Journal of Pain Research

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REVIEW

A Systematic Review and Meta-Analysis of the Effects of Rehabilitation Using Digital Healthcare on Musculoskeletal Pain and Quality of Life

Suhyun Jang[1,*], Boram Lee[2,*], Eunji Lee[1], Jungbin Kim[1], Jong In Lee[3], Jae-Young Lim[4,5], Ji Hye Hwang[6], Sunmee Jang[1]

[1]College of Pharmacy and Gachon Institute of Pharmaceutical Sciences, Gachon University, Incheon, Republic of Korea; [2]Graduate School of Public Health, Seoul National University, Seoul, Republic of Korea; [3]Department of Rehabilitation Medicine, Seoul St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Seoul, Republic of Korea; [4]Department of Rehabilitation Medicine, Seoul National University Bundang Hospital, Seongnam-si, Republic of Korea; [5]Department of Rehabilitation Medicine, Seoul National University College of Medicine, Seoul, Republic of Korea; [6]Department of Physical and Rehabilitation Medicine, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Republic of Korea

*These authors contributed equally to this work

Correspondence: Sunmee Jang, College of Pharmacy and Gachon Institute of Pharmaceutical Sciences, Gachon University, 191 Hambakmoe-Ro, Yeonsu-Gu, Incheon, 21936, Republic of Korea, Tel +82 32 820 4941, Email smjang@gachon.ac.kr; Ji Hye Hwang, Department of Physical and Rehabilitation Medicine, Samsung Medical Center, Sungkyunkwan University School of Medicine, #81 Irwon-Ro, Gangnam-Gu, Seoul, 06351, Republic of Korea, Tel +82 10 9933 2816, Email hwanglee@skku.edu

Abstract: Rehabilitation using digital healthcare (DHC) has the potential to enhance the effectiveness of treatment for musculoskeletal disorders (MSDs) and associated pain by improving patient outcomes, while being cost-effective, safe, and measurable. This systematic review and meta-analysis aimed to evaluate the effectiveness of musculoskeletal rehabilitation using DHC. We searched PubMed, Ovid-Embase, Cochrane Library, and PEDro Physiotherapy Evidence Database from inception to October 28, 2022 for controlled clinical trials comparing DHC to conventional rehabilitation. We used a random-effects model for the meta-analysis, pooling the effects of DHC on pain and quality of life (QoL) by calculating standardized mean differences (SMDs) with 95% confidence intervals (CIs) between DHC rehabilitation and conventional rehabilitation (control). Fifty-four studies with 6240 participants met the inclusion criteria. The sample size ranged from 26 to 461, and the average age of the participants ranged from 21.9 to 71.8 years. The majority of the included studies focused on knee or hip joint MSD (n = 23), and the most frequently utilized DHC interventions were mobile applications (n = 26) and virtual or augmented reality (n = 16). Our meta-analysis of pain (n = 45) revealed that pain reduction was greater in DHC rehabilitation than in conventional rehabilitation (SMD: −0.55, 95% CI: −0.74, −0.36), indicating that rehabilitation using DHC has the potential to ameliorate MSD pain. Furthermore, DHC significantly improved health-related QoL and disease-specific QoL (SMD: 0.66, 95% CI: 0.29, 1.03; SMD: −0.44, 95% CI: −0.87, −0.01) compared to conventional rehabilitation. Our findings suggest that DHC offers a practical and flexible rehabilitation alternative for both patients with MSD and healthcare professionals. Nevertheless, further researches are needed to elucidate the underlying mechanisms by which DHC affects patient-reported outcomes, which may vary depending on the type and design of the DHC intervention.

Keywords: musculoskeletal disorder, rehabilitation, digital healthcare, pain, quality of life, patient-reported outcomes

Introduction

The World Health Organization (WHO) adopted the "Resolution on Digital Health" introduced during the 71st World Health Assembly in May 2018 and recognized the need for digital technology to achieve universal health coverage and sustainable development goals.[1] As such, digital healthcare (DHC), in which digital technology is converging with healthcare, has become increasingly important. Along with the fourth industrial revolution, changes in demographic structure, such as population aging, and social changes, such as smart device

Received: 5 September 2022
Accepted: 5 May 2023
Published: 31 May 2023

popularization, have stimulated the demand for DHC.[2] Above all, the coronavirus disease 2019 pandemic has led to dramatic changes in the healthcare sector. Enabling contactless healthcare services, DHC has spread faster than ever.

Musculoskeletal disorders (MSDs) are a broad spectrum of chronic diseases affecting bones, joints, and soft tissues.[3] Musculoskeletal pain is a typical symptom caused by MSD, and especially, low back and neck pain is the leading causative factor of disability worldwide.[4] Globally, 1.71 billion people suffer from MSDs, which are also the leading cause of disability.[5] Approximately one-third of the UK population has MSDs, such as arthritis and back pain, making MSD the third–largest burden of the National Health System's expenditure.[6] According to a recent study in Korea, where national health insurance is available, one in three Koreans visits healthcare providers for musculoskeletal pain and functional decline; MSD prevalence is also increasing among older patients.[7] Rehabilitation is essential for patients with MSDs. In 2017, when the WHO launched the "Rehabilitation 2030 initiative", everyone should be able to rehabilitate at all life cycle stages, especially for musculoskeletal health.[8] In addition, pain control is a major concern in MSD care and rehabilitation programs. In the MSD rehabilitation program, the specific needs of each patient are considered. An exercise program designed to increase muscle strength, flexibility and mobility is crucial, and through such rehabilitation, the patient can become independent and lead a regular life. Active participation of both patients and their families during this process is essential.[9] Recently, Austria introduced a secondary preventive program for patients with MSD, aiming to prevent rehospitalization. As part of the appraisal for this program, a large observational study was conducted, and the results indicated that physical inactivity is the factor that is most associated with the need for healthcare services.[10]

Using DHC for health improvement is cost-effective, safe, and measurable.[11] In particular, rehabilitation for MSD, which requires physical activity (PA), may have great potential when combined with DHC based on the Internet, smartphone applications, augmented reality (AR), and virtual reality (VR). Currently, most smartphones and smartwatches already include accelerometer-based PA trackers, allowing easy access even for older adults unfamiliar with innovative technology.[12] The development of sensors and wearable devices not only enhances the convenience of systematic health management but also helps healthcare providers access and manage the rehabilitation of patients with MSD in daily life outside hospitals or facilities. In addition, by making the VR and AR content more interactive and engaging, patients can become interested in rehabilitation.

DHC can offer a practical and flexible rehabilitation alternative for both patients and healthcare professionals. However, the effectiveness of DHC remains inadequately assessed; in particular, studies suggesting a relationship between MSD management and DHC are difficult to find.[13] Hence, this systematic review and meta-analysis aimed to evaluate the effectiveness of musculoskeletal rehabilitation using a DHC system.

Materials and Methods

Search Strategy and Study Selection

We evaluated the effectiveness of musculoskeletal rehabilitation using a DHC system compared with that of conventional rehabilitation. DHC refers to the digital and mobile technologies used to support health system needs by promoting healthy behaviors, improving outcomes, and providing remote access to adequate care.[11,14] We defined DHC as a healthcare intervention that utilizes internet-based technologies, telephone-supported technologies, interactive voice response, AR or VR, video conferencing, or mobile phone applications, in line with previous studies.[15]

Our systematic review and meta-analysis was conducted using PRISMA guidelines.[16] We conducted literature searches on July 20, 2020, and updated it on October 28, 2022, using the following databases: PubMed, Ovid-Embase, Cochrane Library, and PEDro Physiotherapy Evidence Database. We used search terms modified to the characteristics of each database according to the PubMed terms. Queries were input using MeSH terms, Boolean conjunctions, and truncation searches (Supplementary Table 1). In addition, references included in the searched studies were reviewed and added as per the inclusion and exclusion criteria. EndNote, a widely used reference

management tool,[17,18] was used to increase efficiency and save time. We imported all the database references into EndNote and deduplicated the datasets by using EndNote's duplicate identification feature.

