

Artificial Intelligence machine learning and conventional physical therapy for upper limb outcome in patients with stroke: a systematic review and meta-analysis

H. MAHMOUD^{1,3}, F. ALJALDI², A. EL-FIKY^{1,3}, K. BATTECHA^{1,4}, A. THABET¹, M. ALAYAT^{1,4}, E. ABD ELKAFY^{1,5}, A. EBID^{1,6}, A. IBRAHIM^{1,4}

¹Department of Physical Therapy, Faculty of Applied Medical Sciences, Umm Al-Qura University, Makkah, Saudi Arabia

²Maternity and Children Hospital, Madinah, Saudi Arabia

³Department of Physical Therapy for Neurology, Faculty of Physical Therapy, Cairo University, Cairo, Egypt

⁴Department of Basic Science, Faculty of Physical Therapy, Cairo University, Cairo, Egypt

⁵Department of Physical Therapy for Pediatrics, Faculty of Physical Therapy, Cairo University, Cairo, Egypt

⁶Department of Surgery, Faculty of Physical Therapy, Cairo University, Cairo, Egypt

Abstract. – OBJECTIVE: The goal of this study was to compare the effect of different artificial intelligence (AI) machine learning and conventional therapy (CT) on upper limb impairments in patients with stroke.

MATERIALS AND METHODS: PubMed, PubMed Central, Google Scholar, MEDLINE, Cochrane Library, Web of Science, Research Gate, and Wiley Online Library were searched. Descriptive statistics about variables were reported to calculate standardized mean differences in outcomes of motor control (the primary outcome), functional independence, upper extremity performance, and muscle tone. The Physiotherapy Evidence Database (PEDro) Scale was used to assess qualitative papers. The primary outcomes of AI and CT have been included in the meta-analyses.

RESULTS: Ten papers with a total of 481 stroke patients were included and upper limb rehabilitation, upper limb functioning, and basic manual dexterity were examined. The heterogeneity test of the whole included measures ($I^2=45\%$) was medium. There were significant differences between the included measures (p -value=0.03) with a total SMD of 0.10 [0.01, 0.19]. According to the test for subgroup difference, it was found that there was a highly significant difference between the subgroups of the included measures (p -value=0.01) and the heterogeneity test ($I^2=59.8\%$).

CONCLUSIONS: AI is a feasible and safe method in post-stroke rehabilitation and improves upper-extremity function compared to

CT. Significant AI post-treatment effects on upper-limb impairments have been observed. The findings showed that higher-quality evidence was detected in six assessment scales. However, a lower quality of evidence was detected in other scales. This indicated large or very large and consistent estimates of the treatment effects, and researchers were confident about the results. Therefore, the included studies are likely to provide an overestimate of the true effect.

Key Words:

Artificial intelligence, Robotics, Stroke, Upper extremity rehabilitation, Virtual reality, Armeo, Rehabilitation.

Introduction

Stroke is the world's second-biggest cause of mortality. It affects 13.7 million people and kills 5.5 million each year. Ischemic stroke comprised 62.4 percent of all stroke incidents in 2019 [7.63 million (6.58-8.96)], intracerebral hemorrhage with 31.9 percent [3.4 million (297-391)], and subarachnoid hemorrhage with 90.7 percent [18.1 million (1.00-1.39)]¹.

Stroke rehabilitation seeks to enhance patients' quality of life by reducing neurological deficits and their repercussions, encouraging family engagement, and allowing social reintegration.

Stroke rehabilitation is divided into three stages. Patients are treated and stabilized in a hospital during the acute phase, which normally lasts several weeks. During the sub-acute phase (1-6 months), the rehabilitation strategy is more effective at restoring functions. In the chronic phase, rehabilitation is utilized to treat and lessen motor squeals (beyond 6 months)².

Following a stroke, upper limb impairments are frequent. These deficits can make it difficult to move and coordinate the arms, hands, and fingers, which can make daily tasks difficult³. The rehabilitation process includes improving arm function, and numerous treatment approaches have been developed⁴, including a variety of exercises or training, specific tools or techniques, as well as prescription medication (pills or injections) to increase arm mobility. According to the International Classification of Functioning (ICF), only 12% of stroke survivors recover completely from upper limb (UL) functional impairments after six months. The remaining 88% continue to experience UL motor impairments, which negatively affect their level of activity and involvement⁵.

Thanks to technological advancements, researchers⁶ have developed new methods to assist clinicians in monitoring and analyzing post-stroke patients, as well as making physiotherapy available to everyone. Artificial intelligence (AI) is a term used to describe the technical imitation of human intelligence by computer-based programs and/or robotics that replicate biological mental processes and bodily expressions⁷. AI-related research and development involved high levels of interdisciplinary application-oriented toolboxes, including machine learning, deep learning, robotics, gesture, facial expression, and cognitive and language processing⁸. AI is expected to help with studying much more complicated (and much closer to real-life) clinical questions, which then leads to better decision-making in stroke management⁹.

A considerable number of research papers on artificial intelligence for post-stroke upper limb rehabilitation have been published, examining the effects of AI alone and in combination with traditional therapy. Some recent stroke guidelines¹⁰ now recommend the use of AI rehabilitation in addition to conventional therapy.

The available scientific research on the efficacy of AI rehabilitation in comparison to conventional treatments is inconclusive. Some studies¹¹ found no overall significant effect in favor of AI

therapy when comparing it to traditional therapy, while others found that AI therapy had a larger benefit than conventional therapy.

Once AI therapy is applied, the results must be interpreted with caution because the quality of the evidence is low or very low, despite differences in intensity, duration, amount of training, kind of treatment, participant characteristics, and assessments employed¹². Finally, a recent meta-analysis¹³ found that it is unclear if the difference between AI therapy and other interventions (such as conventional therapy) is clinically important for stroke patients.

Robotic therapy, as one of AI's techniques, has been offered as a potential strategy for UL rehabilitation, as a way to improve the amount and intensity of therapy while also standardizing it by offering complex yet controlled multimodal stimulation¹⁴. Furthermore, robotic devices can provide quantitative measures of the user's dexterity due to their built-in technology in terms of sensors and actuators¹⁵.

