedback promotes return to normal gait patterns in 3 weeks.

6.2.3 Stage 3: later post-acute rehabilitation

This stage lasts from week 12 to several months after surgery. The main objective on this stage is based on the functional reinsertion, gaining patient's autonomy in the DLAs (**Figure 6**).

Functional training: Since THA prevalence is higher in older adults the independence on DLA is conditioned to several factors. Among the most frequent factors there are physical deconditioning and geriatric syndromes (falls, gait disturbances, memory problems) [62]. Progressive strength training has been demonstrated to be essential for older populations, focused on reducing and preventing disability. Actually, muscle training leads to better static and dynamic postural control. The training strategies are based on leisure, recreational cooperative activities and based on the patient's ADL.

Postural control and dynamic stability: Postural control and dynamic stability depend on the proprioceptors integrity (articular, myotendinous, neuromuscular). Furthermore, after THA, the tissues integrity is lost, producing pain as well as

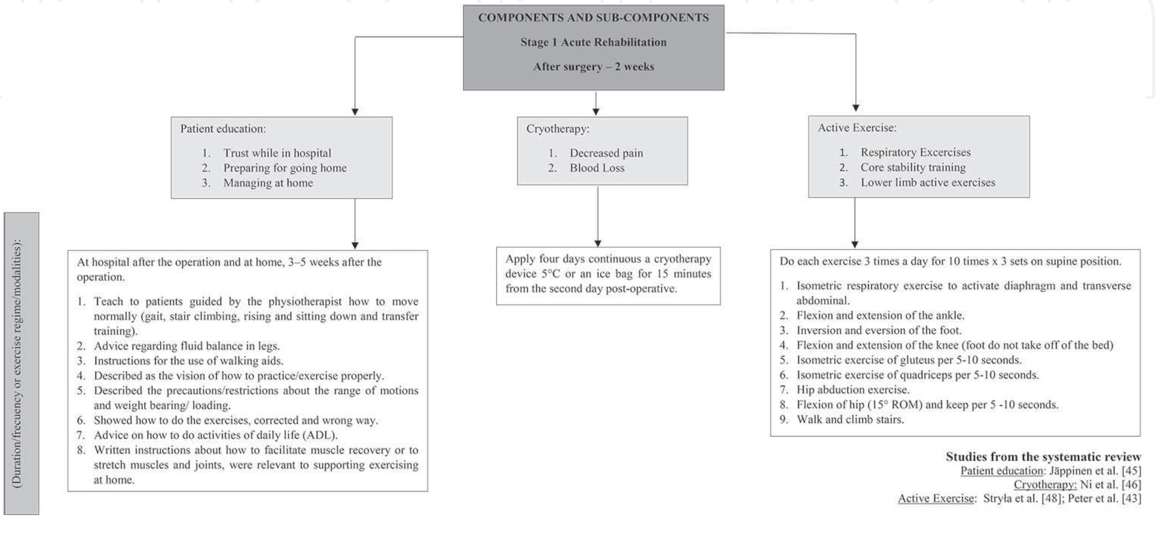

Figure 4.
Stage for acute rehabilitation after total hip and knee arthroplasty [43, 45, 46, 48].

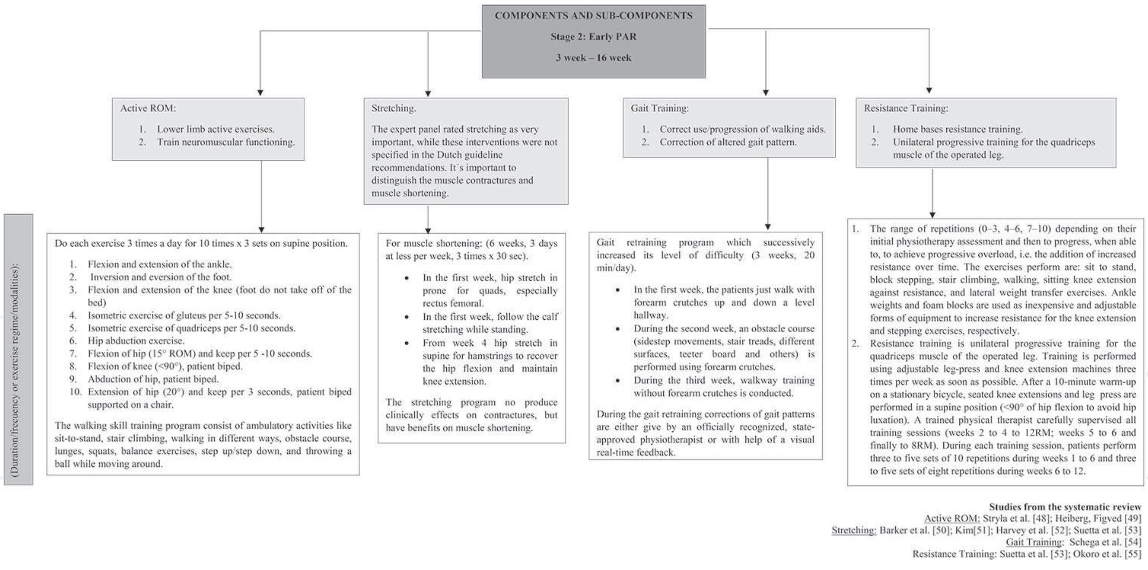

Figure 5.
Components and sub-components for the stage 2 [48–55].