After removing duplicates from the searched studies, the authors (SJ1, BL, EL, and JK) independently selected relevant studies for further analysis. We first selected the studies to be included by reviewing the title and abstract. We further evaluated these studies by checking the full text of the articles. In case of disagreement, all authors were consulted to resolve it and made a consensus. Inclusion/exclusion decisions were made according to the designated criteria.

The inclusion criteria were as follows:

1. MSDs that require rehabilitation (eg MSDs involving chronic pain).
2. Rehabilitation using DHC as a target intervention.
3. Conventional rehabilitation as the control intervention.
4. Reported pain and quality of life (QoL).
5. Randomized controlled or non-randomized controlled studies.
6. Full-text articles published in English.

The exclusion criteria were as follows:

1. Animal experiments or preclinical studies.
2. Target population for immune disorders.
3. Non-original article (letters, comments, and conference abstract).
4. Inability to secure full-text.

Data Extraction

Four authors (SJ1, BL, EL and JK) extracted the data from the selected studies by using the previously set extraction format. The extracted information was as follows:

1. General characteristics of the study (author, publication year, study design, target country, target disease, healthcare setting, and inclusion/exclusion criteria);
2. Characteristics of the participants (sample size, each group size, average age, proportion of women);
3. Intervention information (intervention type, intervention method, intervention period and follow-up period);
4. Outcomes of interest (pain, health-related QoL [HRQoL], and Western Ontario and McMaster Universities Arthritis [WOMAC] index as a disease-specific QoL)[19–21] and measurement tools for the outcomes.

Risk of Bias Assessment

The authors mentioned above also evaluated the risk of bias (RoB) according to Cochrane's risk of bias.[22] Disparity was solved through discussion with all reviewers.

Statistical Analysis

The effects of pain and QoL were pooled in a meta-analysis. To standardize the results measured by different tools, we calculated standardized mean differences (SMD) and 95% confidence intervals (CIs) for each study. SMD expresses a difference in the mean outcome between groups in units of the pooled standard deviation in each study.[23] Several studies reported post-intervention measurements only, others reported changes from baseline only, and others reported both. In the meta-analysis of Da Costa et al, SMD derived from post-intervention estimates did not differ from that derived from change data. Regarding availability for both measurements, we used post-intervention measurements for meta-analysis. The Cochrane Review Manager software (RevMan 5.3, Cochrane Collaboration, Oxford, UK) was used for the inverse variance method, according to Deeks and Higgins.[24] This method assigns more weight to studies with a precise estimate (i.e. low variance) than those

with high variance.[25] A random-effects model assumes the distribution of true effects and considers the within-study and between-study variances when estimating pooled effects.[25,26] We conducted a random-effects meta-analysis accounting for different aspects of variation among studies. In the meta-analysis, a reduction in pain and WOMAC index indicated a better outcome; therefore, the left side of the forest plot favored DHC rehabilitation. The right side also favored DHC rehabilitation because an increase in the score indicates a better outcome for HRQoL. SMD results were interpreted as having no effect (< 0.2), small effect (0.2–0.5), moderate effect (0.5–0.8), or large effect (> 0.8) based on the interpretation of Cohen's d.[27]

Heterogeneity was evaluated by comparing the results between studies using a forest plot and I^2 statistics to measure the proportion of variation. We determined heterogeneity if $I^2 \geq 50\%$.[28] To ensure the robustness of the meta-analysis, we assessed the potential presence of publication bias through the funnel plots of each outcome.

Results

A total of 1366, 762, 76, and 111 articles were assessed from PubMed, EMBASE, Cochrane and PEDro, respectively. Following a search update, additional 597, 484, 403, and 62 articles were assessed for each database, respectively. After deduplication, the titles and abstracts of 2112 articles and 1258 updated articles were checked, and based on the inclusion and exclusion criteria, 94 and 112 were selected, respectively. After reviewing their full text, we finally included 54 (23 records and 31 updated records) studies (Supplementary Figures 1–2).

General Characteristics

Table 1 presents the main characteristics of the 54 included studies, which had a total of 6240 participants.[29–82] The sample size ranged from 26 to 461 participants with an average age range of 21.9–71.8 years, and female representation ranging from 33.3 to 100%. The measurement outcomes, such as pain, physical function, joint range of motion, self-efficacy, and QoL, and the measurement tools varied among studies. Physical function and pain were suggested as the primary outcomes (Supplementary Table 2). We found 1 study using video-based intervention,[74], 1 using artificial intelligence-assisted program,[48] and 2 using telerehabilitation,[35,43] 8 using web-based interventions,[29,30,32,36,56,59,60,66] 16 evaluating interventions used VR or AR,[37,40–42,45,52,57,58,62,65,67,68,70,71,77,82] and 26 using a mobile application.[31,33,34,38,39,44,46,47,49–51,53–55,61,63,64,69,72,73,75,76,78–81]

Most of the included MSD studies (n = 22) were conducted on patients with affected knee or hip joints.[29,30,32,34–38,40,43,46,49–51,54,55,60,67,71,72,78,80] Among these studies, 1 was conducted on patients undergoing hip arthroplasty,[55] and 9 on patients undergoing knee arthroplasty.[35–38,40,43,54,71,80] In addition to studies on carpal tunnel release[31] and shoulder MSD,[33,41] studies on patients with ankle sprains,[42] fibromyalgia,[74] distal radius fractures,[66] and lumbar discs[39] were included. All other studies were for patients with musculoskeletal pain (n = 25).[53,56–59,61–65,68–70,73,75–77,79,81,82]

In five studies evaluating the effectiveness of rehabilitation from hospitalization,[37,38,43,67,71] the follow-up period ranges from less than 1 week to 4 months. In the other studies, it ranged from 2 weeks to 24 months to evaluate the effect of DHC intervention in an outpatient setting.[29–36,39–42,44–66,68–70,72–82] Further detailed descriptions of the intervention included studies are shown in Table 1 and Supplementary Table 2.

Risk of Bias

For randomized controlled trials (RCTs) or non-RCTs, the RoB was evaluated using the Cochrane risk-of-bias tool (version 1) (Supplementary Figure 3).[83] Except for one nonrandomized study,[76] most studies generated random sequences by using computer-generated methods; therefore, in general, we evaluated the low risk of selection bias related to randomization. However, in one study, allocations were made in order of enrollment,[79] thus, we rated it with a high selection bias risk. In studies with independent central randomization using web- or telephone-based methods, the RoB for allocation concealment was low.[30–34,37–39,42–44,46,47,49–51,53–59,61,64,71,73,74,77,80,81] However, the included studies have a relatively tricky design for blinding of participants, because the rehabilitation method differs depending on the assigned group. Among the selected studies, only six were rated as having a low risk of performance bias.[30,44,46,51,64,75] Six studies were marked as having a high risk of attrition bias,[45,46,70,72,78,79] and

