International Doctoral Thesis

EFFECTIVENESS OF DIGITAL HEALTH INTERVENTIONS IN THE RECOVERY OF OLDER ADULTS WITH HIP FRACTURE AND THEIR FAMILY CAREGIVERS

Marta Mora Traverso

UNIVERSIDAD DE GRANADA

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EFECTIVIDAD DE INTERVENCIONES DE SALUD DIGITAL EN LA RECUPERACIÓN DE ADULTOS MAYORES CON FRACTURA DE CADERA Y SUS CUIDADORES INFORMALES

UNIVERSIDAD DE GRANADA

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Que la tesis doctoral titulada "*Effectiveness of digital health interventions in the recovery of older adults with hip fracture and their family caregivers*" que presenta Marta Mora Traverso al superior juicio del tribunal que designe la Universidad de Granada, ha sido realizada bajo mi dirección durante los años 2020-2024, siendo expresión de la capacidad técnica e interpretativa de su autora en condiciones tan aventajadas que le hacen merecedora del título de doctor, siempre y cuando así lo considere el citado tribunal.

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La huella de una profesión dedicada a los demás.

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ABSTRACT

ABSTRACT

Hip fracture is a major public health problem which has a traumatic impact on older adults and their caregivers, usually family members. Older adults suffer severe physical and psychological consequences, and their family caregivers take on a new role of responsibility for which they are often unprepared.

The resources available for the care of older adults with hip fracture are often limited, and this leads to the consideration of alternative options to conventional rehabilitation and care, such as digital health. This option is a promising alternative for providing rehabilitation and health education to both older adults with hip fracture and their family caregivers.

The present doctoral thesis has aimed to provide options for digital health interventions to improve the quality of care for older adults with hip fracture and their family caregivers. Three studies were carried out for this purpose. Through **study I**, we aimed to make it easier for healthcare professionals to follow up on older adults with hip fracture by employing easy-to-use tools. In **study II**, we tried to observe the effects of a hip fracture telerehabilitation intervention called @ctivehip, and delivered through a website, in older adults with hip fracture. Across **study III**, we proposed the protocol of a mobile Health (mHealth) intervention called ActiveHip+ for older adults with hip fracture and their family caregivers and we observed the effects of the intervention.

Our **study I**, a reliability study, with a sample of 60 participants, showed how the Spanish version of the Cumulated Ambulation Score is a reliable and easy tool to

measure basic mobility in older adults with hip fracture during the acute phase of recovery. **Study II**, a non-randomized clinical trial, with a sample of 71 participants, showed the effect of @ctivehip intervention on the improvement of quality of life, psychological factors, and fitness level of older adults with hip fracture. Lastly, through our **study III**, which consisted of the protocol of a ActiveHip+ mHealth intervention, and the subsequent randomized clinical trial of a sample of 105 participants, we observed the positive effect of this intervention on physical and psychological outcomes in older adults with hip fracture and their family caregivers. At the same time, we observed that these effects were not maintained in the long term, at one year follow-up.

Surely, the knowledge gained in the present doctoral thesis improves the understanding of the potential and limitations of digital health for the recovery of older adults with fracture and their family caregivers. At the same time, this doctoral thesis also outlines some aspects, identifying barriers and facilitators to achieve better outcomes in terms of recovery.

RESUMEN

RESUMEN

La fractura de cadera es un importante problema de salud pública que tiene un impacto traumático en los adultos mayores y sus cuidadores, los cuales generalmente son familiares (cuidadores informales). Los adultos mayores sufren graves consecuencias físicas y psicológicas, y sus cuidadores informales asumen un nuevo rol y una nueva responsabilidad para la que a menudo no están preparados.

Los recursos disponibles para la atención de adultos mayores con fracturas de cadera suelen ser limitados, lo que lleva a considerar alternativas a la rehabilitación convencional, como la salud digital. Esta opción es una alternativa prometedora para ofrecer rehabilitación y educación sanitaria tanto a los adultos mayores con fracturas de cadera como a sus cuidadores informales.

La presente tesis doctoral ha tenido como objetivo proporcionar opciones de intervenciones de salud digital para mejorar la calidad asistencial a los adultos mayores con fracturas de cadera y sus cuidadores informales. Para ello se han realizado tres estudios. A través del **estudio I**, pretendíamos facilitar a los profesionales sanitarios el seguimiento de los adultos mayores con fractura de cadera mediante el empleo de herramientas fáciles de usar. En el **estudio II**, intentamos observar los efectos de una intervención de tele rehabilitación llamada @ctivehip, a través de una página web, en adultos mayores con fractura de cadera. A través del **estudio III**, propusimos el protocolo de una intervención a través de salud móvil llamada ActiveHip+, para adultos mayores con fractura de cadera y sus cuidadores informales y observamos los efectos de la misma.

Nuestro **estudio I**, un estudio de fiabilidad, con una muestra de 60 participantes, mostró cómo la versión española de la Cumulated Ambulation Score, es una herramienta fiable y fácil para medir la movilidad básica en adultos mayores con fractura de cadera durante la fase aguda de recuperación. El **estudio II**, un ensayo clínico no aleatorizado, con una muestra de 71 participantes, mostró el efecto de la intervención de @ctivehip en la mejora de la calidad de vida, los factores psicológicos y el nivel de condición física de los adultos mayores con fractura de cadera. Por último, a través de nuestro **estudio III**, que consistió en el protocolo de una intervención ActiveHip+ mHealth, y el posterior ensayo clínico aleatorizado, de una muestra de 105 participantes, pudimos observar el efecto positivo de esta intervención en variables físicas y psicológicas de los adultos mayores con fractura de cadera y sus cuidadores familiares. Al mismo tiempo, observamos que estos efectos no se mantenían a largo plazo, al año de seguimiento.

Sin duda, los conocimientos adquiridos en esta tesis doctoral mejoran la comprensión del potencial y las limitaciones de la salud digital en la recuperación de los adultos mayores con fractura y sus cuidadores informales. Al mismo tiempo, esta tesis doctoral identifica barreras y facilitadores para lograr mejores resultados en términos de recuperación.

ABBREVIATIONS

- **ADLs**: Activities of Daily Living
- **ASA**: American Society of Anaesthesiologists
- **CAS**: Cumulated Ambulation Score
- **CAS-E**: Versión Española del Cumulated Ambulation Score
- **ICT**: Information and Communication Technologies
- **EQ-5D**: EuroQol Quality of Life Questionnaire
- **HADS**: Hospital Anxiety and Depression Scale
- **IFIS**: International Fitness Scale
- **m-Health**: Mobile health
- **FIM**: Functional Independence Measure
- **NMS**: New Mobility Score
- **SPPB**: Short Physical Performance Battery
- **SFES-I**: Short Falls Efficacy Scale-International
- **SPMSQ**: Short Portable Mental State Questionnaire
- **VAS**: Visual Analogue Scale for Pain
- **RCTs**: Randomised Controlled Trials

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GENERAL INTRODUCTION

OSTEOPOROSIS HIP FRACTURE

Osteoporotic hip fracture is an injury which occurs in the proximal femur, between the femoral head and 5 cm to the lesser trochanter (1). In most cases, the fracture occurs as a result of a fall, although in some cases it even happens without a traumatic episode, due to advanced osteoporosis (2).

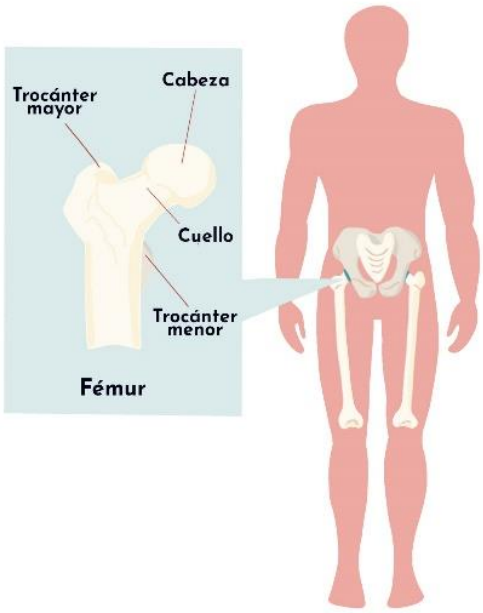


Figure 1. Anatomy of hip (Figure adapted from Guía práctica para pacientes con fractura de cadera (2)).

Hip fractures can be classified according to their relationship to the hip capsule (3). There are two main categories which can be illustrated in Figure 2**. Intracapsular fractures** are fractures that occur at the neck of the femur. It can be divided according to the location of the fracture in subcapital (at the femoral head-neck junction), transcervical (at the centre of the femoral neck), and basicervical (at the

base of the femur) (4). **Extracapsular fractures** are fractures that occur between the femoral neck and up to a distance of 5 cm from the distal part of the lesser trochanter (3). These are divided into intertrochanteric (between femoral neck and lesser trochanter) and subtrochanteric (between the lesser trochanter and 5 cm distal to the lesser trochanter) (4).

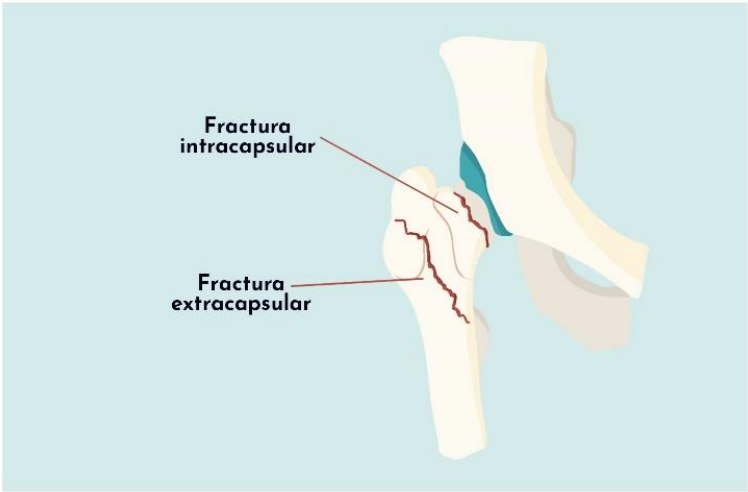


Figure 2. Classification of hip fracture according to the anatomical location (Figure adapted from Guía práctica para pacientes con fractura de cadera (2)).

There are two main strategies for surgically treating hip fractures: prosthesis or osteosynthesis. Prosthesis involves removing the fracture site and replacing the femoral head with a hemiarthroplasty or total hip arthroplasty. Osteosynthesis involves reducing the bone fragments to an acceptable position and retaining them until healing, usually with sliding hip screws, parallel implants or intramedullary screws (5).

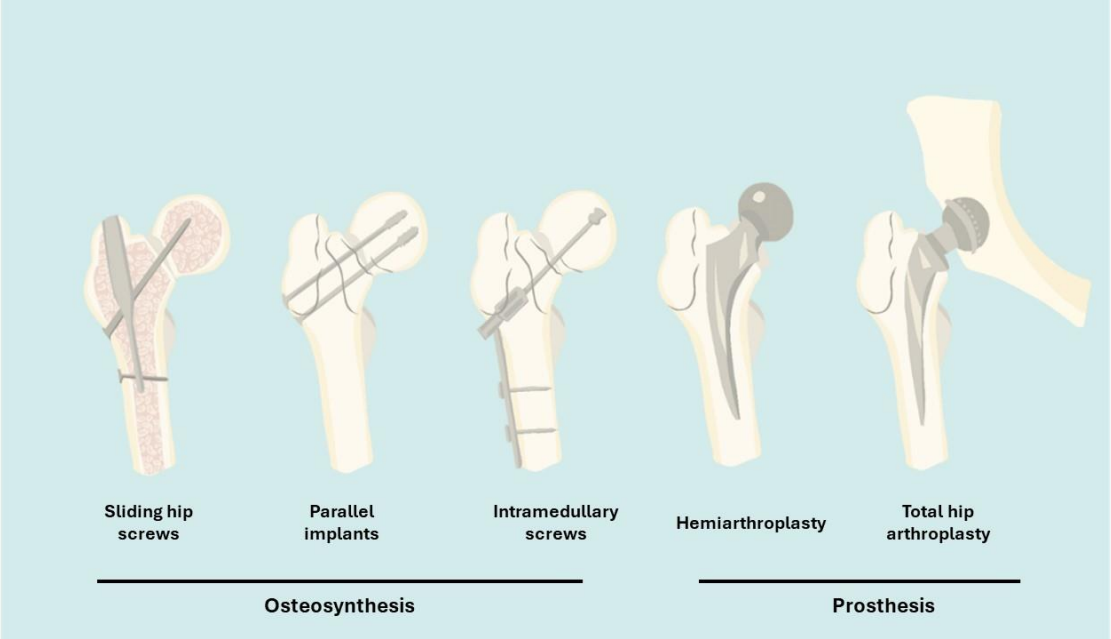


Figure 3. Types of hip fracture surgery (Figure adapted from Guía práctica para pacientes con fractura de cadera (2)).

THE MAGNITUDE OF THE PROBLEM – HIP FRACTURE IMPACT

Osteoporosis is a metabolic bone disease that commonly results in middle-aged and elderly people (6). It results from reduced bone mass and alteration of bone architecture, increasing fragility fractures (7). An increasing in the number of fragility fractures is expected due to the aging of the population, with significant consequences on health, quality of life, and social burden (8). Between fragility fractures due to osteoporosis, vertebral fractures are the most frequent, and hip fractures are the most serious (9).

Hip fracture caused by a fall from standing height or less, may also be termed fragility fracture, are the target population of this thesis. Hip fracture is a critical public health problem due to their incidence and individual and societal repercussions (10–12), which burden older adults and their environments (e.g.

family members). The incidence and number among older adults increased over the past three decades (13), over 10 million cases per year worldwide (14) and 250,000 cases/100,000 in Europe (15). According to epidemiological projections, the annual global figure is expected to increase to 6.26 million by 2050 (16,17), which is related to the increase in the world's elderly population (18), since approximately 17% of the global population is expected to be over 65 years old by 2050 (19). The incidence rate is higher in women with 76% making up the population with hip fracture (20). In Spain, the incidence is approximately 40,000 to 45,000 hip fractures per year (21), of which more than 90% are in adults over 65 years of age (22).

There are temporal and geographic variations in hip fracture incidence rates (7,23,24). Northern Europe and North America currently have the highest number of cases (25). The International Osteoporosis Foundation (IOF) reported that age-standardized incidence rates in women in Europe range from 246 in Romania to 677 in Denmark per 100,000 population (8). Compared to Europe, Asian countries have a lower age-standardised incidence (24). In Spain, Andalusia ranks fifth among Spain's 19 regions, being Valencia the highest region (26). Due to their high incidence and the rapidly growing elderly population, hip fracture constitutes one of the most difficult and fastest growing public health problems, which needs to be addressed.

Worldwide, there is a reported mortality rate of 17% to 25% within 1 year after hip fracture surgery in older adults (20,27), compared to an 11% mortality rate for healthy people with similar characteristics (28). Older adults with a hip fracture have five to eight times greater mortality than older adults without fractures within

3 months of their events, with the increased risk persisting even after 10 years (29). Although there is a higher proportion of hip fractures occurring in women (30), mortality is higher in men (12). In Spain, mortality at 30 days after fracture is 8.3 % and can be as high as 21% per year (31), with an annual in-hospital mortality rate between 3% and 5% (32). Among several prognostic factors associated with postsurgical in-hospital mortality, advanced age has been identified as the most important risk factor in older adults with hip fracture (33).

Hip fracture is also a high socio-economic burden since it requires surgery, hospitalization, and a long period of subsequent rehabilitation (34). Initial hospitalization (e.g. an average of 9 days in Spain (34)) costs an average of €10,000, and the rehabilitation during the first year after the surgery is more than €43,000 (28,35). There is a wide variation in costs between countries, and one of the factors associated with cost variation is the geographical region (28). In Europe, costs ranged from 5,306 euros for each hip fracture in Slovenia (34) to 30,906 euros in Finland (36). In Spain, every older adult who suffers a hip fracture has an economic cost of around €9.700, Madrid has the highest average cost (€12,000), while Andalusia has the lowest (€6,500), caused mainly by the differential length of the first hospital stay and outpatient care in the following months, as Madrid offers the highest number of rehabilitation sessions and days of formal home care, scarce or non-existent resources in Andalusia (37). The main cost driver in Spain is hospitalization (67-91%), followed by outpatient visits (7-17%) and home care (1-15%) (36).

CONSEQUENCES OF A HIP FRACTURE

In older adults

Hip fracture has severe physical and psychological consequences in older adults (38). The deterioration of the musculoskeletal system after a hip fracture surgery has a significant impact on physical performance (39), as loss of muscle strength (40), resulting from a loss of muscle mass (41). This leads them to experience a gradual decline in their functional status that often manifests itself in mobility limitations (42). Up to 60% of older adults are unable to regain their pre-fracture level of mobility (43) and 50% of them have problems walking independently one year after (43). Mobility in older adults with hip fracture surgery is influenced by various factors, such as comorbidity, cognitive function, social support, fatigue, and sleep quality (44). Decline in functional status (45) affects older adults' ability to perform Activities of Daily Living (ADLs) (between 60 to 80% need assistance to perform ADLs such as toileting and dressing (46)). For this reason, recovery their previous functional status becomes the main wish of older adults (5). This last point may prove to be a limiting factor, as they are aware of the long time it takes to recover the functional status they had before the fracture (5) and this ends up influencing their mood (47). There are factors that have a more severe impact following a hip fracture in the older adult; to be older than 85 years, has pre-fracture cognitive impairment, being nursing home residents and had a high American Society of Anaesthesiologists (ASA) rating are associate with worse functional outcomes and mortality after hip fracture (56).

Regarding the psychological consequences previously reported in the literature, (48,49), it is noteworthy that almost half of older adults with hip fracture suffer from anxiety (50) and the overall prevalence of depression is almost 23% (14), which could increase pain and emotional distress after surgery (50). A poor pain management is associated with delayed gait recovery, higher levels of depression, and poorer treatment adherence (51,52). Considering that the impairment of the older adults' functional status leads to fear to fall and it is estimated 95 % of hip fractures are due to falls (38), fear of falling is experienced by 50-65% of older adults (53). An excessive fear of falling may interfere with their ability to adapt to the rehabilitation process, which may, in turn, complicate the recovery process (53). Quality of life also suffers a negative generalized impact (29,54,55), especially in self-care, usual activities, and mobility (56). One month after surgery, quality of life is far from pre-fracture levels and deterioration lasts at least 12 months after fracture (56).

Older adults themselves have reported on the many ways hip fractures have impacted them both physically and with regards to their wellbeing over the years. Most speak of the loss of control over one's life and subsequent disruptions; the feelings of vulnerability; being in unexpected and new situations; and the conflict between self-reliance and dependency (57–59).

For family caregivers

Hip fracture in older adults also has significant physical, social, and economic consequences for family caregivers (29,60). Family caregivers are essential figures for maintaining older adults at home (61), and providing them with physical,

emotional, and social support (62). In Spain, half of older adults who suffer a hip fracture return home after hospital discharge (63), and like in other countries as Asia and South America (64), family caregivers are the primary source of support when older adults are dependent to be in their own home (5,65). They are often a "family member" who does not receive any financial remuneration for the care and support (66).

The unexpected and suddenness of the hip fracture, coupled with the care and acquisition of the new role, ends up turning the recovery process into a burden for them (66). High level of burden are experienced by 20% of family caregivers of older adults with hip fracture (67). Caregiver burden is a state characterized by fatigue, stress, and perceptions of limited social support available (55). The burden placed on family caregivers can negatively affect the functional recovery of older adults with hip fracture (68). The main manifestations that have been reported by them are caregiving burnout (this new role implies an adjustment in the caregivers' routine, as they have to combine care with their daily routine), frustration with communication problems with health care systems and lack of information on how to provide care to their relatives (65). More than half of family caregivers provide 8 hours or more of care per week, and one in five provide more than 40 hours per week (69).

Although caring can also be beneficial, as it allows family caregivers to feel good about themselves, learn new skills, and strengthen family relationships, (70), it has a negative impact on their physical and mental health (71). In fact, fear of their family member falling is also experienced by the family caregiver (72). They

experience chronic stress that may have a significantly negative impact on their quality of life (66), and depression and quality of life of family caregivers of older adults with hip fracture worsen substantially in the first 3 months (55,68). Older caregivers, people of low socioeconomic status, and those with limited support networks report poorer physical and mental health than family caregivers than who are younger and have more economic and interpersonal resources (73).

Despite the critical role that family caregivers play in the recovery process of older adults after a hip fracture, they often feel unprepared, have inadequate knowledge to provide adequate care, and receive little guidance and support during the recovery process (74). Therefore, family caregivers need to be integrated into the recovery process, providing more support and resource (62), as they consider important to be actively involved in the decision-making and in the recovery process (75). Consequently, providing family caregivers with standardized information-exchange tools during care transitions (76), and also training them on how to deal with the recovery process of older adults with a hip fracture would be a possible solution to support them (71).

HIP FRACTURE RECOVERY

Treatment of hip fracture usually consists of a combination of early surgical intervention, pain control, and rehabilitation (77). Surgical intervention is still the mainstay of care, even in very frail older adults with hip fracture, although it is sometimes debated whether surgery is the best option (78). The type of surgical intervention will depend on the site and severity of the fracture and personal factors

of the older adult (77,79). It has a high success rate (close to 85%) and positive clinical outcomes, including a reduction in mortality or morbidity (80,81). Current standards recommend surgical intervention within 24 hours (82) after hospital admission to mitigate the negative outcomes (81), such as bleeding (83), pain (84), immobility (85), or even mortality (86). Delays in the surgery, usually due to factors such as operating room availability or pre-operative medical approval (85), lead to longer hospital stays, which consequently increases the risk of mortality (86).

During the hospital stay, early mobilization and full weight bearing are recommended for shortened length of stay in the hospital, reduced postoperative pain, and increased walking ability (87). It is therefore recommended to bear weight on the operated hip on the same day of surgery or within 24 hours after surgery (88,89) and early assisted ambulation (started within 48 hours of surgery), which accelerates functional recovery and is associated with more direct discharge to home and less discharge to high-level care (90).

Rehabilitation interventions both during hospital stay and at discharge usually focus on physical aspects, such as improving mobility or walking speed (91). However, recovery of functional tasks, such as improving functionality in ADLs, is also necessary to gain greater confidence and independence on their return home (92). Therefore, comprehensive and multidisciplinary interventions are needed, combining physical activity and occupational therapy (93). This approach, based on training in meaningful activities, can lead to an increase in self-efficacy and have a beneficial effect on older adults (94).

Resource constraints in health systems, or capacity overload, have been associated with poorer older adults outcomes (95). Thus, in many cases, older adults with hip fracture receive no rehabilitation or only a few sessions during their hospital stay (96). In addition, in certain cases or situations, older adults have difficulty accessing hospital services, either because they live in rural areas far from the city (97), or in situations such as the coronavirus disease 2019 (COVID-19) pandemic (95).

On the other hand, follow-up of older adults with hip fracture is an important issue during the recovery process, however, there is no consensus on the optimal period for follow-up (98) and it is an essential component of care to ensure optimal outcomes. Follow-up of older adults, who may reside in nursing homes or with family caregivers, is often difficult because of their difficulty in attending postoperative visits to the hospital (99). At the same time, follow-up also places a high burden on health professionals, as is the case in the Spanish health system, which has limited health resources to ensure the continuity of care (100). In such cases, fast, valid, and reliable measurements to assess the progress or deterioration of basic mobility, such as the Spanish version of the Cumulated Ambulation Score (CAS) (101), can be the solution for easing the clinical practice. Careful long-term follow-up, with attention to frail older adults with hip fracture, should certainly be encouraged.

Despite the recognition about family caregivers play an important role in successful recovery and transition home after hospitalization, limited information is available about how family caregivers experience in transition home (102). Previous

interventions which have aimed to support family caregivers with information and some techniques for the management of the older adult with hip fracture (103) are time-limited as they focus on the first few days and are not adapted to the older adult's evolution.

Against this background, more intervention alternatives are needed to address hip fractures and its consequences, such as providing rehabilitation outside the hospital setting, including at the older adult's home, and considering the key role of the family caregivers.

DIGITAL HEALTH

Home-based interventions have gained prominence in recent years due to the omnipresence of devices such as smartphones, tablets, and laptops that allow rehabilitation anywhere (104), allowing more people to access rehabilitation, and reducing travel to hospital.

Digital health, the use of Information and Communication Technologies (ICT) to support healthcare delivery is ideally placed to address the need to develop alternatives for hip fracture rehabilitation, especially now that the use of ICT is becoming more widespread (105). Telerehabilitation, a set of tools to carrying out the rehabilitation process remotely [98], and mobile health (mHealth), the use of mobile and wireless technologies to support the achievement of health goals (106), are two of the types of digital health emerging with particular potential (107).

Digital health is a promising option to provide telerehabilitation and health education, given their potential reach to higher percentage of population and the possibility of monitoring outside the hospital (108). Improving the exchange of information, fostering communication between older adults, their family caregivers, and healthcare professionals (109) and also facilitating follow-up for healthcare professionals, which is essential, as only 30% of older adults with a fracture receive adequate follow-up (110,111). Digital health has proven to be beneficial in reducing travel time to the health centres by 4 h 27 minutes per person (104), and also saving both the older adults and the healthcare professionals time in the treatment (112). However there are also some barriers to implementing digital health in hip fracture recovery, for example, the lack of skills in using mobile devices due to the high average age (113). These barriers can be addressed by including their family caregivers in the recovery process, as they are younger and have better skills with mobile devices (114). In addition, including family caregivers as active agents in the recovery process of the elderly in their care will improve their health and well-being (109).

To date, there are limited evidence of digital health in older adults with hip fracture (107,115,116). All of them being telerehabilitation programs studying the effect of telerehabilitation intervention in older adults with hip fracture. However, there are no interventions that prove the efficacy of digital health interventions in the recovery of older adults with hip fracture, actively involving their family caregivers and providing them with resources for supporting the recovery process.

SUMMARY OF THE CONTRIBUTION OF THIS THESIS

In short, these are the main gaps detected in the evidence about assessment and digital health in older adults with hip fracture:

- There are not enough valid, reliable, and brief assessment tools in Spanish language which can be used by healthcare professionals to measure changes in the recovery process.
- Little is known about the effectiveness of digital health interventions in the recovery of older adults with hip fracture.
- The role of family caregivers is neglected in the recovery of older adults with hip fracture, and they are not included in the design of new interventions.
- There is no evidence for one-year follow-up of older adults with hip fracture who receive digital health interventions.

Based on these literature gaps, the present doctoral thesis provides the following contributions to the current knowledge:

- A reliable instrument which can be used by healthcare professionals to assess the basic mobility status of older adults with a hip fracture (**Study I**).
- The effects of a telerehabilitation intervention called @ctivehip improving the quality of life and the fitness level of older adults with a hip fracture and reducing their anxiety and depression (**Study II**).
- A protocol of the ActiveHip+ m-Health intervention for the recovery of older adults with hip fracture and their family caregivers (**Study III**).

- The effect of the ActiveHip+ mHealth intervention on the recovery of physical and psychological outcomes of older adults with hip fracture and their family caregivers (**Study III**).
- One year follow up of the ActiveHip+ mHealth intervention in older adults with hip fracture and their family caregivers (**Study III**).

AIMS

- The general aim of this doctoral thesis is to test the effectiveness of digital health interventions in older adults with hip fracture and their family caregivers.

SPECIFIC AIMS

OVERALL AIM

- The general aim of this doctoral thesis is to test the effectiveness of digital health interventions in older adults with hip fracture and their family caregivers.

SPECIFIC AIMS

SECTION I. Translation of the Spanish version of the Cumulated Ambulation Score.

Study I:

- To translate the cumulate ambulation score (CAS) into Spanish.
- To measure the inter-rater reliability, concordance, and internal consistency of the CAS Spanish version (CAS-E).

SECTION II. @ctivehip telerehabilitation intervention in older adults with hip fracture.

Study II:

- To test the effectiveness of @ctivehip telerehabilitation intervention on the quality of life, psychological factors, and fitness level of older adults with hip fracture.