Therapists use a variety of upper extremity evaluation measures during patient evaluations to determine the abilities of upper extremity activities. Publications and clinical studies¹⁶ show that the most prevalent are the Fugl-Meyer Assessment (FMA)¹⁷, the Modified Ashworth Scale (MAS)¹⁸, the Chedoke-McMaster Stroke Assessment (CM-SA)¹⁹, and the Box and Block Test (BBT)²⁰.

Several studies^{12,13,15} concerning AI treatments have examined the results of using one device with a traditional therapy strategy. Despite the complexity of the anatomy and motor function of the entire UL, particularly the hand, all commercial devices operate on a small number of joints with a small workspace. During traditional therapy, on the other hand, the entire UL is routinely treated, and the three-dimensional space is examined²¹.

As a result, comparing the effects of AI techniques to traditional procedures is extremely challenging. So, devices that allow the treatment of the full UL (from shoulder to hand) in a workspace similar to that required in normal operations would be preferable. Furthermore, by combining many devices, new organizational models can be implemented, such as one physical therapist supervising multiple patients, boosting the treatment's long-term viability²¹.

Therefore, the primary aim of this systematic review is to compare the effects of AI and CT in the rehabilitation of upper limb disabilities in patients with stroke. The secondary aims were to 1) compare the effectiveness of different artificial intelligence modalities in the rehabilitation of the

upper limb. 2) Provide valuable insights about the relative effects of different types of artificial intelligence training on the upper limb after stroke, describing any obstacles or limitations that may inhibit artificial intervention.

Materials and Methods

The search was carried out for English literature published between 2010 and 2022 through the PEDro, PubMed, Google Scholar, MEDLINE, Cochrane Library, Web of Science, and Research Gate datasets (Figure 1). The search terms were done according to the recent randomized clinical trials about AI with “upper extremity” OR “robotics” OR “upper limb” OR “artificial intelligence” OR “virtual reality” OR “video games”

AND “conventional therapy” OR “traditional therapy” OR “physical therapy” OR “rehabilitation” AND “stroke”. Three investigators (HM, SA, and FA) independently and blindly reviewed the systematic reviews in two phases: the first phase for relevant study analysis and the second phase for related study revision. Following that, each evaluator addressed and discussed the differences by re-reading the full transcript publications. PROSPERO 2022 CRD42022315369 was the trial registration number for this study.

Only RCT studies were included that applied AI as an intervention for the upper limb in stroke patients with a cut-off point of 5 or more on the PEDro scale of internal validation. Papers that did not conduct an effective analysis of AI with a cut-point lower than 5 points or papers published in languages other than English were excluded.

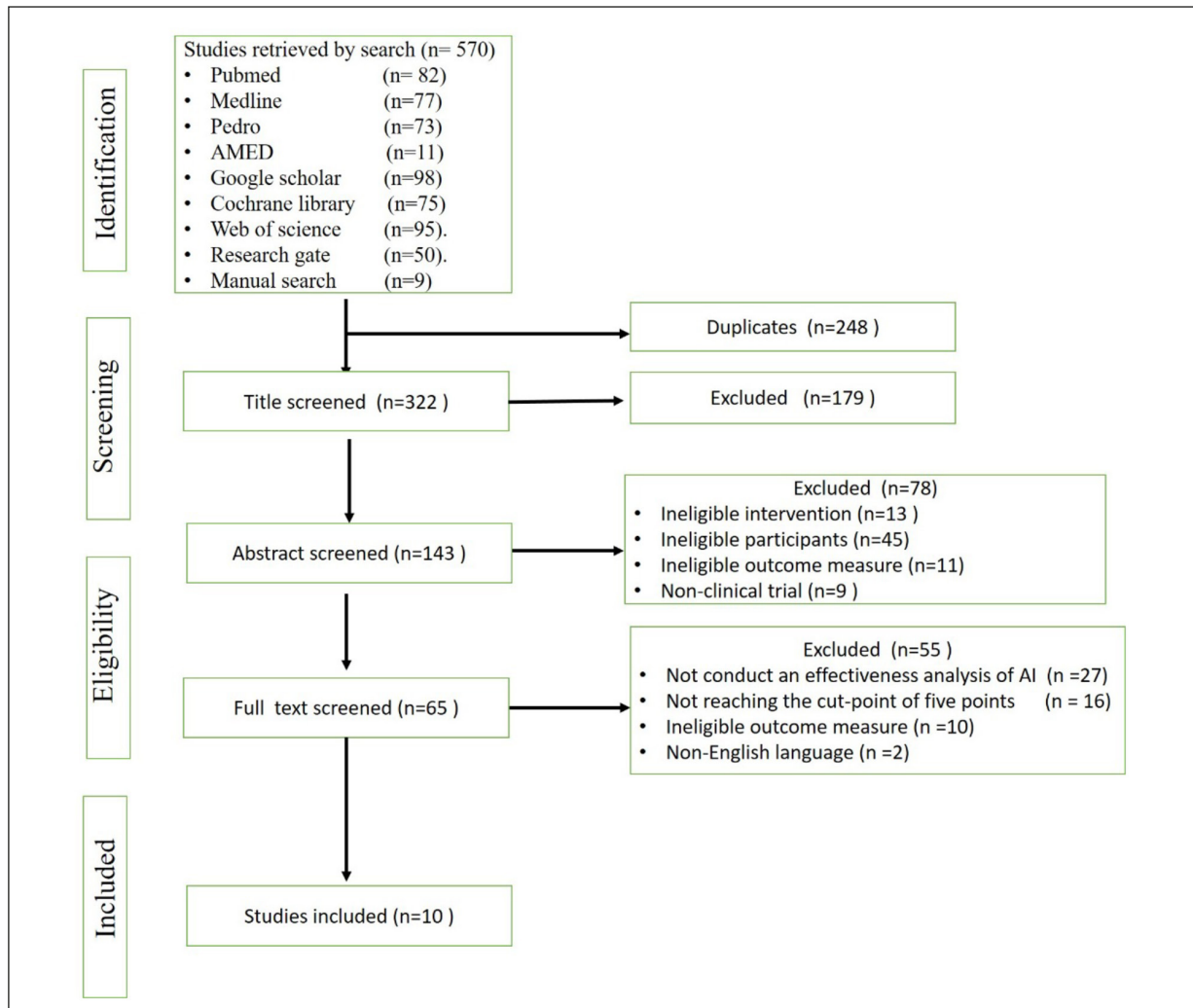


Figure 1. Screening of studies for inclusion.