Table 1 Characteristics of the Included Studies

First Author (Year)	Study Design	Disease	Duration of Disease	Settings	Number of Participants	Age, Mean (SD)	Women, N (%)	Intervention	Intervention Period	Follow-Up Period
Abadiyan (2021)	RCT	Neck pain	>3 months	Outpatient	I: 19 C1: 20 C2 (GPR): 19	I: 41.3 (8.1) C1: 37.4 (9.8) C2 (GPR): 40.3 (7.9)	I: 10 (52.6) C1: 13 (65.0) C2: 10 (52.6)	Mobile application	8 weeks	8 weeks
Afzal (2022)	RCT	Low back pain	>12 weeks	Outpatient	I: 42 C: 42	I: 38.2 (11.8) C: 37.5 (12.5)	I: 29 (69.0) C: 27 (64.3)	VR	4 weeks	4 weeks
Alasfour (2022)	RCT	Knee OA	≥6 months	Outpatient	I: 20 C: 20	I: 53.7 (4.0) C: 55.2 (4.6)	40 (100.0)	Mobile application	6 weeks	6 weeks
Allen (2018)	RCT	Knee OA	NA	Outpatient	I: 142 C1:140 C2:68	I: 65.3 (11.5) C1: 65.7 (10.3) C2: 64.3 (12.2)	I: 98 (69.0) C1: 100 (71.4) C2: 53 (77.9)	Web-based	4 months	12 months
Amorim (2019)	RCT	Low back pain	>12 weeks	Outpatient	I: 34 C: 34	I: 59.5 (11.9) C: 57.1 (14.9)	I: 15 (44.1) C: 19 (55.9)	Telephone-based and mobile application	6 months	6 months
Anan (2021)	RCT	Neck/ Shoulder/Low back Pain	NA	Outpatient	I: 48 C: 46	I: 41.8 (8.7) C: 42.4 (8.0)	I: 9 (18.8) C: 13 (28.3)	AI-assisted health program	12 weeks	12 weeks
Arfaei Chitkar (2021)	RCT	Knee OA	NA	Outpatient	I: 31 C: 29	I: 57.8 (8.6) C: 58.5 (6.3)	60 (100.0)	Mobile application	2 months	2 months
Bäcker (2021)	RCT	TKA	Acute (TKA)	Outpatient	I: 20 C: 15	I: 63.0 (8.3) C: 66.3 (10.6)	14 (60.0)	Mobile application	6 weeks	24 months
Bennell (2018)	RCT	Hip OA	>3 months	Outpatient	I: 73 C:71	I: 61.2 (7.2) C: 61.3 (7.1)	I: 45 (61.6) C: 36 (50.7)	Web-based	24 weeks	24 weeks
Bennell (2020)	RCT	Knee OA	≥3 months	Outpatient	I: 48 C: 49	I: 61.7 (6.7) C: 62.9 (6.8)	I: 35 (62.5) C: 39 (72.2)	Mobile application	24 weeks	24 weeks
Blanquero (2019)	RCT	Carpal tunnel	≤10 days	Outpatient	I: 25 C: 25	I: 51 (8) C: 49 (7)	I: 22 (88.0) C: 19 (76.0)	Mobile application	4 weeks	4 weeks
Bossen (2013)	RCT	Knee and/or hip OA	NA	Outpatient	I: 100 C: 99	I: 61 (5.9) C: 63 (5.4)	I: 60 (60.0) C: 60 (69.7)	Web-based	9 weeks	12 months
Cetin (2022)	RCT	Neck pain	≥6 months	Outpatient	I: 17 C: 17	I: 40.0 (11.9) C: 41.9 (10.8)	I: 12 (70.5) C: 11 (64.7)	VR	6 weeks	6 weeks

(*Continued*)

https://doi.org/10.2147/JPR.S388757

Table 1 (Continued).

First Author (Year)	Study Design	Disease	Duration of Disease	Settings	Number of Participants	Age, Mean (SD)	Women, N (%)	Intervention	Intervention Period	Follow-Up Period
Chhabra (2018)	RCT	Low back pain	>12 weeks	Outpatient	I: 45 C: 48	I: 41.4 (14.2) C: 41.0 (14.2)	NA	Mobile application	12 weeks	12 weeks
Choi (2019)	RCT	Frozen shoulder	≥1 month	Outpatient	I: 42 C: 42	I: 53.7 (8.1) C: 55.3 (5.5)	I: 26 (61.9) C: 31 (73.8)	Mobile application	12 weeks	12 weeks
Clausen (2020)	RCT	Rupture of the ACL	Acute (CL)	Outpatient	I: 14 C: 12	I: 24.9 (9.71) C: 25.6 (6.4)	I: 8 (57.1) C: 6 (50.0)	Mobile application	3 weeks	6 weeks
Crawford (2021)	RCT	THA	Acute (THA)	Outpatient	I: 167 C: 198	I: 62.9 (10.4) C: 59.9 (9.8)	I: 86 (51.5) C: 120 (60.6)	Mobile application w/ a wearable device	90 days	90 days
Crawford (2021b)	RCT	TKA or PKA	Acute (TKA or PKA)	Outpatient	I: 208 C: 244	I: 63.2 (8.6) C: 64.5 (8.9)	I: 136 (55.7) C: 140 (57.4)	Mobile application	90 days	90 days
Del Pozo-Cruz (2012)	RCT	Low back pain	6–12 week	Outpatient	I: 50 C: 50	I: 46.6 (9.1) C: 45.9 (6.9)	I: 34 (84) C: 36 (86)	Web-based	9 months	9 months
Ditchburn (2020)	RCT	Chronic pain	>12 weeks	Outpatient	I: 27 C: 27	I: 71.8 (6.1) C: 69.8 (4.5)	I: 22 (81.5) C: 20 (74.1)	VR	6 weeks	6 weeks
Ebrahimi (2021)	RCT	Patellofemoral pain	>6 months	Outpatient	I: 13 C: 13	I: 29.7 (5.7) C: 31.8 (5.5)	26 (100.0)	VR	8 weeks	8 weeks
Eichler (2019)	RCT	Total hip or knee OA	Acute (CL)	Outpatient	I: 48 C: 39	I: 53.3 (7.0) C: 56.8 (5.7)	I: 26 (54.2) C: 19 (48.7)	Telerehabilitation	3 months	3 months
Fleischman (2019)	RCT	TKA	Acute (TKA)	Outpatient	I1: 96 C1: 97 C2: 97	I: 65 (NA) C1: 66 (NA) C2: 65 (NA)	I: 49 (51.0) C1: 49 (50.5) C2: 50 (51.5)	Web-based	8 weeks	8 weeks
Geraghty (2018)	RCT	Low back pain	2 weeks to 6 months	Outpatient	I1: 25 I2: 22 C: 26	I1: 54.5 (13.7) I2: 59.3 (10.4) C: 60.3 (16.3)	I1: 19 (65.2) I2: 17 (63.0) C: 15 (55.6)	I1: Web-based I2: Web- and telephone-based	6 weeks	6 weeks
Gianola (2020)	RCT	TKA	Acute (TKA)	Inpatient	I: 35 C: 39	I: 66.6 (8.7) C: 70.7 (8.5)	I: 20 (45.5) C: 28 (68.3)	VR	≥ 5 days	≥ 5 days
Gohir (2021)	RCT	Knee OA	≥3 months	Outpatient	I: 48 C: 57	I: 65.2 (9.7) C: 68.0 (8.6)	I: 34 (70.8) C: 37 (64.9)	Web-based	6 weeks	6 weeks
Gruner (2021)	RCT	Knee pain	NA	Outpatient	I: 24 C: 26	I: 58.5 (13.7) C: 55.9 (13.3)	I: 12 (50.5) C: 9 (34.6)	Mobile application	8 weeks	8 weeks