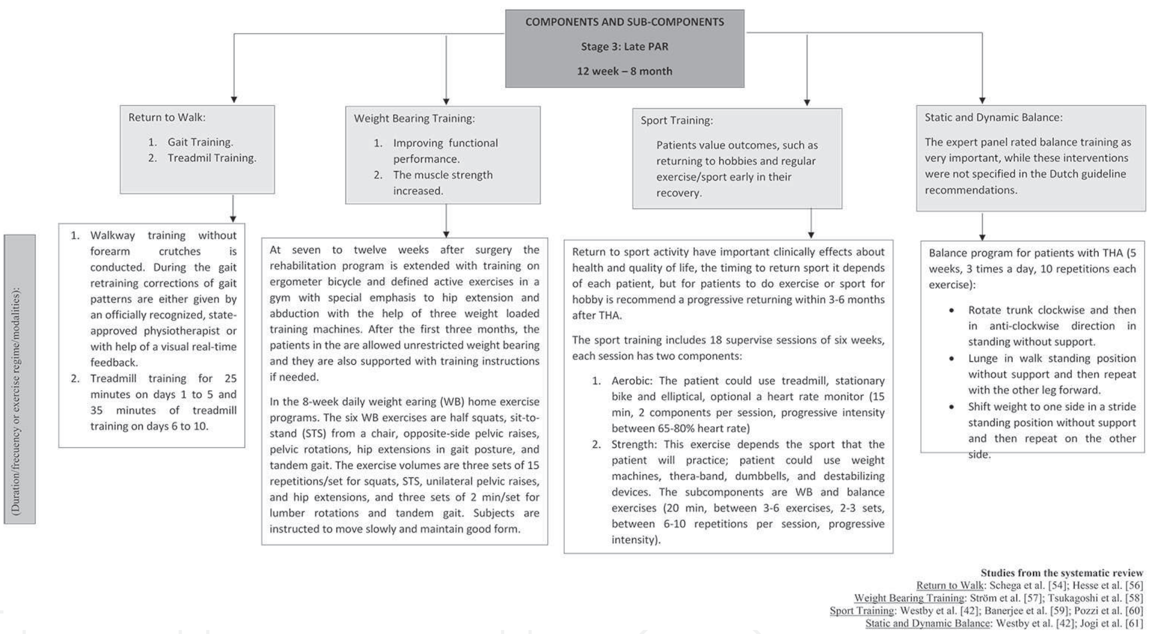

Figure 6.
Components and sub-components for the stage 3 [42, 54, 56–61].

muscle strength and ROM decrement's. This condition produces fear in the patient, leading to a high risk of falls, slowing down the gait, postural alterations and restrictions to perform the DLAs. Proprioceptive training through postural control improvement and dynamic stability aims to recover patient's function, normal gait pattern and quality of life [61].

7. Implementation design

This intervention program was designed as a low-cost online TR platform for self-motor rehabilitation and remote monitoring by health professionals, in order to enhance recovery in patients after hip replacement.

The Kinect camera was used as a natural user interface to capture some exercises performed by patients. The movement quality was evaluated in real time by an assessment module implemented according to a Hidden-Markov Model approach [63]. The exercise protocol was developed to supplement conventional physical therapy executed by patients at the hospital.

Before starting the exercise protocol, the platform requested the user to complete a questionnaire and an assessment about quality of life, functionality and DLAs. The questionnaire evaluates the patient's condition before undergoing the TR program. It is composed of three segments that inquire about pain, skin state and edema. Depending on user's responses, the platform allow the exercise program to be carried out during the session. The questionnaire served as a filter to access the program with the aim to avoid/control possible complications. Quality of life, functionality and DLAs were evaluated through the Oxford Scale for knee arthroplasty [64]. The questionnaire had to be completed at the beginning of each TR session while the functional evaluation at the end of each phase.

We will present the results of one [32], out of three preliminary studies, obtained after the implementation of some exercises proposed in this program. To record all movements a Kinect camera located approximately two meters away from the subjects was used.