SECTION III. ActiveHip+ mHealth intervention in older adults with hip fracture and their family caregivers.

Study III:

- To design the protocol for the ActiveHip+, an m-Health intervention composed of occupational therapy, physical exercise, and health education for older adults with hip fracture supported by their family caregivers.
- To test the effectiveness of ActiveHip+ mHealth intervention on physical and psychological outcomes of older adults with hip fracture and their family caregivers.
- To test the effectiveness of ActiveHip+ mHealth intervention in the follow-up to the year.

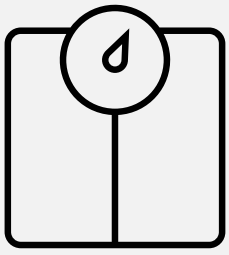
METHODOLOGIES AND RESULTS

TABLE 1. OVERVIEW OF THE METHODOLOGICAL APPROACHES OF THE STUDIES INCLUDED IN THIS THESIS.					
SECTION	**STUDY**	**DESIGN OF THE STUDY**	**SAMPLE**	**INCLUSION AND EXCLUSION CRITERIAS**	**OUTCOMES COLLECTED**
Section I	Study I	Reliability study	**(*n*=60)** 60 older adults with a hip fracture	**Inclusion criteria:** 1. To have undergone surgery for a hip fracture. 2. To be admitted at the trauma service of the Virgen de las Nieves University Hospital, Granada, Spain. 3. To be 65 years or older. 4. To sign informed consent.	Inter-rater reliability (kappa, McNemar-Bowker test, and Bland-Altman analysis).
Section II	Study II	Non-randomized Clinical Trial study	**(*n*=71)** 35 located in the @ctivehip group, and 36 located in the control group	**Inclusion criteria:** 1. To have hip fracture surgery. 2. To be 65 years or older. 3. To have a high (self-reported) pre-fracture functional level the week before the fracture (Functional Independence Measure [FIM] index > 90 points). 4. To allow weight-bearing at 48 h after surgery. 5. To have community-dwelling after hospitalization. 6. To have a family caregiver with internet access. **Exclusion criteria:** 1. Presence of severe cognitive impairment (Mini-Mental State Examination score lower than 24 points). 2. To have a terminal disease. 3. To have post-surgery complications that made it impossible to begin rehabilitation during the first week after surgery.	**Main outcomes** **Of older adults with a hip fracture** Quality of life (EQ-5D) Psychological actors (HADS) Fitness level (IFIS)
Section III	Study III	Protocol study (subsequent Randomized Control Trial study)	**(*n*=105)** 55 located in ActiveHip+ intervention group and 55	**Inclusion criteria:** 1. To be diagnosed with a hip fracture. 2. To be 65 years or older.	**Main outcome:** Physical performance (SPPB) and (handgrip dynamometer) of older adults with hip fracture.

	located in the control group.	3. To allow weight-bearing at 48 hours after the surgery. 4. To have high pre-fracture functional level the week before the fracture (Functional Independence Measure [FIM] index scored more than 90 points). 5. To live at their own home or the home of relatives after hospital discharge. 6. To have an informal or family caregiver who can access Internet to use mobile app. **Exclusion criteria:** 1. The presence of severe cognitive impairment (Pfeiffer test score higher than 4 errors). 2. Institutionalized. 3. To have post-surgery complications that make it impossible to start rehabilitation within the first week post-surgery. 4. The presence of terminal diseases.	**Secondary outcomes:** **In older adults with hip fracture:** Quality of life (EQ-5D) Functional status (FIM) Fear of falling (SFES) Pain (VAS) Psychological factors (HADS) **In family caregivers of older adults with hip fracture:** Quality of life (EQ-5D) Fear of falling (SFES) Fitness self-perception (IFIS)

SECTION I

Translation of the Spanish version of the Cumulated Ambulation Score



STUDY I

Translation of the Spanish version of the Cumulated Ambulation Score.

Disability and Rehabilitation (Q1 in REHABILITATION)

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/ METHODS /

Procesure

We enrolled 60 consecutive older adults with hip fracture, admitted to the trauma service of the Virgen de las Nieves University Hospital, Granada, Spain, between January 2017 and March 2017. We included all older adults aged 65 years and older. For those with cognitive impairment, the informed consent was signed by their relatives. The study was approved by the ethics committee of the Research Center of Granada (CEI-Granada), and all older adults, or their proxy, signed a consent form before starting the study.

We extracted the following descriptive information from the medical chart for each patient: weight, height, type of fracture, and type of surgery. During an in-person interview (conducted between day 2 and 6 post-surgery) we collected the following sociodemographic and clinical information: age, gender, highest level of education, residence (pre-fracture and discharge), cognitive status [Short Portable Mental State Questionnaire (SPMSQ, 0-11 points) coding the following subgroups: <3 points = no cognitive impairment; 3-4 points=mild cognitive impairment; 5-7 points = moderate cognitive impairment; and >8 points = severe cognitive impairment] [26], self-perceived health (5 item Likert scale: 1 = excellent; 2 = very good; 3 = average; 4 = fair; and 5 = poor), pre-fracture functional level [Functional Independence Measure [FIM, 18 (minimum level of independence) to 126

(maximum level of independence)] (27), and pain [visual analogue scale (VAS, from 0 (no pain) to 10 points (maximum pain)] (28).

The Cumulated Ambulation Score (CAS)

The CAS describes three basic mobility activities: (i) getting in and out of bed with the sequence of events as follows: the older adult starts in the supine position on the bed, moves to sitting, standing ,or transferring to a chair next to the bed, then returns to sitting, and then supine position on the bed; (ii) sit to stand to sit from a chair with armrests (with or without assistance from aids), and (iii) walking indoors (with or without walking aids) (7). All three CAS activities are graded out of two points, and they are summed to generate a total one-day score from 0 (dependent [bed bound]) to 6 (independent). Each activity is scored with 2 points when verbal or physical assistance is not required (independent), even for safety reasons; 1 point is assigned when human assistance (verbal or physical assistance) is required from one or more persons; and no points are given when the older adult is not able to do the activity despite human assistance (dependent) (7). Overall, it takes 5-10 minutes (depending on the older adult's mobility level) for the clinician to observe the older adult complete the three activities of the CAS in the clinical setting.

Translation of the CAS

We followed the recommendations provided by Ramada-Rodilla and colleagues (29) to translate the comprehensive English version of the CAS manual (30). Two

people (occupational therapists unfamiliar with the CAS) independently translated it from English to Spanish using the expressions of the Spanish culture and language (to preserve the original intent of the test). A third person (physiotherapist) without knowledge of the original version of the CAS synthesized the two versions described above. The objective in this phase was to identify possible differences, difficulties, or errors of the Spanish translation compared with the original English version, and to reach consensus on the final CAS-E version. The back translation was conducted by a fourth person (physician) who was a native English speaker. The English version was forwarded to Dr. Kristensen, one of the original CAS developers (7), for confirmation. Some minor corrections were needed for the original CAS scoring procedure, which were added to the new CAS-E procedure. The final version of the CAS-E was approved by everyone involved in the translation process and is available as supplementary material.

Inter-rater Reliability

We followed the procedures outlined by Kottner and colleagues (31) to exam inter-rater reliability for the CAS-E. One senior dual-trained occupational and physiotherapist (Dr. Ariza-Vega who was trained by the CAS developer, Dr. Kristensen) and one novice CAS user (a graduate student and occupational therapist; blinded for peer-review) tested inter-rater reliability of the CAS-E. For our preliminary work, the raters first met to confirm all procedures. Following this, the senior therapist (Dr. Ariza-Vega) completed the CAS-E with 15 in- older adults with hip fracture, while the novice CAS user (Ms Mora-Traverso) observed the procedure.

No adjustments in the CAS-E score manual were necessary during this process. The following day, the two raters evaluated six older adults with the CAS-E in the same session (data not included in the results of this study) and discussed their CAS scores to reach a mutual understanding for scoring older adults.

We followed standardized procedures to assess the inter-rater reliability of the CAS-E based on published literature for reliability studies (7,32). The entire test procedure was conducted as part of daily clinical practice before the usual therapy sessions. Each of the two raters was the lead on 30 assessments, with the order of raters' tasks randomly assigned. During a data collection session, the lead rater provided instruction and supervision to older adults. During this time, the other rater was present to score the outcome (32). Raters were instructed to score older adult's abilities independently and did not discuss their ratings until the end of the study (32). A third person collected the score sheets from both raters at the end of each day.

Sample size

We based the sample size on the recommendations of Nunnally (33), who consider a minimum of five participants per questionnaire item, and Hopkins (34) who suggests precision for reliability estimates require a minimum of 50 study participants. We included 10 additional older adults (total n=60) to increase the precision of the estimate.

Statistical analysis

We present continuous data as means (standard deviation), medians (q25, q75) or number and percentages depending on the data and its distribution. We used the Shapiro-Wilk Test for examination of normal distribution of continuous data, and Chi-square or Fisher's Exact test to explore differences for categorical data. We used Cronbach's α coefficient (35) to test for internal consistency. The Cronbach's α coefficient ranges from 0 to 1: values lower than 0.70 are considered unacceptable, values between 0.70 and 0.80 acceptable, and values higher than 0.80 good (36,37). To calculate the inter-rater reliability (for individual activities and the total CAS-E) we used a linear weighted kappa with 95% confidence intervals (130) for ordinal scales. We used the guide provide by Landis and Koch (24) for interpreting kappa values where values between 0.0 and 0.2 indicate slight agreement, between 0.21 and 0.40 indicate fair agreement, between 0.41 and 0.60 indicate moderate agreement, between 0.61 and 0.80 indicate substantial agreement, and between 0.81 and 1.0 indicate almost perfect agreement. We calculated the percent agreement between raters and the prevalence of scores 0–2 for the three activities and the total CAS-E. Second, we assessed systematic between-rater bias using the McNemar-Bowker test. Third, we provide a Bland-Altman plot to illustrate differences between scores of the two raters. Finally, we report the standard error of measurement (SEM= SD x $\sqrt{}$(1- $ICC_{2.1}$)) (39) and the smallest real difference (SRD = SEM x $\sqrt{}$2 x 1.96) (40) to compare the measurement error with previous CAS reliability studies (7,17). The ICC cut off values provided by Cicchetti DV (41) indicate poor agreement for values lower than 0.40, fair agreement from 0.40 to 0.59, good agreement from 0.60 and 0.74, and excellent

agreement from 0.75 to 1. We used IBM SPSS Statistics Version 20.0 (IBM Corp., Armonk, New York), and set the level of significance at $P<0.05$.

/ RESULTS /

Few challenges were translating the English version of the CAS into Spanish (CAS-E). The final version of the CAS-E was very similar to the two versions translated by the two occupational therapists. The main differences were related to the nuances of the Spanish language, and the use of the passive verbal form to assign the score of each of the three items. The back translation had only two ambiguities resulting from semantic and or idiomatic peculiarities of English and Spanish. They included: i) "... to sitting in chair placed beside the bed...." (The initial CAS-E instructions for bed transfers did not specify chair position or the option to stand up from the bed; the final version of the CAS-E clarified this item.); and ii) categories of scores"... from one or more person" (The initial CAS-E version stated the assistance of one or more person; however, the instructions were changed to “human assistance”. Finally, the term “extensive” was included in the final CAS-E version when the scores described the need of “extensive physical assistance” and or “extensive assistance”. The initial version of the CAS-E used the terms “physical assistance” and “assistance”.

We provide sociodemographic and clinical data for the 60 consecutive in-older adults with hip fracture, which were recruited in 48 days (Table 2). All older adults were evaluated by the two raters between day 2 and 6 post-surgery.

Table 2. Characteristics of older adults.

Variable	N (%)
Age, y mean (SD); min-max	81.6 (6.8); 64-96
Gender	
Women	46 (77)
Men	14 (23)
Body Mass Index, (BMI) kg/m^2	
Underweight, BMI < 18.5	1 (2)
Normal, BMI =18.5-24.9	18 (30)
Overweight, BMI ≥ 25	41 (68)
Highest level of Education	
Cannot read and write	16 (27)
Can read and write	25 (42)
Primary school	13 (22)
High School	3 (5)
College (University)	3 (5)
Type of fracture	
Intracapsular	40 (67)
Extracapsular	20 (33)
Type of Surgery	
Dynamic Hip Screw / Intra Medullar Hip Screw	32 (53)
Hemiarthroplasty	28 (47)
Cognitive Status	
No cognitive impairment	27 (45)
Mild cognitive impairment	14 (23)
Moderate cognitive impairment	10 (17)
Severe cognitive impairment	9 (15)
Self-perceived health	
Excellent	1 (2)
Very Good	21(35)
Average	23 (38)
Fair	12 (20)
Poor	3 (5)
Pre-fracture Functional Level (measured by FIM)	102 (79-124)
Pain during activity (measured by VAS)	5.15 (2.41); 0-9
Pre-fracture residence	
Home, lives alone	17 (28)
Home, lives with someone	28 (47)
Relative´s home	9 (15)
Nursing home	6 (10)
Discharge destination	
Home, lives alone	4 (7)
Home, lives with someone	30 (50)
Relative´s home	18 (30)
Nursing home	8 (13)
Total CAS-E, mean (SD); min-max	
novice therapist	3.32 (1.86); 0-6
senior therapist	3.30 (1.91); 0-6

Values are presented as median (q25-q75); number of older adults (%) and mean (standard deviation); minimum-maximum, as appropriate.

Inter-rater reliability: The weighted kappa was ≥ 0.83 for the three activities and the total CAS-E, while the percent agreement ranged from 0.87 (total CAS-E) to 0.97 (getting in and out of bed) as shown in Table 3. The ICC for the total CAS-E was 0.97. The SEM and the SRD for the total CAS-E (0-6) were 0.30 and 0.83 CAS-E points respectively, while the corresponding values for the three activities ranged from 0.13 to 0.18 (SEM) and from 0.36-0.50 (SRD), respectively (Table 3). The scores by the two raters differed in eight of the 60 older adults but the difference was only 1 point, except for 2 points in one older adult, and with no systematic between-rater bias for the three individual activities or the total CAS-E, as illustrated in the Bland-Altman plot (Figure 4). Nor was there any statistically significant difference in any of the clinical and sociodemographic characteristics shown in Table 2 between the eight older adults with score differences and the 52 older adults with equal scores. The Cronbach's α for the CAS-E was 0.89 for both raters when evaluated separately.

Table 3. Inter-rater reliability and agreement of the Cumulated Ambulation Score (CAS) between an experienced and inexperienced occupational therapist score user in older adults with hip fracture.

	Linear weighted Kappa value	Observed agreement	Prevalence in % of CAS score 0-2			SEM	SRD
Activity (score)	(95% CI)	n (%)	0	1	2		
Getting in and out of bed (0-2)	0.94 (0.86-1.0)	58 (96.7)	13	60	27	0.13	0.36
Sit-to-stand-to-sit from a chair (0-2)	0.94 (0.87-1.0)	58 (96.7)	17	53	30	0.13	0.36
Walking with an aid, indoor (0-2)	0.90 (0.80-1.0)	56 (93.4)	27	43	30	0.18	0.50
Total CAS (0-6)	0.83 (0.73-0.94)	52 (86.8)	n/a	n/a	n/a	0.30	0.83

CI: confidence interval; SEM: Standard Error of Measurement; SRD: Smallest Real Difference.

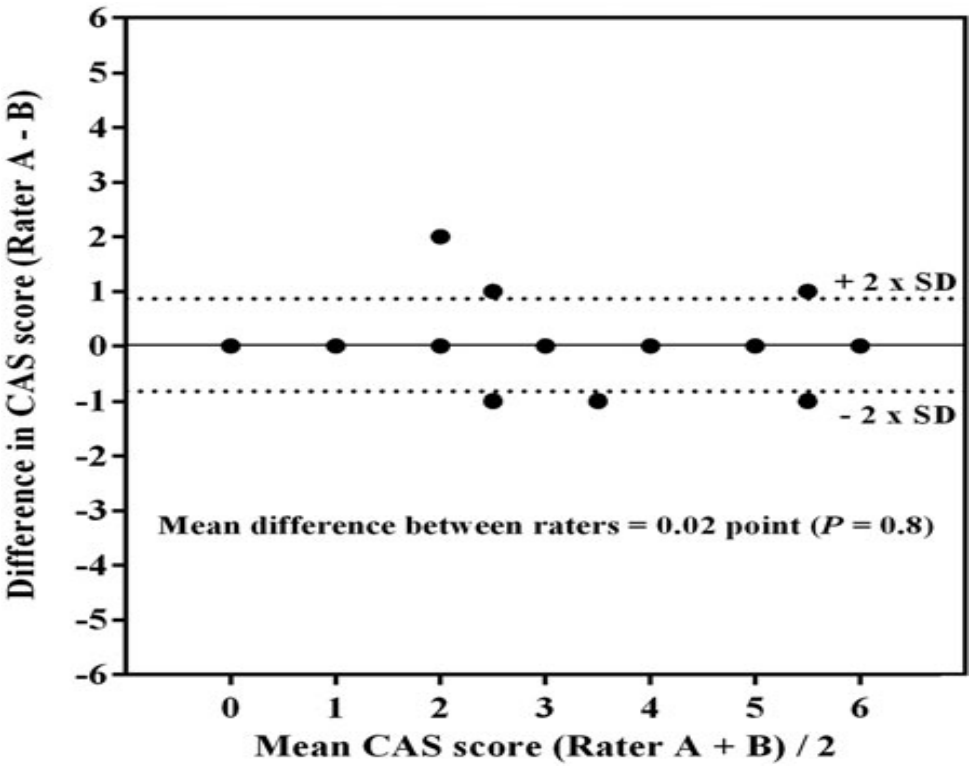


Figure 4. Bland-Altman plot of a novice (rater A) and senior (rater B) occupational therapists scores for the Spanish version of the Cumulated Ambulation Score (CAS-E).

/ SUPLEMENTARY MATERIAL /

Spanish version of the Cumulated Ambulation Score (CAS-E)

Escala de Movilidad Acumulada (CAS-E)			
Actividad	Capaz de hacerlo independientemente (Sin guía verbal ni ayuda física), 2 puntos	Capaz de hacerlo con guía verbal o ayuda física de una o varias personas, 1 punto	Incapaz de hacerlo incluso con ayuda física de otras personas, 0 puntos
Levantarse de la cama y acostarse			

Levantarse y sentarse en una silla ***con reposabrazos***			
Caminar dentro de casa con o sin dispositivo de apoyo terapéutico para caminar			
Puntuación Total, 0-6 puntos:			

Figure 5. Spanish version of the Cumulated Ambulation Score (CAS-E) tool.

Spanish Instructions of the tool

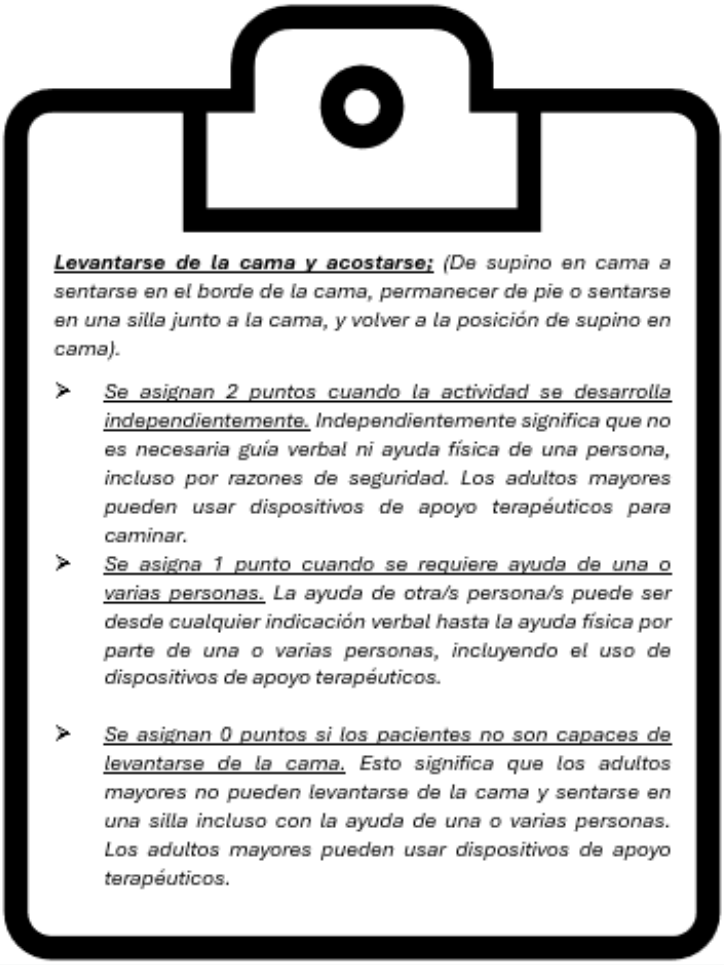
El CAS es una escala que puede ser utilizada para la evaluación diaria de la movilidad básica y su evolución hasta que se consigue la deambulación independiente. Incluye:

- *Levantarse de la cama y acostarse*
- *Levantarse y sentarse en una silla con apoyabrazos*
- *Caminar dentro de la casa con o sin la ayuda de un dispositivo de apoyo terapéutico para caminar*

Cada una de las tres actividades puede ser puntuada entre 0 y 2 puntos, dando como resultado una puntuación diaria total de 0 a 6 puntos (CAS-E de un día) (120,136,137).

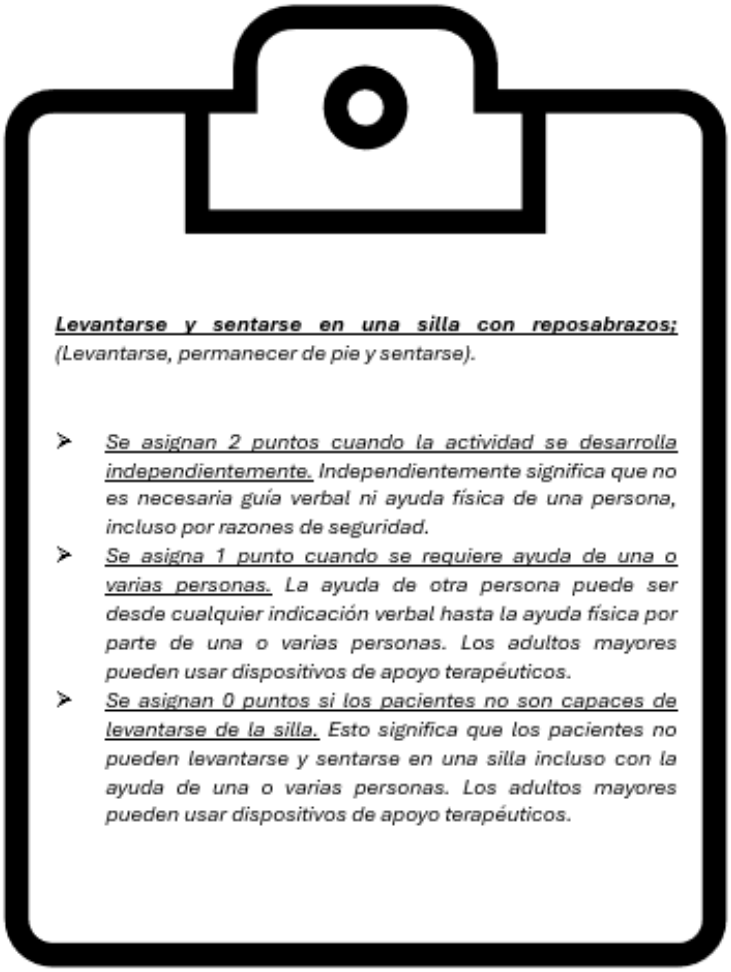
El CAS ha demostrado ser una escala fiable y útil para la predicción temprana de la rehabilitación /hospitalización. Para dicha predicción se considera la suma de los tres primeros días, obteniendo una puntuación total del CAS de 0 a 18 puntos (CAS de tres días consecutivos) (138).
Un CAS > 9 puntos en los 3 primeros días postoperatorios ha mostrado ser predictivo del alta hospitalaria durante los primeros 14 días, del alta directamente al domicilio del adulto mayor, de la ausencia de complicaciones médicas mayores, y de la supervivencia a los 30 días en adultos mayores con fractura de cadera (138).

La descripción de cómo se puntúa el CAS está descrita en el apéndice del estudio de confiabilidad del CAS de 2009 (139).



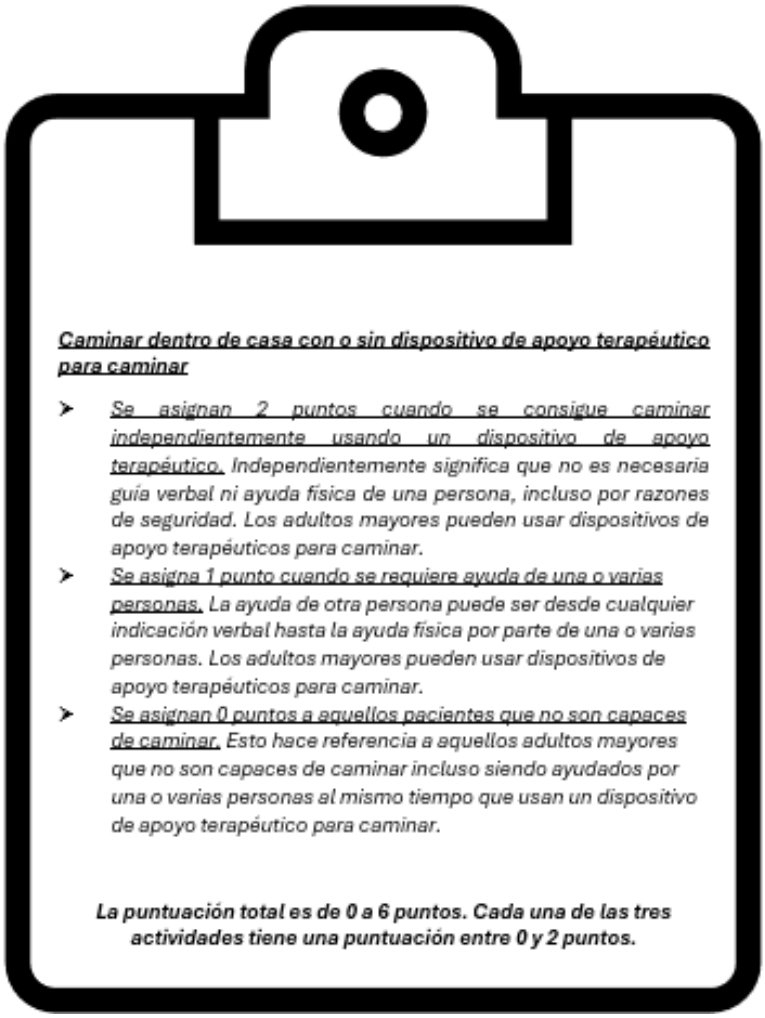
Levantarse de la cama y acostarse; *(De supino en cama a sentarse en el borde de la cama, permanecer de pie o sentarse en una silla junto a la cama, y volver a la posición de supino en cama).*

- *Se asignan 2 puntos cuando la actividad se desarrolla independientemente. Independientemente significa que no es necesaria guía verbal ni ayuda física de una persona, incluso por razones de seguridad. Los adultos mayores pueden usar dispositivos de apoyo terapéuticos para caminar.*
- *Se asigna 1 punto cuando se requiere ayuda de una o varias personas. La ayuda de otra/s persona/s puede ser desde cualquier indicación verbal hasta la ayuda física por parte de una o varias personas, incluyendo el uso de dispositivos de apoyo terapéuticos.*
- *Se asignan 0 puntos si los pacientes no son capaces de levantarse de la cama. Esto significa que los adultos mayores no pueden levantarse de la cama y sentarse en una silla incluso con la ayuda de una o varias personas. Los adultos mayores pueden usar dispositivos de apoyo terapéuticos.*



Levantarse y sentarse en una silla con reposabrazos; *(Levantarse, permanecer de pie y sentarse).*

- *Se asignan 2 puntos cuando la actividad se desarrolla independientemente. Independientemente significa que no es necesaria guía verbal ni ayuda física de una persona, incluso por razones de seguridad.*
- *Se asigna 1 punto cuando se requiere ayuda de una o varias personas. La ayuda de otra persona puede ser desde cualquier indicación verbal hasta la ayuda física por parte de una o varias personas. Los adultos mayores pueden usar dispositivos de apoyo terapéuticos.*
- *Se asignan 0 puntos si los pacientes no son capaces de levantarse de la silla. Esto significa que los pacientes no pueden levantarse y sentarse en una silla incluso con la ayuda de una o varias personas. Los adultos mayores pueden usar dispositivos de apoyo terapéuticos.*



Caminar dentro de casa con o sin dispositivo de apoyo terapéutico para caminar

- *Se asignan 2 puntos cuando se consigue caminar independientemente usando un dispositivo de apoyo terapéutico. Independientemente significa que no es necesaria guía verbal ni ayuda física de una persona, incluso por razones de seguridad. Los adultos mayores pueden usar dispositivos de apoyo terapéuticos para caminar.*
- *Se asigna 1 punto cuando se requiere ayuda de una o varias personas. La ayuda de otra persona puede ser desde cualquier indicación verbal hasta la ayuda física por parte de una o varias personas. Los adultos mayores pueden usar dispositivos de apoyo terapéuticos para caminar.*
- *Se asignan 0 puntos a aquellos pacientes que no son capaces de caminar. Esto hace referencia a aquellos adultos mayores que no son capaces de caminar incluso siendo ayudados por una o varias personas al mismo tiempo que usan un dispositivo de apoyo terapéutico para caminar.*

La puntuación total es de 0 a 6 puntos. Cada una de las tres actividades tiene una puntuación entre 0 y 2 puntos.