Quality Assessment

The qualitative aspect of each submitted study was assessed by three independent reviewers using the Physiotherapy Evidence Database PEDro Scale. The PEDro scale was developed to help researchers to quickly identify trials with sufficient statistical evidence for clinical decision-making. This scale is a valid instrument for assessing the quality of RCTs and is commonly used in systematic reviews to evaluate the risk of bias. It consisted of 11 elements (yes/no responses) that were used to measure the related bias hazard: eligibility criteria, random assignment, hidden assignment, baseline comparability, subjects who were blind, therapists who were blind, evaluators who were blind, sufficient follow-up, assessment with the intention to cure, between-group analyses, point estimates, and variability. The included investigations were graded as being of low quality (grade 3), good quality (4-5), or excellent quality (grade >6). Two independent reviewers (HM and FA) examined the methodological quality, and another third reviewer (SA) handled any discrepancies.

Quality of Evidence

The Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach was used to evaluate the quality of the evidence. The GRADE test scores were described as follows: (a) "Excellent Quality" (very confident in the estimated effect). The genuine impact is comparable to performance and evaluation. (b) "Moderate Quality" (moderately confident in the estimated effect). The real impact is probably like the estimates, although it is possible that it is much more distinct, and (c) "Low Quality" (limited confidence in the estimated effect). Genuine effects may differ significantly from our best knowledge, and (d) "Very Low Quality" means we have very little confidence in the estimated effect. The genuine effects will probably differ significantly from the estimated effect.

Statistical Analysis

A meta-analysis was conducted, and qualitative (descriptive) analysis was used and presented as tables, while quantitative analysis was represented by a forest plot. The primary outcome (upper limb function) was included in meta-analyses to compare the efficacy of AI and CT in patients with upper limb deficiency after stroke. Subset analysis was used to determine the effectiveness of AI as a therapeutic approach compared to CT as a control group. Meta-analyses were carried

out using Review Manager Software (RevMan, version 5.4, The Cochrane collaboration, Copenhagen, Denmark). The standard mean difference (SMD) was used to substitute the mean difference (MD) as the effect size, and its 95 percent confidence interval (CI) was calculated. There are three types of effect sizes: small (0.2), medium (0.5), and large (1.0). The I^2 statistics were used to assess and quantify the potential for heterogeneity among researchers. If there was heterogeneity in the data ($I^2 < 50\%$, $p\text{-value} < 0.05$), a sensitivity analysis was performed to determine how good and consistent the results were.

Results

Study Selection

A total of 570 records were identified through the initial electronic searches of healthcare search databases involving PubMed (n=82), the MEDLINE database (n=35), the PEDro database (n=73), AMED (n=11), Google Scholar (n=98), the Cochrane Library database (n=65), the Web of Science database (n=30), Research Gate (n=20), and finally a manual search (n=9). After completing the applicable screening procedure, including the reasons for exclusions, 248 articles were eliminated for duplication, while 137 papers were excluded following title and abstract screening.

The remaining 65 articles were read in their entirety. After screening the whole text, 55 articles were deleted once the entire material was reviewed. These articles were disqualified for a variety of reasons, including the fact that some of them were not written in English, others did not reach the cut-point of five points, and they did not undertake an effective analysis of AI (n=27). The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA), a 27-item checklist, was used to improve transparency in systematic reviews. These items cover all aspects of the manuscript. Ten papers^{11,22-30} were chosen for qualitative assessment, methodological quality assessment, and evidence quality assessment. The details of the study selection were presented in a flow diagram (Figure 1)

Study Characteristics

Ten RCTs studies^{11,22-30} published between 2014 and the end of 2022 met the inclusion criteria (Table I). Three studies^{11,22,23} included follow-up assessment(s), while seven studies²⁴⁻³⁰ reported only the post-treatment assessments.

Table I. Internal validity analysis (PEDro scale).

	Eligibility criteria	Random allocation	Concealed allocation	Baseline comparability	Blind subjects	Blind therapists	Blind assessors	Adequate follow-up	Intention-to treat analysis	Between-group comparisons	Point estimates and variability	Total score
Norouzi-Gheidari et al ²³	Yes	Yes	Yes	Yes	No	No	Yes	No	No	Yes	Yes	7
Villafañe et al ²⁸	No	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	7
Abd El-Kafy et al ²⁹	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	8
Tomic et al ²⁴	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	7
Saposnik et al ³⁰	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	7
Taveggia et al ¹¹	No	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	7
Popović et al ²⁷	Yes	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	7
Park et al ²⁶	No	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	5
Sale et al ²²	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	9
Klamroth-Marganska et al ²⁵	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	9

Subjects

A total of 10 studies^{11,22-30} of stroke-related upper-limb intervention, involving 481 participants diagnosed with both acute and chronic stroke were included. The population in each of the ten trials ranged from 18 to 121, and their ages ranged from 22 to 90 for both males and females.

Outcome Measured

Fugl-Meyer assessment

The Fugl-Meyer assessment for the upper extremity functions (FMA-UE) was used in six studies²²⁻²⁷. According to one study²⁶, neither the artificial intelligence group (AIG) nor the conventional therapy group (CG) substantially varied in the pre-intervention homogeneity test, but both groups showed significant improvement in all post-treatment measures. There was no significant difference between AI and CG according to two studies^{23,26}. Three studies^{22,24,25} revealed a substantial difference between the two groups. Klamroth-Marganska et al²⁵ (2014), showed significant differences between both groups over the course of the study regarding the FMA-UE. Another study²⁴ showed a significantly greater increase in FMA-UE score (p -value=0.002) and FMA-UE shoulder/elbow score (p -value=0.006) in the AI group compared to the CG. In the study done by Norouzi-Gheidari et al²³, no significant differences between the two groups were found.