Seven healthy subjects participated in the study comparing the assessment completed by four physiotherapists (PTs) with the evaluation performed by the TR platform algorithm.

The subjects were trained to perform a hip abduction movement, slow hip and knee flexion, hip extension and a sequence of steps forward, to the side and backwards. These sequences were repeated 11 times (one of them was used as a reference). The PTs had to follow an unknown script and it was randomized between participants (**Figure 7**).

The script was composed of six executions with normal ROM, two movements with an incorrect ROM and three compensatory movements. For each test, PTs were asked to evaluate all angles (ROM and compensations). The results of the

POSITION	MOVEMENT or EXERCISE	DESCRIPTION	TRAINING PATTERNS	OBSERVATIONS
Standing	Forward-sideway-backward sequence	Move the leg forward – return / – sideway-return/ and backward- return	- Sets: 3. -Repetitions per set: 10 - Rest between sets: 15 seconds	Return to initial position after each movement

Example

Figure 7.
Exercise for weight bearing training stage 3 (late PAR). (A) Initial position, (B) forward, (C) sideway, (D) backward.

evaluations were grouped into two categories that corresponded to incorrect or normal movement execution. The average of the four PTs scores were retained for the analyses. In case of a tie, the trial was discarded. Then, each average of this dichotomy variable (incorrect versus normal) were compared with the evaluation made by the algorithm. It was expected that the result would be different depending on the decision threshold.

The results showed that the algorithm corresponds in an 88% with the evaluation made by the PTs. There is certain variability in the performance of the assessment from one exercise to another. For example, the best results are obtained for the evaluation of the ROM for hip abduction and the forward and backward sequence (accuracy percentage > 90%).

The results of other studies were similar to these showing that it is possible to capture and analyze movement using a low cost system [32]. Consequently, the assessment of different types of movements, both in healthy people and in patients, has a high consistency rate among PTs and the system that is intended to be incorporated into a low-cost rehabilitation platform. A recent study validated the use of the Kinect within a TR system for THA (KiReS) [65]. This system allows PTs to define sets of exercises recorded in front of the Kinect. Successively, the patient executes the movement and his performance is compared to that of the PT. The movements analyzed were flexion, extension and abduction of the left and right hip. The unipodal equilibrium and squat movement executed with the lower left and right limb were also analyzed. The results showed a 91.88% consistency between the therapist's performance and that of the patient.

Our results are consistent with this study although our objective was to compare the simultaneous clinical assessment of several PTs with the system. However, the algorithms proposed in the three preceding studies not only evaluated and analyzed the limbs movement but also the compensatory movements. Patients often use compensatory strategies to facilitate movements [66]. Compensatory movements limit the limb affected functional recovery and can cause pain. This is the reason why a TR system should capture, limit and quantify the compensations. Compensatory movements adopted by patients create altered movement patterns that could limit the proper use of the affected limb in ADL [67, 68].

The Kinect camera works well especially when the user is facing the device, but the recognition of the skeleton from the top and side is not accurate. Moreover, in one of our studies the patient's clothing made it difficult to recognize the skeleton.

The TR could help solve accessibility limitations to rehabilitation services for many patients with THA. In addition, it can help reduce health care costs by allowing patients to empower themselves in their rehabilitation process. However, one of the biggest challenges is to convince the patient of the remote service. One study evaluated the feasibility of introducing a TR program for patients with THA, through a survey. The results indicated that TR in patients with THA is feasible from the perspective of access, feelings and preferences about technology [69]. Another study compared the implementation of a telerehabilitation program at home with a conventional rehabilitation program [70]. The results showed that the patients who got TR reached the same results for the evaluations on functional activities, exercises and patient education. Finally, a study comparing a TR program to a conventional THA program did not find significant differences in the results between the two programs [71].

8. Conclusions

The systematic review found 19 studies that explained the conventional physical therapy for THA. Commonly, the functional recovery is composed of three stages (acute, early and later rehabilitation). Based on this review, we designed exercises considering parameters such as ROM, coordination and compensation for a low cost TR web-platform. The exercises were evaluated at the same time by the PTs and by the platform. The algorithm used was able to recognize in real time the movements executed correctly and incorrectly in the three parameters mentioned above. The results showed compatibility between 88 and 91% (according to the movement assessed) between the TR system and the clinical assessment performed by the PTs. Furthermore, it is important to note that not all exercises applied in conventional physical therapy are possible to replicate in a TR system. This is due to the limitations of the movement capture by low-cost systems. Thus, for the moment this system can be used as a complement to conventional physical therapy. We can conclude that some exercises used as well as the movement analysis system can be implemented in a low-cost TR platform.

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Conflict of interest

No conflicts of interest have been reported by the authors or by any individuals in control of the content of this article.

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