SECTION II

@ctivehip telerehabilitation intervention in older adults with hip fracture

STUDY II

Effects of the @ctivehip telerehabilitation intervention on the quality of life, psychological factors, and fitness level of older adults with hip fracture.

Journal of Telemedicine and Telecare (Q1 in HEALTH CARE SCIENCIES & SERVICES)

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/METHODS /

Study design and population

The present study is a non-randomized clinical trial, conducted according to the established guidelines by the Helsinki Declaration and Law 14/2007 on Biomedical Research. This project was approved by the Ethics Committee of the Research Center of Granada (CEI-GRANADA) and registered at ClinicalTrials.gov (Identifier: NCT02968589).

The inclusion criteria to be included in the study were: [1] to have hip fracture surgery; [2] to be 65 years or older; [3] to have a high (self-reported) pre-fracture functional level the week before the fracture (Functional Independence Measure (FIM) index > 90 points); [4] to allow weight-bearing at 48 h after surgery; [5] to have community-dwelling after hospitalization; and [6] to have a family caregiver with internet access. The exclusion criteria were: [1] the presence of severe cognitive impairment (Mini-mental State Examination score lower than 24 points) (140); [2] to have a terminal disease; or [3] to have post-surgery complications, that made it impossible to begin rehabilitation during the first week after surgery. A total of 71 older adults with hip fracture were assigned to the intervention group [*n*=35] or to the control group [*n*=36]. All signed consent forms.

Recruitment, Allocation and Blinding

Older adults' recruitment took place at the Granada University Hospital, between the months of January 2017 and July 2018. During this time interval, all older adults

who met the inclusion criteria were invited to participate by an occupational therapist or a physiotherapist who worked at the hospital. The assignment was not random due to an ethical question based on the preference of older adults and family caregivers derived from problems for access to the platform or lack of time among others.

It was not possible to blind the older adults to the group assignment. However, data collection was done by an occupational therapist, a physical therapist, and a sport science specialist who were previously trained for the assessment and blinded to the group assignment.

Intervention

Telerehabilitation Group:

This group of older adults received a home-based multidisciplinary telerehabilitation intervention, which lasted 12 weeks. This program included a program of occupational therapy and physical exercise and recommendations for older adults and their family caregivers (about postoperative older adults management and home environment recommendations) provided through a website. This group had the opportunity to perform five 50-to-60-minute online-based sessions per week (two of occupational therapy and three sessions of physical exercise) that used content delivered through the @ctivehip online platform. The difficulty of the sessions was categorized into four levels (Beginners, Moderate, Advanced 1, and Advanced 2), and each older adults was individually

assigned to the most appropriate level. A broader description of the intervention program was provided elsewhere (141).

Control group:

The control group received the usual care and rehabilitation delivered by the Andalusian Public Health Care System (between 5-15 sessions of home-base in person rehabilitation). The total number of rehabilitation sessions performed by each older adults was recorded and were controlled for the statistical analyses. The control group also received an information leaflet with recommendations and physical exercises to do at home.

Common intervention of both groups

All older adults (telerehabilitation and control groups) received a few sessions of rehabilitation during their hospital stay. In addition, both older adults and family caregivers were invited to participate in the workshops offered about handling older adults twice a week at the Traumatology Service by the @ctivehip team during the hospital stay of the older adults. The workshops were focused on training family caregivers in handling older adults and providing them useful information and recommendations to help older adults during the recovery process after surgery.

Outcomes

All older adults enrolled in the study were assessed at three time points: [1] during the first week after surgery (at hospital discharge); [2] one month later; and [3] three months after hospital discharge (end of the telerehabilitation intervention).

Quality of life

The quality of life was measured through the EuroQol Quality of Life Questionnaire (EQ-5D).(142) The EuroQol (EQ-5D) is an older adults-reported outcome measure used to evaluate the generic quality of life of the older adults. The questionnaire consists of five main areas (mobility, self-care, usual activities, pain, depression) and is used to evaluate perceived health status from a range of 0 (the worst score) to 100 (the best score) (143). This outcome measure has previously been used to evaluate older adults with a hip fracture (144) and has been reported to have good internal consistency (Cronbach's α = 0.83) (145).

Psychological factors

The psychological factors were measured by the Hospital Anxiety and Depression Scale (HADS).(146) The HADS measures the presence of anxiety and depression in older adults. It has a total of 14 items, each one with four possible answers (0–3 points), divided into two subscales: seven items for status of depression and the remaining items for presence of anxiety. The maximum score of each subscale is 21 points, where scores below 11 indicate the presence of depression or anxiety. The internal consistency of the HADS is good with Cronbach's α = 0.80 (146).

Fitness level

The fitness level was measured by the International Fitness Scale (IFIS) (147). The IFIS is a scale consisting of five questions concerning the older adults's perception of his/ her general physical condition (cardio-respiratory, muscular, agility and flexibility). Each question has five possible answers (very poor, poor, average, good and very good) scored from 1 to 5 points, where the highest score corresponds to

the best perception of fitness. The test–retest reliability of the IFIS, as measured by the average weighted K, is 0.45 (147).

Sample size

A priori sample size analysis was performed using functional status data (primary outcome) from the telerehabilitation intervention in older adults with hip fracture carried out by Tappen et al. (148). By adding 35% to account for potential losses, this study required 70 participants (35 intervention, 35 control group) for 80% power at an alpha error of 5% using a two-sample t-test. We used the Epidat 3.1 Software (Xunta of Galicia) for the sample size calculation. We set the alpha error at 5% and used a two-sample t-test. We also considered the minimal clinically significant difference in the FIM index (11 points) between groups at three months.

Statistical analyses

Before performing the analyses, the continuous variables were checked for normal distribution via the visual inspection of histograms together with the Kolmogorov-Smirnov test. Those variables demonstrating a non-normal distribution were transformed using the Blom formula (149). The characteristics of the sample are presented as mean values and SDs or percentages. To test baseline differences between the telerehabilitation group and the control group, we used an independent sample t-test for continuous variables and an χ^2 test or Mann–Whitney U test for categorical binomial and polynomial, respectively.

The main effects of the telerehabilitation program were tested with the per-protocol approach, which included those participants who met the following criteria: 1) to have valid data in both pre- and post-intervention assessments and 2) to have completed at least 10 sessions of the telerehabilitation program, criterion that only applies to the telerehabilitation group. The statistical test used was the analysis of covariance (ANCOVA). The post-rehabilitation outcomes were used as dependent variables, the group (i.e., tele-rehab vs. control) as a fixed factor, and the baseline outcomes as a covariate. The z-scores for each outcome at the post-rehabilitation were also formed by dividing the difference of the post-rehabilitation raw score of each participant from the baseline mean by the baseline standard deviation (i.e., (post-rehabilitation individual raw value – baseline mean) / baseline SD). This way of reporting the effects has been used in recent leading RCTs (150) and has two main advantages: 1) it provides standardized estimates that allow comparisons among outcomes with different original measurement units and 2) these z-scores of change can be interpreted as effect size indicators, e.g., 0.5 z-score means that the mean value at post-rehabilitation is 0.5 SDs higher than the mean value at baseline, which indicates a positive medium-size change. As for effect size indicators, they can be interpreted according to the standard benchmarks, i.e., a value around 0.2 is considered a small effect size, 0.5 is considered a medium effect size and 0.8 is considered a large effect size (151). The @ctivehip effects in categorical variables (i.e., EQ-5D and IFIS individual tests) were tested with the Wilcoxon signed-rank and Mann–Whitney U tests to examine the within-group and between-group changes, respectively. The intention-to-treat analyses are presented as supplementary material and followed the same procedure as the

explained above for the per-protocol analyses. For the intention-to-treat approach all participants (N=71) were included and those without valid data were imputed through multiple imputation.

All analyses were performed using the SPSS software (version 24.0, IBM Corporation) and the level of significance was set at $p < 0.05$.

/ RESULTS /

Figure 6 shows the flowchart with the included participants for both the intention-to-treat and per-protocol analyses.

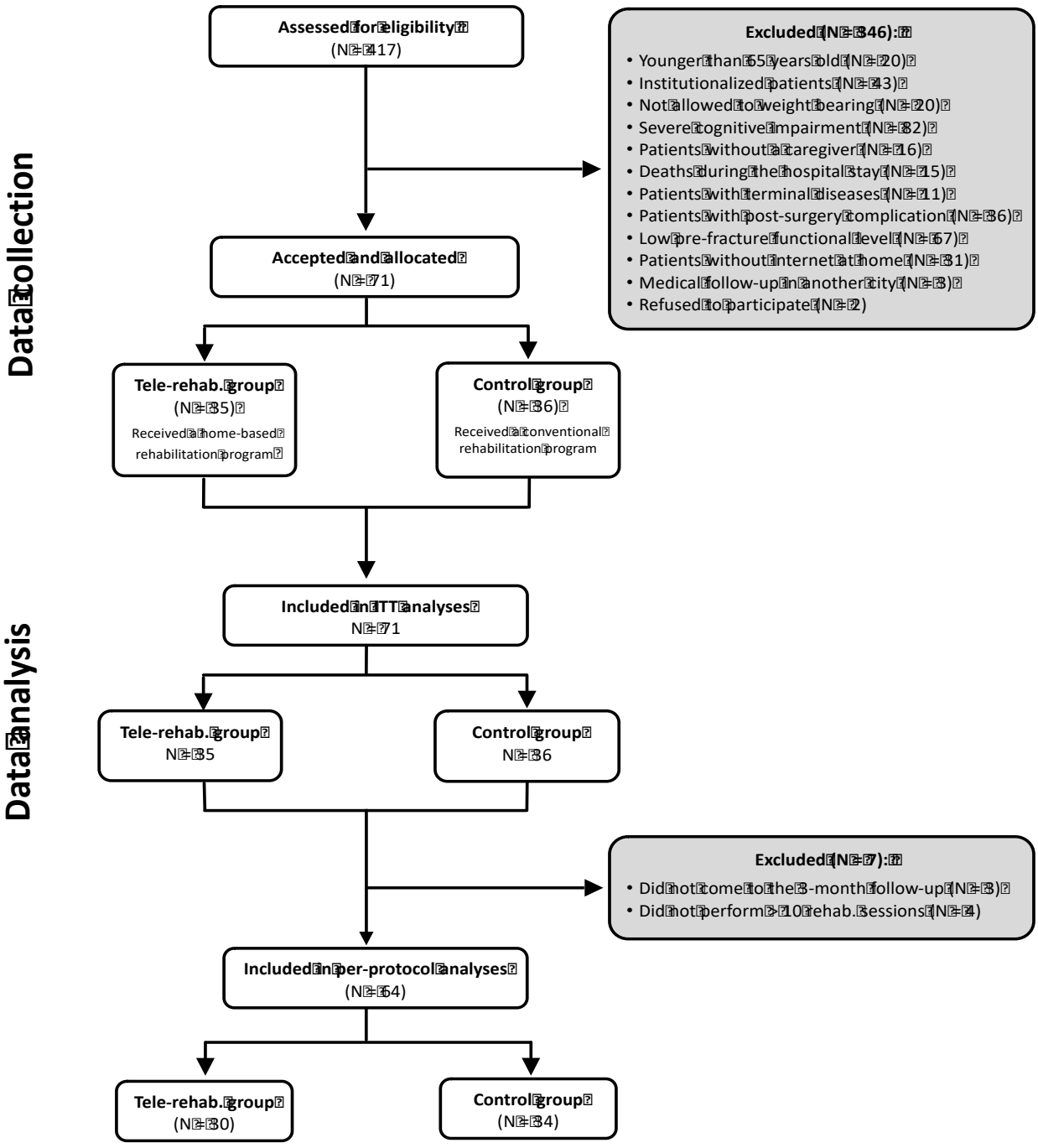

Figure 6. Flowchart describing the included participants for both the intention-to-treat and per-protocol analyses.

A total of 417 potentially eligible older adults with hip fracture were identified, of which 71 of them met the inclusion criteria and were allocated into the control (N = 36) or telerehabilitation (N = 35) groups. The per-protocol analysis included 64 older adults (34 in the control group and 30 in the telerehabilitation group), while the intention-to-treat analysis considered the whole sample of 71 older adults. The adherence was 17% (n = 6) to the full @ctivehip rehabilitation intervention (50-60 sessions), 69% (n = 24) to at least 20 sessions and 89% (n = 31) to at least 10 sessions. The latter was considered a minimum criterion to be included in the per-protocol analysis. The characteristics of all older adults and divided by telerehabilitation and control groups are shown in Table 4 for the per-protocol analysis. Participants in the telerehabilitation group were younger and had a higher fitness level (all $P < 0.05$) in comparison with the control group at baseline.

Table 4. Baseline characteristics of the sample divided by telerehabilitation and control group.

	All sample (n=64)	Tele-rehab. (n=30)	Control (n=34)	*P*
Age (years)	78.22 ± 6.02	75.77 ± 5.67	80.38 ± 5.54	**0.002**
Weight (kg)	68.43 ± 9.86	67.79 ± 9.67	69.15 ± 10.21	0.614
Height (cm)	159.53 ± 7.96	160.75 ± 7.07	158.04 ± 8.83	0.220
Body mass index (kg/m^2)	26.9 ± 3.76	26.29 ± 3.86	27.63 ± 3.58	0.202
Gender				0.390
Men	15 (23%)	8 (27%)	7 (21%)	
Women	49 (77%)	22 (73%)	27 (79%)	
Quality of life (EQ5D)				
Self-perceived health (0 - 100)	58.81 ± 18.96	62.97 ± 20.76	55.15 ± 16.67	0.100
Total index (-0.65 - 1)	0.25 ± .36	0.20 ± 0.40	0.29 ± 0.32	0.320
Anxiety and depression (HADS)				
Total score (0 – 14)	9.17 ± 6.31	8.4 ± 5.02	9.85 ± 7.27	0.362
Anxiety (0 – 7)	5.45 ± 4.28	5.2 ± 3.79	5.68 ± 4.72	0.661
Depression (0 – 7)	3.78 ± 3.08	3.2 ± 2.64	4.29 ± 3.37	0.158
Fitness level (IFIS)				
Total score (5 – 25)	18.16 ± 4.1	19.4 ± 3.25	17.06 ± 4.49	**0.021**

SD = standard deviation; n=sample size; IFIS: International Fitness Scale; HADS: Hospital Anxiety and Depression Scale.
Values are presented as mean ± SD or percentages. For continuous variables, p value was obtained by an independent samples T-test, whereas for categorical variables, p value was obtained by a chi-square test. Significant differences ($p < 0.05$) are highlighted in bold.

The per-protocol analysis is presented in Table 5, which shows the differences between the telerehabilitation and control groups three months after hip fracture surgery adjusting for baseline values. The quality of life of the telerehabilitation group increased, evidenced in the EQ5D total index, while the control group scored worst at the 3-month follow up (medium effect size: 0.67 Cohen's d; $p = 0.010$). Regarding the fitness level, the telerehabilitation group recovered values closer to the level prior to the hip fracture, experiencing a better recovery in comparison with the control group (medium effect size: 0.70 Cohen's d; $p = 0.008$). Lastly, the telerehabilitation group demonstrated a greater decrease than the control group in the total HADS score (medium effect size: 0.70 Cohen's d; $p = 0.007$) and its subscales: the anxiety (medium effect size: 0.69 Cohen's d; $p = 0.008$) and depression scores (medium effect size: 0.58 Cohen's d; $p = 0.026$). Differences between the telerehabilitation and the control group were similar at the 3-month follow up for the rest of the self-perceived health. All these results are graphically presented in Figure 7.

Table 5. Intervention effects of the @ctivehip project considering baseline and 3-month assessments (per-protocol analysis).

	Adjusted mean (95% CI)			*P*
	Tele-rehab. (N = 30)	Control group (N = 34)	Groups difference (Rehab – Control)	
Quality of life (EQ5D)				
Self-perceived health				
Raw score	69.08 (61.24 to 76.92)	62.67 (55.31 to 70.02)	6.41 (-4.45 to 17.28)	0.242

z Score	0.60 (0.18 to 1.02)	0.25 (-0.14 to .65)	0.34 (-0.24 to 0.93)	
EQ5D total index				
Raw score	0.69 (0.57 to 0.82)	0.47 (0.35 to 0.58)	0.23 (0.06 to 0.40)	**0.010**
z Score	1.20 (0.85 to 1.55)	0.56 (0.24 to 0.89)	0.64 (0.16 to 1.12)	
Anxiety and depression (HADS)				
HADS total				
Raw score	0.42 (0.33 to 0.50)	0.57 (0.50 to 0.65)	-0.16 (-0.27 to -0.05)	**0.007**
z Score	-0.34 (-0.65 to -0.04)	0.24 (-0.04 to 0.52)	-0.58 (-1.00 to -0.17)	
HADS anxiety				
Raw score	0.42 (0.33 to 0.50)	0.58 (0.50 to 0.66)	-0.17 (-0.29 to -0.05)	**0.008**
z Score	-0.35 (-0.68 to -0.02)	0.27 (-0.04 to 0.58)	-0.62 (-1.07 to -0.17)	
HADS depression				
Raw score	0.43 (0.35 to 0.51)	0.56 (0.48 to 0.64)	-0.13 (-0.24 to -0.02)	**0.026**
z Score	-0.30 (-0.61 to 0.01)	0.19 (-0.10 to 0.47)	-0.49 (-0.91 to -0.06)	
Fitness level (IFIS)				
IFIS total				
Raw score	16.94 (15.63 to 18.24)	14.44 (13.22 to 15.66)	2.49 (0.67 to 4.32)	**0.008**
z Score	-0.24 (-0.56 to 0.08)	-0.85 (-1.15 to -0.55)	0.61 (0.17 to 1.06)	

CI = confidence interval; n=sample size; IFIS: International Fitness Scale; HADS: Hospital Anxiety and Depression Scale.

A one-way analysis of covariance (ANCOVA) was used to test raw and z-score differences between the tele-rehab and control group at the post-intervention, adjusting for basic pre-intervention values. Adjusted means and confidence intervals of the mean are represented. Differences between groups are presented as: post-intervention mean minus pre-intervention mean. Significant differences ($p < 0.05$) are highlighted in bold.

Figure 7. Effect sizes of the @ctivehip project on quality of life, anxiety and depression and fitness level (per-protocol analysis).

A one-way analysis of covariance (ANCOVA) was used to test z-score differences between the telerehabilitation and control groups at the 3-month assessment, adjusting for baseline values. Bars represent 95% confidence interval.

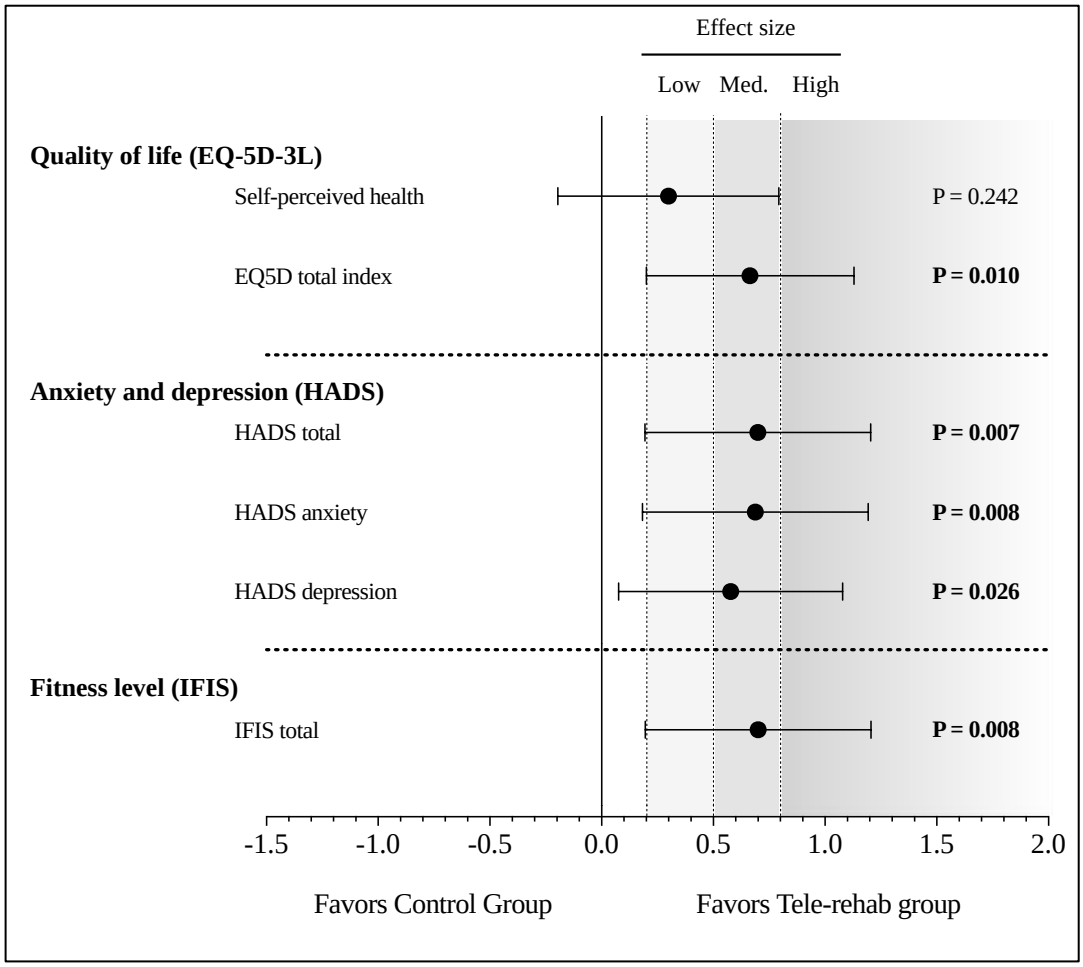

Figure 7. Effect sizes of the @ctivehip project on quality of life, anxiety and depression and fitness level (per-protocol analysis).
A one-way analysis of covariance (ANCOVA) was used to test z-score differences between the telerehabilitation and control groups at the 3-month assessment, adjusting for baseline values. Bars represent 95% confidence intervals.

Results from categorical variables (i.e., scores ranging from 1 to 5 points) are presented in Table 6. In regard to the quality of life assessment, both the telerehabilitation and control groups improved their scores in the self-care (Z = -4.05 and -1.97; p = <0.001 and 0.049, respectively) and usual care dimensions (Z = -4.56 and –2.42; p = <0.001 and 0.016 respectively), while only the telerehabilitation group improved the mobility (Z = -3.84; p = <0.001) and anxiety (Z = -2.36; p = 0.018)

domains. Focusing on the fitness level, both the telerehabilitation and control groups improved the strength (Z = -2.06 and -2.57; p = 0.040 and 0.010 respectively), speed (Z = -2.98 and -2.86; p = 0.003 and 0.004 respectively) and flexibility (both Z = -2.43; both p = 0.015). On the other hand, only the control group improved the general fitness domain (Z = -2.31; p = 0.021). In regard with the between-group analysis, the telerehabilitation group had a better improvement in the mobility, self-care and usual care dimensions (Z = -3.79, -2.97 and -3.38; p = <0.001, 0.003 and 0.001, respectively).

The intention-to-treat analysis is presented in the Supplementary Material (Table S1, S2 and S3). The effects of the @ctivehip telerehabilitation intervention found in this analysis were less beneficial in comparison with the per-protocol analysis since there was not a significant improvement in the HADS total score and subscales of anxiety and depression (all p >0.050). The effects in the EQ5D total index and IFIS total scores remained superior favoring the @ctivehip intervention (medium effect size: 0.58 Cohen's d; p = 0.018, and medium effect size: 0.58 Cohen's d; p = 0.018, respectively), although there was an attenuation in the effect sizes in comparison with the per-protocol analysis. Lastly, results from categorical variables remained almost similar in the intention-to-treat analysis, with the exception that the @ctivehip group alone improved the anxiety domain in the EQ5D (Z = -2.36 and p = 0.018), whereas none of the two groups improved the cardiorespiratory category in the IFIS assessment (both p > 0.050).

Table 6. Within-group and between-group changes in the individual tests of quality of life and fitness level (per-protocol analysis).

Variables	Baseline						3-month assessment						Within-group change		Between-group change	
	Mean (SD)	Scores (N)					Mean (SD)	Scores (N)								
		1	2	3	4	5		1	2	3	4	5	Z	p	Z	P
Quality of life (EQ-5D)																
Mobility															-3.788	**<0.001**
Tele-rehab	2.03 (0.32)	1	27	2	-	-	1.43 (0.50)	17	13	0	-	-	-3.838	**<0.001**		
Control	2.03 (0.17)	0	33	1	-	-	1.94 (0.34)	3	30	1	-	-	-1.342	0.180		
Self-care															-2.974	**0.003**
Tele-rehab	2.30 (0.70)	4	13	13	-	-	1.37 (0.62)	21	7	2	-	-	-4.054	**<0.001**		
Control	2.12 (0.48)	2	26	26	-	-	1.82 (0.67)	11	18	5	-	-	-1.966	**0.049**		
Usual care															-3.379	**0.001**
Tele-rehab	2.47 (0.68)	3	10	17	-	-	1.37 (0.56)	20	9	1	-	-	-4.562	**<0.001**		
Control	2.32 (0.48)	0	23	11	-	-	1.94 (0.65)	8	20	6	-	-	-2.419	**0.016**		
Pain															-0.086	0.932
Tele-rehab	2.00 (0.53)	4	22	4	-	-	1.77 (0.73)	12	13	5	-	-	-1.410	0.159		
Control	1.97 (0.72)	9	17	8	-	-	1.74 (0.62)	12	19	3	-	-	-1.496	0.135		
Anxiety															-1.204	0.229
Tele-rehab	1.63 (0.62)	13	15	2	-	-	1.30 (0.70)	25	1	4	-	-	-2.357	**0.018**		
Control	1.74 (0.71)	14	15	5	-	-	1.56 (0.71)	19	11	4	-	-	-1.414	0.157		
Fitness level (IFIS)																
General fitness															-0.777	0.437
Tele-rehab	3.87 (0.97)	1	1	7	13	8	3.57 (0.82)	1	1	10	16	2	-1.403	0.161		
Control	3.56 (0.93)	0	3	16	8	7	2.97 (0.90)	3	4	19	7	1	-2.315	**0.021**		
Cardiorespiratory															-0.614	0.539
Tele-rehab	3.87 (0.82)	0	0	12	10	8	3.53 (0.86)	9	4	9	14	3	-1.895	0.058		
Control	3.41 (0.99)	0	6	14	8	6	3.18 (0.72)	0	6	16	12	0	-1.286	0.199		
Strength															-0.631	0.528
Tele-rehab	3.83 (0.75)	0	1	8	16	5	3.40 (0.89)	1	3	11	13	2	-2.057	**0.040**		
Control	3.47 (1.02)	0	6	13	8	7	2.82 (0.83)	2	9	16	7	0	-2.573	**0.010**		
Speed															-0.076	0.939
Tele-rehab	4.07 (0.83)	0	1	6	13	10	3.37 (0.89)	1	4	9	15	1	-2.976	**0.003**		
Control	3.38 (1.05)	0	8	11	9	6	2.62 (0.85)	4	9	17	4	0	-2.865	**0.004**		
Flexibility															-0.340	0.734
Tele-rehab	3.70 (1.09)	1	3	8	10	8	3.27 (0.87)	1	4	12	12	1	-2.430	**0.015**		
Control	3.29 (1.09)	1	7	13	7	6	2.71 (0.76)	3	7	21	3	0	-2.430	**0.015**		

EQ-5D scores: 1 = no problems; 2 = some problems; 3 = severe problems. IFIS scores: 1 = very poor; 2 = poor; 3 = average; 4 = good; 5 = very good.
Wilcoxon signed-rank and Mann–Whitney U were used to test within-group and between-group changes respectively. Significant differences ($p < 0.05$) are highlighted in bold.

