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Robot-assisted therapy for balance function rehabilitation after stroke: A systematic review and meta-analysis

Qing-Xiang Zheng[a], Li Ge[a,*], Carol Chunfeng Wang[b], Qi-Shou Ma[c], Yan-Tan Liao[c], Ping-Ping Huang[a], Guan-Dong Wang[a], Qiu-Lin Xie[a], Mikael Rask[d]

[a] School of Nursing, Fujian University of Traditional Chinese Medicine, Fuzhou, China
[b] School of Nursing and Midwifery, Edith Cowan University, Joondalup, WA 6027, Australia
[c] Rehabilitative Hospital Affiliated to Fujian University of Traditional Chinese Medicine, Fuzhou, China
[d] Department of Health and Caring Sciences, Linnaeus University, S-35195, Växjö, Sweden

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ABSTRACT

Objective: To identify the rehabilitative effects of robot-assisted therapy on balance function among stroke patients.
Design: A systematic review and meta-analysis of randomized controlled trials.
Data sources: Thirteen electronic databases were systematically searched from inception to March 2018: Web of Science, PubMed, EMBase, The Cochrane Library, Science Direct, CINAHL, MEDLINE, AMED, Physiotherapy Evidence Database, SPORTDiscus, WanFang Data, China National Knowledge Infrastructure and Chinese Scientific Journal Database.
Review methods: Randomized controlled trials were retrieved for identifying the effects of robot-assisted therapy on balance function among stroke patients. Two authors independently searched databases, screened studies, extracted data, and evaluated the methodological quality and risk bias of each included study. A standardized protocol and data-collection form were used to extract information. Effect size was evaluated by mean difference with corresponding 95% confidence intervals. Methodological quality and risk bias evaluation for each included study followed the quality appraisal criteria for randomized controlled trials that were recommended by Cochrane Handbook. Meta-analysis was conducted by utilizing Review Manager 5.3, a Cochrane Collaboration tool. Data was synthesized with descriptive analysis instead of meta-analysis where comparisons were not possible to be conducted with a meta-analysis.
Results: Thirty-one randomized controlled trials with a total of 1249 participants were included. The majority of the included studies contained some methodological flaws. The results of the meta-analysis indicated that robot-assisted therapy produced positive effects on balance function, as shown by an increase in the Berg balance scale score [random effects model, mean difference = 4.64, 95%CI = 3.22–6.06, $P<0.01$], as well as Fugl-Meyer balance scale scores [fixed effects model, mean difference = 3.57, 95% CI = 2.81–4.34, $P<0.01$]. After subgroup and sensitivity analyses, the positive effects were not influenced by different types of robotic devices, by whether robot-assisted therapy was combined with another intervention or not, or by differences in duration and intensity of intervention.
Conclusion: Evidence in the present systematic review indicates that robot-assisted therapy may produce significantly positive improvements on balance function among stroke patients compared with those not using this method. More multi-center, high-quality and large-scale randomized controlled trials following the guidelines of CONSORT are necessary to generate high-quality evidence in further research.

What is already known about the topic?

- Stroke has become the second leading cause of death worldwide and is also regarded as a major cause of disability burden.
- Balance dysfunction, as one of the most common symptoms after stroke, seriously affects patients in terms of physical and psychological recovery, ability to cope with daily life and their quality of life.

* Corresponding author at: School of Nursing, Fujian University of Traditional Chinese Medicine, No.1 Qiu Yang Road, Shangjie, Minhou, Fuzhou, Fujian Province, China.
E-mail address: 2000005@fjtcm.edu.cn (L. Ge).

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- Studies indicated that robot-assisted therapy might improve balance function among stroke patients, but the evidence was inconsistent.

What this paper adds

- Robot-assisted therapy had positive effects on improving balance function among stroke patients compared with those not using this method.
- Due to methodological problems in a majority of included studies, more large-scale, high-quality and rigorously performed randomized controlled trials are needed to generate high-quality evidence for robot-assisted therapy.

1. Introduction

Stroke has become the second leading cause of death worldwide (World Health Organization, 2017) and is also regarded as a major cause of disability burden (Lohse et al., 2014). Although the mortality, prevalence and incidence of stroke have declined in the past 20 years, the total burden of stroke has increased worldwide (Feigin et al., 2016). Balance dysfunction, which is one of the most common symptoms after a stroke, is in particular a heavy burden on society and family members of stroke patients (Wu et al., 2015). It can lead to constricting the ability of stroke patients to sit, stand, transfer and walk, and to increasing the risk of falling (Maeda et al., 2015). The latter causes not only secondary injuries, such as fractures and skin lacerations, but also leads to a strong sense of fear (Di et al., 2017). This fear may reduce their confidence in performing daily activities and thus reduce their activity levels, which can in turn severely affect their physical and psychological recovery and quality of life (Ibid.). Normal balance function can thus be seen as a guarantee for daily living activities among stroke patients (Zhu et al., 2017).