Hardt (2018)	RCT	TKA	Acute (TKA)	Inpatient	I: 33 C: 27	I: 66.3 (9.3) C: 68.5 (10.3)	I: 18 (55.5) C: 16 (59.3)	Mobile application	7 days	7 days
Hou (2019)	RCT	Lumbar spinal surgery	Acute (surgery)	Outpatient	I: 84 C: 84	I: 51.1 (9.5) C: 49.4 (9.5)	I: 48 (57.1) C: 42 (50.0)	Mobile application	≥ 2 months	24 months
Itoh (2022)	RCT	Low back pain	>3 months	Outpatient	I: 48 C: 51	I: 47.9 (10.2) C: 46.9 (12.3)	I: 21 (43.8) C: 23 (45.1)	Mobile application	12 weeks	12 weeks
Jin (2018)	RCT	TKA	Acute (TKA)	Outpatient	I: 33 C: 33	I: 66.5 (3.5) C: 66.3 (4.4)	I: 18 (54.6) C: 20 (60.6)	VR	NA	6 months
Kazemi (2021)	RCT	Low back pain	≥6 weeks	Outpatient	I1: 60 I2: 60 C: 60	I1: 36 (5.8) I2: 37 (5.7) C: 37.0 (7.8)	180 (100.0)	Mobile application	6 months	6 months
Kim (2014)	RCT	Low back pain	>2 months	Outpatient	I: 15 C: 15	I: 44.3 (NA) C: 50.5 (NA)	30 (100.0)	VR	4 weeks	4 weeks
Lara (2022)	RCT	Distal radius fractures	Acute (fx)	Outpatient	I: 21 C: 28	I: 54 (46–63)* C: 58 (46–67)*	I: 15 (71.4) C: 16 (57.1)	Web-based digital video	10 weeks	≥10 weeks
Li (2021)	RCT	Low back pain	>3 months	Outpatient	I: 11 C1: 11 C2 (MCE): 12	I: 21.9 (2.4) C1: 25.4 (3.7) C2 (MCE): 23.8 (4.1)	I: 8 (72.7) C1: 10 (90.9) C2: 7 (63.6)	VR	2 weeks	2 weeks
Li (2022)	RCT	Knee injury including fractures	Acute (knee injury)	Inpatient	I: 20 C: 20	I: 33.6 (8.1) C: 31.8 (7.4)	I: 12 (60.0) C: 10 (50.0)	AR	4 weeks	3 months
Meinke (2022)	RCT	Low back pain	NA	Outpatient	I: 13 C: 14	I: 40.9 (15.2) C: 40.1 (12.4)	I: 8 (61.5) C: 9 (64.3)	Mobile application w/ a tablet	3 weeks	9 weeks
Nusser (2021)	RCT	Neck pain	>3 months	Outpatient	I: 17 C1: 18 C2 (SMG): 16	I: 51.2 (8.8) C1: 49.8 (8.1) C2 (SMG): 53.1 (5.7)	I: 9 (52.9) C1: 12 (66.7) C2: 11 (68.8)	VR	3 weeks	3 weeks
Pekyavas (2017)	RCT	SAIS and scapular dyskinesis	NA	Outpatient	I: 15 C: 15	I: 40.3 (13.2) C: 40.6 (11.8)	I: 14 (93.3) C: 13 (86.7)	VR	6 weeks	10 weeks
Pournajaf (2022)	RCT	TKA	Acute (TKA)	Inpatient	I: 29 C: 27	I: 68.3 (8.1) C: 71.1 (5.8)	I: 15 (51.7) C: 19 (70.4)	VR	3 weeks	3 weeks
Punt (2016)	RCT	Ankle Sprains	NA	Outpatient	I: 30 C1: 30 C2: 30	I: 34.7 (10.7) C1: 34.7 (11.3) C2: 33.5 (9.5)	I: 11 (36.7) C1: 10 (33.3) C2: 18 (60.0)	VR	6 weeks	6 weeks

(*Continued*)

https://doi.org/10.2147/JPR.S388757

Table 1 (Continued).

First Author (Year)	Study Design	Disease	Duration of Disease	Settings	Number of Participants	Age, Mean (SD)	Women, N (%)	Intervention	Intervention Period	Follow-Up Period
Rafiq (2021)	RCT	Knee OA	>3 months	Outpatient	I1: 38 I2: 38 C: 38	I1: 51.7 (4.9) I2: 54.0 (4.4) C: 52.9 (4.6)	I1: 21 (55.3) I2: 21 (55.3) C: 22 (57.9)	Mobile application	3 months	3 months
Rezaei (2019)	RCT	Neck pain	>3 months	Outpatient	I: 21 C: 21	I: 36.2 (9.8) C: 31.2 (9.5)	I: - (42.9) C: - (52.4)	VR	4 weeks	9 weeks
Sandal (2021)	RCT	Low back pain	≤8 weeks	Outpatient	I: 232 C: 229	I: 48.3 (15.0) C: 46.7 (14.4)	I: 121 (52.2) C: 134 (58.5)	Mobile application	3 months	9 months
Serrat (2022)	RCT	Fibromyalgia	≥3 months	Outpatient	I1: 110 I2: 110 C: 110	I1: 52.8 (8.6) I2: 52.5 (9.8) C: 53.5 (8.9)	I1: 109 (99.1) I2: 107 (97.3) C: 103 (96.7)	Video-based	12 weeks	12 weeks
Shebib (2019)	RCT	Low back pain	≥6 weeks	Outpatient	I: 113 C: 64	I: 43 (11) C: 43 (12)	I: - (37) C: - (48)	Mobile application	12 weeks	12 weeks
Sitges (2022)	Non-RCT	Low back pain	>12 weeks	Outpatient	I: 23 C: 27	I: 45.0 (9.1) C: 48.6 (7.5)	I: 20 (74.1) C: 13 (56.5)	Mobile application	4 weeks	4 weeks
Tejera (2020)	RCT	Neck pain	NA	Outpatient	I: 22 C: 22	I: 32.7 (11.6) C: 26.7 (9.2)	I: 11 (50.5) C: 12 (54.5)	VR	4 weeks	3 months
Thiengwittayaporn (2021)	RCT	Knee OA	NA	Outpatient	I: 42 C: 40	I: 62.2 (6.8) C: 63.0 (9.7)	I: 36 (85.7) C: 37 (92.5)	Mobile application	4 weeks	4 weeks
Toelle (2019)	RCT	Low back pain	≤2 weeks	Outpatient	I: 48 C: 46	I: 41 (10.6) C: 43 (11.0)	I: 35 (72.9) C: 31 (67.4)	Mobile application	3 months	12 weeks
Tousignant (2011)	RCT	TKA	Acute (TKA)	Inpatient	I: 24 C: 24	I: 66 (10) C: 66 (13)	NA	Telerehabilitation	2 months	4 months
Tripuraneni (2021)	RCT	TKA	Acute (TKA)	Outpatient	I1 (compliance≥90%): 54 I2 (compliance<90%): 99 C: 184	I1: 62.8 (NA) I2: 63.9 (NA) C: 65.1 (NA)	NA	Mobile application	6 weeks	12 months
Weise (2022)	RCT	Back pain	NA	Outpatient	I: 108 C: 105	I: 57.4 (13.8) C: 57.3 (13.5)	I: 51 (47.2) C: 62 (59.1)	Mobile application	12 weeks	12 weeks
Yilmaz Yelvar (2017)	RCT	Low back pain	>2 months	Outpatient	I: 22 C: 22	I: 46.3 (3.4) C: 52.8 (11.5)	I: 10 (45.5) C: 18 (81.8)	VR	2 weeks	2 weeks

Abbreviations: I, Intervention group; C, control group; C1, UC; C2, WL; SD, standard deviation; NA, not reported; ACL, the anterior cruciate ligament; AI, artificial intelligence; BGA, behavior graded activity; GPR, global postural reeducation; IBET, internet-based exercise training; MCE, Motor control exercise; NRS, numerical rating scale; NSAID, nonsteroidal anti-inflammatory drugs; OA, osteoarthritis; PCST, Pain coping skills training; PKA, partial knee arthroplasty; PT, physical therapy; RCT, randomized controlled study; SAIS, subacromial impingement syndrome; SMG, sensorimotor group; THA, total hip arthroplasty; TKA, total knee arthroplasty; UC, usual care; VR, Virtual Reality; WL, waiting list.

the occurrence of this bias remained uncertain in some of the studies.[41,44,62,65,67,68,82] Furthermore, some studies confirmed having unreported results; therefore, the risk of reporting bias was evaluated as high.[34,43,52,69,76] The possibility of another bias was evaluated using limitations and the funding of each study, and eight studies were assessed as having a high RoB because the author was an intervention developer[32] or received benefits related directly or indirectly to work.[32,51,54,61–63,68,75,80,81] The results of the evaluation for the RoB were represented in the Supplementary Figure 3.