/ SUPLEMENTARY MATERIAL /

Table S1. Baseline characteristics of the sample divided by telerehabilitation (tele-rehab.) and control group (intention-to-treat analysis).

	All sample (n=71)	Tele-rehab. (n=35)	Control (n=36)	*P*
Age (years)	78.75 ± 6.12	76.71 ± 6.04	80.72 ± 5.59	**0.005**
Weight (kg)	69.15 ± 9.12	68.61 ± 9.46	69.68 ± 8.89	0.626
Height (cm)	158.44 ± 7.87	160.38 ± 6.57	156.56 ± 8.64	**0.040**
Body mass index (kg/m^2)	27.64 ± 3.90	26.75 ± 3.93	28.52 ± 3.71	0.055
Gender				0.580
Men	18 (25%)	9 (26%)	9 (25%)	
Women	53 (75%)	26 (74%)	27 (75%)	
Quality of life (EQ5D)				
Self-perceived health (0 - 100)	57.94 ± 18.65	61.69 ± 20.12	54.31 ± 16.57	0.096
Total index (-0.65 - 1)	0.27 ± 0.36	0.24 ± 0.39	0.30 ± 0.32	0.483
Anxiety and depression (HADS)				
Total score (0 – 14)	9.35 ± 6.45	8.6 ± 5.03	10.08 ± 7.59	0.337
Anxiety (0 – 7)	5.58 ± 4.36	5.37 ± 3.85	5.78 ± 4.86	0.698
Depression (0 – 7)	3.83 ± 3.10	3.23 ± 2.57	4.42 ± 3.48	0.107
Fitness Level (IFIS)				
Total score (5 – 25)	17.9 ± 4.08	18.94 ± 3.46	16.89 ± 4.42	**0.033**

SD = standard deviation; n=sample size; IFIS: International Fitness Scale; HADS: Hospital Anxiety and Depression Scale.

Values are presented as mean ± SD or percentages. For continuous variables, p value was obtained by an independent samples T-test, whereas for categorical variables, p value was obtained by an chi-square test. Significant differences ($p < 0.05$) are highlighted in bold.

Table S2. Intervention effects of the @ctivehip project considering baseline and 3-month assessments (intention-to-treat analysis).

	Adjusted mean (95% CI)			*P*
	Tele-rehab. (N = 34)	Control group (N = 35)	Groups difference (Rehab – Control)	
Quality of life (EQ5D)				
Self-perceived health				
Raw score	68.67 (61.7 to 75.65)	62.05 (55.17 to 68.92)	6.63 (-3.27 to 16.53)	0.186
z Score	0.58 (0.20 to 0.95)	0.22 (-0.15 to 0.59)	0.36 (-0.18 to 0.89)	
EQ5D total index				
Raw score	0.68 (0.56 to 0.79)	0.48 (0.37 to 0.59)	0.20 (0.03 to 0.36)	**0.018**
z Score	1.14 (0.82 to 1.47)	0.60 (0.28 to 0.91)	0.55 (0.10 to 1.00)	
Anxiety and depression (HADS)				
HADS total				
Raw score	0.47 (0.38 to 0.55)	0.57 (0.49 to 0.66)	-0.10 (-0.22 to 0.02)	0.091
z Score	-0.19 (-0.47 to 0.10)	0.16 (-0.12 to 0.44)	-0.35 (-0.75 to 0.06)	
HADS anxiety				
Raw score	0.47 (0.37 to 0.56)	0.58 (0.49 to 0.67)	-0.12 (-0.25 to 0.02)	0.085
z Score	-0.20 (-0.51 to 0.12)	0.19 (-0.12 to 0.50)	-0.39 (-0.83 to 0.05)	
HADS depression				
Raw score	0.49 (0.40 to 0.58)	0.56 (0.47 to 0.64)	-0.07 (-0.20 to 0.06)	0.269
z Score	-0.13 (-0.43 to 0.17)	0.11 (-0.19 to 0.41)	-0.24 (-0.67 to 0.19)	
Fitness Level (IFIS)				
IFIS total				
Raw score	16.51 (15.35 to 17.68)	14.49 (13.34 to 15.64)	2.02 (0.36 to 3.68)	**0.018**
z Score	-0.34 (-0.63 to -0.06)	-0.84 (-1.12 to -0.55)	0.50 (0.09 to 0.90)	

CI = confidence interval; n=sample size; IFIS: International Fitness Scale; HADS: Hospital Anxiety and Depression Scale.

A one-way analysis of covariance (ANCOVA) was used to test raw and z-score differences between the tele-rehab and control group at the post-intervention, adjusting for basic pre-intervention values. Adjusted means and confidence intervals of the mean are represented. Differences between groups are presented as: post-intervention mean minus pre-intervention mean. Significant differences ($p < 0.05$) are highlighted in bold.

Table S3. Within-group and between-group changes in the individual tests of quality of life and fitness level (intention-to-treat analysis).

Variables	Baseline						3-month assessment						Within-group change		Between-group change	
	Mean (SD)	Scores (N)					Mean (SD)	Scores (N)								
		1	2	3	4	5		1	2	3	4	5	Z	p	Z	P
Quality of life (EQ-5D)																
Mobility															-3.689	**<0.001**
Tele-rehab	2.03 (0.30)	0	35	1	-	-	1.47 (0.50)	3	32	1	-	-	-3.962	**<0.001**		
Control	2.03 (0.17)	1	32	2	-	-	1.94 (0.33)	18	17	0	-	-	-1.342	0.180		
Self-care															-2.942	**0.003**
Tele-rehab	2.29 (0.67)	2	28	6	-	-	1.39 (0.60)	13	18	5	-	-	-4.353	**<0.001**		
Control	2.11 (0.47)	4	17	14	-	-	1.79 (0.67)	23	10	2	-	-	-2.270	**0.023**		
Usual care															-3.084	**0.002**
Tele-rehab	2.43 (0.66)	0	25	11	-	-	1.42 (0.55)	9	21	6	-	-	-4.756	**<0.001**		
Control	2.31 (0.47)	3	14	18	-	-	1.91 (0.65)	21	13	1	-	-	-2.559	**0.010**		
Pain															-0.504	0.614
Tele-rehab	1.97 (0.51)	9	19	8	-	-	1.79 (0.72)	13	20	3	-	-	-1.188	0.235		
Control	1.97 (0.70)	5	26	4	-	-	1.71 (0.61)	13	16	6	-	-	-1.653	0.098		
Anxiety															-0.545	0.586
Tele-rehab	1.60 (0.60)	15	15	6	-	-	1.35 (0.73)	21	11	4	-	-	-1.964	0.050		
Control	1.75 (0.73)	16	17	2	-	-	1.53 (0.69)	28	2	5	-	-	-1.713	0.087		
Fitness Level (IFIS)																
General fitness															-0.756	0.450
Tele-rehab	3.77 (0.97)	0	3	18	8	7	3.47 (0.81)	3	4	21	7	1	-1.508	0.132		
Control	3.53 (0.91)	1	2	9	15	8	2.96 (0.88)	1	2	13	17	2	-2.315	**0.021**		
Cardiorespiratory															-0.813	0.416
Tele-rehab	3.83 (0.86)	0	6	16	8	6	3.46 (0.85)	0	6	18	12	0	-2.208	**0.027**		
Control	3.39 (0.96)	0	1	13	12	9	3.17 (0.70)	0	5	12	15	3	-1.286	0.199		
Strength															-0.296	0.767
Tele-rehab	3.74 (0.78)	0	7	14	8	7	3.31 (0.87)	2	9	18	7	0	-2.309	**0.021**		
Control	3.42 (1.03)	0	2	10	18	5	2.84 (0.82)	1	4	15	13	2	-2.434	**0.015**		
Speed															-0.012	0.991
Tele-rehab	3.94 (0.87)	0	9	12	9	6	3.27 (0.89)	4	9	19	4	0	-2.753	**0.006**		
Control	3.33 (1.04)	0	2	8	15	10	2.63 (0.83)	1	6	11	16	1	-3.089	**0.002**		
Flexibility															-0.447	0.655
Tele-rehab	3.60 (1.06)	1	7	15	7	6	3.2 (0.83)	3	7	23	3	0	-2.430	**0.015**		
Control	3.28 (1.06)	1	4	11	11	8	2.72 (0.74)	1	5	16	12	1	-2.240	**0.025**		

EQ-5D scores: 1 = no problems; 2 = some problems; 3 = severe problems. IFIS scores: 1 = very poor; 2 = poor; 3 = average; 4 = good; 5 = very good.
Wilcoxon signed-rank and Mann–Whitney U were used to test within-group and between-group changes respectively. Significant differences (p,0.05) are highlighted in bold.

SECTION III

ActiveHip+ mHealth intervention in older adults with hip fracture and their family caregivers.

ActiveHip+

STUDY III

An m-Health telerehabilitation and health education program on physical performance in older adults with hip fracture and their family caregivers: study protocol for the ActiveHip+ randomized controlled trial

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/METHOD/

Design

The ActiveHip+ is a multicenter randomized controlled trial (RCT) that follows a parallel-group design (1:1). Three Spanish hospitals participated in this study: Virgen de las Nieves University Hospital (Granada), Puerto Real University Hospital (Cádiz), and Jerez de la Frontera University Hospital (Cádiz). The project has been registered in ClinicalTrials.gov and was carried out according to the guidelines established by the Helsinki Declaration and Law 14/2007 on Biomedical Research. ActiveHip+ has been approved by the Ethics Committee of Granada (CEI-GRANADA).

Study population

Older adults with hip fracture and their family caregivers were assigned to the intervention or to the control group.

The inclusion criteria were: 1) diagnosed with a hip fracture, 2) 65 years or older, 3) allowed weight-bearing at 48 hours after the surgery, 4) high pre-fracture functional level the week before the fracture (Functional Independence Measure [FIM] index scored more than 90 points), 5) live at their own home or the home of relatives after hospital discharge, and 6) have an informal or family caregiver who has the ability to access Internet to use the app ActiveHip+ and to manage the basic settings of the mobile phone.

The exclusion criteria were: 1) the presence of severe cognitive impairment (Pfeiffer test score higher than 4 errors), 2) institutionalized, 3) post-surgery complications that make impossible to start rehabilitation within the first week post-surgery (i.e., re-surgery, breathing or heart problems) and 4) the presence of terminal diseases.

Recruitment, allocation, and blinding

The recruitment took place at three large hospitals in cities located in Andalusia, Spain. Hospitalized older adults and their family caregivers were invited to participate during their hospital stay after hip fracture surgery. Following the inclusion criteria mentioned above, the investigator explained to older adults and family caregivers the main characteristics of the intervention. After consent was obtained, participants were assigned to the intervention or control group using sealed numbered envelopes. Due to the characteristics of the intervention, blinding of participants was not possible since they were aware that they were performing the m-Health rehabilitation intervention. Regarding the blinding of the research team, investigators who perform testing to assess participant outcomes and analyze study data were blinded to group. Furthermore, the investigators assessing the outcomes were not the same pre- and post-rehabilitation to ensure an optimal blinding strategy and, therefore, avoid possible risk of bias during the assessment process.

Sample size and power

The G*Power V.3.1.7 software (Franz Faul, Christian-Albrechts-Universitätzu Kiel, Kiel, Germany) (version 3.0.1) was used to calculate the sample size required. Power calculation was based on the pilot study preceding the ActiveHip+ mHealth intervention (152). We extracted the effect sizes derived from a telerehabilitation intervention on the main outcomes, physical performance, and functional status. Considering an 80% power, an alpha error of 5%, and a dropout rate of 15%, the study needed 104 participants (52 for the ActiveHip+ group and 52 for the control group) to obtain a reliable statistical power in the main outcomes. Finally, a total of 110 participants were recruited (55 to the ActiveHip+ group and 55 to the control group).

Intervention

ActiveHip+ intervention

Older adults and their family caregivers allocated to the intervention group received access to the ActiveHip+ mobile app loaded in their owns smartphones for a period of 12 weeks. The family caregiver had a key role in ensuring the continuity of the monitoring of the older adults' rehabilitation intervention, since in most cases the family caregiver was the person who had access the smartphone app and then showed and delivered the sessions to the older adult.

The contents included in the ActiveHip+ project had been co-created by several focus groups comprised of older adults with experience in hip fracture recovery, family caregivers and health professionals (i.e., endocrinologists, nurses, nursing

assistants, occupational therapists, orthopedic surgeons, physiatrists, physical therapists, and physical education specialists). In Supplementary Material we provided a detailed explanation about the creation process.

The ActiveHip+ m-Health intervention included two virtual environments for intervention delivery: 1) the health professionals' environment to prescribe and guide the intervention and 2) the older adults and caregivers' environment to carry out the intervention. Figure 8 summarizes the main features offered in each environment. Moreover, Figure 9 shows a graphical representation of examples of the content provided in the older adults and caregivers' environment. Older adults and family caregivers had two main resources: a health educational program and a home-based multidisciplinary telerehabilitation program consisting of physical exercise and occupational therapy. The content of the telerehabilitation program is summarized in Figure 10 (physical exercise) and Figure 11 (occupational therapy), whereas Supplementary Material provides a more detailed description.

The older adults had the opportunity to perform three smartphone-based sessions per week (two sessions of physical exercise and one of occupational therapy), preferably performed on non-consecutive days with each session lasting 30-60 minutes. Each session was performed at home with the help of pre-recorded videos which include spoken instructions that describe the prescribed activities. Both the physical exercise and occupational therapy programs included four levels of difficulty, which were prescribed by health professionals according to the older adults' physical and functional level evaluated through the Short Physical

Performance Battery (SPPB) and Functional Independence Measure (FIM) questionnaires.

The educational program had a total of 7 modules. Five modules were for older adults and family caregivers, and two modules were specifically for family caregivers. Each module was comprised of videos with varying content related to hip fracture recovery and prevention of a second fracture (e.g., recovery process during hospital stays or keys to the physical and mental well-being of caregivers).

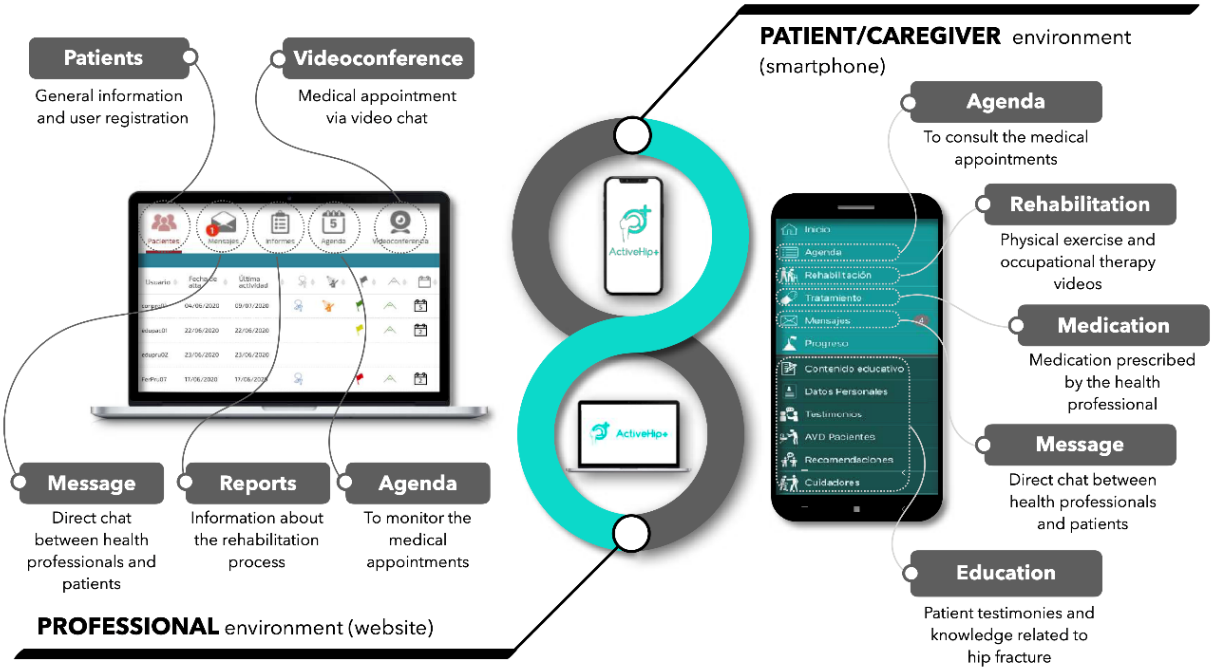


Figure 8. Main features offered in both the health professionals' environment, and the older adults' and caregivers' environment.

Finally, the mobile application included a section of general recommendations for older adults and family caregivers as well as a section of Activities of Daily Living; this last one aims to facilitate the day-to-day life through videos.

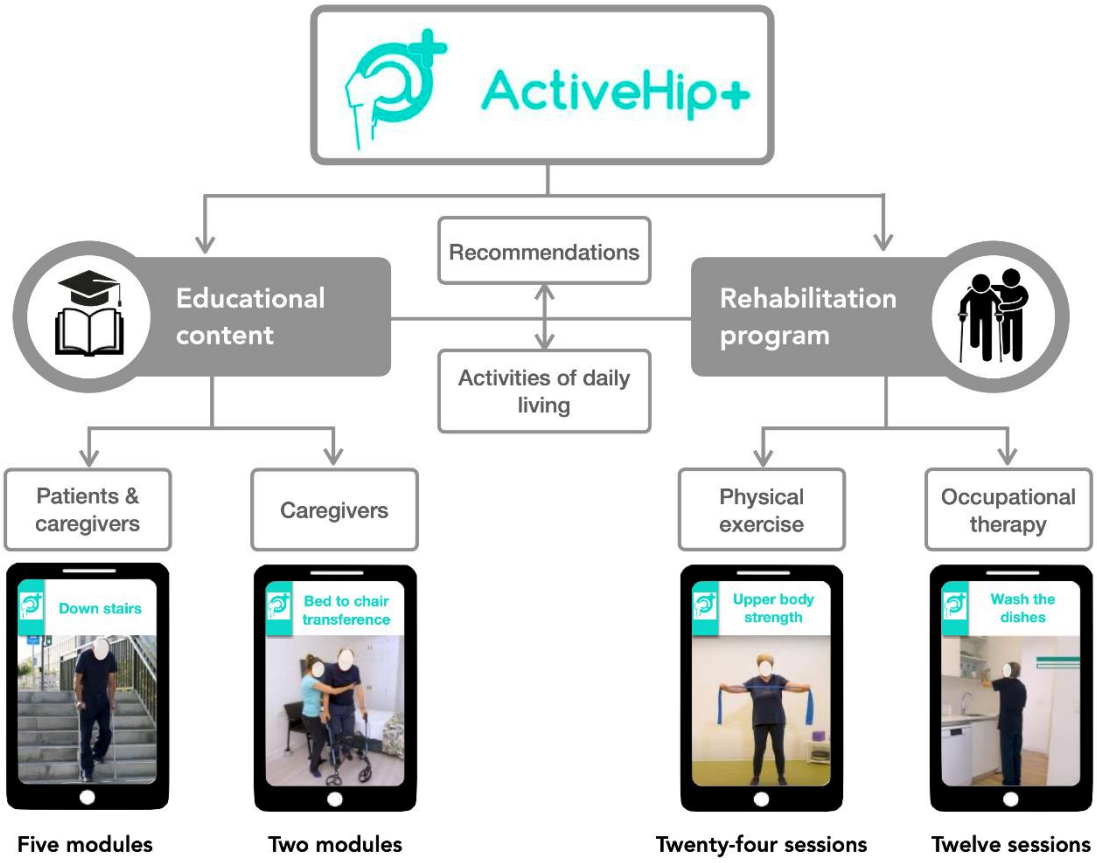


Figure 9. ActiveHip+ content provided to older adults and caregiver.

Adherence strategies and facilitators

The older adults and their family caregivers were verbally encouraged via videoconference to participate in the program, perform sessions and attend each assessment in hospital settings. Older adults had the opportunity to check the progression of the telerehabilitation program by milestone indicators represented by flags to motivate them during the recovery process. During the intervention period, an investigator recorded how often older adults and family caregivers accessed the app and the number of sessions performed. Furthermore, the educational program included two questions at the end of each module to verify the learning of the content. The health professionals called participants (once per week

during the first two weeks, and once every two weeks during the following 10 weeks) to encourage them to continue performing the exercises and answer any questions. The tools that were used to keep in contact are messages through the health professional's website and the mobile application and video conferences based on the participants or health professionals' requirements.

Control group

Older adults assigned to the control group received the usual rehabilitation protocol offered by the Andalusian Public Healthcare System. It consists of 5-10 face-to-face rehabilitation sessions focused on general recommendations for improving balance and functional capacity (153). Sessions were delivered by physiotherapists and occupational therapists after hospital discharge at older adults' homes, and therapists had certain autonomy in the rehabilitation process within the above-mentioned recommendations. Additionally, the control group received an informative booklet with recommendations on physical exercise and activities of daily living. The total number of rehabilitation sessions performed by each older adults (including those provided by the workers from the public health system and any private rehabilitation sessions paid for by the older adults) were recorded so that portion of rehabilitation received by each older adults can be controlled for in the statistical analyses.

Common intervention in both groups

Both groups received the same rehabilitation process during the post-operative hospital stay, which usually lasts 1 week. This in older adults' rehabilitation consists of 3-5 face-to-face rehabilitation sessions of physiotherapy and occupational therapy conducted at the hospital facilities. Thereafter, the intervention group received the ActiveHip+ rehabilitation in the home whereas the control group receives the above-mentioned protocol.

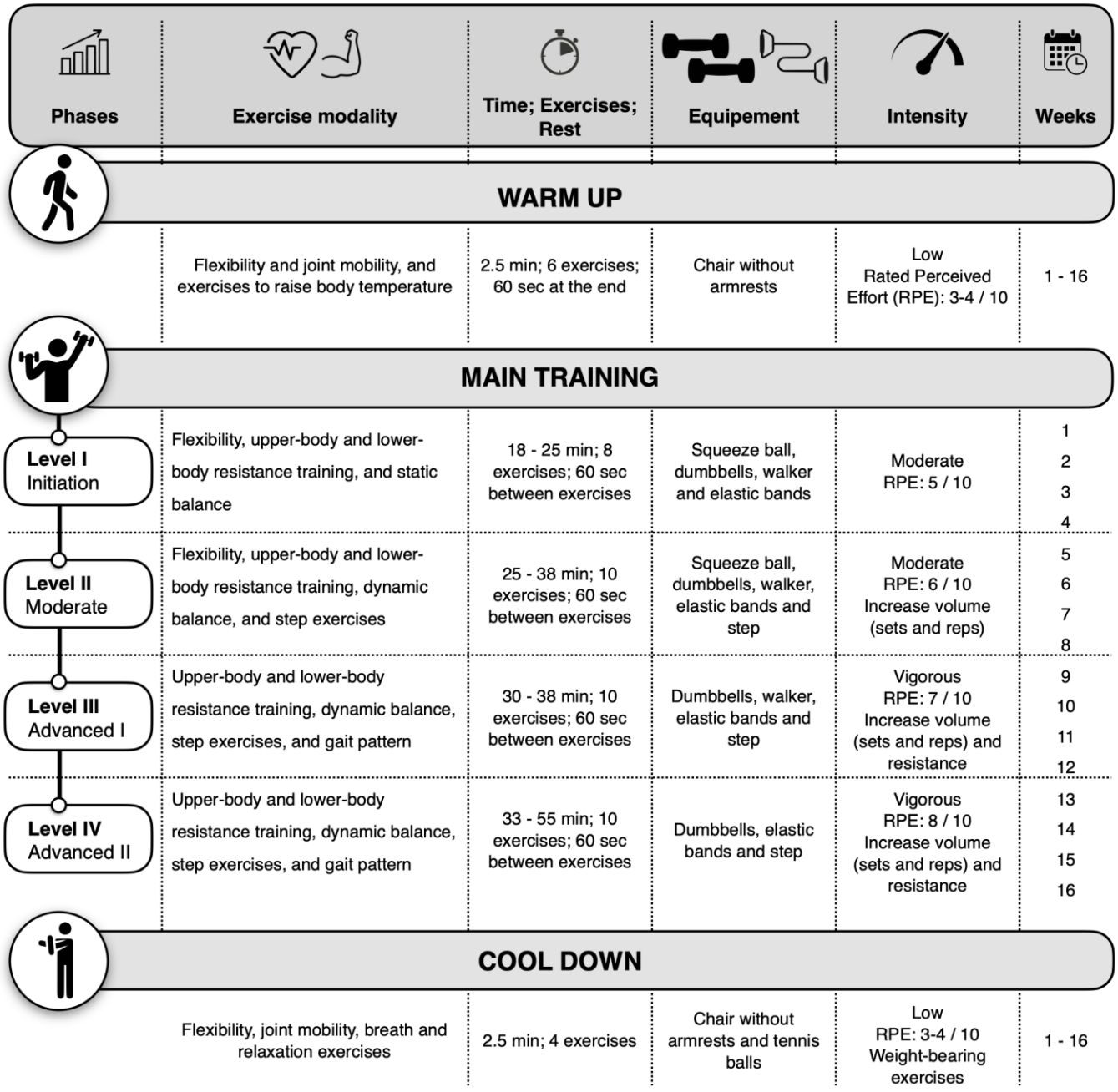
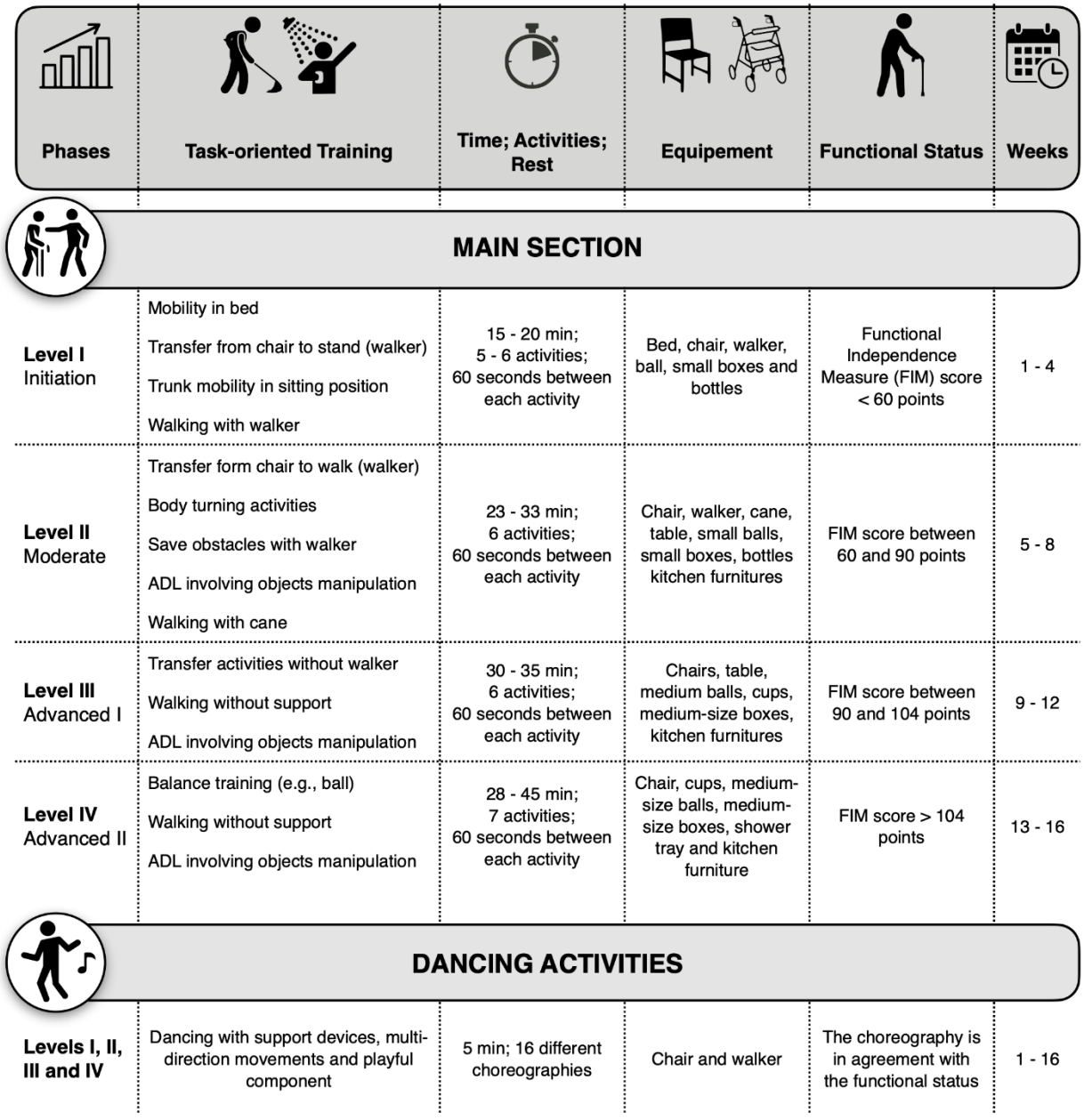


Figure 10. Description of the ActiveHip+ physical exercise program.