There are currently several common approaches to help stroke patients regain the ability to control their balance. These mainly include conventional physical therapy and drug therapy (Li et al., 2018). As one of the most common rehabilitation approaches for stroke patients, physical therapy is concerned with maintaining and restoring maximum movement potential and functional ability within the spheres of treatment/intervention and rehabilitation (Hugues et al., 2017). In clinical practice, physical therapy is applied to improve functioning among stroke patients by using mechanical force and movements, manual therapy, exercise therapy, and electrotherapy. However, manual therapy and exercise therapy are both time and energy consuming for the therapists and nurses (Zou et al., 2018). It is also difficult for patients to receive high-dosage and repetitively task-oriented training and instant objective evaluation when using manual therapy and exercise therapy. The application of many new techniques, as either an alternative or a complementary approach, to physical therapy frequently achieves positive effects (Eglė et al., 2017). It is thus important for therapists and nurses to introduce new effective technologies in therapy and care in order to better improve the balance function of stroke patients.

Robot-assisted therapy, which has been a promising technology in recent decades, uses robotic devices as a therapeutic approach for treating neurological injuries and assisting in stroke rehabilitation training by automating the rehabilitation therapy process (Morone et al., 2017). The robotic devices for motor functional recovery are divided into two types: end-effector-type robots and exoskeleton-type robots (Chang and Kim, 2013). The end-effector-type robots, such as LokoHelp and Gait Trainer, are used for the distal limb segments by applying mechanical force (Ibid.). All end-effector devices can provide some form of body weight support (Sale et al., 2012). The end-effector devices are easily set-up, but may lead to abnormal movement patterns due to the limitation of controlling the proximal limb joints (Chang and Kim, 2013). The exoskeleton-type robots, such as Lokomat and Autoambulator robot, consist of an external mechatronic system with segments and joints corresponding to those of stroke patients, which can move in parallel with the skeleton of stroke patients (Sale et al., 2012). The construction is more complex than the end-effector type robots, and can offer direct control of individual joints thus reducing adverse effects and abnormal posture. The acceptance by and the compliance of stroke patients is high due to the safety and high efficiency of the robotic equipment (Luo et al., 2014).

There is substantial potential for limb function rehabilitation of stroke patients with robot-assisted therapy, where the major advantage of the therapy is its capability for providing stroke patients with high-dosage and high-intensity task-oriented training (Poli et al., 2013) and for producing a more complex and controlled multisensory stimulation (Morone et al., 2017). The robotic devices can allow active movement practice for limbs and feet even when this is impossible in conventional conditions due to them providing the required amount of support for limb and foot movements, thus increasing the potential for intensive training (Sale et al., 2012). The task-oriented training provided by robot-assisted therapy can enhance muscle strength and movement coordination in stroke patients with neurological impairments (Ibid.). In addition, the robotic system can objectively assess the limb function recovery by providing biofeedback, limb movement reports, measurement of interaction forces and range of motion (Hussain et al., 2011; Morone et al., 2017), thus reducing the subjectivity of manual training and assessment (Hussain et al., 2011). Moreover, therapists are relieved from the onerous task of manual training due to the robots' contribution (Ibid.), which can thus allow therapists to concentrate on the goal of rehabilitation training, and to supervise a few stroke patients simultaneously (Poli et al., 2013). The therapists' time and expertise can thus be better used, and the effectiveness and efficiency of the functional rehabilitation program can be increased (Tucker et al., 2015).

Previous research has indicated that robot-assisted therapy might improve balance function among stroke patients, but the results have been inconsistent. A systematic review indicated that robot-assisted gait training could improve the balance function among stroke patients, but it was unclear whether the improvements were greater in comparison with those not using this method (Swinnen et al., 2014). On the other hand, the results of several studies have showed that robot-assisted therapy could produce significantly positive improvements on balance function among stroke patients compared with those not using this method (Bang and Shin, 2016; Dragin et al., 2014; Giovanni et al., 2016). A recently updated Cochrane systematic review showed that physiotherapy in combination with robotic gait training as more likely to increase the odds of walking independently among stroke patients than physiotherapy without robotic gait training, especially for those who could not walk or were in the first three months after a stroke (Mehrholz et al., 2017). More studies have been carried out in recent years due to the further development and appliance of robot-assisted therapy (Bang and Shin, 2016; Bizovičar et al., 2017; Giovanni et al., 2016; Han et al., 2016; Watanabe et al., 2017; Liu et al., 2017; Tian et al., 2016). It thus appears to be important to synthesize the results from more randomized controlled trials (RCTs) and high-quality studies in order to gain further evidence concerning the potentially rehabilitative effects of robot-assisted therapy on balance function among stroke patients. The aim of this systematic review and meta-analysis is thus to explore the rehabilitative effects of robot-assisted therapy on balance function among stroke patients. The operational definition of robot-assisted therapy in this review is therapies that use any robotic technology for stroke rehabilitation to treat neurological injuries or motor dysfunction.

2. Methods

This systematic review was completed following the PRISMA guidelines (Moher et al., 2009).

2.1. Search strategy

Thirteen electronic databases were systematically searched from inception to March 2018: Web of Science, PubMed, EMBase, The Cochrane Library, Science Direct, CINAHL, MEDLINE, AMED, Physiotherapy Evidence Database (PEDro), SPORTDiscus, WanFang Data, China National Knowledge Infrastructure (CNKI) and Chinese Scientific Journal Database (VIP). The search strategies were developed through a combination of Mesh terms and free words. The following Mesh terms and keywords were used: “Robot”, “Robotic”, “Robot-assisted training”, “Robotic-assisted training”, “Robot-assisted therapy”, “Automatic orthosis”, “Motorized training”, “Stroke”, “Cerebrovascular Disorder”, “Cerebrovascular accident”, “Apoplexy”, “Cerebral infarction” and “Cerebral hemorrhage”, “Cerebrovascular Occlusion”, “Brain Infarction”, “Brain Vascular Accident” and “Brain Vascular Disorder”. The retrieval approaches were tailored to the different features of each database without any language restriction. The search strategies for the ten English databases are shown in Appendix A online. Furthermore, the reference lists of the finally included studies and relevant review articles were screened to identify additional studies.