Effectiveness of DHC

Pain

We pooled the results of 45 studies evaluating pain (Figure 1).[29–33,37–42,44–48,50–53,56,57,59–79,81,82] A visual analog scale[31,33,34,37,39–42,44,45,52,58,62,64–68,71,73–77,82] was used in 25 studies, and a numerical rating scale in 16.[32,34,38,46–48,51,53,59,60,63,69,70,73,79,81] Pooled results with substantial heterogeneity showed that rehabilitation using DHC significantly improved pain compared to the control (SMD: −0.55, 95% CI: −0.74, −0.36; I^2 = 88%). We divided the studies into subgroups based on the duration of disease. Acute was defined as less than 1 month, and chronic was defined as 3 months or longer.[84,85] In individuals with acute or subacute musculoskeletal pain, DHC rehabilitation resulted in more favorable outcomes compared to the control group (SMD: −0.44, 95% CI −0.69, −0.16 for acute pain; SMD: −0.93, 95% CI −1.40, −0.46 for subacute pain), whereas in individuals with chronic pain, the difference was marginally significant (SMD −0.42, 95% CI −0.83, −0.00). (Figure 1). Subgroup analysis was conducted based on follow-up duration, revealing that DHC intervention significantly reduced pain compared to conventional rehabilitation regardless of follow-up duration (Figure 2). The greatest reduction in pain was observed with a follow-up duration of less than one month (SMD: −0.75, 95% CI −1.32, −0.18). The effect of DHC on pain reduction decreased as follow-up duration increased. In addition, the funnel plot appears symmetrical, suggesting a low potential for publication bias (Supplementary Figure 4).

QoL

We pooled the results of 18 studies assessing HRQoL[30,32,35,37,39,44,50,51,54–56,63,69,73,78–80,82] (Figure 3). In each study, HRQoL was measured using various measurement tools, such as the Assessment of QoL instrument,[30] subscales of Knee Injury and Osteoarthritis Outcome Score,[50,51,78] Hip Injury OA Outcome Score,[32] 36-item Short-Form Health Survey,[35,39,44] World Health Organization QoL,[69] Veterans RAND 12-Item Health Survey,[79] Nottingham Health Profile,[82] and EuroQol 5-Dimension health questionnaire.[37,39,54–56,63,73,80] In the meta-analysis, rehabilitation using DHC was found to significantly improve HRQoL compared to the control group (SMD: 0.66, 95% CI: 0.29, 1.03; I^2 = 95%) (Figure 2 and Figure 3). The improvement in HRQoL was not significant in each group based on the duration of pain (SMD: 0.45, 95% CI −0.05, 0.94 for acute pain; SMD: 1.24, 95% CI −0.23, 2.72 for subacute pain; and SMD: 0.82, 95% CI −0.33, 1.98 for chronic pain, respectively). However, there was a significant improvement in HRQoL in studies where the duration of the pain could not be confirmed (SMD: 0.76, 95% CI 0.53, 1.00).

We also estimated the pooled results for disease-specific QoL using the WOMAC global index (Figure 4).[29,30,35,37,40,49,60] The meta-analysis included five out of seven studies that mentioned the WOMAC index as a measuring outcome.[29,35,37,40,49] Two studies were excluded due to the lack of reported total WOMAC index results.[30,60] The pooled results indicated that DHC rehabilitation had a marginally favorable effect on disease-specific QoL (SMD: −0.44, 95% CI: −0.87, −0.01; I^2 = 81%). In addition, a subgroup meta-analysis of three studies focusing on WOMAC showed a significant improvement (SMD: −0.27; 95% CI −0.53, −0.01). The funnel plots appear asymmetrical, and studies with favorable control groups are relatively scarce; therefore, the risk of publication bias is high (Supplementary Figure 4).

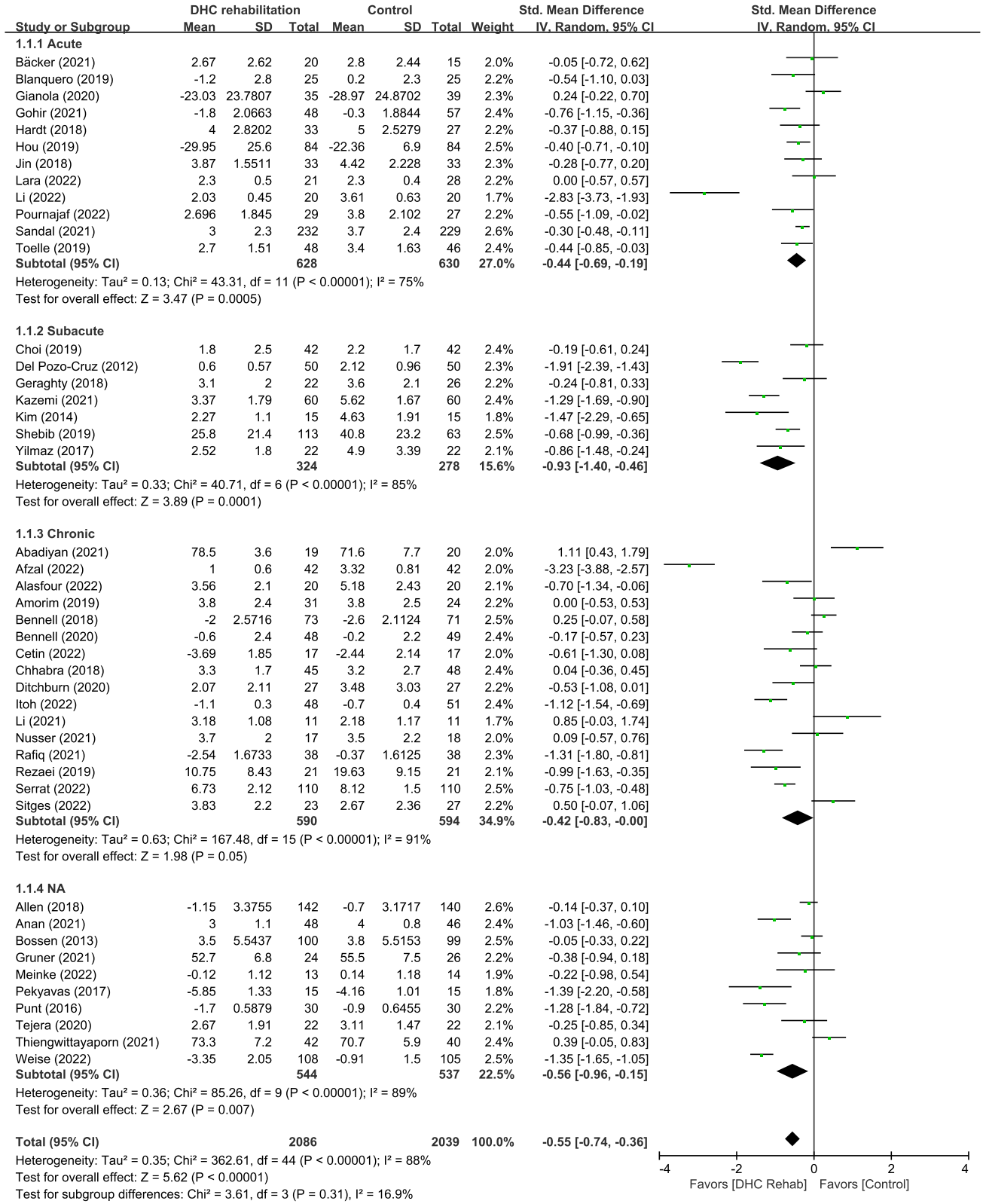

Figure 1 Forest plot of the standardized mean difference between DHC rehabilitation and control in pain.
Note: Acute is defined as less than 1 month, and chronic is defined as 3 months or longer.
Abbreviations: IV, inverse variance; 95% CI, 95% confidence interval; Rehab, Rehabilitation.