Phases	Task-oriented Training	Time; Activities; Rest	Equipement	Functional Status	Weeks
MAIN SECTION					
Level I Initiation	Mobility in bed Transfer from chair to stand (walker) Trunk mobility in sitting position Walking with walker	15 - 20 min; 5 - 6 activities; 60 seconds between each activity	Bed, chair, walker, ball, small boxes and bottles	Functional Independence Measure (FIM) score < 60 points	1 - 4
Level II Moderate	Transfer form chair to walk (walker) Body turning activities Save obstacles with walker ADL involving objects manipulation Walking with cane	23 - 33 min; 6 activities; 60 seconds between each activity	Chair, walker, cane, table, small balls, small boxes, bottles kitchen furnitures	FIM score between 60 and 90 points	5 - 8
Level III Advanced I	Transfer activities without walker Walking without support ADL involving objects manipulation	30 - 35 min; 6 activities; 60 seconds between each activity	Chairs, table, medium balls, cups, medium-size boxes, kitchen furnitures	FIM score between 90 and 104 points	9 - 12
Level IV Advanced II	Balance training (e.g., ball) Walking without support ADL involving objects manipulation	28 - 45 min; 7 activities; 60 seconds between each activity	Chair, cups, medium-size balls, medium-size boxes, shower tray and kitchen furniture	FIM score > 104 points	13 - 16
DANCING ACTIVITIES					
Levels I, II, III and IV	Dancing with support devices, multi-direction movements and playful component	5 min; 16 different choreographies	Chair and walker	The choreography is in agreement with the functional status	1 - 16

Figure 11. Description of the ActiveHip+ occupational therapy program.

Clinical outcomes

The primary outcome (physical performance) and secondary outcomes for both groups were assessed at hospital discharge and 3 months later (timepoint coincides with their first postoperative visit). Additionally, a 1-year follow-up after surgery was included to assess whether the potential benefits of the intervention are maintained in the long term after cessation of the ActiveHip+ intervention. An overview of the included outcomes and the study design is presented in **Figure 12**.

Physical performance

The Short Physical Performance Battery (SPPB) assessment had previously been used to evaluate older people and older adults with hip fracture (154–156). This tool consists of three tasks: balance, walking, and chair stands (154). The SPPB evaluates the ability to maintain balance for 10 seconds in certain positions, time to walk 4 meters, and time required to sit and stand up from a chair 5 times. We considered the individual scores to enhance understanding of older adults' physical performance. The total score ranges from 0 to 12 points, where higher scores indicate better mobility. The SPPB has been demonstrated to be valid and reliable (i.e., Intraclass Correlation Coefficient [ICC] > 0.83) in older adult populations (157). Furthermore, internal consistency is high with a Cronbach's α = 0.87 (158).

Additionally, the handgrip strength test was used as an objective indicator of muscular strength. Handgrip strength is a valid indicator of vitality and physical

function in older adults (159) and has demonstrated a high test-retest reliability in clinical settings (160). Participants performed the test standing and will be asked to squeeze as strong as they can twice per hand. The final output will be the average strength in kilograms of each hand, which was divided by the participant's body weight to avoid the biasing effects of body size in muscular strength.

Quality of life

The EuroQol (EQ-5D) is an older adults-reported outcome measure used to evaluate the overall quality of life of the older adults (143). The questionnaire consists of five dimensions (mobility, self-care, usual activities, pain, and depression) and is used to evaluate perceived health status on a range from 0 (the worst health status) to 100 (the best health status) (143). This outcome measure has previously been used to evaluate older adults with a hip fracture (144). The EQ-5D is valid, shows a good test-retest reliability (i.e., ICC = 0.74) and presents good internal consistency (Cronbach's α = 0.83) (142,161).

Functional level

The functional level was assessed using two scales: The Functional Independence Measure (FIM) and the New Mobility Score (NMS). The FIM consists of 18 items, of which 13 concern physical activities divided into four categories: self-care, sphincter control, transfers, and locomotion (162). The remaining five items relate to aspects of cognitive and social functioning divided in two categories: communication and social cognition. The total FIM score range is between 18 and 126 points. Higher scores indicate a higher level of independence. The internal consistency of the score has been reported as very good, with a Cronbach's α = 0.95

(163). The NMS consists of three questions to measure walking mobility across activities of daily living such as indoor walking, outdoor walking and walking during shopping (164). This questionnaire evaluates the pre-fracture functional level with a score from 0 (not able to walk) to 9 (fully independent). The test-retest reliability of the NMS is very high and has been recommended to evaluate the pre-fracture functional level in older adults with acute hip fracture (164). The internal consistency of the NMS is good with a Cronbach's α close to 1 (165).

Fear of falling

The Short Falls Efficacy Scale-International (SFES-I) consists of seven items with four possible answers corresponding to the level of concern (166). The total score range is from 7 to 28 points, where higher scores indicate a higher level of fear of falling (166). The SFES-I has demonstrated to be valid when compared with the history of falls, muscular strength, and functional status, and has high internal consistency with a Cronbach's α = 0.92 (167).

Fitness self-perception

The International Fitness Scale (IFIS) consists of five questions concerning the older adults' perception of his/ her general physical fitness (cardio-respiratory, muscular, agility and flexibility) (168). Each question has five possible answers (very poor, poor, average, good, and very good) scored from 1 to 5 points, where the highest score corresponds to the best perception of physical fitness (168). The IFIS is valid against objectively-measured physical fitness in older adults (169). Furthermore, a recent systematic review with meta-analysis found a moderate-to-substantial test-

retest reliability of the IFIS, where the pooled Kappa coefficient of agreement was higher than 0.60 in most of the dimensions (170).

Cognitive status

The Short Portable Mental State Questionnaire (SPMSQ) has 10 items that assess various functions: orientation, recall memory, concentration, and calculation (117). For clinical use, a cut off of 3 errors appears to be most useful to detect cognitive deterioration (117). The internal consistency of the SPMSQ is good with a Cronbach's α, = 0,82 (171).

Pain

The Visual Analogue Scale for Pain (VAS) test is a fast and convenient way to evaluate the intensity of pain perceived by the older adults (119). The older adults indicated the perceived pain by pointing out on a physical scale a value from 0 (without pain) to 10 (maximum pain) (119). The test–retest reliability is good with the r = 0.94 (145).

Low back pain

Family caregivers are at risk of developing low back pain due to activities such as back bending, lifting and carrying older adults (172). Therefore, we used the self-administered Oswestry Disability Index questionnaire to explore how a possible low back pain affects the caregivers' ability to manage in everyday life (173). This tool consists of 10 questions scored from 0 to 5, and the final score is calculated by summing the score of each section. The percentage of the total score over the maximum possible score (i.e., 50 points) is calculated and interpreted as follows: 0 – 20%: minimal disability; 21 – 40% moderate disability; 41 – 60% severe disability;

61 – 80% crippled; and 81-100% bed-bound or exaggerating symptoms (173). The internal consistency of the Oswestry questionnaire is good with Cronbach's α = 0,82 (174).

Caregiver burden

The Caregiver Strain Index consists of 13 items with a dichotomous answer (i.e., Yes or No) (175). “Yes” responses are summed. Higher numbers indicate a greater level of stress. The internal consistency of this test is acceptable with a Cronbach's α, = 0.73 (175).

Emotional status

The Hospital Anxiety and Depression Scale (HADS) consists of 14 items, each with four possible answers (0–3 points), divided into two subscales: seven items for status of depression and the remaining items for presence of anxiety (176). The maximum score of each subscale is 21 points; scores below 11 indicate the presence of depression or anxiety (176). The internal consistency of the HADS is good with a Cronbach's α = 0.80 (177).

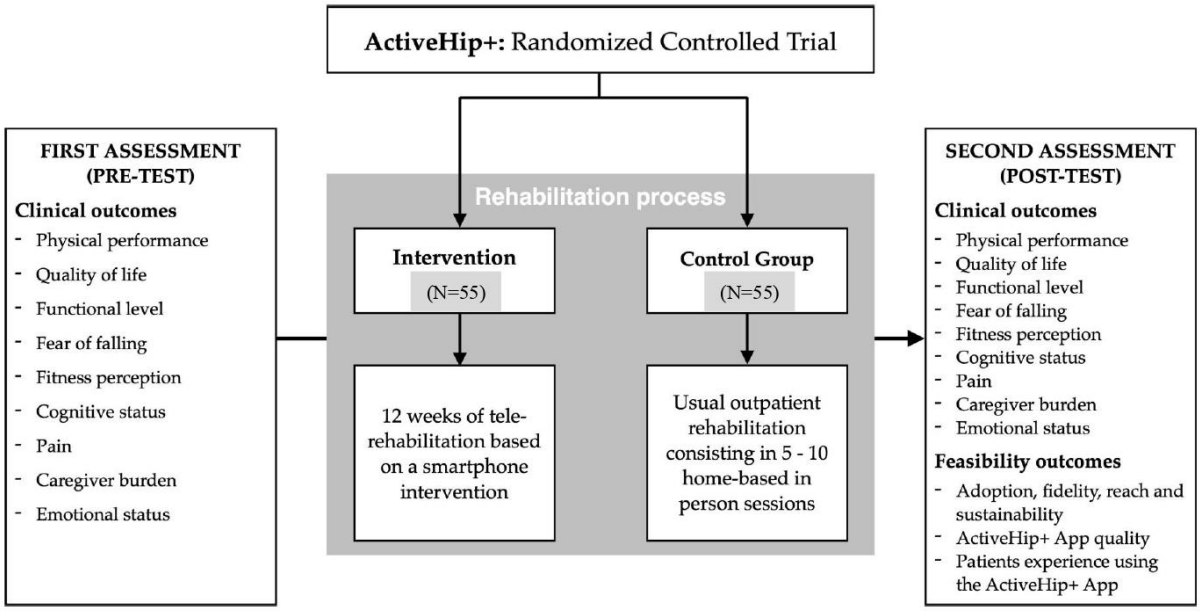


Figure 12. Included outcomes in the ActiveHip+ project at pre- and post-rehabilitation.

Data analyses and management

The normal distribution of the data was checked with the Kolmogorov-Smirnov test. Descriptive characteristics of the sample was presented as mean and standard deviation (SD) or frequency and percentage when appropriate. Baseline differences between groups was tested using an independent sample t-test for continuous variables and $\chi 2$ test or Mann–Whitney U test for categorical binomial and polynomial, respectively. The main effects of the ActiveHip+ was tested with the intention-to-treat approach. The criteria of the per-protocol approach are shown in the supplementary results will be: (1) to have valid data in both pre- and post-intervention assessments and (2) to have accessed to the app at least half of the 84 days that the health educational and telerehabilitation programs delivered through the ActiveHip+ app lasts.

The effects of the ActiveHip+ intervention was tested using constrained baseline longitudinal analysis via a linear mixed model using the 'LMMstar' R-package.(178) The dependent variable were outcomes included at three-time points: baseline, 3-month, and 1-year after surgery follow-up. The independent variables were the intervention option (ActiveHip+ mHealth vs Control Group), time (baseline, 3-month, and 1-year after surgery follow-up), and rehabilitation-by-time interaction. Data were presented as means and differences in the mean changes with standard error (SE) as an indicator of variance. The adequacy of the models was investigated via the predicted values and residuals. We examined linearity, representing a linear dose-response relationship, by treating each rehabilitation category as a continuous variable in the main model and confirming it through visual inspections.

Per-protocol analyses is presented as supplementary material, and it followed the same procedure as the explained above for the intention-to-treat analyses. For the intention-to-treat approach, all participants were included. Missing data were handled through a listwise deletion approach. All analyses were performed using IBM SPSS Statistics (SPSS, IBM Corporation version 25.0; Armonk, NY) and the software R version 4.3.1 and RStudio version 2023.09.0+463, and the level of significance was set at $p < 0.05$.

/RESULTS/

After the protocol, a controlled clinical trial of the ActiveHip+ mHealth intervention was conducted. The results obtained were as follows:

Between June 2021 and June 2022, 233 older adults with fracture were admitted to the hospitals included in this study to undergo hip surgery. Out of these 233, 124 meet the inclusion criteria and were invited to participate in this study, 110 accepted to use ActiveHip+ intervention. Half of them were randomly allocated to intervention group and half of them to the control group. In the intervention group, out of these 55 participants who accepted, 51 older adults with hip fracture were included in the final analysis. In the control group, 54 were included. The exclusion and dropouts of older adults in both groups are detailed in the CONSORT 2021 flowchart (Figure 13).

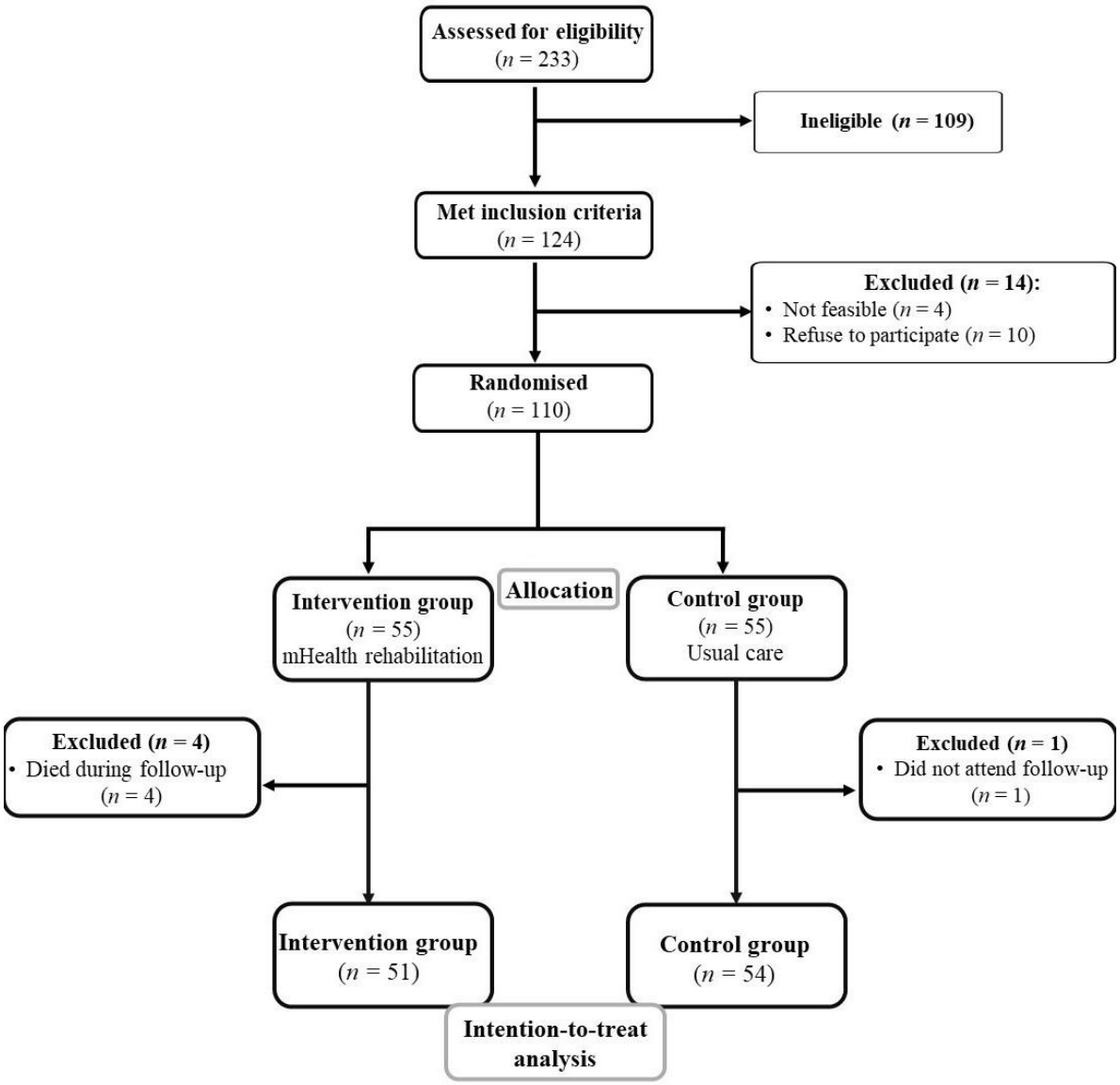


Figure 13. Consort flowchart of the sample recruited for this study.

Table 7 shows the sociodemographic characteristics of the participants by allocation groups. There were no statistically significant differences in any of the outcomes included.

Table 7. Baseline characteristics of participants included in intention-to-treat analyses.

Variable	Intervention group (*n*= 51)	Control group (*n*= 54)
Age (years), Mean (SD)	79·55 (7·1)	80·07 (7·7)
Sex, *n* (%)		
Women	37 (73)	38 (70)
Men	14 (27)	16 (30)
Type of injury, *n* (%)		
Fracture Cervical Femoral (Intracapsular)	29 (57)	30 (56)
Fracture Trochanteric (Extracapsular)	22 (43)	24 (44)
Type of surgery, *n* (%)		
Prosthesis	16 (65)	13 (24)
Screw Plate	33 (31)	36 (67)
PFN-A Nail	2 (4)	5 (9)
Falls in the previous year, *n* (%)		
Yes	16 (31)	18 (33)
No	35 (69)	36 (67)
Pre-fracture residence, *n* (%)		
Own home	49 (96)	54 (100)
Nursing or relative´s home	2 (4)	0 (0)
Post-fracture residence, *n* (%)		
Own home	45 (88)	47 (87)
Nursing or relative´s home	6 (12)	7 (13)
Hospital stay (days), Mean (SD)	6·76 (4·1)	5·6 (3·3)
Older adults' outcomes		
Objectively measured physical performance (SPPB 0-12)	2·76 (0·97)	2·63 (1·22)
Functional status (FIM, 18-126)	79·05 (17·10)	80·47 (14·40)
Emotional status (HADS, 0-42)	15·59 (5·09)	15·04 (5·78)
Pain level (NRS, 0-10)	5·92 (2·2)	6·52 (1·78)
Fear of falling (SFES-I, 7-28)	19·54 (7·1)	20·02 (5·15)
Quality of life (EQ5D -0·65-1)	0·20 (0·31)	0·35 (0·49)
Family caregivers' outcomes		
Caregivers burden (CSI, 0-13)	5·98 (1·88)	6·72 (1·83)
Emotional status (HADS, 0-42)	11·49 (3·86)	12·90 (3·59)

Low back pain (ODI, 0-50)	10·92 (13·51)	9·00 (12·56)
Quality of life (EQ5D, -0·65-1)	0·80 (0·34)	0·85 (0·21)
Fear of falling (SFES-I, 7-28)	21·04 (6·79)	20·67 (5·72)
Self-reported fitness (IFIS, 4-20)	17·27 (3·49)	17·02 (3·24)

Values are Mean (SD) unless otherwise indicated. CSI: Caregivers' Strain Index; EQ5D: EuroQol-5D; FIM= Functional Independence Measure; HADS: Hospital Anxiety and Depression Scale; IFIS: International Fitness Scale; NRS= Numeric rating scale; ODI: Oswestry Low Back Disability; PFN-A= Proximal Femoral Nail; SD= standard deviation; SFES-I= Short Falls Efficacy Scale; SPPB: Short Physical Performance Battery.

The main analyses are presented in Table 8 for older adults with fracture and in Table 9 for family caregivers. Both tables show the constrained linear mixed model between the intervention group and control group at baseline (reference), 3-month and 1-year after surgery follow-up.

Table 8. Differences in older adults' outcomes between groups at 3-month after surgery (post intervention): intention-to-treat analyses

		Intervention group (ActiveHip+ mHealth)			Control group (Usual care)			
Measurement	Month	*n*	Mean (SE)	Change from Baseline, Mean (SE)	*n*	Mean (SE)	Change from Baseline, Mean (SE)	Differences in change from baseline (ActiveHip+ vs. Usual care), Mean (SE)	p-value Diffs
Objectively measured physical performance (SPPB, 0-12)	0	51	2·69 (0·11)	Reference	54	2·69 (0·11)	Reference	Reference	Reference
	3	51	7·11 (0·33)	4·43 (0·34)	54	5·71 (0·32)	3·02 (0·33)	-1·40 (0·36)	**<0·001**
	12	31	6·34 (0·35)	3·66 (0·35)	29	5·18 (0·34)	3·49 (0·35)	-0·19 (0·47)	0·68
Balance (SPPB, 0–4)	0	51	1·48 (0·06)	Reference	54	1·48 (0·06)	Reference	Reference	Reference
	3	51	3·59 (0·10)	2·11 (0·12)	54	3·18 (0·09)	1·70 (0·12)	-0·40 (0·16)	**0·01**
	12	31	4·03 (0·18)	2·56 (0·20)	29	3·91 (0·18)	2·44 (0·19)	-0·08 (0·19)	0·67
Gait speed (SPPB, 0–4)	0	51	0·68 (0·05)	Reference	54	0·68 (0·05)	Reference	Reference	Reference
	3	51	1·76 (0·13)	1·08 (0·14)	54	1·26 (0·13)	0·58 (0·14)	-0·49 (0·13)	**<0·001**
	12	31	1·91 (0·08)	0·51 (0·09)	29	1·27 (0·05)	0·59 (0·09)	0·05 (0·17)	0·76
Chair stand (SPPB, 0–4)	0	51	1·42 (0·04)	Reference	54	1·42 (0·04)	Reference	Reference	Reference
	3	51	1·77 (0·14)	1·36 (0·14)	54	1·26 (0·13)	0·85 (0·14)	-0·51 (0·17)	**0·002**
	12	31	1·86 (0·19)	1·45 (0·20)	29	1·76 (0·20)	1·34 (0·21)	-0·21 (0·22)	0·36
Handgrip strength: Kg	0	51	18·20 (0·51)	Reference	54	18·20 (0·51)	Reference	Reference	Reference

	3	49	20·40 (0·50)	2·26 (0·49)	52	19·90 (0·46)	1·72 (0·47)	-0·57 (0·65)	0·38
	12	28	20·14 (0·95)	1·94 (0·58)	28	19·16 (0·59)	1·41 (0·59)	-0·63 (0·84)	0·45
Functional status (FIM, 18-126)	0	51	77·30 (1·51)	Reference	54	77·30 (1·51)	Reference	Reference	Reference
	3	51	114·50 (1·34)	37·20 (1·76)	54	110·80 (1·30)	33·50 (1·73)	-3·36 (2·65)	0·21
	12	36	107·90 (2·73)	30·54 (3·00)	37	105·80 (2·67)	28·47 (2·94)	-2·60 (3·15)	0·41
FIM self-care (6–42)	0	51	19·00 (0·54)	Reference	54	19·00 (0·54)	Reference	Reference	Reference
	3	51	36·80 (0·70)	17·74 (0·81)	54	34·60 (0·68)	15·52 (0·80)	-2·16 (1·08)	**0·047**
	12	36	34·90 (1·11)	15·85 (1·19)	37	33·60 (1·10)	14·52 (1·17)	-1·26 (1·29)	0·33
FIM sphincter (2–14)	0	51	11·30 (0·34)	Reference	54	11·30 (0·34)	Reference	Reference	Reference
	3	51	13·30 (0·14)	2·08 (0·27)	54	12·90 (0·14)	1·64 (0·27)	-0·44 (0·36)	0·22
	12	36	12·90 (0·29)	1·61 (0·38)	37	12·10 (0·29)	0·87 (0·38)	-0·71 (0·43)	0·10
FIM transfer (3-21)	0	51	8·40 (0·56)	Reference	54	8·40 (0·56)	Reference	Reference	Reference
	3	51	18·40 (0·31)	9·96 (0·56)	54	17·80 (0·31)	9·40 (0·57)	-0·34 (0·81)	0·67
	12	36	17·00 (0·62)	0·61 (0·82)	37	17·20 (0·61)	8·79 (0·81)	0·09 (0·97)	0·92
FIM locomotion (2-14)	0	51	5·19 (0·34)	Reference	54	5·19 (0·34)	Reference	Reference	Reference
	3	51	11·99 (0·23)	6·80 (0·37)	54	11·51 (0·22)	6·32 (0·37)	-0·43 (0·52)	0·42
	12	36	11·03 (0·45)	5·84 (0·55)	37	11·53 (0·44)	6·34 (0·54)	0·27 (0·63)	0·67
FIM communication (2-14)	0	51	13·50 (0·09)	Reference	54	13·50 (0·09)	Reference	Reference	Reference

	3	51	13·90 (0·08)	0·34 (0·12)	54	13·70 (0·08)	0·16 (0·12)	-0·13 (0·20)	0·50
	12	36	13·30 (0·24)	-0·26 (0·25)	37	12·90 (0·23)	-0·68 (0·24)	-0·44 (0·23)	0·06
FIM psychosocial (3-21)	0	51	19·90 (0·19)	Reference	54	19·90 (0·19)	Reference	Reference	Reference
	3	51	20·30 (0·21)	0·39 (0·27)	54	20·20 (0·20)	0·33 (0·26)	-0·02 (0·38)	0·97
	12	36	19·40 (0·42)	-0·54 (0·44)	37	18·80 (0·41)	-1·06 (0·43)	-0·65 (0·45)	0·15
Emotional status (HADS, 0-42)	0	51	15·30 (0·57)	Reference	54	15·30 (0·57)	Reference	Reference	Reference
	3	51	11·60 (0·65)	-3·65 (0·76)	54	14·10 (0·63)	-1·20 (0·75)	2·38 (1·00)	**0·018**
	12	31	15·30 (0·78)	-0·03 (0·99)	37	15·40 (0·77)	0·13 (0·97)	-0·08 (1·21)	0·95
HADS anxiety (0-21)	0	51	7·66 (0·49)	Reference	54	7·66 (0·41)	Reference	Reference	Reference
	3	51	4·03 (0·49)	-3·62 (0·56)	54	6·51 (0·47)	-1·15 (0·55)	2·48 (0·73)	**<0·001**
	12	35	5·66 (0·56)	-1·99 (0·71)	37	5·90 (0·55)	-1·76 (0·69)	0·02 (0·87)	0·99
HADS depression (0-21)	0	51	7·61 (0·25)	Reference	54	7·61 (0·24)	Reference	Reference	Reference
	3	51	7·66 (0·35)	-0·01 (0·36)	54	7·54 (0·31)	-0·07 (0·35)	0·07 (0·46)	0·87
	12	35	7·61 (0·39)	-1·95 (0·45)	37	9·52 (0·38)	1·91 (0·45)	-0·03 (0·55)	0·96
Pain (NRS, 0-10)	0	51	6·23 (0·20)	Reference	54	6·23 (0·20)	Reference	Reference	Reference
	3	51	1·29 (0·28)	-4·94 (0·34)	54	2·16 (0·27)	-4·07 (0·34)	-4·90 (0·34)	**0·049**
	12	36	2·02 (0·37)	-4·21 (0·42)	37	2·11 (2·11)	-4·11 (0·41)	-4·17 (0·38)	0·79
Fear of falling (SFES, 7–28)	0	51	19·80 (0·60)	Reference	54	19·80 (0·60)	Reference	Reference	Reference

	3	51	12·10 (0·78)	-7·73 (0·95)	54	13·30 (0·76)	-6·51 (0·94)	1·18 (1·11)	0·29
	12	36	13·30 (0·89)	-6·52 (1·02)	37	13·10 (0·87)	-6·68 (1·00)	-0·10 (1·32)	0·94
Quality of life (EQ5D, -0·65–1)	0	51	0·30 (0·05)	Reference	54	0·30 (0·05)	Reference	Reference	Reference
	3	51	0·49 (0·06)	0·19 (0·07)	54	0·32 (0·05)	0·02 (0·07)	-0·09 (0·09)	0·30
	12	35	0·49 (0·07)	0·19 (0·08)	37	0·54 (0·07)	0·24 (0·08)	0·05 (0·10)	0·64
Self-perceived health (EQ5D-VAS, 0-100)	0	51	54·64 (2·21)	Reference	54	56·64 (2·21)	Reference	Reference	Reference
	3	51	80·00 (2·18)	25·42 (2·69)	54	72·22 (2·06)	17·53 (2·64)	-9·15 (3·51)	**0·009**
	12	35	73·23 (2·22)	17·72 (3·30)	37	69·29 (2·84)	15·24 (3·26)	-3·29 (4·17)	0·42

EQ5D: EuroQol-5D; FIM= Functional Independence Measure; HADS: Hospital Anxiety and Depression Scale; HG: Handgrip; *n*=sample size; NRS= Numeric rating scale; SE: Standard Error SFES-I= Short Falls Efficacy Scale; SPPB: Short Physical Performance Battery. Significant differences ($p < 0·05$) are highlighted in bold.