2.2. Inclusion and exclusion criteria

The inclusion criteria of the present study are: (1) RCTs; (2) all the participants in the included studies meeting the clinical diagnosis criteria for a stroke or were diagnosed as having had a stroke by MRI or CT, and not suffering from comorbidity, such as: severe cognitive impairment, heart failure, and exercise contraindication; (3) no limitations in terms of country, age, gender and treatment duration; (4) robot-assisted therapy was used as the intervention method, either combined with or without other treatments; while the control groups received treatment and care with routine methods, including physical therapy or other common rehabilitation approaches; (5) outcome measures were assessments of balance function obtained by any measurement scale; (6) studies published in English or Chinese. Studies were excluded when the relevant data could not be extracted or constituted duplicated publication.

2.3. Study selection and data extraction

Based on the selection and inclusion criteria, two authors independently screened the title, abstract and full text of the retrieved studies, and excluded the irrelevant studies, and extracted and cross-checked the data. The two authors (Zheng and Huang) discussed together or turned to the third author (Ge) to identify the eligibility of a study when agreement was not attained. The data of the included studies were extracted by a standardized protocol and a data-collection form. The information mainly included: (1) basic information about each included study, such as name of first author, study design, publication date and sample size; (2) characteristics of participants, such as country and age; (3) robotic devices; (4) duration and intensity of interventions; (5) outcome measurements.

2.4. Quality appraisal of the included studies

All included studies were independently evaluated and cross-checked for bias risk and methodological quality using Review Manager 5.3, a Cochrane Collaboration tool, by two authors (Zheng and Huang) (Higgins and Green, 2011). The evaluation items included “random sequence generation”, “allocation concealment”, “blinding of participants and personnel”, “blinding of outcome assessment”, “incomplete outcome data”, “selective outcome reporting” and “other bias” (Ibid.). The items were evaluated for risk for bias; “high risk”, “unclear risk” or “low risk”. If more than one item of a study was ranked as having a “high risk for bias”, the quality of this study would be rated as having a “high risk for bias”. For any discrepancy, the two authors (Zheng and Huang) discussed together or turned to the third author (Ge).

2.5. Data synthesis

Meta-analysis with the Review Manager 5.3 was utilized to analyze the data of all included studies. Descriptive analysis was performed when data could not be extracted for the meta-analysis or were reported in one study. Two authors (Zheng and Huang) entered these data and cross-checked them in order to ensure a correct input. For continuous variables, the mean difference (MD) was calculated when the outcomes of the included studies were measured with the same instruments; otherwise the standardized mean difference (SMD) was utilized (Higgins and Green, 2011). The Chi-squared test and I^2 test were applied for estimating the statistical heterogeneity between trials. If the Chi-squared test was $P > 0.01$ and $I^2 < 50\%$, the studies were assessed as having high homogeneity, and then the fixed-effects model was applied for meta-analysis. If the Chi-squared test was $P < 0.01$ and $I^2 > 50\%$, the studies were assessed as having significant heterogeneity, and then the random-effects model was utilized to merge the results with a careful explanation (Ibid.). The potential sources of clinical heterogeneity were investigated for the included studies by subgroup or sensitivity analyses. When there were at least two included studies with a high level of heterogeneity (heterogeneity test, $I^2 > 50\%$), sensitivity analyses were conducted to confirm the potential source of high heterogeneity and to test the reliability of the results. Subgroup analyses were carried out a priori based on types of robotic devices and whether the robot-assisted therapy was combined with another intervention or not. Based on the characteristics of each included study, the intervention duration was divided into three types; short-term, medium-term and long-term intervention in order to explore short-term, medium-term and long-term effect on the balance function among stroke patients. The intervention intensity of all included studies was also divided into three types: low-intensity, medium-intensity and high-intensity in order to confirm the effects of variations in robot-assisted therapy intensity on balance function. The random-effects model was transformed into the fixed-effects model to ensure the reliability of the results. Confidence intervals (95%) were calculated for each statistical analysis. U test was used for hypothesis testing ($\alpha = 0.05$), and $P < 0.05$ indicated significance. If the meta-analysis comparison included more than 10 studies, potential publication bias was tested by funnel plot analyses.