Study or Subgroup	DHC rehabilitation Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.2.1 1m								
Afzal (2022)	1	0.6	42	3.32	0.81	42	2.0%	-3.23 [-3.88, -2.57]
Blanquero (2019)	-1.2	2.8	25	0.2	2.3	25	2.2%	-0.54 [-1.10, 0.03]
Gianola (2020)	-23.03	23.7807	35	-28.97	24.8702	39	2.3%	0.24 [-0.22, 0.70]
Gohir (2021)	-1.8	2.0663	48	-0.3	1.8844	57	2.4%	-0.76 [-1.15, -0.36]
Hardt (2018)	4	2.8202	33	5	2.5279	27	2.2%	-0.37 [-0.88, 0.15]
Kim (2014)	2.27	1.1	15	4.63	1.91	15	1.8%	-1.47 [-2.29, -0.65]
Lara (2022)	2.3	0.5	21	2.3	0.4	28	2.2%	0.00 [-0.57, 0.57]
Li (2022)	2.03	0.45	20	3.61	0.63	20	1.7%	-2.83 [-3.73, -1.93]
Pournajaf (2022)	2.696	1.845	29	3.8	2.102	27	2.2%	-0.55 [-1.09, -0.02]
Sitges (2022)	3.83	2.2	23	2.67	2.36	27	2.2%	0.50 [-0.07, 1.06]
Thiengwittayaporn (2021)	73.3	7.2	42	70.7	5.9	40	2.4%	0.39 [-0.05, 0.83]
Yilmaz (2017)	2.52	1.8	22	4.9	3.39	22	2.1%	-0.86 [-1.48, -0.24]
Subtotal (95% CI)			**355**			**369**	**25.6%**	**-0.75 [-1.32, -0.18]**
Heterogeneity: Tau² = 0.93; Chi² = 141.26, df = 11 (P < 0.00001); I² = 92%								
Test for overall effect: Z = 2.58 (P = 0.010)								
1.2.2 1m-3m								
Abadiyan (2021)	78.5	3.6	19	71.6	7.7	20	2.0%	1.11 [0.43, 1.79]
Alasfour (2022)	3.56	2.1	20	5.18	2.43	20	2.1%	-0.70 [-1.34, -0.06]
Anan (2021)	3	1.1	48	4	0.8	46	2.4%	-1.03 [-1.46, -0.60]
Cetin (2022)	-3.69	1.85	17	-2.44	2.14	17	2.0%	-0.61 [-1.30, 0.08]
Choi (2019)	1.8	2.5	42	2.2	1.7	42	2.4%	-0.19 [-0.61, 0.24]
Ditchburn (2020)	2.07	2.11	27	3.48	3.03	27	2.2%	-0.53 [-1.08, 0.01]
Geraghty (2018)	3.1	2	22	3.6	2.1	26	2.2%	-0.24 [-0.81, 0.33]
Gruner (2021)	52.7	6.8	24	55.5	7.5	26	2.2%	-0.38 [-0.94, 0.18]
Meinke (2022)	-0.12	1.12	13	0.14	1.18	14	1.9%	-0.22 [-0.98, 0.54]
Pekyavas (2017)	-5.85	1.33	15	-4.16	1.01	15	1.8%	-1.39 [-2.20, -0.58]
Punt (2016)	-1.7	0.5879	30	-0.9	0.6455	30	2.2%	-1.28 [-1.84, -0.72]
Rafiq (2021)	-2.54	1.6733	38	-0.37	1.6125	38	2.3%	-1.31 [-1.80, -0.81]
Rezaei (2019)	10.75	8.43	21	19.63	9.15	21	2.1%	-0.99 [-1.63, -0.35]
Serrat (2022)	6.73	2.12	110	8.12	1.5	110	2.5%	-0.75 [-1.03, -0.48]
Shebib (2019)	25.8	21.4	113	40.8	23.2	63	2.5%	-0.68 [-0.99, -0.36]
Tejera (2020)	2.67	1.91	22	3.11	1.47	22	2.1%	-0.25 [-0.85, 0.34]
Toelle (2019)	2.7	1.51	48	3.4	1.63	46	2.4%	-0.44 [-0.85, -0.03]
Weise (2022)	-3.35	2.05	108	-0.91	1.5	105	2.5%	-1.35 [-1.65, -1.05]
Subtotal (95% CI)			**737**			**688**	**39.5%**	**-0.64 [-0.89, -0.40]**
Heterogeneity: Tau² = 0.20; Chi² = 76.23, df = 17 (P < 0.00001); I² = 78%								
Test for overall effect: Z = 5.17 (P < 0.00001)								
1.2.3 3m-12m								
Allen (2018)	-1.15	3.3755	142	-0.7	3.1717	140	2.6%	-0.14 [-0.37, 0.10]
Amorim (2019)	3.8	2.4	31	3.8	2.5	24	2.2%	0.00 [-0.53, 0.53]
Bennell (2018)	-2	2.5716	73	-2.6	2.1124	71	2.5%	0.25 [-0.07, 0.58]
Bennell (2020)	-0.6	2.4	48	-0.2	2.2	49	2.4%	-0.17 [-0.57, 0.23]
Bossen (2013)	3.5	5.5437	100	3.8	5.5153	99	2.5%	-0.05 [-0.33, 0.22]
Chhabra (2018)	3.3	1.7	45	3.2	2.7	48	2.4%	0.04 [-0.36, 0.45]
Del Pozo-Cruz (2012)	0.6	0.57	50	2.12	0.96	50	2.3%	-1.91 [-2.39, -1.43]
Itoh (2022)	-1.1	0.3	48	-0.7	0.4	51	2.4%	-1.12 [-1.54, -0.69]
Jin (2018)	3.87	1.5511	33	4.42	2.228	33	2.3%	-0.28 [-0.77, 0.20]
Kazemi (2021)	3.37	1.79	60	5.62	1.67	60	2.4%	-1.29 [-1.69, -0.90]
Li (2021)	3.18	1.08	11	2.18	1.17	11	1.7%	0.85 [-0.03, 1.74]
Nusser (2021)	3.7	2	17	3.5	2.2	18	2.0%	0.09 [-0.57, 0.76]
Sandal (2021)	3	2.3	232	3.7	2.4	229	2.6%	-0.30 [-0.48, -0.11]
Subtotal (95% CI)			**890**			**883**	**30.3%**	**-0.34 [-0.65, -0.03]**
Heterogeneity: Tau² = 0.27; Chi² = 110.56, df = 12 (P < 0.00001); I² = 89%								
Test for overall effect: Z = 2.14 (P = 0.03)								
1.2.4 12m-24m								
Bäcker (2021)	2.67	2.62	20	2.8	2.44	15	2.0%	-0.05 [-0.72, 0.62]
Hou (2019)	-29.95	25.6	84	-22.36	6.9	84	2.5%	-0.40 [-0.71, -0.10]
Subtotal (95% CI)			**104**			**99**	**4.5%**	**-0.34 [-0.62, -0.06]**
Heterogeneity: Tau² = 0.00; Chi² = 0.88, df = 1 (P = 0.35); I² = 0%								
Test for overall effect: Z = 2.41 (P = 0.02)								
Total (95% CI)			**2086**			**2039**	**100.0%**	**-0.55 [-0.74, -0.36]**
Heterogeneity: Tau² = 0.35; Chi² = 362.61, df = 44 (P < 0.00001); I² = 88%								
Test for overall effect: Z = 5.62 (P < 0.00001)								
Test for subgroup differences: Chi² = 4.34, df = 3 (P = 0.23), I² = 30.9%								