Barthel Index (BI)

Four studies^{24,26,28,30} used BI to assess upper-limb functions following rehabilitation. Three studies^{24,28,30} showed no significant difference between the AIG and the CG. In the pre-intervention homogeneity test, neither the AIG nor the CG significantly differed from each other, but both groups significantly improved in all post-treatment variables, according to Park et al²⁶.

Another study²⁴ found no significant differences in BI between the two groups. This may be due to the short duration of the treatment since BI reflects global physical abilities, which depend on the restoration of many other functions and associated comorbidities. Another study²⁸ concluded that time plays a significant role in the outcome of BI. The post hoc analysis revealed clinically and statistically significant differences between the baseline and the following 3-week outcomes. The effect size scores for the difference between groups were moderate. Another finding³⁰ showed that patients in both groups had similar scores

with respect to grip strength, recovery in activities of daily living, hand function, and quality of life measured by BI following 2 weeks of intervention. Similar results were observed 4 weeks post-intervention.

Modified Ashworth Scale

The Modified Ashworth scale (MAS) scale was used to measure upper extremity tonal changes after stroke in five studies^{11,22,25,27,29}. The results revealed large scores change in the effect sizes between groups with no significance for time or group-by-group interactions²⁸. Another study²² revealed statistically significant improvements in MAS in the AIG, with non-significant improvements in the CG. Also, in a study by Abd El-Kafy et al²⁹, results revealed a significant tonal reduction of elbow, wrist, and fingers flexors in robotic training group (AIG) when compared to CG (p -value<0.01), and the research confirmed the effectiveness of robotic training in modulating spasticity and improving upper limb function after stroke. Another finding²⁵ stated no significant differences between the two groups regarding the MAS outcomes. Another study¹¹ showed a significant reduction in spasticity after treatment for both groups; however, the significant decrease of AIG was higher (p -value=0.001) than that of CG (p -value=0.027), and no differences were observed between the groups after six weeks of follow-up (p -value=0.432)¹¹.

Wolf Motor Function Test

Four studies^{24,25,29,30} applied Wolf Motor Function Test (WMFT). One study showed an improvement in WMFT (p -value=0.025) and shoulder/elbow portion of WMFT (p -value=0.010) was significantly greater in the AIG group. All effect sizes were large²⁴. A significant difference (p -value<0.01) between pre- and post-treatments for each treatment group was recorded, with significant differences (p -value<0.05) detected in favor of the AI group²⁹. According to Klamroth-Marganska et al²⁵, no significant differences between the two groups were found. In the study by Saposnik et al³⁰, the multivariable analysis revealed no significant differences between groups at the end of the treatment with respect to WMFT performance.

Stroke Impact Scale

Stroke impact scale (SIS) was detected in three studies^{23,25,30}. The findings of these studies varied widely. One study²⁵ found no significant

differences between the two groups. Another finding³⁰ was that secondary outcome measures did not differ between groups. A study conducted by Norouzi-Gheidari et al²³ recorded a difference change between the two groups with a higher improvement in AIG compared to CG. Although none of these differences were statistically significant, overall, SIS changes between baseline and post-treatment with AIG were statistically significant.

Motricity Index

Motricity Index (MI) was applied in three studies^{11,22,28}. One study¹¹ showed a significant MI increase after treatment for both groups. Although the increase of AIG was higher (p -value=0.001) than that of CG (p -value=0.041), the recorded differences between the two groups after the treatment (p -value=0.482) were non-significant. Significant differences were observed at the follow-up for the AIG (p -value=0.001) and evident differences between groups were observed at the follow-up (p -value=0.001)¹¹. Another study²⁸ found that the MI scores of the effect sizes for group differences were significant. In a study²², AIG significantly improved more than CG after the first 15 sessions (p -value=0.0001 and p -value=0.008, respectively).

Motor Activity Log (MAL)

Two studies^{23,25} out of 10 studies measured post-stroke upper limb rehabilitation using MAL. One study²⁵ detected no significant differences between the two groups. Comparisons between both groups in the study by Norouzi-Gheidari et al²³ revealed that AIG had higher gains in the MAL-QOM score than CG. Regarding AIG alone, the gain in the MAL-QOM score from baseline was significant.

Box and Blocks Test (BBT)

Two studies^{23,30} used BBT to assess post-stroke upper limb rehabilitation. According to the Saposnik et al's study³⁰, AIG performed better in the BBT at the end of treatment. There were no significant differences between the two groups in this study²³.

Intervention

The frequency of treatment sessions ranged from 2 to 7 days a week. Treatment duration ranged from 2 to 8 weeks, with session periods ranging from 25 minutes to 2 hours. There were no documented side effects from the treatment.

Risk of Bias Assessment

The quality of the studies' report varied. The risk of bias for assessment is displayed in Table II. The PEDro scale assessment revealed nine high-quality studies^{11,22-25,27-30} and one fair-quality²⁶. According to the GRADE scale system, studies showed low-quality evidence with lower effect size (ES) (SMD 0.26, 0.7, and 0.08) in studies using FMA-UE-BBT, FMA-UE - MAL-QOM and FMA-UE - SIS, higher ES (SMD=0.01) for studies that only used FMA-UE, and higher ES in FMA-UE - MAS-S, FMA-UE - WMFT, FMA-UE - BI, FMA-UE - MI and FMA-UE - FIM (SMD=0.07, 0.27, 0.21, 0.66, and 0.26) respectively (Table III).

The Quantitative Results

For the current meta-analysis, 10 studies^{11,22-30} were included to compare the impact of artificial intelligence and conventional therapy in the rehabilitation of upper limb disabilities in post-stroke patients.

Fugl-Meyer Assessment

The meta-analysis of the effect of robotic-assisted therapy indicates that FMA-UE had no significant difference between the two groups of the six included studies²²⁻²⁷ [SMD 0.01 (-0.25, 0.27)] (p -value=0.94). The heterogeneity test (I^2) was very low (<25%).