3. Results

The PRISMA flow chart of study selection is shown in Fig. 1. A total of 5360 studies were identified from 13 electronic databases, of which 3404 studies were excluded after a double check. The title and abstract of the remaining 1956 studies were screened carefully, 1868 of these studies were then excluded due to study design, participants, interventions and outcome measurements

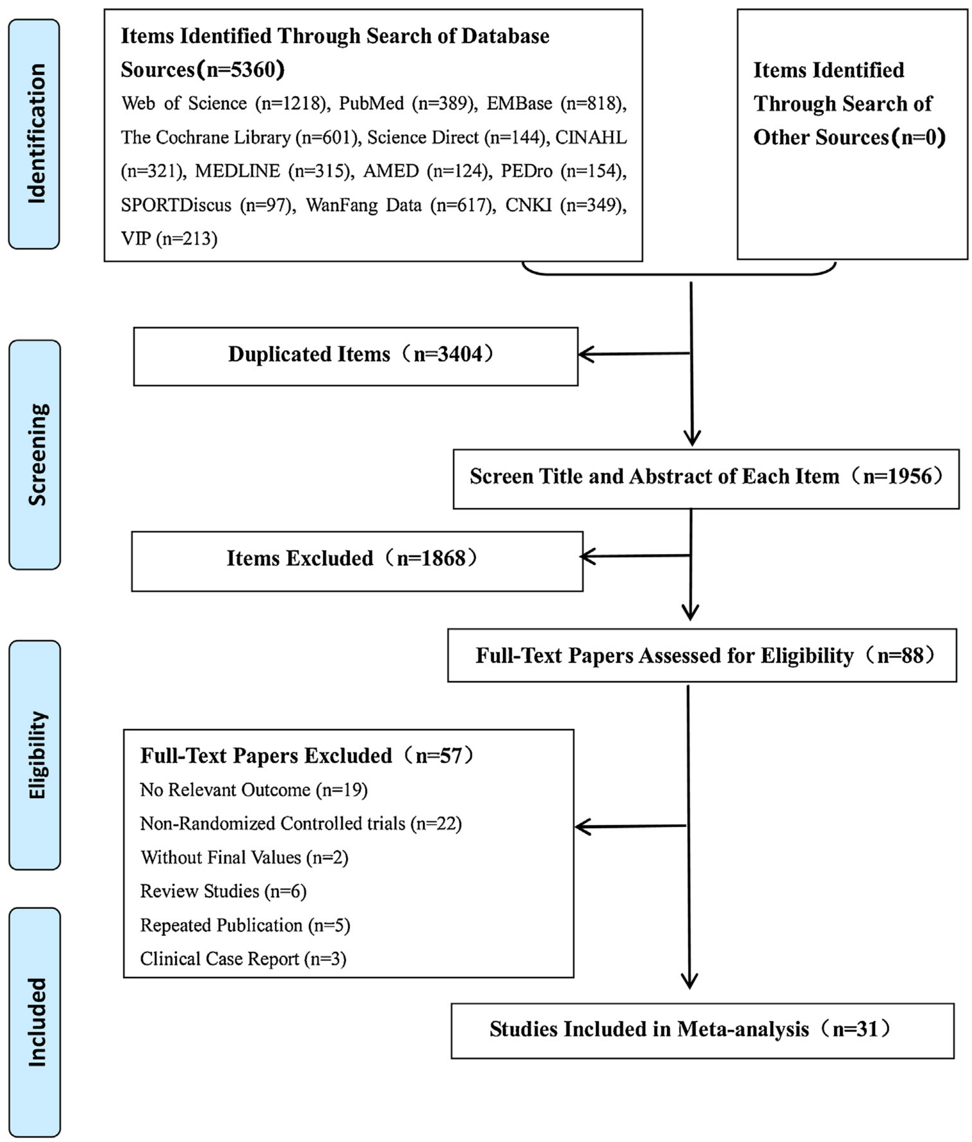

Fig. 1. PRISMA flow chart of study selection.

not conforming to the inclusion criteria. The full-text versions of the remaining 88 studies were then checked for eligibility and 57 were then excluded due to: no relevant outcomes (n = 19), not RCTs (n = 22), lacking final values (n = 2), review studies (n = 6), repeated publication (n = 5) and clinical case reports (n = 3). A final total of 31 studies were obtained for analysis in the study, which included 15 studies in English and 16 in Chinese (Table 1).

3.1. Characteristics of the included studies

Thirty-one RCTs with a total of 1249 participants were included in this review (Table 1). The average number of participants in each included study was approximately 40, ranging from 16 to 100. The included studies originated from Japan, Korea, the United States, Serbia, Netherlands, Slovenia, Italy, Finland and China. The types of robotic devices included in these studies were: Lokomat – nine studies, LokoHelp - five, Gait Trainer - three, two studies for Autoambulator robot and A3 lower limb rehabilitation robot, and one for Ankle robot, A portable ankle rehabilitation robot, I-Walker, Walkaround, E-go device, G-EO System® lower limb rehabilitation robot, AVATAR-02 lower limb rehabilitation robot, YASKAWA lower limb rehabilitation robot, robot suit hybrid assistive limb (HAL®) and robotic leg brace. The outcome measurements of balance function included: the Berg balance scale (BBS) - 23 studies, Fugl-Meyer balance scale (FM-B) - three, Timed-up-and-go test (TUG) - three, Tinetti balance assessment - two, and one study for Activities-specific balance confidence Scale (ABC), Standing forward reach test (SFRT), Trunk impairment scale (TIS), Postural sway tests including Static balance test (AP speed of COP), Static balance test (ML speed of COP), Dynamic balance time and Dynamic balance trip. The intervention frequencies ranged from twice to ten times, and the most common frequencies were three and five times per week. The duration of intervention ranged from three to twelve weeks, and the most common intervention duration were four weeks, six weeks and eight weeks (Mean $\pm$ SD = 6.13 $\pm$ 2.735 weeks). In order to observe short-term, medium-term and long-term effect on the balance function among stroke patients, the intervention duration of all included studies was divided into three types: short-term ($\leq$ 4 weeks), medium-term (>4 weeks - <8 weeks) and long-term ($\geq$ 8 weeks). Moreover, the intensity of intervention ranged from 1020 min for each occasion and 6 times per week (60120 min per week) to 60 min for each occasion and 5 times per week (300 min per week). The most common intervention intensity were 30 min for each occasion and

Table 1
Characteristics of the included studies.