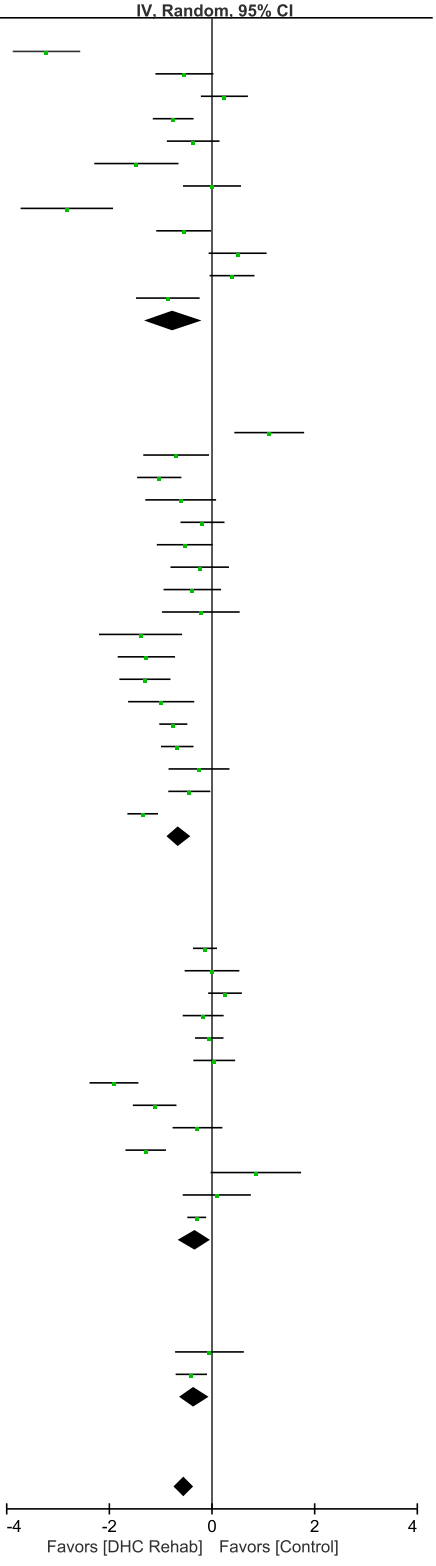

Figure 2 Forest plot of the standardized mean difference between DHC rehabilitation and control in pain according to the follow-up duration.
Abbreviations: IV, inverse variance; 95% CI, 95% confidence interval; Rehab, Rehabilitation.

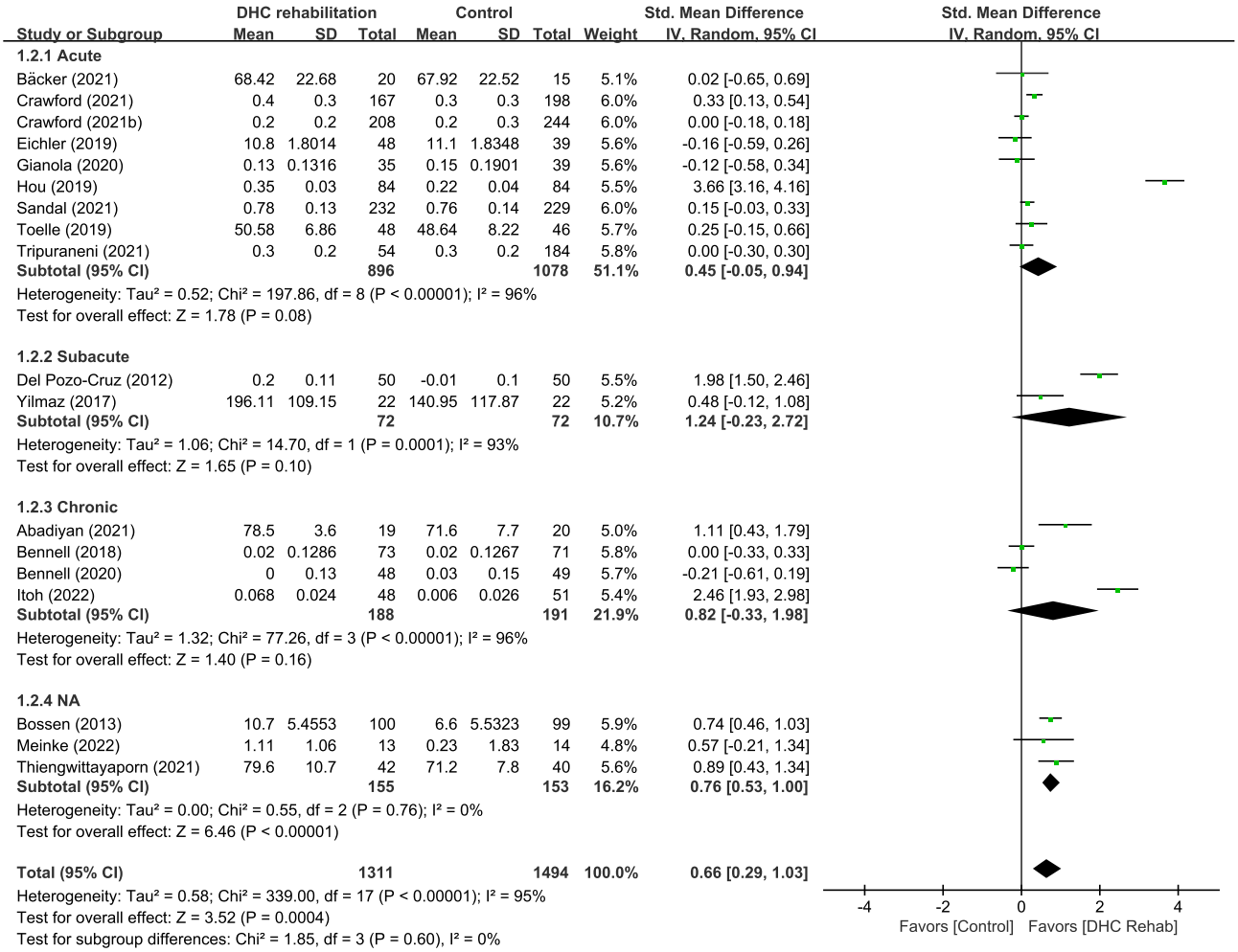

Figure 3 Forest plot of the standardized mean difference between DHC rehabilitation and control in the quality of life.
Abbreviations: IV, inverse variance; 95% CI, 95% confidence interval; Rehab, Rehabilitation.