At 3-month post-fracture surgery follow-up (post intervention), older adults in the intervention group had a greater recovery in objectively measured physical performance (1·40 ±0·36 points; p<0·001), emotional status (-2·38 ±1 points; p = 0·02), pain relief (-4·90 ± 0·34 points; p=0·049) and self-perceived health (9·15± 3·51 points; p=0·01) than those in the control group. No effects were observed for the remaining older adults' outcomes at 3-month follow-up (all, p > 0·20) and none of the previous effects were maintained at 1-year after surgery follow-up (all, p > 0·40). All these results are depicted in Table 8 and illustrated in Figure 14.

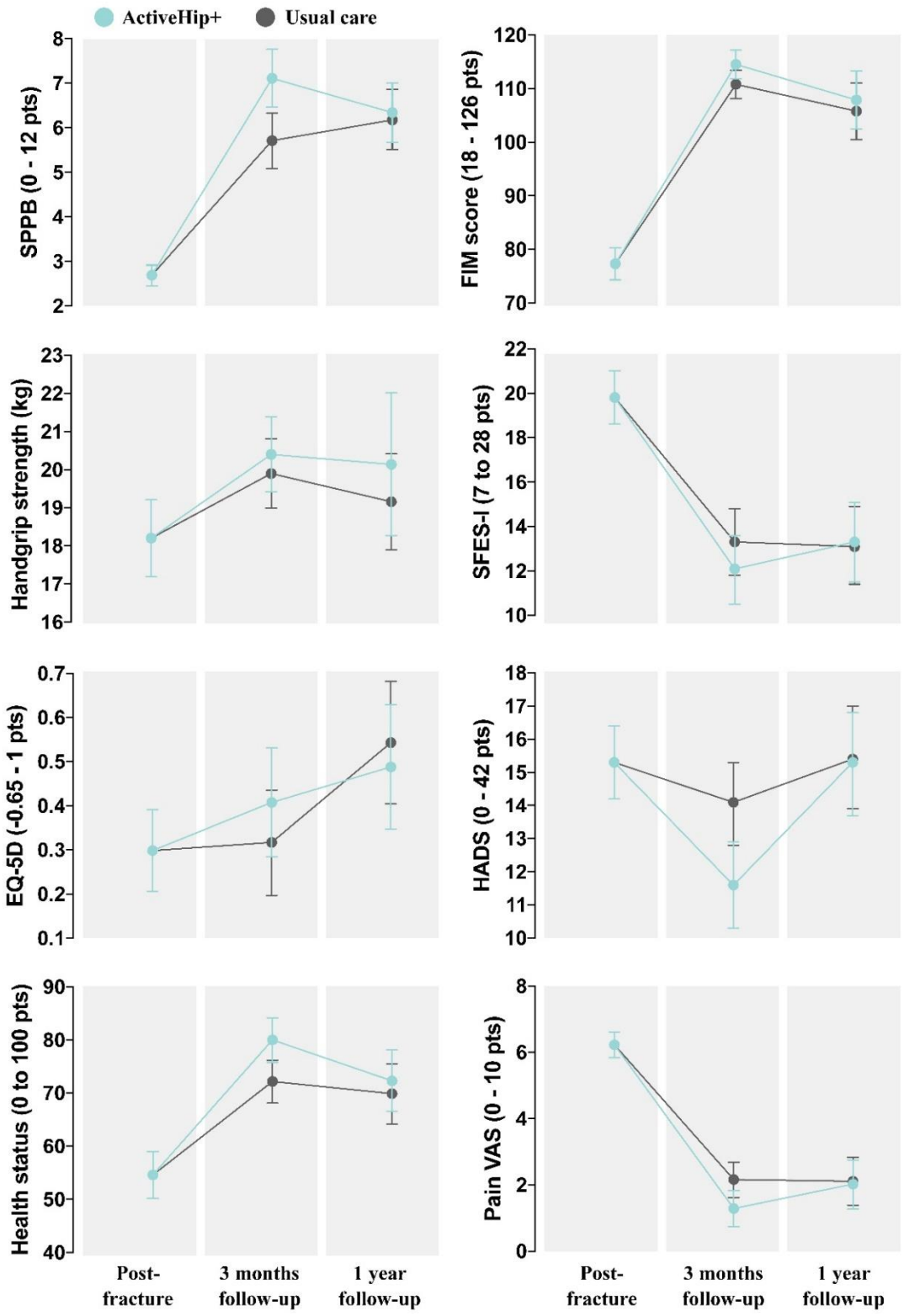


Figure 14. Changes in older adults' outcomes by time and group: intention-to-treat analyses. Data points represent the model-estimated means and 95% confidence intervals (indicated by the I bars) from a constrained linear mixed model (cLMM) with baseline means constrained to be equal across study arms, reflecting the pre-randomisation nature of the baseline assessment.

Regarding family caregivers at the 3-month post-fracture surgery follow-up (post intervention), those in the intervention group had a greater decrease of the burden (-0·96 ± 0·46 points; p = 0·04) and depression status (-1·00 ± 0·41 points; p = 0·02) compared to controls. No effects were observed for the remaining family caregivers' outcomes at 3-month follow-up (all, p > 0·09) and none of the previous effects were maintained at 1-year after surgery follow-up (all, p > 0·23). All these results are depicted in Table 9 and illustrated in Figure 15.

Table 9. Differences in family caregivers' outcomes between groups at 3-month after surgery (post intervention): intention-to-treat analyses

		Intervention group (ActiveHip+ mHealth)			Control group (Usual care)				
Outcome	Months	*n*	Mean (SE)	Change from Baseline, Mean (SE)	*n*	Mean (SE)	Change from Baseline, Mean (SE)	Differences in change from baseline (ActiveHip+ vs. Usual care), Mean (SE)	p-value Diffs
Caregiver' burden (CSI, 0-13)	0	51	6·36 (0·18)	Reference	54	6·36 (0·18)	Reference	Reference	Reference
	3	51	3·64 (0·34)	-2·72 (0·35)	54	4·59 (0·33)	-1·77 (0·34)	0·95 (0·46)	**0·04**
	12	34	3·79 (0·52)	-2·57 (0·54)	31	3·89 (0·54)	-2·47 (0·56)	0·01 (0·57)	0·99
Emotional status (HADS, 0-42)	0	51	12·44 (0·42)	Reference	54	12·44 (0·42)	Reference	Reference	Reference
	3	51	9·24 (0·54)	-3·20 (0·68)	54	10·63 (0·52)	-1·18 (0·67)	1·29 (0·77)	0·10
	12	34	16·16 (0·62)	3·72 (0·74)	31	15·34 (0·65)	2·90 (0·76)	-0·77 (0·98)	0·43
HADS anxiety (0-21)	0	51	3·94 (0·31)	Reference	54	3·94 (0·31)	Reference	Reference	Reference
	3	51	2·07 (0·33)	-1·88 (0·46)	54	2·44 (0·32)	-1·51 (0·45)	0·27 (0·52)	0·60
	12	34	7·19 (0·40)	3·24 (0·50)	31	6·97 (0·42)	3·03 (0·51)	-0·16 (0·67)	0·81
HADS depression (0-21)	0	51	8·50 (0·20)	Reference	54	8·50 (0·20)	Reference	Reference	Reference
	3	51	7·18 (0·34)	-1·31 (0·38)	54	8·18 (0·33)	-0·32 (0·38)	1·00 (0·41)	**0·02**
	12	34	8·95 (0·31)	0·45 (0·36)	31	8·30 (0·32)	-0·20 (0·37)	-0·62 (0·53)	0·24
Quality of life (EQ5D, -0·65–1)	0	51	0·83 (0·03)	Reference	54	0·83 (0·03)	Reference	Reference	Reference
	3	51	0·90 (0·03)	0·07 (0·04)	54	0·86 (0·03)	0·04 (0·04)	-0·03 (0·05)	0·47
	12	34	0·85 (0·04)	0·02 (0·05)	31	0·87 (0·04)	0·05 (0·05)	0·03 (0·06)	0·60
Health today (EQ5D-VAS, 0-100)	0	51	73·20 (2·24)	Reference	54	73·20 (2·24)	Reference	Reference	Reference
	3	51	85·40 (1·46)	12·20 (2·45)	54	84·20 (1·42)	11·05 (2·43)	-1·27 (3·17)	0·70
	12	34	84·50 (1·69)	11·36 (2·79)	31	82·60 (1·73)	9·46 (2·82)	-2·96 (4·02)	0·46
Low back pain (ODI, 0-50)	0	51	9·94 (1·29)	Reference	54	9·94 (1·29)	Reference	Reference	Reference
	3	51	5·47 (1·43)	-4·48 (1·91)	54	6·61 (1·39)	-3·33 (1·88)	1·31 (2·35)	0·58

	12	34	10·67 (2·30)	0·72 (2·59)	31	13·49 (2·37)	3·54 (2·65)	3·55 (2·98)	0·23
Fear of falling (SFES-I, 7-28)	0	51	20·80 (0·60)	Reference	54	20·80 (0·60)	Reference	Reference	Reference
	3	51	11·20 (0·73)	-9·63 (0·91)	54	11·90 (0·71)	-8·92 (0·89)	0·76 (1·07)	0·48
	12	34	12·20 (0·89)	-8·63 (0·99)	31	11·40 (0·90)	-9·48 (1·00)	-0·45 (1·35)	0·74
Self-reported fitness (IFIS,4–20)	0	51	17·10 (0·33)	Reference	54	17·1 (0·327)	Reference	Reference	Reference
	3	51	17·60 (0·40)	0·47 (0·48)	54	17·5 (0·394)	0·39 (0·47)	-0·08 (0·59)	0·90
	12	34	17·20 (0·47)	0·09 (0·56)	31	16·4 (0·490)	-0·73 (0·58)	-0·72 (0·74)	0·33

CSI: Caregivers' Strain Index; EQ5D: EuroQol-5D; HADS: Hospital Anxiety and Depression Scale; IFIS: International Fitness Scale; *n*=sample size; ODI: Oswestry Low Back Disability; SE: Standard Error; SFES-I= Short Falls Efficacy Scale. Significant differences ($p < 0·05$) are highlighted in bold.

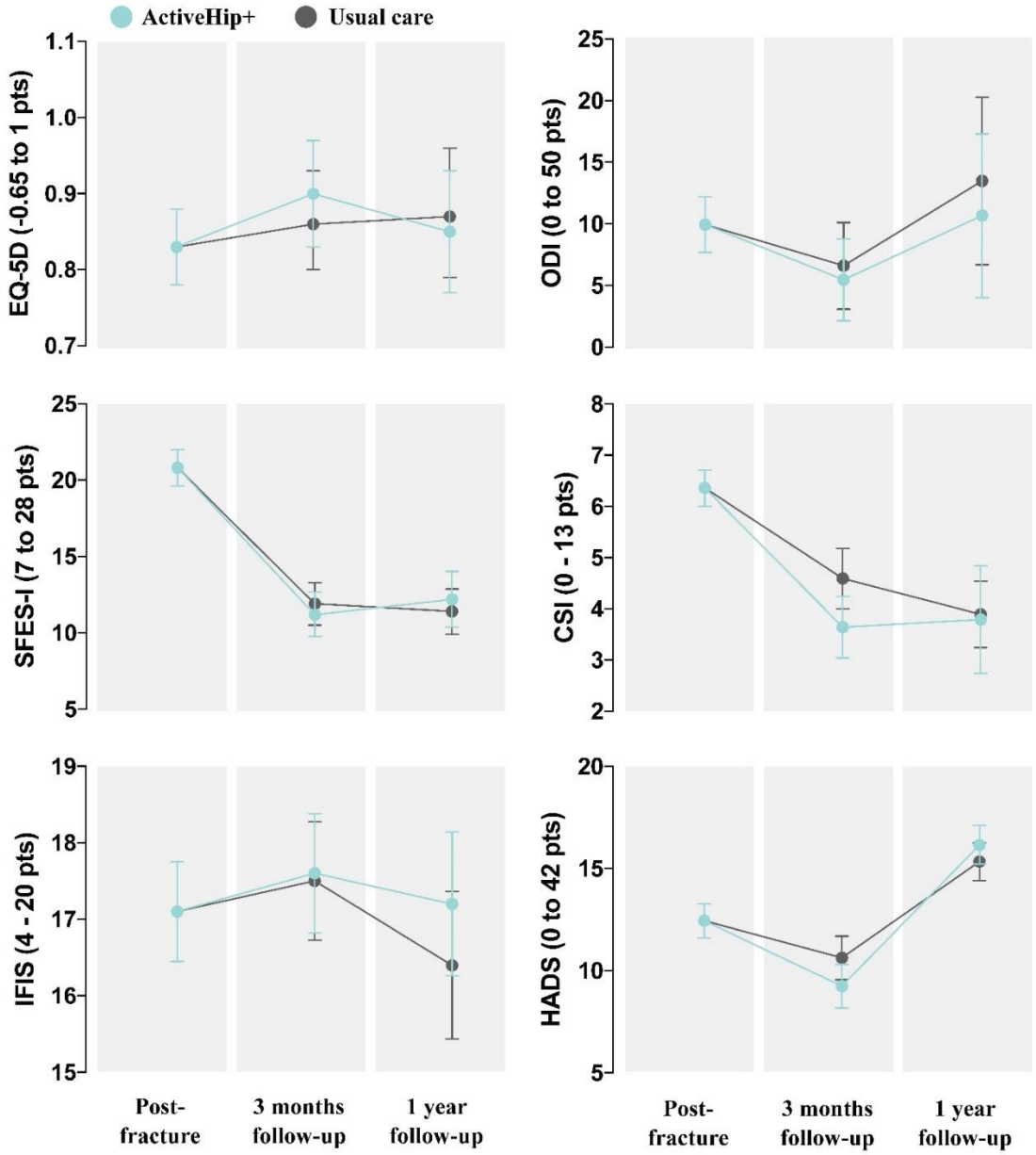


Figure 15. Changes in family caregivers' outcomes by time and group: intention-to-treat analyses. Data points represent the model-estimated means and 95% confidence intervals (indicated by the I bars) from a constrained linear mixed model (cLMM) with baseline means constrained to be equal across study arms, reflecting the pre-randomisation nature of the baseline assessment.

The per-protocol which represents the secondary analysis are shown in supplementary material (Figure S1, Table S4, Table S5, Table S6, Figure S2 and Figure S3). Overall, effects size was similar to the results of the intention-to-treat approach.

/SUPLEMENTARY MATERIAL/

Table S4. Physical exercise sessions divided by four difficulty levels.

Level 1. Initiation
WARMING UP (3 repetitions on each side)
Neck mobility “yes” and “no”
Shoulders mobility up / down
Walk on the spot (alternate toes)
Walk on the spot (alternate toes) Side bends
Ankle mobility. Support toe / support heel
Walk on the spot (alternate toes)
MAIN TRAINNING (5-10 rep. on each side)
Mobility
• Shoulder abduction / adduction 80º approximately
• Open / close 90º in front of the face
Tighten hand pre-float
Walk on the spot
Cross arms in front of chest
Bending / extending elbows above head
Wrist flexion / extension
Stomp
Cross arms in front of chest
Bending / extending elbows above head
Wrist flexion / extension
March on the spot
Supported hip flexion
Supported hip extension
Tiptoe feet together with support
COOL DOWN (20’’)
Chest stretch sitting
Calf stretch standing
Ball myofacial release
Level 2. Moderate
WARMING UP (3 times on each side)
Neck movements ear / shoulder tilt
Shoulders movements rotation: Arms cross (palm up / down)
Shoulders movements raise arms over head
Thoracic Ext (hump / chest)
March on the spot (military march with arms)
Skier sitting and legs back standing
MAIN TRAINNING (10 times on each side)
Abductions / Adductions from shoulder 80º from front
Triceps, lift from chair to arms extended
Tighten hand pre-float
March on the spot
Supported hip flexion
Supported Hip Extension
Toes together with support
Draw circles on the ground (5 and 5)
Stride back alternate start with support

Step front raise and lower with support
Cross arms in front of chest
Overhead elbow flexion / extension
Wrist flexion / extension
Step-touch aerobics with reference
March on the spot on the site with reference
Abd / hip add across front with support
45º start squat with support and reference (135º)
Turns with walker
Start alternate lateral stride with support
COOL DOWN (20'')
Triceps.
Side stretches
Hamstring stretches

Level 3. Advanced I

WARMING UP (3 times on each side)
Neck movements "yes" and "no"
Shoulders movements up / down
Walk on the spot (alternate toes)
Walk on the spot (alternate toes). Side bends (lateral)
Ankle movements. Support toe / support heel
Walk on the spot (alternate toes)
MAIN TRAINNING (2x10 times on each side)
Wall flexion
Open / close band hip-diagonal up
Open / close band in line with shoulders
Dead weight
Abduction / Adduction hip with reference
Hip Flexion
Hip extension
45º isometric squat
Tiptoe
Front / back shoulder circles
Abduction / Adduction from shoulders 80º from front standing
Hip abduction / adduction across the front
Turns with walker
Alternate superman standing
Alternating start lateral lunge
Maintain balance 1 bent leg
COOL DOWN (20'')
Chest stretch sitting
Calf stretch standing
Anteversion / hip retroversion with breathing (5 times on each side)

Level 4. Advanced II

WARMING UP (3 times on each side)
Neck movements ear / shoulder tilt
Shoulders movements rotation cron arms cross (palm up / down)
Shoulders movements raise arms over head.
Thoracic Ext (hump / chest).
March on the spot (military march with arms).
Skier sitting and legs back standing.
MAIN TRAINNING (3x7 times on each side)
Front / back shoulder circles
Open / close 90º in front of the face standing
Touching the ankles in the supine position with rolling
Superman alternate ground knee (leg only possible)

Pelvis hip / knee flexion forward Monster lateral walk Squats 60º Step 1 leg squat Step up front + 7 abduction + down Walk + lateral stride every 3 step Overhead elbow flexion / extension Boxing Plank with knees and elbows Glute bridge Alternating hip flexion (knee-chest Tiptoe Walk + stride back every 3 steps Step up and down front Step 1 leg squat Step up front + 5 ext. Hips + lower **COOL DOWN (20'')** Standing back stretch (bending video) Trunk Rotation Ball myofascial release Hip anterior and posterior tilt with breathing.

Table S5. Description of the Occupational Therapy sessions divided by four difficulty sessions.

Level 1. Initiation
Mobility in bed: **(6-10 rep)** • Moving laterally in bed • Roll over in bed. • Sit on the edge of the bed and lie down. **Transfer** **(4-6 rep)** • Get up and sit in a chair with a walker. • Transfer between two chairs with turn and front step with walker. • Get up and sit in a chair with armrest support. • Transfer between two chairs with side step. **Trunk mobility in sitting position** **(2 min)** • Hitting a ball with alternate feet in a sitting position. • Return a balloon with reference and grab. • Return a seated balloon thrown to the sides and at different heights. • Catch a ball while sitting with a basket while sitting. • Throwing balls into the basket held by the caregiver (front table and back chair). **Use of walking aids (walker) :** **(2 rep go and back)** • Zig-zag circuit
Level 2. Moderate
Transfer (5-7 rep) • Get up and sit in a chair with armrest support. • Transfer between chairs making zig zag circuit with walker. • Get up and sit in a chair with one hand on the walker and one on the knee. • Transfer between two chairs with side step. • Get up and sit in a chair without support arms parallel to the body with reference. **Semi-twists** **(2 sets of 6 reps)** • Change surface objects with small twist without grip. **Save obstacles walking with support** **(5 reps go and back)** • Walk straight by jumping on a shoebox forward with two-handed grip

- Walk straight jumping shoe boxes going forward with one hand grip, stop between box and box and step between box and box to prepare next jump.

Change de position of a objet (bottle of water). **(2 sets of 6 (3 twists each side))**

- Change surface objects with small twist without grip.
- Squats to change surface objects between table and box with grip and reference behind.
- Change surface objects with side step.
- Change position objects with front step.
- Change objects position with side step without grip.

Use of walking aids (cane) : **(3 min)**

Level 3. Advanced I

Transfer **(2 sets of 4 changes (2 each side))**

- Transfer between two chairs by doing 8 without walker with chair grip when turning (short distance between chairs)

Walking **(2 sets of 2 round trips)**

- Walk straight jumping shoe boxes going forward with one hand grip, stop between box and box and step between box and box to prepare next jump.
- Walk front and back with reference.
- Walk bouncing a ball with both hands forward reference.
- Walk straight jumping shoe boxes going forward without grip, stop between box and step between box and box to prepare next jump.
- Walk straight jumping shoe boxes going forward without grip, stop between box and box without step to prepare jump.

Change position of objects (bottle of water) **(2 sets of 4 to 8 reps (on each side)**

- Changing objects in height with both hands without grip.
- Change height objects with forward diagonal step and grip.
- Change height objects with one hand with steps to climb on a grip stool.
- Change surface object with sequence take object more walking with grip.
- Change height objects (between tall furniture and bench) with knee flexion with grip || Change tall objects (between tall furniture and floor) with grip knee bend.

Level 4. Advanced II

Standing balance with balloon **(2 min)**

- Return an unreferenced balloon with front and side steps
- Return a balloon by lifting opposite lower limb with reference

Walking without aids. **(2 sets of 2 round trips)**

- Walk bouncing a ball with both hands forward reference.
- Walking down and raising objects from chairs to boxes bending knees || Walk by lowering and raising objects from chairs to the floor bending knees.
- Zig-zag circuit without technical assistance to walk backwards.
- Walk carrying objects on a tray making 8 between boxes
- Walking down and raising objects from chairs to boxes bending knees || Walk by lowering and raising objects from chairs to the floor bending knees.
- Walk between chairs without dropping a balloon.
- Walk straight jumping shoe boxes going forward no grip jumping a box with each step.

Change position of objects (Bottle of water) **(2 sets of 4-8 rep (on each side)**

- Change objects in height position on tiptoe (isometric) with grip
- Change objects in height and surface with sequence front step to reach, diagonal step, squat and front step and squat
- Change height and surface objects between tall unit and bench with twist and squat || Switch height and surface objects between tall unit and floor with twist and squat.
- Change objects in height and surface with sequence front step to reach, diagonal step, squat and front step and squat.
- Change height objects with both hands with steps to climb on the bench without grip.

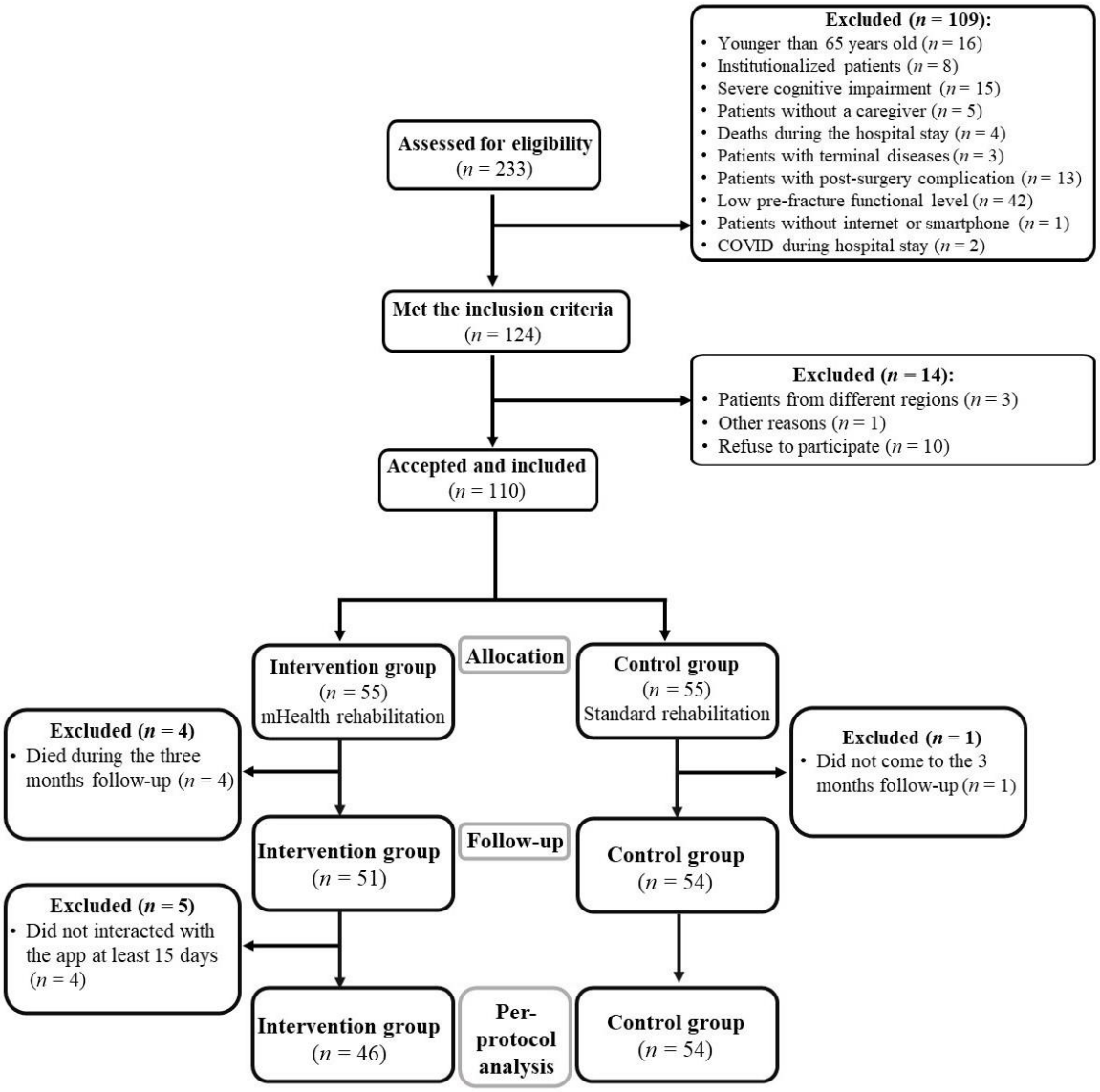


Figure S1. Consort flowchart of the sample recruited for this study.