Authors, year& setting	Robotic devices	Patients characteristic (Intervention/Control)	Intervention		Duration & frequency of studies period	Outcomes	Follow-up
			Intervention group	Control group			
Bang and Shin, 2016 Korea	Lokomat	I(n = 9), Age:53.56 ± 3.94 y; C (n = 9), Age:53.67 ± 2.83 y;	Lokomat robot assisted gait training	Treadmill gait training	60 minutes, 5 times per week for 4 weeks	BBS;ABC;	Not reported
Bei et al., 2015 China	Lokomat	I(n = 40), Age:61.7 ± 6.32 y; C (n = 40), Age:62.7 ± 6.48 y;	Lokomat robot assisted training + Limb function training	Therapists assisted walking training + Limb function training	20 minutes, 6 times per week for 6 weeks	BBS;	Not reported
Han et al., 2016 Korea	Lokomat	I(n = 30), Age:67.89 ± 14.96 y;C (n = 26), Age:63.20 ± 10.62 y;	Lokomat robot assisted gait training + Conventional rehabilitation therapy	Conventional rehabilitation therapy.	30 minutes, 5 times per week for 4 weeks	BBS;	Not reported
Liu et al., 2017 China	Lokomat	I(n = 20), Age:46.50 ± 8.50 y;C (n = 20) Age:46.50 ± 8.50 y;	Lokomat robot assisted training + Conventional rehabilitation therapy	Conventional walking training + Conventional rehabilitation therapy	30 minutes, 6 times per week for 6 weeks	BBS;	Not reported
Ma et al., 2012 China	Lokomat	I(n = 40), Age:54.56 ± 10.23 y; C (n = 40), Age:57.31 ± 9.47 y;	Lokomat robot assisted walk training + Conventional physical therapy	Conventional physical therapy	30 minutes, 3 times per week for 10 weeks	FM-B;	Not reported
Nunen et al., 2015 Netherlands	Lokomat	I(n = 16), Age:50.00 ± 9.60 y;C (n = 14), Age:56.00 ± 8.70 y;	Lokomat robot assisted training + Conventional physical therapy	Conventional physical therapy	60 minutes, 2 times per week for 8 weeks	BBS; TUG;	6-month follow-up, 9-month follow-up
Wang et al., 2015 China	Lokomat	I(n = 20), Age:41.60 ± 11.30 y;C (n = 20), Age:42.90 ± 12.70 y;	Lokomat robot assisted training + Conventional rehabilitation therapy	Therapists assisted walking training + Conventional rehabilitation therapy	30 minutes, 5 times per week for 4 weeks	BBS;	Not reported
Westlake and Patten, 2009 The United States	Lokomat	I(n = 8), Age:58.60 ± 16.90 y;C (n = 8), Age:55.10 ± 13.60 y;	Lokomat robot assisted training + Manually-assisted body-weight supported treadmill training	Manually-assisted body-weight supported treadmill training	60 minutes, 3 times per week for 4 weeks	BBS;	Not reported
Zhao et al., 2012 China	Lokomat	I(n = 20), Age:51.80 ± 10.14 y;C (n = 20), Age:57.60 ± 8.22 y;	Lokomat robot assisted training + Conventional rehabilitation therapy	Conventional rehabilitation therapy	30 minutes, 3 times per week for 10 weeks	BBS;	Not reported
Luo et al., 2014China	Lokohelp	I(n = 17), Age:62.56 ± 4.56 y;C (n = 18), Age:62.12 ± 4.11 y;	Lokohelp robot assisted training + Conventional rehabilitation therapy	Therapists assisted walking training + Conventional rehabilitation therapy	30 minutes, 10 times per week for 12 weeks	BBS;	Not reported
Luo et al., 2015 China	Lokohelp	I(n = 20), Age:63.50 ± 4.00 y;C (n = 20), Age:62.70 ± 4.00 y;	Lokohelp robot assisted training + Conventional rehabilitation therapy	Lower limb walk training + Conventional rehabilitation therapy	30 minutes, 7 times per week for 12 weeks	BBS;	Not reported
Tian et al., 2016 China	Lokohelp	I(n = 50), Age:50.20 ± 8.40 y;C (n = 50), Age:50.20 ± 8.40 y;	Lokohelp robot assisted walk training + Conventional physical therapy	Conventional walk training + Conventional physical therapy	30 minutes, 5 times per week for 6 weeks	BBS;	Not reported
Yao and Xi, 2016 China	Lokohelp	I(n = 33), Age:65.18 ± 5.27 y;C (n = 33), Age:64.27 ± 5.38 y;	Lokohelp robot assisted training	Conventional physical therapy + Patient self-training	30 minutes, 6 times per week for 8 weeks	BBS;	Not reported
Zhang et al., 2016 China	Lokohelp	I(n = 25), Age:56.23 ± 7.24 y;C (n = 25), Age:53.20 ± 8.13 y;	Lokohelp robot assisted training + Conventional physical therapy	Conventional physical therapy	40 minutes, 5 times per week for 4 weeks	BBS;	Not reported
Fisher et al., 2011 The United States	Autoambulatorrobot	I(n = 10), Age:60.00 ± 14.00 y;C (n = 10), Age:60.00 ± 14.00 y;	AutoAmbulator robot assisted gait training + Conventional physical therapy	Conventional physical therapy	30 minutes, 24 sessions total for 6 or 8 weeks	Tinetti balance assessment;	Not reported
Liu et al. 2013 China	Autoambulator robot	I(n = 20), Age:54.00 ± 5.45 y;C (n = 20), Age:57.70 ± 7.39 y;	AutoAmbulator robot assisted walk training + Body weight support treadmill training + Conventional physical therapy	Body weight support treadmill training + Conventional physical therapy	30 minutes, 5 times per week for 8 weeks	BBS;	Not reported
Ng et al., 2008 Hongkong, China	Gait Trainer	I(n = 17), Age:66.6 ± 11.3 y;C (n = 21), Age:73.4 ± 11.5 y;	Gait Trainer assisted walk training + Conventional physical therapy	Conventional physical therapy	20 minutes, 5 times per week for 4 weeks	BBS;	6-month follow-up