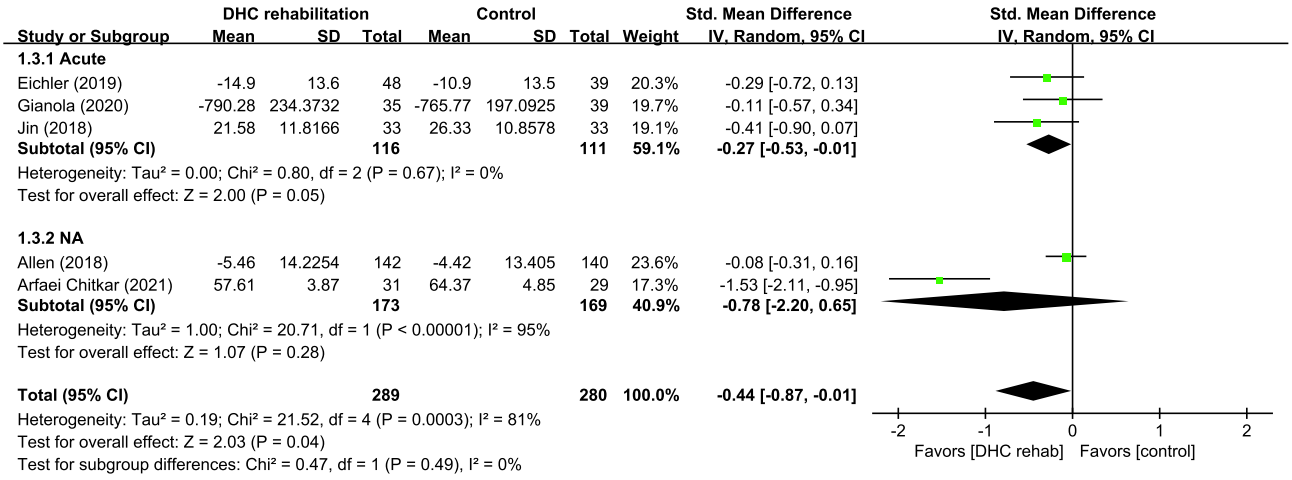

Figure 4 Forest plot of the standardized mean difference between DHC rehabilitation and control in the disease-specific quality of life (WOMAC index).
Abbreviations: IV, inverse variance; 95% CI, 95% confidence interval; Rehab, Rehabilitation.

Discussion

DHC has introduced new alternatives for the rehabilitation of patients with MSDs. In this systematic review and meta-analysis, we assessed the effects of rehabilitation based on digital technologies in patients with MSD. The meta-analyses of the studies were divided into 45, 16 and 5 studies evaluating pain, general HRQoL, and disease-specific QoL (measured with WOMAC), respectively. Our meta-analysis demonstrated that DHC rehabilitation was significantly more effective in reducing pain than conventional rehabilitation, with a moderated effect size (SMD: −0.55, 95% CI: −0.74, −0.36). This suggests that DHC-based interventions have potential for ameliorating MSD pain. The effectiveness of DHC rehabilitation in reducing pain remained significant in subgroups with acute or chronic pain (SMD: −0.44, 95% CI: −0.69, −0.19 for acute; SMD: −0.42, 95% CI: −0.83, −0.00 for chronic), indicating the potential use of DHC rehabilitation for pain management in individuals with MSDs in both short- and long-term pain conditions. Furthermore, although the effect size decreased somewhat with more extended follow-up periods, a significant effect was observed over the long term. In our meta-analysis of general HRQoL, significant improvement was more noted in the DHC group than in the control group (SMD: 0.66, 95% CI: 0.29, 1.03). However, subgroup analysis based on the duration of pain, did not reveal a significant improvement in HRQoL for the DHC group. This lack of significance may be attributed to the heterogeneity of studies included in the synthesis. As for the meta-analysis of disease-specific QoL measured using the WOMAC index, the improvement showed a marginal difference (SMD: −0.44, 95% CI: −0.87, −0.01).

The potential impact of DHC has already been widely studied. However, if limited to the rehabilitation of patients with MSD or pain via DHC, attempts to comprehend previous studies by adopting systematic reviews and meta-analyses have been relatively few. Nicholl et al[86] systematically reviewed the effects of digital support interventions in the self-management of lower back pain but owing to high heterogeneity, they were unable to identify how DHC could be optimally used. Conversely, Cottrell et al[13] succeeded in proving the possibility of real-time telerehabilitation in patients with MSD. They concluded that the target intervention group exhibited significantly better performance in terms of physical function and disability than the control group receiving usual care. Furthermore, Gumaa et al[87] systematically reviewed controlled clinical trials for orthopedic rehabilitation through VR and performed a meta-analysis. They reported their findings regarding general MSD and region-specific MSD separately and confirmed that VR can effectively ameliorate chronic neck pain and shoulder impingement syndrome. Hewitt et al[3] also conducted a systematic review of digital health interventions in patients with MSDs, demonstrating the clinical benefits of digital health interventions in reducing pain and alleviating dysfunction.

Most of the included studies reported pain as their outcome, and our pooled results found that rehabilitation using DHC is more likely to reduce pain than the usual rehabilitation. Pain is an easily perceived symptom in patients with MSD and the main reason why patients visit healthcare providers.[88] Therefore, daily pain management is important as part of the care and rehabilitation programs for patient with MSD. Conventional rehabilitation services may have few hurdles because of physical constraints, such as the travel distance to medical institutions, shortage of healthcare providers, and a long waiting time. DHC has been demonstrated as a powerful and promising alternative to conventional rehabilitation. Using innovative technology, DHC can help reduce inequality in access to healthcare.

We specified QoL in the inclusion criteria because chronic pain can easily deteriorate the QoL of patients with MSD. The included studies used various instruments and scales to measure QoL. The synthesized result across the whole HRQoL outcomes showed statistical significance. In addition, in the subgroup analysis using the WOMAC index, DHC rehabilitation obtained favorable results. Considering the multidimensional and subjective aspects of QoL, positive possibilities are still noted in rehabilitation using DHC.

While previous systematic reviews reported only qualitative and comprehensive results. However, this study attempted to quantitatively analyze the evidence collected through a systematic review. In patients with MSD, as in other diseases, reduction in pain and promotion of QoL are important health outcomes. Clinical deterioration affects patients' ability to work and perform daily activities. Pain affects the QoL, daily life, and social relationships of patients with MSD.[89–91] The pain and HRQoL assessed in the present study are representative of patient-reported outcomes (PROs). As one of the key components of patient-centered medicine, the PROs should be identified by healthcare providers for continuous patient care. Carefully assessing patients' experiences helps evaluate the effectiveness of

treatment or disease progression.[92,93] In many clinical trials, PROs were used not only as primary or secondary endpoints[94–96] but also for measuring health outcomes for economic evaluation.[97,98]

This study has several limitations. First, only studies published in English were included. Second, presenting more consistent results was challenging because of the heterogeneity between studies. Although the effects of DHC rehabilitation on MSD and associated pain could be evaluated extensively, the characteristics of the disease itself may vary and may have contributed to significant heterogeneity. Third, further consideration is needed for different types and designs of DHC. Nevertheless, we made efforts to integrate the results of various studies by clearly defining the types of DHC included in the study. Despite our evaluation of the impact of DHC on PROs, further research is needed to comprehensively ascertain the potential benefits of DHC-based interventions for pain management and improvement in physical function.

Conclusion

DHC-based interventions may serve as a valuable alternative for rehabilitating patients with MSD and associated pain. This present study found significant pain reduction and improvement in QoL in response to DHC intervention. Nevertheless, further research is needed to elucidate the underlying mechanism by which DHC affects PROs, as this may vary depending on the type and design of the DHC intervention.

Abbreviations

AR, augmented reality; CI, confidence intervals; DHC, digital healthcare; HRQoL health-related quality of life; MSDs, musculoskeletal disorders; PA, physical activity; PROs, patient-reported outcomes; QoL, quality of life; RCTs, randomized controlled studies; RoB, risk of bias; SMD, standardized mean differences; VR, virtual reality; WHO, World Health Organization.

Data Sharing Statement

The datasets used in this study can be obtained from the corresponding authors upon reasonable request.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

This research was supported by the Korea Health Technology R&D Project through the Korea Health Industry Development Institute, funded by the Ministry of Health & Welfare, Republic of Korea (grant number: HI19C0781).

Disclosure

The authors have no conflicts of interest to declare.

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