Modified Ashworth Scale

The test of the overall effect of MAS revealed no significant difference between the studied groups in the five included investigations^{11,22,25,27,29} (p -value=0.48), with SMD=-0.09 [-0.34, 0.16]. The heterogeneity test was recorded (I^2 =74%).

Wolf Motor Function Test

The test of the overall effect regarding WMFT indicated a significant difference comparing the two groups of the four included studies^{24,25,29,30} (p -value=0.0007) with SMD=0.42 [0.18, 0.66]. The heterogeneity test was recorded (I^2 =79%).

Barthel Index

According to meta-analyses of the effect of BIS between the studied groups, it was found that there was no significant difference detected (p -value=0.11); the SMD was 0.21 [-0.04, 0.46]. The heterogeneity test (I^2) was low.

AI and physical therapy in stroke patients

Table II. Characteristics of included studies.

Author	Intervention	Aim	Method	Outcome measures	Result/conclusion	Significance of results (measures)
Taveggia et al ¹¹	Armeo Spring	To assess the efficacy of robotic-assisted motion (ARMEO) and activity in addition to physical and rehabilitation medicine (PRM) for upper limb rehabilitation in post-stroke inpatients.	AIG: 27 participants, received Armeo Spring training and conventional treatment CG: 27 participants, received PT (according to the Bobath concept) 30 sees (5d/wk.) for 1 hour.	Primary outcomes: FIM MI Secondary outcomes: MAS VAS	Armeo spring may aid in the recovery of disability, pain, and spasticity in the upper limb following a stroke. Positive outcomes obtained from the safe and functional robotic rehabilitation	Significant • MI • MAS • VAS Non-significant: • FIM
Sale et al ²²	Robot-assisted upper limb rehabilitation	To evaluate the short-time efficacy of intensive robot-assisted therapy compared to usual physical therapy performed in the early phase after stroke onset.	AIG: 26 participants received robot-assisted therapy CG: 27 participants received standard therapy 30 minutes per-session, 5 days a week, during the 4-week training period	Primary outcome: FM Secondary outcome: pROM and MI	In sub-acute stroke, robot-assisted upper limb recovery can help improve functional recovery.	FM improved significantly in both groups statistically significant improvements in pROM and MI in the AIG, whereas the CG showed statistically significant improvements in MI and a not statistically
Norouzi et al ²³	Exergaming trainings in combination with appropriate therapy sessions	Examine the safety and feasibility of an additional exergame system and assess its preliminary clinical efficacy.	A total of 18 participants AIG: (n = 9) received usual rehabilitation services and additional training with the rehabilitation exergaming system. CG: (n = 9) received usual rehabilitation services Two sess/ week, for 4 weeks, 44 min. per session	Primary outcome: UE motor function (measured by the Fugl-Meyer Assessment (FMA-UE)- and the Box and Block test (BBT)) Secondary outcomes: self-reported health status (measured by Stroke Impact Scale (SIS); and self-reported measure of UE use (measured by Motor Activity Log (MAL))	Using virtual reality exergaming technology as an adjunct to traditional therapy is feasible and safe in post-stroke rehabilitation and may be beneficial to upper extremity functional recovery.	By using the exergame system, there were no adverse events.
Tomic et al ²⁴	Arm Assist robotic (AA) training	To establish the preliminary efficacy of the AA robotic device in contrast to conventional arm training.	AIG: 13 participants received AA training CG: 13 participants received OT and PT 15 sess (3w) 30 minutes	Primary outcome: (FMA-UE) Secondary outcome: (WMFT-FAS) (BI)	Arms training with the AA robotic device reduced impairment and activity-related motor deficits more effectively than conventional arm training. • The Arm Assist is simple low-cost and less dependent on therapist assistance.	Significant FMA-UE WMFT-FAS Non-significant: BI.

Table continued

Table II (Continued). Characteristics of included studies.

Author	Intervention	Aim	Method	Outcome measures	Result/conclusion	Significance of results (measures)
Klamroth-Marganska et al ²⁵	ARMin-an exoskeleton robot	To determine if robotic training of an affected arm allows task-specific training in three dimensions reduces motor impairment more than conventional treatment.	AIG: 38 participants, received robotic therapy CG: 35 participants, received PT or OT 24 sees (3d/wk.\8 wk.) for 45 min.	Primary outcome: (FMA-UE) Secondary outcome: WMFTgrip strength MAL (QOM)	Exoskeleton robot, can improve motor function in a chronically impaired paretic arm more than traditional therapy. ARMin-an exoskeleton robot was shown to be safe and recovery is faster with robot-assisted therapy than with conventional therapy.	Significant FMA-UE was small and of weak significance between both groups. Non-significant: WMFTgrip strength MAL(QOM)
Park et al ²⁶	Conventional physical therapy. A game-based virtual reality (VR) rehabilitation program.	Investigate the impact of a rehabilitation program and a glove-type smart watch on specific upper extremity functioning.	A total of 44 patients AIG: (n = 22) was requested to wear a glove-type device while they were administered a game-based virtual reality (VR) CG: (n = 22) conventional physical therapy 30 mins per session, 5sess/wk/4 wks.	Primary outcome: Fungl-Meyer assessment scale (FMA) hand strength test. Secondary outcome: Jebsen-Taylor hand function tests for upper limb function	A rehabilitation program that used a smart watch in alongside traditional physiotherapy is more efficient than regular treatment alone in increasing upper limb mobility, activity of everyday living efficiency, and rehabilitation involvement.	In the pre-intervention homogeneity test, neither the intervention nor the control groups differed significantly, but both categories exhibited significant enhancement in all post-intervention response variable.
Popovic et al ²⁷	Feedback-mediated exercise (FME)	Examine the effectiveness of videogames in rehabilitation by addressing its impact on patient motivation, endurance in training, and motor function improvement	AIG: 10 participants, received FME CG: 10 participants, received (NFE) 15 sees (5d/wk.) for 25 min.	mDT; RTT; IMI;	High levels of motivation were found. Therapy endurance improved throughout the intervention. Participants suggested changing the game task into a more interesting activity.	More Significant in FME group: IMI; mDT; RTT;
Villafane et al ²⁸	Robot therapy with the hand Gloreha	Assess the efficacy of robot-assisted motion and activity in addition to (PT) and (OT) in stroke patients with hand paralysis.	AIG: 16 participants received robot therapy with the hand Gloreha CG: 16 participants received an additional 30 minutes of PT and OT in addition to traditional rehabilitation. 15sess (3 d/wk) for 30 minutes.	(NIHSS), Modified Ashworth Scale BI MI QuickDASH), and VAS)	Robot-assisted mobilization combined with traditional PT and OT is as effective as conventional rehabilitation.	Significant: • NIHSS; • BI • MI • (Quick DASH) • VAS

Table continued

Table II (Continued). Characteristics of included studies.