Table 1 (*Continued*)

Authors, year& setting	Robotic devices	Patients characteristic (Intervention/Control)	Intervention		Duration & frequency of studies period	Outcomes	Follow-up
			Intervention group	Control group			
Tong et al., 2006 Hongkong, China	Gait Trainer	I(n = 15), Age:66.6 ± 9.9 y; C (n = 20), Age:71.4 ± 14.0 y;	Gait Trainer assisted walk training + Conventional physical therapy	Conventional physical therapy	20 minutes, 5 times per week for 4 weeks	BBS;	Not reported
Peurala et al., 2005 Finland	Gait Trainer	I(n = 15),Age:51.2 ± 7.9 y;C (n = 15),Age:52.3 ± 6.8 y;	Gait Trainer assisted walk training + Physical therapy	Over ground walk exercise + Physical therapy	20 minutes, 5 times per week for 3 weeks	Static balance test (AP speed of COP and ML speed of COP) ;Dynamic balance time; Dynamic balance trip;	6-month follow-up
Forrester et al., 2014 The United States	Ankle robot	I(n = 18), Age:63.30 ± 2.30 y;C (n = 16), Age:60.00 ± 3.10 y;	Ankle robot assisted training + Conventional physical therapy	Manual stretching training + Conventional physical therapy	60 minutes, 5 times per week for 2 weeks	BBS;	Not reported
Waldman et al., 2013 The United States	A portable ankle rehabilitation robot	I(n = 12), Age:51.30 ± 8.00 y;C (n = 12), Age:53.00 ± 7.10 y;	A portable ankle rehabilitation robot assisted training	Instructed exercise training	60 minutes, 3 times per week for 6 weeks	BBS;	1.5-month follow-up
Giovanni et al., 2016 Italy	I-Walker(a servo-assistive robotic walker)	I(n = 21), Age:61.50 ± 10.97 y;C (n = 21), Age:64.09 ± 16.27 y;	I-Walker training + Conventional walking oriented therapy	Conventional walking oriented therapy	40 minutes, 5 times per week for 4 weeks	Tinetti balance assessment;	6-month follow-up
Dragin et al., 2014 Serbia	Walkaround	I(n = 11), Age:57.30 ± 10.90 y;C (n = 11), Age:58.10 ± 11.40 y;	Body postural support assisted by the Walkaround gait training	Conventional gait training	30 minutes, 5 times per week for 4 weeks	BBS;	6-month follow-up
Bizovičar et al., 2017 Slovenia	E-go device	I(n = 9), Age:52.00 ± 8.00 y;C (n = 10), Age:60.00 ± 10.00 y;	Walk training by E-go device	Conventional physiotherapy	45 minutes, 7 times per week for 3 weeks	BBS;	Not reported
Ding et al., 2014 China	G-EO System® lower limb rehabilitation robot	I(n = 20), Age:62.50 ± 9.38 y;C (n = 20), Age:61.50 ± 9.97 y;	The G-EO System® robot assisted training + Conventional rehabilitation therapy	Lower limb intelligent feedback training system A1 + Conventional rehabilitation therapy	30 minutes, 5 times per week for 8 weeks	BBS;	Not reported
Li et al., 2014 China	A3 lower limb rehabilitation robot	I(n = 30), Age:62.40 ± 10.30 y;C (n = 30), Age:60.80 ± 9.60 y;	A3 robot assisted walk training + Conventional physical therapy	Conventional walk training + Conventional physical therapy	60 minutes, 5 times per week for 8 weeks	FM-B;	Not reported
Wang et al., 2016China	A3 lower limb rehabilitation robot	I(n = 15), Age:60.34 ± 12.67 y;C (n = 14), Age:59.12 ± 14.13 y;	A3 robot assisted gait training + Conventional physical therapy	Conventional physical therapy	30 minutes, 5 times per week for 3 weeks	SFRT; TIS;	Not reported
Wang et al. 2013China	AVATAR-02 lower limb rehabilitation robot	I(n = 21), Age:48.50 ± 11.80 y;C (n = 21), Age:49.40 ± 12.50 y;	Lower limb rehabilitation robot assisted training + Conventional rehabilitation therapy	Conventional rehabilitation therapy	1020 minutes, 6 times per week for 8 weeks	BBS;	Not reported
Lu et al., 2016 China	YASKAWA lower limb rehabilitation robot	I(n = 20), Age:55.25 ± 10.88 y;C (n = 20), Age:59.15 ± 12.20 y;	Lower limb rehabilitation robot assisted training + Conventional rehabilitation therapy	Conventional rehabilitation therapy	30 minutes, 5 times per week for 6 weeks	FM-B;	Not reported
Watanabe et al. 2017 Japan	Robot suit hybrid assistive limb(HAL®)	I(n = 8), Age:66.90 ± 16.00 y;C (n = 11), Age:76.80 ± 13.80 y;	Robot suit hybrid assistive limb training	Conventional gait training	20 minutes, 3 times per week for 4 weeks	TUG;	2-month follow-up
Stein et al., 2014 The United States	Robotic leg brace	I(n = 12), Age:57.60 ± 10.70 y;C (n = 12), Age:56.60 ± 15.10 y;	Robotic leg assisted gait training + Individualized physical therapy	Exercise training + Physical therapy	60 minutes, 3 times per week for 6 weeks	BBS; TUG;	1-month follow-up, 3-month follow-up