Table S6. Baseline characteristics of participants included in per-protocol analysis.

Variable	Intervention group (*n*= 46)	Control group (*n*= 54)
Age (years), Mean (SD)	79·70 (7·2)	79·94 (7·8)
Sex, *n* (%)		
Women	33 (72)	38 (70)
Men	13 (28)	16 (30)
Type of injury, *n* (%)		
Fracture Cervical Femoral (Intracapsular)	26 (57)	30 (56)
Fracture Trochanteric (Extracapsular)	20 (43)	24 (44)
Type of surgery, *n* (%)		
Prosthesis	14 (65)	13 (24)
Screw Plate	30 (31)	36 (67)
PFN-A Nail	2 (4)	5 (9)
Falls in the previous year, *n* (%)		
Yes	16 (35)	18 (33)
No	30 (65)	36 (67)
Pre-fracture residence, *n* (%)		
Own home	45 (98)	54 (100)
Nursing or relative´s home	1 (2)	0 (0)
Post-fracture residence, *n* (%)		
Own home	42 (91)	47 (87)
Nursing or relative´s home	4 (9)	7 (13)
Hospital stay (days), Mean (SD)	6·83 (4·2)	5·64 (3·3)
Older adults' outcomes		
Objectively measured physical performance (SPPB 0-12)	2·67 (0·86)	2·63 (1·22)
Functional status (FIM, 18-126)	76·08 (17·52)	80·47 (14·40)
Emotional status (HADS, 0-42)	15·30 (4·92)	15·04 (5·78)
Pain level (NRS, 0-10)	6·23 (2·10)	6·52 (1·78)
Fear of falling (SFES-I, 7-28)	19·70 (7·33)	20·02 (5·15)
Quality of life (EQ5D -0·65-1)	0·30 (0·28)	0·35 (0·49)
Family caregivers' outcomes		
Caregivers burden (CSI, 0-13)	6·30 (1·94)	6·72 (1·83)

Emotional status (HADS, 0-42)	12·43 (4·01)	12·90 (3·59)
Low back pain (ODI, 0-50)	10·13 (12·97)	9·00 (12·56)
Quality of life (EQ5D, -0·65-1)	0·82 (0·29)	0·85 (0·21)
Fear of falling (SFES-I, 7-28)	20·5 (6·56)	20·67 (5·72)
Self-reported fitness (IFIS, 4-20)	17·14 (3·32)	17·02 (3·24)

Values are Mean (SD) unless otherwise indicated. CSI: Caregivers' Strain Index; EQ5D: EuroQol-5D; FIM= Functional Independence Measure; HADS: Hospital Anxiety and Depression Scale; IFIS: International Fitness Scale; NRS= Numeric rating scale; ODI: Oswestry Low Back Disability; PFN-A= Proximal Femoral Nail; SD= standard deviation; SFES-I= Short Falls Efficacy Scale; SPPB: Short Physical Performance Battery.

Table S7. Differences in older adults' outcomes between groups at 3-month after surgery (post intervention): per-protocol analyses

		Intervention group (ActiveHip+ mHealth)			Control group (Usual care)				
Outcome	Month	N	Mean (SE	Change from Baseline, Mean (SE)	n	Mean (SE)	Change from Baseline, Mean (SE)	Differences in change from baseline (ActiveHip+ vs. Usual care), Mean (SE)	p-value Diffs
Objectively measured physical performance	0	46	2.67 (0.12)	Reference	54	2.67 (0.12)	Reference	Reference	Reference
(SPPB, 0-12)	3	46	7.15 (0.34)	4.48 (0.35)	54	5.71 (0.31)	3.04 (0.33)	-1.44 (0.36)	**<0.001**
	12	28	6.48 (0.35)	3.81 (0.36)	29	6.17 (0.34)	3.50 (0.35)	-0.34 (0.48)	0.48
Balance (SPPB, 0–4)	0	46	1.48 (0.06)	Reference	54	1.48 (0.06)	Reference	Reference	Reference
	3	46	3.59 (0.10)	2.11 (0.13)	54	3.18 (0.09)	1.70 (0.12)	-0.40 (0.16)	**0.015**
	12	28	4.12 (0.19)	2.64 (0.20)	29	3.91 (0.18)	2.44 (0.19)	-0.18 (0.20)	0.36
Gait speed (SPPB, 0–4)	0	46	0.67 (0.05)	Reference	54	0.67 (0.05)	Reference	Reference	Reference
	3	46	1.78 (0.14)	1.11 (0.15)	54	1.26 (0.13)	0.58 (0.14)	-0.51 (0.14)	**<0.001**
	12	28	1.21 (0.09)	0.54 (0.09)	29	1.27 (0.05)	0.59 (0.09)	0.03 (0.18)	0.87
Chair stand (SPPB, 0–4)	0	46	0.39 (0.05)	Reference	54	0.39 (0.05)	Reference	Reference	Reference
	3	46	1.79 (0.14)	1.40 (0.15)	54	1.26 (0.13)	0.86 (0.14)	-0.60 (0.23)	**0.008**
	12	28	1.93 (0.20)	1.54 (0.21)	29	1.74 (0.20)	1.35 (0.21)	-0.35 (0.27)	0.20
Handgrip strength: Kg	0	46	18.10 (0.52)	Reference	54	18.10 (0.52)	Reference	Reference	Reference
	3	44	20.60 (0.48)	2.44 (0.50)	52	19.90 (0.46)	1.74 (0.47)	-0.74 (0.68)	0.278
	12	24	20.40 (0.62)	2.24 (0.63)	28	19.60 (0.59)	1.47 (0.59)	-0.94 (0.88)	0.29
Functional status (FIM, 18-126)	0	46	76.80 (1.54)	Reference	54	76.80 (1.54)	Reference	Reference	Reference
	3	46	114.90 (1.41)	38.13 (1.82)	54	110.70 (1.31)	33.91 (1.74)	37.99 (2.18)	0.14
	12	32	108.40 (2.80)	31.63 (3.06)	37	105.80 (2.59)	28.95 (2.87)	32.95 (2.52)	0.28
FIM self-care (6–42)	0	46	19.00 (0.56)	Reference	54	19.00 (0.56)	Reference	Reference	Reference
	3	46	37.10 (0.73)	18.12 (0.85)	54	34.50 (0.68)	15.58 (0.80)	-2.49	**0.026**
	12	32	35.00 (1.18)	15.99 (1.26)	37	33.50 (1.10)	14.59 (1.18)	-1.42	0.29
FIM sphincter (2–14)	0	46	12.20 (0.25)	Reference	54	12.20 (0.25)	Reference	Reference	Reference
	3	46	12.40 (0.14)	2.23 (0.28)	54	12.90 (0.13)	1.68 (0.27)	-0.54 (0.37)	0.14
	12	32	13.00 (0.30)	1.73 (0.39)	37	12.20 (0.28)	0.95 (0.38)	-0.77 (0.44)	0.08
FIM transfer (3-21)	0	46	8.13 (0.56)	Reference	54	8.13 (0.56)	Reference	Reference	Reference
	3	46	18.40 (0.34)	10.26 (0.59)	54	17.77 (0.31)	9.64 (0.57)	-0.41 (0.80)	0.61
	12	32	17.15 (0.62)	9.02 (0.80)	37	17.19 (0.57)	9.06 (0.77)	-0.13 (0.97)	0.89
FIM locomotion (2-14)	0	46	5.10 (0.34)	Reference	54	5.10 (0.34)	Reference	Reference	Reference
	3	46	12.00 (0.24)	6.90 (0.39)	54	11.50 (0.22)	6.40 (0.37)	-0.46 (0.53)	0.38
	12	32	5.10 (0.34)	6.01 (0.55)	37	11.50 (0.43)	6.42 (0.53)	0.15 (0.63)	0.81
FIM communication (2-14)	0	46	13.50 (0.10)	Reference	54	13.50 (0.10)	Reference	Reference	Reference
	3	46	13.90 (0.09)	0.35 (0.13)	54	13.70 (0.08)	0.19 (0.13)	-0.12 (0.20)	0.54
	12	32	13.40 (0.24)	-0.13 (0.25)	37	12.90 (0.22)	-0.67 (0.24)	-0.53 (0.24)	**0.023**
FIM psychosocial (3-21)	0	46	19.90 (0.20)	Reference	54	19.90 (0.20)	Reference	Reference	Reference
	3	46	20.20 (0.20)	0.35 (0.28)	54	20.20 (0.20)	0.34 (0.27)	0.03 (0.39)	0.93

	12	32	19.40 (0.44)	-0.45 (0.46)	37	18.80 (0.41)	-1.05 (0.43)	-0.73 (0.46)	0.12
Emotional status (HADS, 0-42)	0	46	15.30 (0.58)	Reference	54	15.30 (0.58)	Reference	Reference	Reference
	3	46	11.50 (0.69)	-3.88 (0.80)	54	14.10 (0.63)	-1.25 (0.76)	2.57 (1.01)	**0.011**
	12	31	15.50 (0.80)	0.15 (0.97)	37	15.44 (0.73)	0.05 (0.92)	-0.31 (1.22)	0.80
HADS Anxiety (0-21)	0	46	7.67 (0.41)	Reference	54	7.67 (0.41)	Reference	Reference	Reference
	3	46	3.94 (0.51)	-3.73 (0.58)	54	6.51 (0.47)	-1.16 (0.55)	2.52 (0.73)	**<0.001**
	12	31	5.76 (0.57)	-1.92 (0.69)	37	5.89 (0.52)	-1.78 (0.65)	-0.07 (0.89)	0.94
HADS Depression (0-21)	0	46	7.66 (0.25)	Reference	54	7.66 (0.25)	Reference	Reference	Reference
	3	46	7.52 (0.34)	-0.14 (0.38)	54	7.55 (0.31)	-0.11 (0.35)	0.02 (0.47)	0.97
	12	31	9.73 (0.41)	2.07 (0.48)	37	9.52 (0.38)	1.86 (0.45)	-0.18 (0.57)	0.76
Pain (NRS, 0-10)	0	46	6.23 (0.20)	Reference	54	6.23 (0.20)	Reference	Reference	Reference
	3	46	1.21 (0.29)	-5.02 (0.36)	54	2.16 (0.27)	-4.07 (0.34)	0.88 (0.41)	**0.031**
	12	32	1.78 (0.40)	-4.45 (0.43)	37	2.14 (0.34)	-4.09 (0.40)	0.40 (0.49)	0.42
Fear of Falling (SFES-I, 7-28)	0	46	19.70 (0.62)	Reference	54	19.70 (0.62)	Reference	Reference	Reference
	3	46	11.70 (0.80)	-8.01 (0.97)	54	13.30 (0.74)	-6.46 (0.92)	1.50 (1.13)	0.19
	12	32	13.40 (0.97)	-6.35 (1.09)	37	13.10 (0.89)	-6.61 (1.02)	-0.22 (1.36)	0.87
Quality of Life (EQ5D, -0.65–1)	0	46	0.30 (0.05)	Reference	54	0.30 (0.05)	Reference	Reference	Reference
	3	46	0.41 (0.07)	0.19 (0.07)	54	0.32 (0.06)	0.01 (0.07)	-0.10 (0.09)	0.28
	12	32	0.47 (0.08)	0.16 (0.08)	37	0.54 (0.07)	0.24 (0.08)	0.07 (0.11)	0.50
Health Today (EQ5D, 0-100)	0	46	54.70 (2.25)	Reference	54	54.70 (2.25)	Reference	Reference	Reference
	3	46	79.90 (2.25)	25.18 (2.79)	54	72.10 (2.08)	17.40 (2.65)	-9.15 (3.57)	**0.011**
	12	32	73.50 (3.00)	18.80 (3.37)	37	69.80 (2.80)	15.06 (3.19)	-4.49 (4.25)	0.29

EQ5D: EuroQol-5D; FIM= Functional Independence Measure; HADS: Hospital Anxiety and Depression Scale; HG: Handgrip; n=sample size; NRS= Numeric rating scale; SE: Standard Error SFES-I= Short Falls Efficacy Scale; SPPB: Short Physical Performance Battery. Significant differences ($p < 0{\cdot}05$) are highlighted in bold.

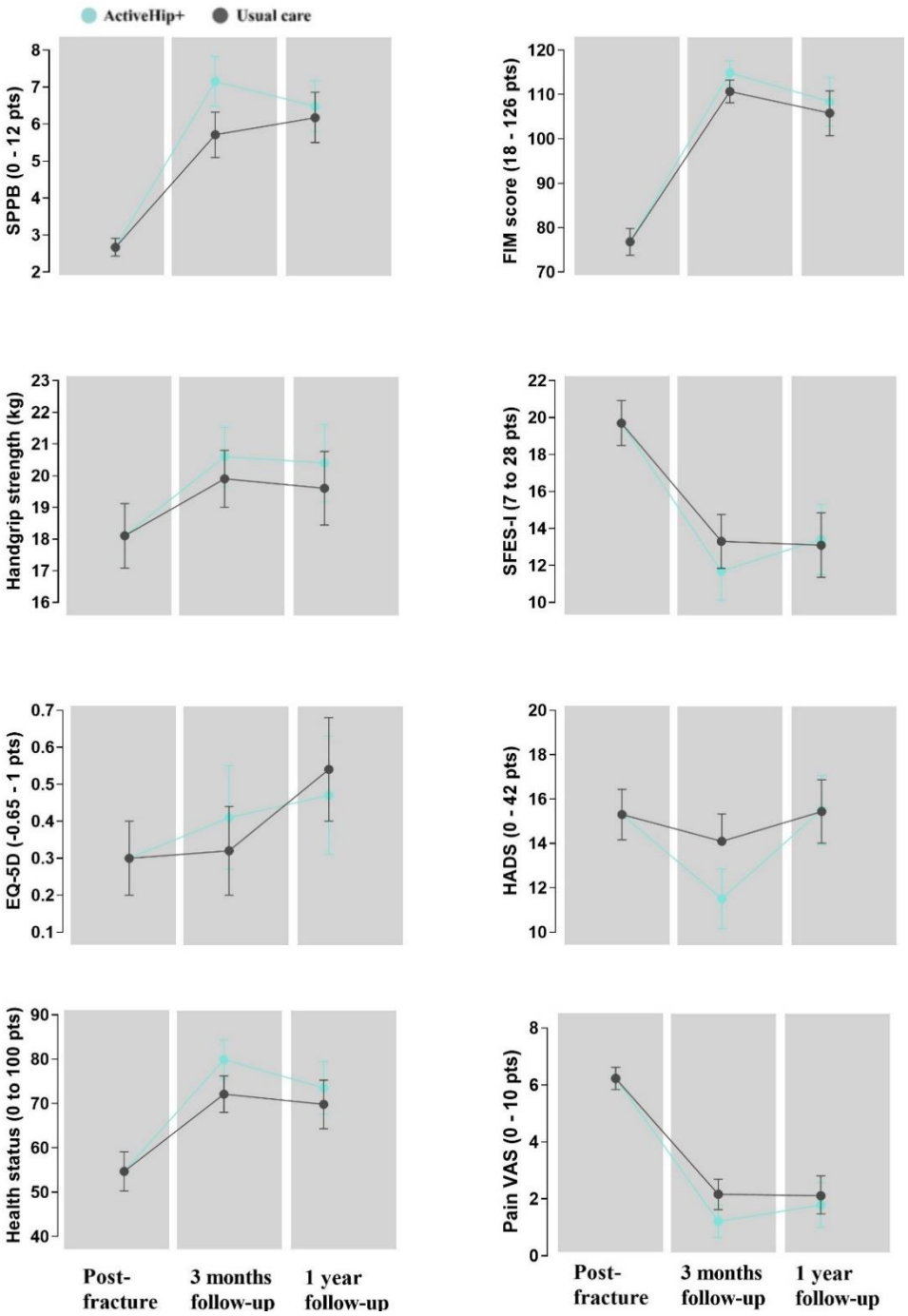


Figure S2. Changes in older adults' outcomes by time and group: per-protocol analyses. Data points represent the model-estimated means and 95% confidence intervals (indicated by the I bars) from a constrained linear mixed model (cLMM) with baseline means constrained to be equal across study arms, reflecting the pre-randomisation nature of the baseline assessment.

Table S8. Differences in family caregivers' outcomes between groups at 3-month after surgery (post intervention): per-protocol analyses

		Intervention group (ActiveHip+ mHealth)			Control group (Usual care)				
Outcome	Months	n	Mean (SE)	Change from Baseline, Mean (SE)	n	Mean (SE)	Change from Baseline, Mean (SE)	Differences in change from baseline (ActiveHip+ vs. Usual care), Mean (SE)	p-value Diffs
Care Strain (CSI, 0-13)	0	46	6.30 (0.19)	Reference	54	6.30 (0.19)	Reference	Reference	Reference
	3	46	3.65 (0.35)	-2.65 (0.37)	54	4.58 (0.33)	-1.72 (0.35)	0.93 (0.47)	**0.046**
	12	30	3.75 (0.56)	-2.55 (0.58)	31	3.91 (0.54)	-2.39 (0.56)	-0.04 (0.59)	0.95
Emotional status (HADS,0–42)	0	46	12.43 (0.44)	Reference	54	12.43 (0.44)	Reference	Reference	Reference
	3	46	9.07 (0.56)	-3.36 (0.71)	54	10.62 (0.52)	-1.81 (0.68)	1.45 (0.80)	0.07
	12	30	16.04 (0.68)	3.61 (0.79)	31	15.32 (0.66)	2.89 (0.78)	-0.65 (1.02)	0.52
HADS anxiety (0-21)	0	46	3.91 (0.32)	Reference	54	3.91 (0.32)	Reference	Reference	Reference
	3	46	1.87 (0.35)	-2.04 (0.48)	54	2.44 (0.32)	-1.47 (0.46)	0.46 (0.54)	0.40
	12	30	7.09 (0.43)	3.18 (0.53)	31	6.97 (0.42)	3.06 (0.52)	-0.05 (0.69)	0.94
HADS depression (0-21)	0	46	8.52 (0.34)	Reference	54	8.52 (0.34)	Reference	Reference	Reference
	3	46	7.20 (0.34)	-1.32 (0.39)	54	8.18 (0.32)	-0.34 (0.37)	0.99 (0.42)	**0.020**
	12	30	8.92 (0.34)	0.40 (0.38)	31	8.30 (0.33)	-0.22 (0.38)	-0.61 (0.54)	0.26
Quality of Life (EQ5D, -0.65–1)	0	46	0.82 (0.03)	Reference	54	0.82 (0.03)	Reference	Reference	Reference
	3	46	0.92 (0.03)	0.10 (0.04)	54	0.86 (0.03)	0.04 (0.04)	-0.06 (0.05)	0.24
	12	30	0.85 (0.04)	0.03 (0.05)	31	0.87 (0.04)	0.05 (0.05)	0.03 (0.06)	0.65
Health Today (EQ5D,0–100)	0	46	73.50 (2.25)	Reference	54	73.50 (2.25)	Reference	Reference	Reference
	3	46	84.90 (1.81)	11.40 (2.48)	54	84.20 (1.43)	10.69 (2.41)	-0.84 (3.21)	0.79
	12	30	73.50 (2.25)	11.47 (2.85)	31	82.60 (1.75)	9.08 (2.81)	-3.29 (4.08)	0.42
Low back pain (ODI,0–50)	0	46	10.13 (1.35)	Reference	54	10.13 (1.35)	Reference	Reference	Reference
	3	46	4.78 (1.48)	-5.35 (1.97)	54	6.63 (1.36)	-3.50 (1.88)	1.99 (2.41)	0.41
	12	30	10.35 (2.43)	0.21 (2.73)	31	13.53 (2.36)	3.39 (2.67)	3.81 (3.07)	0.22
Fear of Falling (SFES-I, 7–28)	0	46	20.50 (0.61)	Reference	54	20.50 (0.61)	Reference	Reference	Reference
	3	46	11.20 (0.95)	-9.29 (0.94)	54	11.90 (0.71)	-8.64 (0.89)	0.61 (1.09)	0.58
	12	30	12.20 (0.95)	-8.34 (0.89)	31	11.30 (0.91)	-9.23 (1.01)	-0.56 (1.39)	0.69
Self-reported Fitness (IFIS, 4–20)	0	46	17.10 (0.33)	Reference	54	17.10 (0.33)	Reference	Reference	Reference
	3	46	17.50 (0.43)	0.44 (0.50)	54	17.50 (0.40)	0.42 (0.47)	-0.01 (0.61)	0.98
	12	30	17.20 (0.50)	0.07 (0.60)	31	16.40 (0.50)	-0.69 (0.60)	-0.68 (0.76)	0.37

CSI: Caregivers' Strain Index; EQ5D: EuroQol-5D; HADS: Hospital Anxiety and Depression Scale; IFIS: International Fitness Scale; n=sample size; ODI: Oswestry Low Back Disability; SE: Standard Error; SFES-I= Short Falls Efficacy Scale. Significant differences ($p < 0{\cdot}05$) are highlighted in bold.

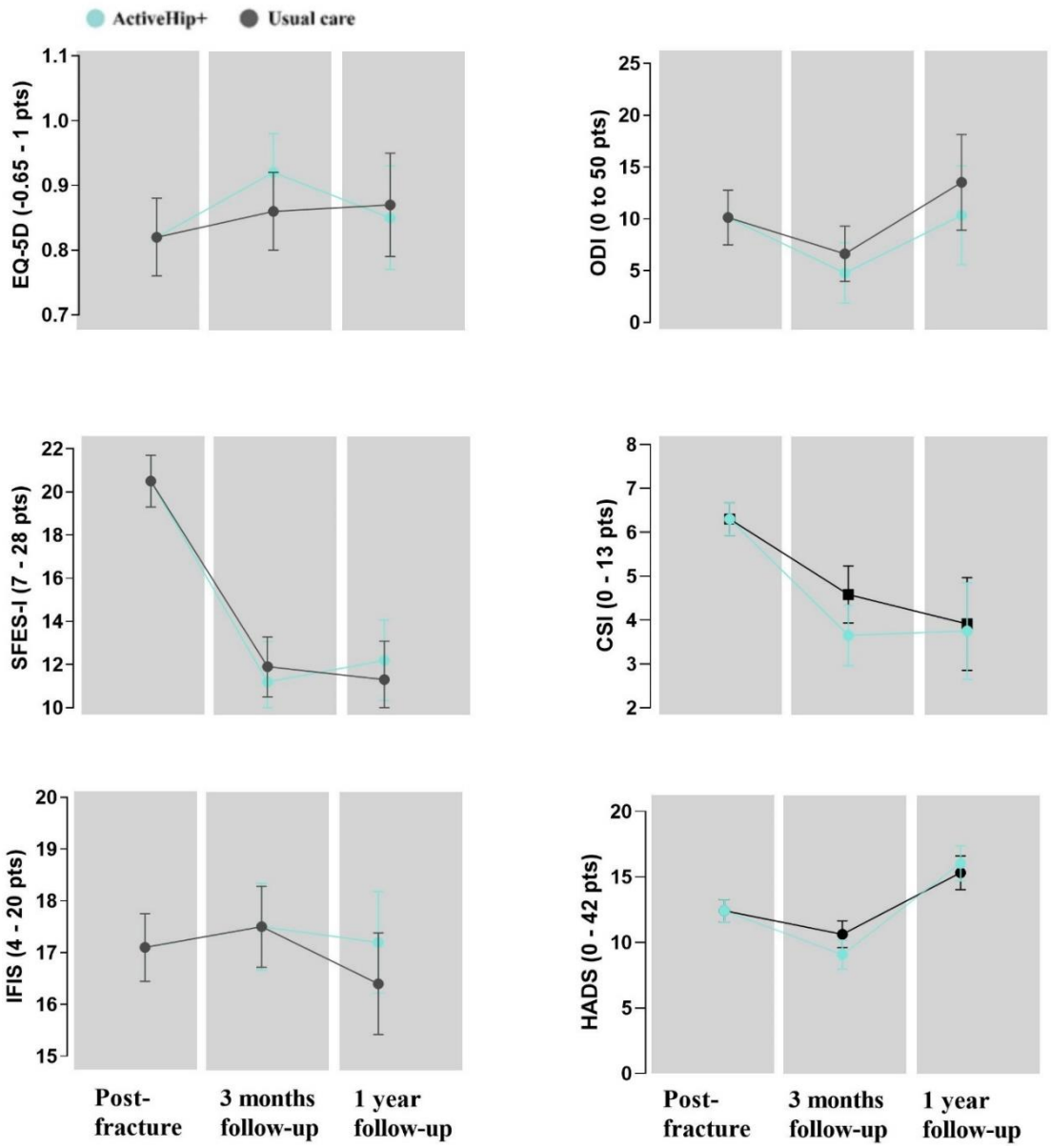


Figure S3. Changes in family caregivers' outcomes by time and group: per-protocol analyses. Data points represent the model-estimated means and 95% confidence intervals (indicated by the I bars) from a constrained linear mixed model (cLMM) with baseline means constrained to be equal across study arms, reflecting the pre-randomisation nature of the baseline assessment.

GENERAL DISCUSSION

GENERAL DISCUSSION

The present doctoral thesis contributes to improving our understanding of the effect of digital health interventions on the recovery of older adults with hip fracture and their family caregivers. **Study I** provides a brief and easy-to-use assessment tool (Spanish version of the Cumulated Ambulation Score), which allows healthcare professionals to assess basic mobility in older adults after hip fracture surgery. **Study II** shows the positive effect of a telerehabilitation intervention called @ctivehip, on the quality of life, psychological factors, and fitness level of older adults with hip fracture. **Study III** describes the protocol of a mHealth intervention called ActiveHip+, composed of occupational therapy, physical exercise, and health education for older adults with hip fracture where it includes, the active role of their family caregivers. In addition, this latter study includes the effect of ActiveHip+ mHealth in improving the physical performance of older adults with hip fracture as well as in reducing anxiety and pain. In turn, it also demonstrates its effectiveness in reducing the burden and depression of family caregivers. It also shows that the effect of the ActiveHip+ mHealth intervention is not sustained at the one-year follow-up.

Characteristics of the sample

Sample of older adults

The sample of the present doctoral thesis is focused on older adults aged 65 years and older, who have suffered a hip fracture. **Study I** included all consecutive older adults admitted to an orthopaedic acute units with the diagnostic of hip fracture,

with and without cognitive impairment (45% of them without impairment) and with characteristics regarding age (mean 80 years) and gender (mainly women) that are similar to the ones showed in other studies (115,179,180). All older adults with hip fracture recruited for **studies II and III** have had some similarities with other studies (e.g. 70% of the older adults in the sample have been women (115,179,180)), but it had also some differences. The mean age of the sample has been around 78 years, which is characterized by being somewhat below the mean of previous studies conducted in older people with hip fracture (181,182). This could have been beneficial for our studies since younger older adults have greater skills in the use of digital tools (183,184). The sample was independent in performing ADLs before hip fracture, which may have motivated them more to participate in digital health rehabilitation and try to recover their pre-fracture functional status (22, 311). Furthermore, older adults with severe cognitive impairment have not been included. This feature was considered essential to be able to follow the remote rehabilitation instructions offered by @ctivehip and ActiveHip+ interventions. Lastly, older adults have had to rely on the support of a family caregiver to support them during the recovery process, since it has been proven that social support can facilitate older adults to use digital technology (185). Therefore, the outcomes showed by the older adults and their family caregivers who used the digital health interventions provided in this thesis, may not be generalizable to the entire population of older adults with hip fracture and may only fit the sample profile described.