Author	Intervention	Aim	Method	Outcome measures	Result/conclusion	Significance of results (measures)
Abd El-Kafy et al ²⁹	Training with robot-mediated virtual reality gaming & Conventional physiotherapy	Investigate the effects of training with robot-mediated virtual reality gaming on motor functions and spasticity of upper limb in patients with chronic stroke	AIG: 20 stroke patients received training with robot-mediated virtual reality gaming CG: another 20 patients received conventional physical therapy 12 Sess (3/w) For 2H /sess.	Outcome: ARAT WMFT WMFT-Time MAS, AROM HGS	Robot-mediated virtual reality gaming training was effective than conventional therapy in spasticity modulation & in upper limbs motor functions improvement in individuals with chronic stroke	There was a significant improvement of AIG in all outcome measures more than CG
Saposnik et al ³⁰	(VRWii) Mini games (playing cards, bingo, Jenga, or ball game).	To compare the effectiveness of virtual reality versus recreational therapy in patients recovering from an acute stroke.	AIG: 59 participants received VRWii therapy CG: 62 participants in recreational therapy) 10 sess. (5d\wk.) for 1 hour.	Primary outcome WMFT Secondary outcomes BI FIM SIS Grip Strength	No significant difference of clinical outcomes was found.	No-significant difference between groups in primary and secondary outcomes.

AIG: Artificial intelligence group, **CG:** Conventional Therapy group, **FMA-UE:** Fugel-Meyer assessment for upper extremity, **MAS:** Modified Ashworth Scale, **WMFT:** Wolf Motor Function Test, **BI:** Barthel Index, **SIS:** Stroke Impact Scale, **MI:** Motricity Index, **QOM:** Quality of Movement, **BBT:** Box and blocks test, **FIM:** Functional Independence Measure, **Quick DASH:** Short version of the Disabilities of the Arm, **VAS:** Visual Analog Scale, **RT:** Robot-assisted therapy, **FME:** feedback-mediated exercise, **NFE:** No-feedback exercise, **MDT:** Mechanical Diagnosis and Therapy, **RTT:** Repetitive Task Training, **IMI:** Intrinsic Motivation Inventory, **ARAT:** Action Research Arm Test, **FAT:** Frenchay Arm Test, **MRS:** Modified Rankin Scale, **MS:** Motor Status Score, **pROM:** passive Range of motion, **AROM:** Active Range of Motion, **HGS:** Hand grip Strength, **OPQOL:** Older People's Quality of Life Questionnaire.

Table III. Level of quality evidence (GRADE).

Certainty assessment N. of studies	N. of patients		Effect absolute (95% CI)
	FMA-UE	Placebo	
FMA-UE - FMA-UE 6	119	116	SMD 0.01 higher (0.25 lower to 0.27 higher)
FMA-UE – MAS 4	107	105	SMD 0.07 higher (0.21 lower to 0.34 higher)
FMA-UE - -WMFT 3	122	118	SMD 0.27 higher (0.02 higher to 0.53 higher)
FMA-UE – BI 4	122	121	SMD 0.21 higher (0.04 lower to 0.46 higher)
FMA-UE – SIS 3	118	114	SMD 0.08 lower (0.33 lower to 0.18 higher)
FMA-UE – MI 3	69	70	SMD 0.33 higher (0.01 lower to 0.66 higher)
FMA-UE – MAL-QOM 3	164	162	SMD 0.7 lower (0.93 lower to 0.47 lower)
FMA-UE – BBT 2	80	79	SMD 0.26 lower (0.57 lower to 0.05 higher)
FMA-UE – FIM 2	98	97	SMD 0.26 higher (0.03 lower to 0.54 higher)

FMA-UE: Fugl-Meyer assessment for upper extremity, MAS: Modified Ashworth Scale, WMFT: Wolf Motor Function Test, BI: Barthel Index, SIS: Stroke Impact Scale, MI: Motricity Index, QOM: Quality of Movement, BBT: Box and blocks test, FIM: Functional Independence Measure, CI: confidence interval; SMD: standardized mean difference.

Stroke Impact Scale

As shown in the forest plot (Figure 2), there was no significant difference between the three studied^{23,25,30} papers regarding SIS (p -value=0.57) with SMD=-0.08 [-0.33, 0.18]. The heterogeneity test (I^2) was low.

Motricity Index

The test of the overall effect of MI indicated that there was a significant difference between the three included outcome results (p -value=0.05) with SMD 0.33 [-0.01, 0.66]. The heterogeneity test (I^2) was low.

Motor Activity Log (MAL)

The test of the overall effect of MAL indicated that there was no significant difference between the two included outcome results (p -value=0.81) with SMD 0.05 [-0.36, 0.46]. The heterogeneity test (I^2) was low.

Box and Blocks Test

The overall effect of the BBT test revealed no statistically significant difference between the three included outcome results (p -value=0.10), with SMD -0.26 [-0.57, 0.05]. The heterogeneity test (I^2) was low.

The heterogeneity test of the whole set of included measures ($I^2=45%$) was medium. There was a significant difference between the included measures (p -value=0.03) and the total SMD of 0.10 [0.01, 0.19]. According to the test for subgroup difference, it was found that there was a highly significant difference between the subgroups of the included measures (p -value=0.01), and the heterogeneity ratio ($I^2=59.8%$) was high.