Abbreviations: TUGThe Timed-up-and-go Test; BBSBerg Balance Scale; FM-BFugl-Meyer Assessment of Balance;ABC Activities-specific Balance Confidence Scale; SFRT Standing Forward Reach Test; TIS Trunk Impairment Scale.

5 times per week (150 min per week) and 30 min for each occasion and 6 times per week (180 min per week) (Mean ± SD = 179.8 ± 67.7 min). In order to confirm the effects of different robot-assisted therapy intensity on balance function, the intervention intensity of all included studies was divided into three types: low-intensity (≤ 120 min per week), medium-intensity (>120 min per week - <240 min per week) and high-intensity (≥ 240 min per week). All data sources for this review originated from RCTs. The characteristics of each RCT are shown in Table 1.

3.2. Methodological quality and risk of bias

The methodological quality and risk for bias for each included study are presented in Fig. 2. The method of randomization sequence generation was reported in 22 of the 31 studies, while the method of allocation concealment was reported for ten studies. The intention-to-treat analyses were utilized for 13 studies, while the dropout rate was only reported for one study. Furthermore, the blinding of outcome assessment was reported for nine studies. The sample size of all the included studies was not estimated in advance; and the sample sizes of 24 studies (77.42%) were fewer than 50 participants. All included studies were judged as having a “low risk for bias” in terms of “blinding of participants and personnel”. There were five studies in “low risk for bias” among the assessment of the methodological quality and risk for bias.

3.3. Rehabilitative effects of robot-assisted therapy on balance function

The outcome measurements of the balance function are named above in 3.1. The summary of the meta-analysis concerning BBS, FM-B and TUG is shown in Table 2, while the final value of the Tinetti balance assessment in one study (Giovanni et al., 2016) could not be extracted for the meta-analysis. We thus performed a descriptive analysis for this assessment. Furthermore, descriptive analyses for the outcome measurements of ABC, SFRT, TIS, and Postural sway tests were performed due to these measurements being only reported in one study.

3.3.1. Evaluation of therapeutic efficiency with Berg balance scale

The balance function of 929 participants in 23 studies was measured using the Berg Balance Scale (BBS). The results of the meta-analysis indicated that the BBS scores in the intervention group were higher compared with those in the control group [random effects model, MD = 4.64, 95%CI = 3.22–6.06, *P*<0.01]. In view of significant heterogeneity, we conducted four subgroup analyses depending on different robotic devices, robot-assisted therapy combined with another intervention or not, differences in duration and intensity of intervention (Table 2). The results of the subgroup analyses for different robotic devices indicated that the BBS scores for Lokomat [random effects model, MD = 4.25, 95%CI = 3.11–5.39, *P*<0.01], for LokoHelp [random effects model, MD = 7.95, 95%CI = 3.53–12.37, *P*<0.01], and for other devices [random effects model, MD = 3.19, 95%CI = 0.25–6.13, *P*<0.05] were higher in the intervention group than for those in the control group. On the other hand, the BBS scores in the Gait Trainer subgroup [random effects model, MD = 5.10, 95%CI=-4.66 to 14.87, *P* = 0.31] did not differ between the intervention group and the control group. For the robot-assisted therapy combined with another intervention or not, the findings of the subgroup analyses showed that the BBS scores for ‘only robot-assisted therapy subgroup’ [random effects model, MD=4.78, 95%CI=-1.93 to 11.49, *P* = 0.16] did not differ between the intervention group and the control group. On the other hand, the BBS scores for ‘robot-assisted therapy combined with another intervention subgroup’ [random effects model, MD= 4.49, 95%CI=3.41 to 5.57, *P*<0.01] were higher