Sample of family caregivers

Profile of the sample of family caregivers included in the **study III**, is consistent with previous studies (186–188). Profile mainly female, representing almost 70% of the sample, and made up of middle-aged adult daughters (64,188) of older adults with hip fracture. The average age was 56 years, which agrees with previous studies carried out on the population of family caregivers in Spain (186,187,189). In terms of support from other family caregivers, the study by Lin et al.(190) found that more than 70% of family caregivers share caregiving responsibility with other family members, a percentage similar to the sample in our study III. Another characteristic of our sample of informal caregivers is that most of them are employed, aligning with Tsakiri et al. (191). Of these, half work in the service sector, which we believe is due to a characteristic of the Spanish population, where the majority work in this sector (191). It is important to note, that the profile of family caregivers can change over the years, adapting to cultural changes. Nowadays, both the traditional discourse, of caregiving as a moral duty associated with women and the more modern discourse, of caregiving as a responsibility that can be delegated are in use (191). However, the literature studying the role of the family caregiver in our society is still scarce and these changes have not been proven as yet. This leads us to consider the cultural changes, in particular, the role of women in society, which could contribute to the continuous evolution of the family caregivers profile (191). The profile may also be influenced by the country or even the region where they live. Some European countries such as the Nordic countries, the Netherlands and Germany have formal caregiver profiles for providing home care (192). However, the services providing formal caregiving are mainly private in Spain. Moreover, the situation in our country also change depending on the region where you live (37).

There are 17 different types of public healthcare systems, and as mentioned in the introduction of this doctoral thesis, the resources available vary significantly from one region to another. Andalusia for example, is one of the least benefited (37). In these less well-resourced regions, the role of family caregivers is undoubtedly essential for the management of older adults at home and the sustainability of the healthcare system. Therefore, the profile of family caregivers in society should be taken more into account in future studies.

The suitability of measuring progress of the recovery of older adults with hip fractures (Study I)

It has been shown that a comprehensive assessment of the physical, psychological, and social spheres of older adults usually takes more than 60 minutes (193). The lack of time for healthcare professionals to carry out such assessment and the subsequent follow-up needed for older adults with hip fracture (100,194), calls for assessment tools of short duration and ease to use which can be used during clinical practice and guide rehabilitation (195). The Spanish version of the Cumulated Ambulation Score (CAS-E), obtained in **Study I**, it is an ideal tool to be used in time- and resource-constrained clinical settings, to measure the basic mobility of older adults in the initial early mobility phase. However, this tool has a ceiling effect (196,197), and limits its use to older adults who reach a level of basic independent mobility. This is why, the CAS-E should be used in the acute and post-acute clinical setting to measure basic mobility in older adults with hip fracture and once basic mobility is achieved, use another tool to further assess mobility progress, as it is shown previously (198,199). In fact, the sample of our studies **II**

and III, has required more in-depth assessment of those older adults who reach a level of basic mobility, as well as an adequate follow-up of the functional status of older adults with hip fracture. An example of a tool could be the New Mobility Score (NMS) (165), which measure mobility both inside and outside the home (164), and also allow an adequate follow-up of the functional status. This is why the use of this latter tool has been considered in the overall assessment of the studies of this doctoral thesis.

Digital health, a promising solution for older adults with hip fracture, facing the challenge of limited health system rehabilitation resources (Study II and III)

The digital health interventions, which **studies II and III** performed in older adults with hip fractures, have been found to have positive effects on physical and psychological outcomes, when are compared to conventional rehabilitation currently offered in the Andalusian Public Healthcare system. Digital health has been shown to improve the physical performance of older adults in both studies. However, to our surprise, the positive results obtained in **study II** through self-reported measures, were not obtained in the self-reported measures of the **study III**. Our **Study III**, observed improvements in physical performance through objective measures (performance-based test (157)), but no effects were observed for subjective assessments of physical function (i.e., functional status through self-reported measures). The reason could be related to the different programs performed in each study. In addition, the number of weekly sessions devoted to physical exercise and those devoted to occupational therapy were different. In study III, participants had twice-weekly physical exercise sessions, mainly aimed at

improving physical performance, and only one occupational therapy session focused on improving functional status through practice and repetition of ADLs, thus improving older adults' self-efficacy (93). And therein lies the key; the improvement of physical performance components, such as balance, strength, or walking speed as assessed through objective measures (157) has not guaranteed transfer to improved performance in ADLs. Considering that perceived self-efficacy improves with practice and repetition of tasks in which the person feels competent (200) . This reason becomes more relevant, considering that in **study II**, there were more weekly occupational therapy sessions (2 per week) than in study III (1 per week), which may have contributed to improved self-efficacy.

The results obtained in **study III** on anxiety are shared with those obtained in **study II.** Digital Health interventions are effective in improving anxiety levels. In the case of our **study III**, the reason for this improvement may be linked to the health education program of Activehip+ mHealth intervention. The contents of the program included for example a roadmap of hip fracture recovery journey and guidance to manage the new situation. The above contents could have contributed to increased awareness of the recovery process which tends to correlate with lower anxiety levels (201,202). The educational program also includes information on self-management of pain, which has been found to be reduced after our mHealth intervention (203). Therefore, the positive effect of educational program, becomes even more relevant. However, ActiveHip+ mHealth intervention had no effect on depression, fear of falling and quality of life in older people with hip fractures. It is possible that these outcomes were not improved because the intervention did not

specifically target them, unlike anxiety and pain levels, which were specifically addressed. To our knowledge, there are no previous studies that have tested mHealth interventions to improve these outcomes in older adults with hip fracture, and further mHealth interventions are certainly warranted to examine strategies to achieve improvements in these outcomes, due to the negative effect they have on the recovery process (204,205).

The active role of family caregivers in a mHealth intervention (Study III)

Our **Study III** found ActiveHip+ mHealth intervention reduces family caregiver burden and their levels of depression. We strongly believe those results are due to the active role that family caregivers have taken during the recovery process (206,207). The improvement in caregivers burden (71,208), following the ActiveHip+ mHealth intervention may be due to the following reasons: 1] the health education program incorporated in this mHealth intervention, which has provided relevant contents for family caregivers during the recovery process (e.g. strategies to promote the physical and mental well-being of family caregivers or recommendations for ADLs), and [2] the exchange of information that has enabled this mHealth intervention between family caregivers and healthcare professionals (209,210). Previous literature highlights the importance of communication between family caregivers and healthcare professionals (209–213), as the resolution of concerns before hospital discharge, contributes to increased family caregiver knowledge and skills. This may have improved caregiver self-efficacy (214), since, as Lin et al. have pointed out in the past, lower self-efficacy correlates with higher caregiver burden (215). However, improving self-efficacy requires more than the

provision of knowledge. In this sense, the teach-back method used in previous studies (72,152), and also included in our intervention during follow-up, has made it possible to clarify everything they need to know about their health through videoconferences and messages. ActiveHip+ mHealth has also been successful in reducing depression among family caregivers after their intervention. This could be related to the improvement of caregiver burden, as it has previously been related that improvements in caregiver burden decrease levels of depression (216,217). In addition, the training provided through educational content on how to treat older adults with hip fractures during their hospital stay, discharge planning, and even specific psychoeducation content could contribute to this improvement.

Surprisingly, ActiveHip+ mHealth intervention had no positive effect on the other clinical outcomes measured in family caregivers such as anxiety, low back disability, quality of life, and self-reported fitness level. This suggests that our intervention did not pay adequate attention to these outcomes and that our study has not achieved a holistic, multi-component approach. Consequently, a future review of ActiveHip+ mHealth or future new interventions should work in this direction.

Follow-up one year after a mHealth intervention (Study III)

Results at one year after surgery follow-up in **Study III** demonstrate that the effect achieved at the end of the intervention in all clinical outcomes measured in this study, were not maintained in long term, suggesting that a 3-month intervention may have been insufficient to promote long-lasting behavioural changes. Behavioural change in older adults, are one of the most ambitious aims of each

health intervention (218). The literature has highlighted the great challenge of achieving behavioural change in older adults (219). Some possible interventions that should be included in the future adjustments of the ActiveHip+ mHealth intervention could be behavioural change techniques (220). To the best of our knowledge, this is the first study to conduct a long-term follow-up in older adults with hip fracture who received mHealth interventions, and from previous studies, we know that there is no strong evidence in support of the effectiveness of mHealth intervention in improving health behaviours (221). Neither is clear whether habit-forming interventions offer a pathway to lasting behaviour change (221). Definitely, this aspect should be explored deeply in future research.

Clinical implications of the present doctoral thesis

Table 10 shows a summary of the main findings and clinical implications of the present thesis. Our finding suggests firstly, the Spanish version of the Cumulated Ambulation Score can be used in Spanish-speaking settings to indicate small changes in basic mobility in the acute and subacute phase of older adults with hip fracture and secondly, the potential use of digital health interventions as alternative and complementary option for the recovery of older adults with hip fracture and their family caregivers. Although face-to-face rehabilitation never can be substituted, many individuals in today's society do not receive adequate continued care and rehabilitation, due to limited healthcare resources. In these cases, @ctivehip and ActiveHip+ mHealth interventions appear to be promising options to be considered. The implementation of ActiveHip+ mHealth , because it is our most up-to-date digital health intervention and it has proven to be feasible in healthcare

systems (222), could improve the quality of care by contributing to the continued care and helping to reduce the current burden.

Table 10. Summary of implications in clinical practice of the studies of the present doctoral thesis

	Main finding	Implication for clinical practice
STUDY I	▪ The Spanish version of the Cumulative Ambulation Score (CAS-E) is an assessment tool, which allows to evaluation of the early basic mobility in older adults with hip fracture. ▪ The CAS-E is a reliable, quick, and easy-to-use tool that describes small changes in basic mobility in older adults with hip fracture.	▪ CAS-E can be integrated into Spanish-speaking health systems to indicate small changes in the basic mobility of older adults with hip fracture in the acute stage of the recovery process.
STUDY II	▪ @ctivehip telerehabilitation program is effective in improving the quality of life, psychological factors, and fitness level of older adults with a hip fracture.	▪ Telerehabilitation programs should be considered as an alternative or complementary treatment for older adults who do not have access to appropriate face-to-face treatment with healthcare professionals.
STUDY III	▪ ActiveHip+ mHealth intervention is effective for recovering physical performance in older adults with hip fracture. ▪ ActiveHip+ mHealth intervention is effective in reducing the burden in family caregivers of older adults with hip fracture. ▪ ActiveHip+ mHealth intervention promotes psychosocial benefits in older adults and their family caregivers. ▪ The effects of ActiveHip+ mHealth intervention are not sustained one year after surgery follow-up.	▪ ActiveHip+ mHealth intervention offers a promising solution to the challenge of limited rehabilitation resources within healthcare systems which older adults with hip fracture find. ▪ The digital and multidisciplinary nature of ActiveHip+ mHealth, including family caregivers makes it a pioneering intervention.

LIMITATIONS AND STRENGTHS OF IMPLEMENTING DIGITAL HEALTH FOR HIP FRACTURE RECOVERY

An integrative view of the general limitations and strengths of the present Doctoral Thesis can be found in Table 11.

Table 11. Limitations and strengths of the present doctoral thesis.

SECTION	LIMITATIONS	STRENGTHS
SECTION I-STUDY I	▪ Ceiling effect when a basic level of mobility is reached.	▪ Heterogeneity in the hip fracture sample.
SECTION II-STUDY II	▪ Non-randomized control trial. ▪ The use of digital health through a website. ▪ Involvement of family caregivers in the recovery process was not objectively measured.	▪ Inclusion of family caregivers during the recovery process with and active role. ▪ Despite the possible bias, provided an opportunity to appreciate older adult's preferences to support future clinical decision-making.
SECTION III- STUDY III	▪ Inclusion criteria are not extrapolated to all populations. ▪ COVID-19 period, when the study was carried out and the distance imposed may have affected the analyses, not collecting some objective measurement data that were planned. ▪ The participation of the family caregivers in the recovery process was not objectively measured. ▪ Period of intervention (3 months) insufficient to guarantee results and behavioural change after one year.	▪ Randomized clinical trial. ▪ Characteristics of the tool: 1. A physical exercise + occupational therapy program, in which a multidisciplinary approach is included 2. A health education program, for older adults and their family caregivers. ▪ Involving family caregivers with an active role. ▪ Pioneer in yearly monitoring

FUTURES LINES OF RESEARCH

Based on the results obtained in the present Doctoral Thesis, a series of future lines of research are proposed.

- Future digital health interventions should create digital health intervention with a higher holistic vision, which address aspects we have not been able to cover, since key aspects of recovery process of older adults with a hip fracture, such as psychological and nutritional interventions, could unfortunately only be addressed through the educational program, potentially affecting our results.
- In the future, digital health intervention should also aim to be more dynamic and include the possibility of adaptations over time and respond to the needs of older adults with hip fracture in post-acute stages (e.g. including artificial intelligence in the provision of the interventions). This could help us to meet the challenge of behavioural change in older adults (219,223).
- Another possible line of future research is combined alternatives (i.e. combining e.g. mobile health with face-to-face support), also known as hybrid models of care (224), to optimise older users' engagement with mobile health interventions should be considered in future lines of eHealth research (225).
- Another line of improvement for the future would be to make the necessary adaptations of ActiveHip+ mHealth intervention, in order to be able to implement it in nursing homes by training formal caregivers.

- Lastly, user engagement with digital health interventions often remains low in older adults, due to insufficient physical and psychological capacities and motivational barriers. Working on overcoming these motivational barriers would be a research challenge, as it would help the acquisition of greater engagement in the use of new technologies in older adults. However, it is motivating to think***, in the near future, today's young people will become tomorrow's older adults, making the use of digital health almost universal in this age group as well*** (226).

CONCLUSIONS

GENERAL CONCLUSIONS

Digital health has been shown to be effective in the recovery of older adults with hip fracture and their family caregivers. The @ctivehip and ActiveHip+ interventions are tools able to have a positive effect on physical and psychological outcomes of older adults with hip fracture and their family caregivers. Digital health also facilitates communication between those affected with healthcare professionals, while providing individualised interventions with information related to both the recovery process and the prevention of future fractures. These are promising solutions when rehabilitation resources are limited.

SPECIFIC CONCLUSIONS

SECTION I. Translation of the Spanish version of the cumulated ambulation score.

STUDY I.

- The Cumulated Ambulation Score has been translated into Spanish (CAS-E).
- CAS-E is a reliable and stable outcome measure to assess the basic mobility status of older adults with hip fracture.
- CAS-E is a highly valuable instrument that can be integrated into clinical practice to monitor the progress older adults' function.

SECTION II. @ctivehip telerehabilitation intervention in older adults with hip fracture.

STUDY II.

- @ctivehip telerehabilitation intervention is effective in improving the quality of life and the self-perceived fitness level of older adults with a hip fracture and reduces their anxiety and depression compared to those who receive the conventional home-based in-person rehabilitation offered so far by the Andalusian Public Health Care System.

SECTION III. ActiveHip+ mHealth intervention in older adults with hip fracture and their family caregivers.

STUDY III.

- ActiveHip+ mHealth intervention is effective improving physical performance and reduces anxiety and pain among older adults with hip fracture.
- ActiveHip+ mHealth intervention benefits family caregivers by reducing burden and depression.
- ActiveHip+ mHealth intervention is not able to maintain the results obtained in the follow-up after one year.

CONCLUSIONES

CONCLUSION GENERAL

La salud digital ha demostrado ser eficaz en la recuperación de los adultos mayores con fractura de cadera y sus cuidadores informales. Las intervenciones @ctivehip y ActiveHip+ son herramientas capaces de tener un efecto positivo sobre variables físicas y psicológicas de los adultos mayores con fractura de cadera y sus cuidadores informales. La salud digital también facilita la comunicación entre los afectados y los profesionales sanitarios, al tiempo que proporciona intervenciones individualizadas con información relacionada tanto con el proceso de recuperación como con la prevención de futuras fracturas. Se trata de soluciones prometedoras cuando los recursos de rehabilitación son limitados.

CONCLUSIONES ESPECÍFICAS

SECCIÓN I. Traducción de la versión española de la Cumulated Ambulation Score.

ESTUDIO I

- Se ha traducido al castellano la Cumulated Ambulation Score (CAS-E).
- CAS-E es una medida de resultado fiable y estable para evaluar el estado básico de movilidad de adultos mayores con fractura de cadera.
- CAS-E es un instrumento de gran valor que puede integrarse en la práctica clínica para monitorizar el progreso funcional de los adultos mayores.

SECCIÓN II. @ctivehip, intervención de telerehabilitación para adultos mayores con fractura de cadera.

ESTUDIO II.

- La intervención @ctivehip, es eficaz para mejorar la calidad de vida y la condición física auto percibida de los adultos mayores con fractura de cadera, y reducir su ansiedad y depresión, en comparación con aquellos que reciben la rehabilitación convencional ofrecida hasta el momento por el Sistema Sanitario Público de Andalucía.

SECCIÓN III. ActiveHip+ , intervención a través de salud móvil en adultos mayores con fractura de cadera y sus cuidadores informales.

ESTUDIO III.

- La intervención a través de salud móvil, ActiveHip+, es efectiva mejorando el rendimiento físico y reduciendo la ansiedad y el dolor entre los adultos mayores con fractura de cadera.
- La intervención a través de salud móvil, ActiveHip+, beneficia a los cuidadores informales reduciendo la carga y la depresión.
- La intervención a través de salud móvil, ActiveHip+, no es capaz de mantener los resultados obtenidos en el seguimiento al año.

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TRANSFERENCE OF THE PRESENT DOCTORAL THESIS

TRANSFERENCE OF THE PRESENT DOCTORAL THESIS

The present doctoral thesis has been able to develop a digital health tool for older adults with hip fracture and their family caregivers, which is currently being implemented in different public healthcare systems in Spain and abroad.

Currently, health professionals from fourteen Spanish healthcare systems and one in Belgium, have been trained to use the ActiveHip+ intervention. Figure 15 shows some of them.

Figure 16. Geographical location of healthcare systems which were trained in the use of ActiveHip+ mHealth.

The members of the @ctivehip and ActiveHip+ projects have developed an international dissemination network with different types of audiences and some of

the most scientifically valuable organizations involved in hip fracture, such as, the Fragility Fracture Network and the International Osteoporosis Foundation.

A leaflet was designed and provided to older people and family caregivers to facilitate the use of ActiveHip+. Another of the dissemination work, has been the design of a guide (collaboration with patient's organisations such as the Spanish Association for Osteoporosis and Osteoarthritis (AECOSAR) and the Osteoarthritis Foundation International (OAFI)), offered to older adults with hip fracture and their family caregivers. This guide describes (through text, illustrations and videos linked to QR codes) the process of recovery of a hip fracture, from the first days in hospital (before and after the operation) to the first days after discharge from hospital and some advice on how to prevent secondary fractures. This guide can be printed out in hospitals as a tool to take with you on discharge or downloaded from the ActiveHip+ project website: **https://www.activehipplus.com/**. In the following **annexes**, some images of the dissemination and implementation process are shown.

ANNEXES

ANNEXES. DISSEMINATION NETWORK

Image 1. Presentation of ActiveHip+ to the rehabilitation service at University Hospital of Jerez de la Frontera, Cádiz (Spain). September 2020.

Image 2 and 3. Training sessions with healthcare professionals from the North Lisbon University Hospital Centre, Lisbon, Portugal. March 2021.

Image 4. Lecture at the XXV Congress of the Spanish Society for Bone and Mineral Metabolism Research. October 2021.

Image 5. Training session on the use of ActiveHip+ for healthcare professionals from the rehabilitation service of the university hospital of Jerez de la Frontera, Cádiz (Spain). June 2022.

Image 6. Lecture at the 18º WFOT CONGRESS occupational R-Evolution. August 2022

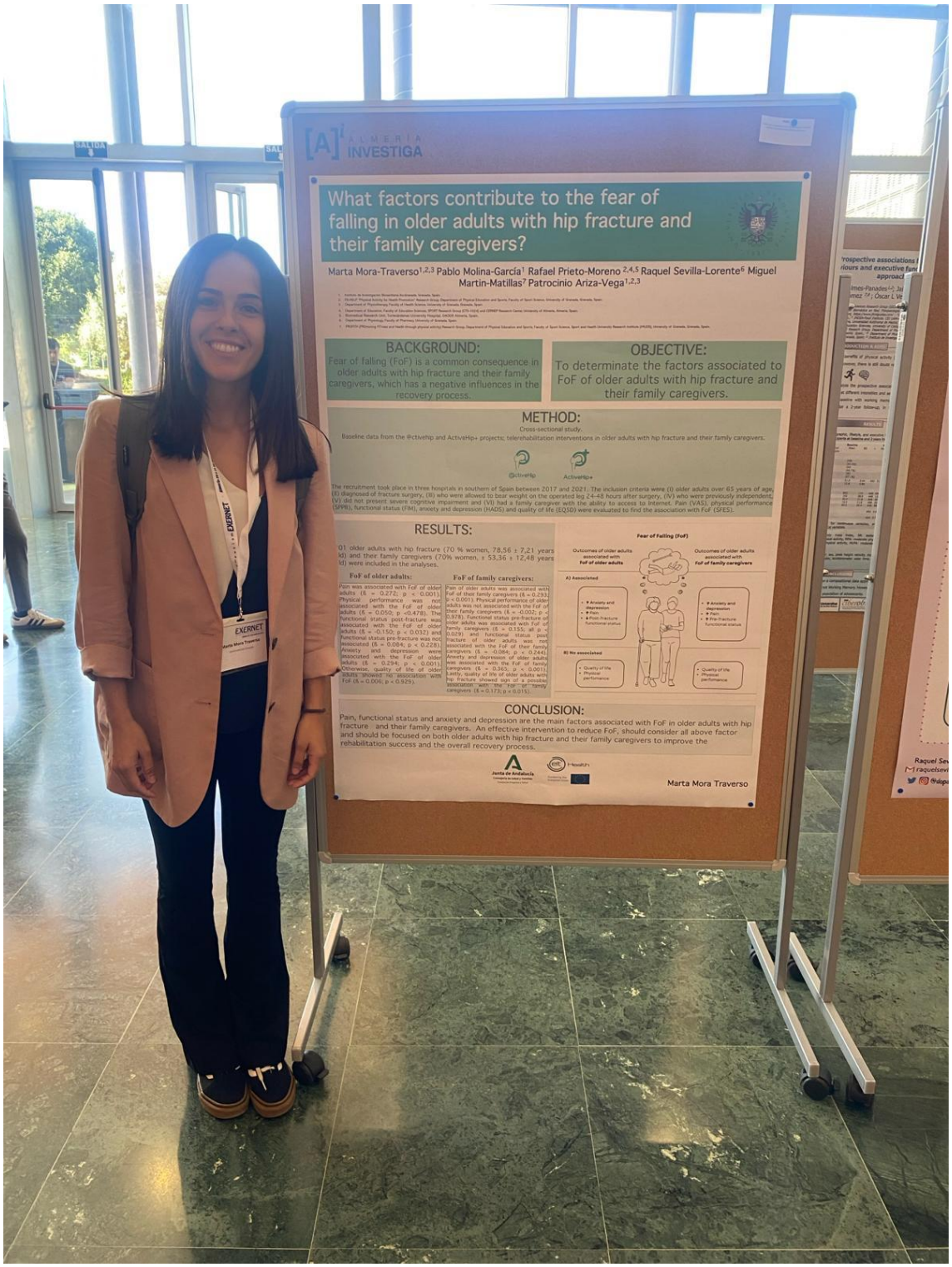

Image 7. Lecture at VIII EXERNET Symposium: Physical exercise for lifelong health. October 2023.

Image 8. Lecture at Barts Bone & Joint Health department, from Queen Mary University of London during my international research stay. March 2024.

Image 9. With the supervisor of my international research stay, Katie Sheehan, presenting ActiveHip+.

Image 10. Leaflet provided to older adults and family caregivers to facilitate the use of the app.

Image 11. Landing page of the ActiveHip+ website where all the contents have been uploaded so that they are on demand for anyone interested.

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A home-based tele-rehabilitation protocol for patients with hip fracture called @ctivehip

Research in Nursing & Health

Ortiz-Piña M, Salas-Fariña Z, **Mora-Traverso M**, Martín-Martín L, Galiano-Castillo N, García-Montes I, Cantarero-Villanueva I, Fernández-Lao C, Arroyo-Morales M, Mesa-Ruíz A, Castellote-Caballero Y, Salazar-Graván S, Kronborg L, Martín-Matillas M, Ariza-Vega P

- DOI: 10.1002/nur.21922. IF: 2.163. Q1

Translation, inter-rater reliability, agreement, and internal consistency of the Spanish version of the cumulated ambulation score in patients after hip fracture

Disability and Rehabilitation

Ariza-Vega P, **Mora-Traverso M**, Ortiz-Piña M, Ashe MC, Kristensen MT

- DOI: 10.1080/09638288.2019.1577499. IF: 2.222. Q1

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Journal of Geriatric Physical Therapy

Ariza-Vega P, Ortiz-Piña M, **Mora-Traverso M,** Martín-Martín L, Salazar-Graván S, Ashe MC.

- DOI: 10.1519/JPT.0000000000000230. IF: 3.396. Q1

Effects of the @ctivehip telerehabilitation program on the quality of life, psychological factors and fitness level of patients with hip fracture

Journal of Telemedicine and Telecare

Mora-Traverso M, Prieto-Moreno R, Molina-Garcia P, Salas-Fariña Z, Martín-Martín L, Martín-Matillas M, Ariza-Vega P.

- DOI: 10.1177/1357633X211073256; IF: 6.344; Q1

An m-Health telerehabilitation and health education program on physical performance in patients with hip fracture and their family caregivers: Study protocol for the ActiveHip+ randomized controlled trial

Research in Nursing & Health

Mora-Traverso M, Molina-Garcia P, Prieto-Moreno R, Borges-Cosic M, Cruz Guisado V, Del Pino Algarrada R, Moreno-Ramírez P, Gomez-Jurado G, Gomez Tarrias C, Hidalgo Isla M, Jimenez Andrés P, Linares Gago M, Lirola-Liebanas A, Mesa-Ruiz A, Muñoz-Garach A, Salazar-Graván S, Estevez-Lopez F, Martín-Matillas M, Ariza-Vega P.

- DOI: 10.1002/nur.22218; IF: 2.238; Q2

Co-creation of an mHealth Intervention for Older Adults with Hip Fracture and Family Caregivers: a qualitative study

Disability and Rehabilitation-Assistive Technology

Ariza-Vega P, Prieto-Moreno R, **Mora-Traverso M**, Molina-García P, Ashe MC, Martín-Matillas M.

- DOI: 10.1080/17483107.2022.2138999; IF: 1.834; Q2

ActiveHip+: A feasible mHealth system for the recovery of older adults after hip surgery during the COVID-19 pandemic

Digital Health

Prieto-Moreno R, Estévez-López F, Molina-Garcia P, **Mora-Traverso M**, Deschamps K, Claeys K, de Buyser J, Ariza-Vega P.

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Effectiveness and cost-effectiveness of telerehabilitation for musculoskeletal disorders: A systematic review and meta-analysis

Annals of Physical and Rehabilitation Medicine

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27-29 octubre 2021 - XXV Congreso Sociedad Española de Investigación Ósea y del Metabolismo Mineral -
¿Puede la tele-rehabilitación ayudar a disminuir el miedo a la caida en pacientes con fractura de cadera y sus cuidadores informales?
(Comunicación-poster)

27-31 agosto 2022 - 18th World Federation of Occupational Therapist Congress
- The effects of a home-based multidisciplinary tele-rehabilitation program (@ctivehip) after a hip fracture
in the quality of life, anxiety and physical condition of older people.
(Comunicación oral)

28-29 septiembre 2022 - XPAtient Barcelona
Congress 2022 - ActiveHip+ Activating older
people after a hip fracture
(Comunicación- poster)

13, 14 y 15 abril 2023- III Congreso Internacional y VIII Encuentros Hispano Cubanos en Ciencias de la Salud "Sociedad, Entorno y Salud"
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"What factors contribute to the fear of falling in patients with hip fractures and their family caregivers?".
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Today's young people will become tomorrow's older adults, making the use of digital health almost universal in this age group