Discussion

The goal of this systematic review and meta-analysis was to compare the effect of different artificial intelligence (AI) machine learning and conventional therapy (CT) on upper limb impairments in patients with stroke. A systematic review of RCTs was conducted and provided low to high GRADE-based quality evidence and low to high methodological quality for the productiveness of AI and CT in the rehabilitation of upper limb disabilities in post-stroke patients. The included artificial intelligence measurements were: Fugl-Meyer assessment, Modified Ashworth scale, Wolf Motor Function Test, Barthel Index, Stroke Impact Scale, Motor Activity Log, and Box and Blocks Test.

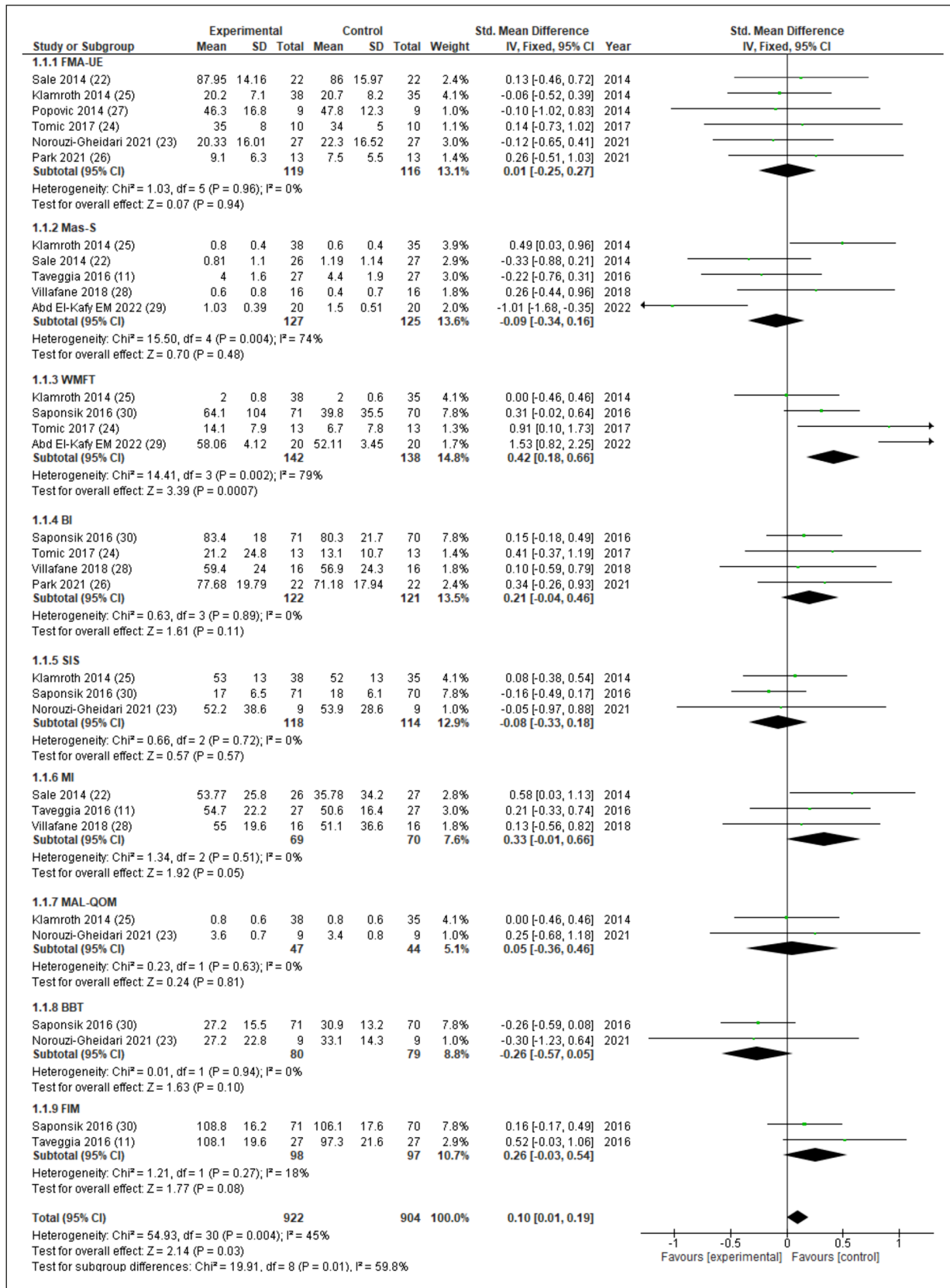


Figure 2. Meta-analysis of the effect the artificial intelligence compared to conventional therapy.

The outcome of this systematic review revealed no significant difference between the included measures (p -value=0.63) and the total SMD [-0.02 (-0.11, 0.07)]. The heterogeneity test of the whole set of included measures ($I^2=67%$) was medium. According to the test for subgroup difference, there was a highly significant difference between the subgroups of the included measures (p -value<0.001) and the heterogeneity ratio ($I^2=85%$) was high.

This study emphasizes the importance of quality assessment tools used in reviewing AI-based treatment modalities based on the level of quality evidence. According to the included studies, higher-quality evidence was detected in six assessment scales (FMA-UE, MAS, WMFT, BI, MI, and FIM). However, SIS, MAL-QOM, and BBT revealed lower-quality evidence. This means that there were large or very large and consistent estimates of the treatment effects and researchers may be confident about the results. Therefore, the included observational studies are likely to provide an overestimate of the true effect.

The findings were consistent with a prior systematic review³¹, which revealed that regardless of the post-stroke rehabilitation period (i.e., acute, subacute, or chronic), the effects of robotic training were like those of dose-matched CT or standard treatment³¹.

Another systematic review³² found that non-significant effects were found in all selected outcomes at post-treatment up to 12 months post-treatment and the evidence was generally rated as low-to-moderate quality for improving motor control, functional independence, upper extremity performance, muscle tone, and quality of life in patients in the early stage of post-stroke rehabilitation³².

The FMA of the upper limb included eight sub-items, namely, reflex, flexor cooperative movement, extensor cooperative movement, activity with the cooperative movement, activity out of the cooperative movement, normal reflex, wrist joint stability, hand movement, coordination ability, and speed³³. In the current systematic review, six studies²²⁻²⁷ applied the (FMA-UE) assessment; one study²⁶ showed that in the pre-intervention homogeneity test, neither the AIG nor the CG differed significantly, but both groups exhibited significant enhancement in all post-treatment response variables. Two studies^{23,27} showed no significant difference between the AIG and CG. Three studies^{22,24,25} showed a significant difference between the two groups.

In the study by Klamroth-Marganska et al²⁵ (2014), the FMA-UE differences between both groups over the course of the study were significant. The findings showed that there was a significantly greater increase in FMA-UE score (p -value=0.002) and FMA-UE shoulder/elbow score (p -value=0.006) in the AIG compared to the CG²⁴. Another study²³ showed that no significant differences were found between the two groups. This could be interpreted as robotic devices being able to provide force feedback for sensorimotor-type rehabilitative training and assist patients by passively moving the limb³⁴. It has been reported³⁵ that the repetitive training of isolated movements and robot training can have a greater effect on stroke-related motor impairments than increased therapy time alone.

According to the Barthel Index, findings²⁴ showed that there were no significant differences in the BI between both groups. This may be due to the short duration of the treatment since BI reflects global physical abilities, which depend on the restoration of many other functions and associated comorbidities³⁶. In another finding²⁸, the outcome of BI demonstrated a significant time factor but not for group-by-time interaction. The post hoc analysis revealed both clinically and statistically significant differences between the baseline and outcome scores after 3 weeks. Scores of the effect sizes for the changes between groups were moderate. Previous findings³⁰ revealed that patients in both groups had similar scores with respect to grip strength, recovery in activities of daily living measured by the BI, hand function, and quality of life at the end of the 2-week intervention. Similar results were observed 4 weeks post-intervention³⁰.

MAS scores of the effect sizes for the change between groups were large. For spasticity measured over the MAS, there was no significance for time or group-by-time interactions²⁸. Previous findings²² revealed that the primary outcome analysis showed statistically significant improvements in MAS for shoulder and elbow in the experimental group and not a statistically significant decreasing trend of MAS of the shoulder and an increasing trend of MAS of the elbow was found in the control group²². However, other findings²⁹ recorded significant differences between pre- and post-treatments for both groups, with significant differences detected in favor of the experimental group.

Findings²⁴ showed that the improvements in WFMT-FAS (p -value=0.025) and shoulder/elbow portion of WFMT (p -value=0.010) were

significantly greater in the AIG, and all effect sizes were large²⁴. Another finding²⁵ revealed that there were no significant differences between the two groups. In addition, other findings³⁰ showed that multivariable analysis revealed no significant difference between groups at the end of the treatment with respect to WMFT performance. Furthermore, post-treatment means values of WFMT revealed better improvement in the experimental group than in the control group²⁹.

According to Saposnik et al³⁰, the AIG performed better in the BBT at the end of the intervention. Hence, when the dose of RT (Robotic training) was matched with conventional therapy or usual care or even acted as an adjunct therapy to usual care, the additional benefit of RT for producing high-intensity movement no longer existed²⁴. In other words, the gains in motor and functional outcomes in stroke patients' post-treatment appeared to be attributed to highly intensive and repetitive movements, regardless of whether they were delivered by therapists or robotic devices³⁷. It was also found³⁸ that adverse events were uncommon and the mean attrition rate at post-intervention was low (approximately 10%), indicating that RT is generally safe and acceptable to most participants at the sub-acute phase of stroke.

Limitations

The current study encountered some limitations as the included RCTs were written in English, which may have inadvertently omitted other relevant studies that were published in other languages. For a more comprehensive evaluation of AI, future studies could include more patient-reported and practical (e.g., safety, adherence, and cost) outcomes to explore participants' experiences receiving AI and investigate its long-term effects. Aside from superiority trials to determine whether AI has greater therapeutic effects than CT, future research may investigate equivalence trials, given that AI may offer significant benefits over currently available standard treatment in terms of convenience, adherence, and lower manpower costs.

Conclusions

AI is feasible and safe in post-stroke rehabilitation and improves upper-extremity function compared to CT. Significant post-treatment AI effects on upper-limb impairments have been observed. The findings showed that higher-quality evidence

was detected in six assessment scales. However, SIS, MAL-QOM, and BBT revealed a lower quality of evidence. This indicated large or very large and consistent estimates of the treatment effects, and researchers were confident about the results. Therefore, the included observational studies are likely to provide an overestimate of the true effect.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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Availability of Data and Materials

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Authors' Contribution

All authors contributed to the study's conception and design. Material preparation, data collection and analysis were performed by all authors. The first draft of the manuscript was written by Hayam Mahmoud and Fatma Aljalidi and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript. The First Author (Hayam Mahmoud) conceived the idea for the article, reviewed the literature search and data analysis, and drafted and/or critically revised the work. Hayam Mahmoud: study conception and design, project administration and supervision, methodology (evaluate the methodological quality and quality of evidence), writing (the first draft). Fatma Aljalidi: investigation (assessing the articles for relevance and reviewing the extracted data from articles), methodology (evaluating the methodological quality), writing (revising and editing the first draft). Amir El Fiky: study conception and design, searching for the included articles using the keywords in different databases, methodology (data extraction for included articles). methodology (data extraction for included articles). Kadreya Battecha: formal analysis (review the founded articles for eligibility, remove duplication by endnote), investigation (assessing the articles for relevance and reviewing the extracted data from articles), Aly Thabet: provide final linguistic editing, provide PRISMA checklists, and getting registration number. Mohamed Alayat: searching for the included articles using the keywords in different databases, methodology (evaluate the methodological quality and quality of evidence) formal analysis (meta-analysis software) Ehab Abdelkafy: provide validation in the methodological quality (a third reviewer), writing (revised and editing the first draft), PRISMA checklist revision. Abeer Ibrahim: revise the overall research with references revision, and meta-analysis revision.

Ethics Approval

The protocol of this work has been approved as a systematic review by our Institutional Ethical Review Board (Scientific Research Committee, Department of Physical Therapy, College of Applied Medical Sciences, Umm Al-Qura University) and had been registered on PROSPERO.

Informed Consent

Not applicable.

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