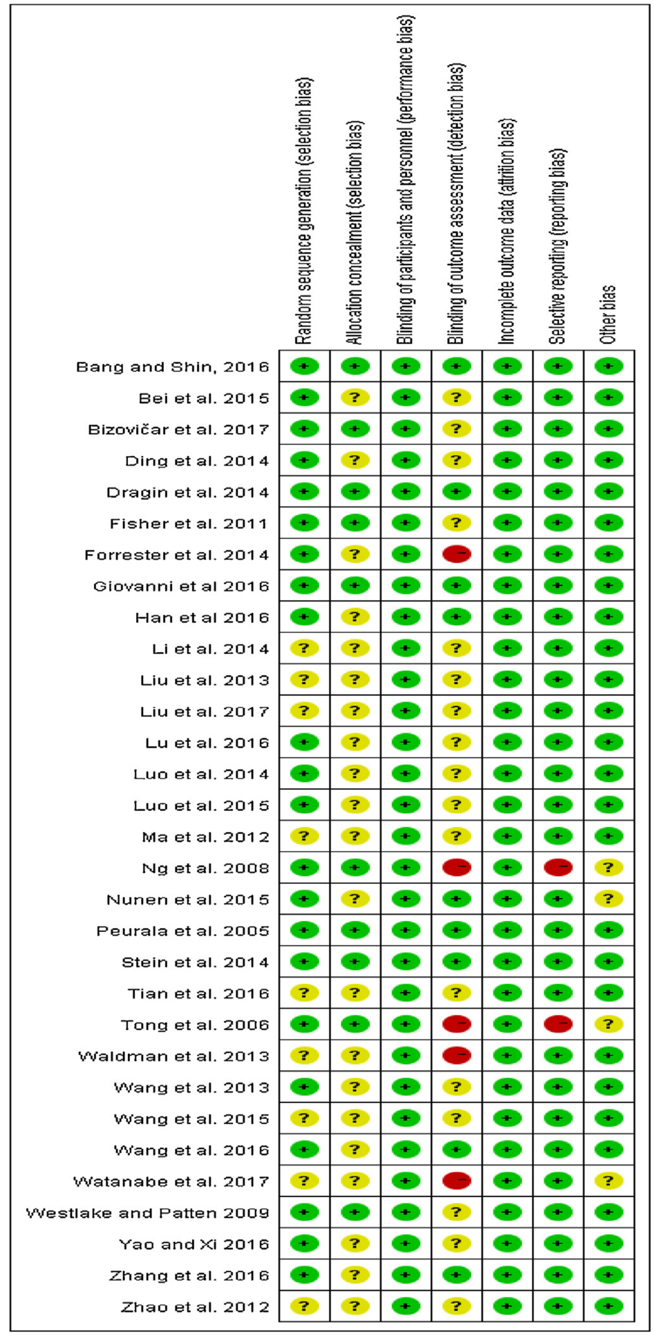

Fig. 2. The risk for bias assessment of all included studies.

in the intervention group than those in the control group. In terms of differences in duration of intervention, the findings of subgroup analyses indicated that short-term interventions [random effects model, MD = 4.24, 95%CI = 1.56–6.93, *P*<0.01], medium-term interventions [random effects model, MD = 4.71, 95%CI = 3.49–5.94, *P*<0.01] and long-term interventions [random effects model, MD = 4.65, 95%CI = 0.96–8.34, *P*<0.05] improved balance function compared with those in the control group. Moreover, the results of subgroup analyses of varying intensity of intervention illustrated that the BBS scores in low-intensity intervention subgroup [random effects model, MD = 4.31, 95%CI = 2.70–5.92, *P*<0.01], medium-intensity intervention subgroup [random effects model, MD = 4.71, 95%CI = 2.63–6.79, *P*<0.01], and high-intensity intervention subgroup [random effects model, MD = 4.92, 95%CI = 1.85–

Table 2
Meta-analysis of rehabilitative effects of robot-assisted therapy on the balance function.

Outcomes/subgroup	Number of studies	Number of participants	Statistical method	Effect estimate	The value of *P*	Heterogeneity (I^2)
Robot-assisted therapy for the balance function with Berg balance scale scores						
Berg balance scale scores	23	929	Mean difference (IV, Random, 95%CI)	4.64[3.22 to 6.06]	<0.00001	>50%
Different robotic devices for the balance function with Berg balance scale scores						
Lokomat device	8	320	Mean difference (IV, Random, 95%CI)	4.25[3.11 to 5.39]	<0.00001	>50%
Lokohelp device	5	291	Mean difference (IV, Random, 95%CI)	7.95[3.53 to 12.37]	0.0004	>50%
Gait Trainer	2	73	Mean difference (IV, Random, 95%CI)	5.10[-4.66 to 14.87]	0.31	35%
Other robotic devices	8	245	Mean difference (IV, Random, 95%CI)	3.19[0.25 to 6.13]	0.03	>50%
robot-assisted therapy combined with another intervention or not for the balance function with Berg balance scale scores						
Only robot-assisted therapy	5	149	Mean difference (IV, Random, 95%CI)	4.78[-1.93 to 11.49]	0.16	>50%
Robot-assisted therapy combining with another intervention	18	780	Mean difference (IV, Random, 95%CI)	4.49[3.41 to 5.57]	<0.00001	>50%
Differences in duration of intervention for the balance function with Berg balance scale scores						
Short-term intervention (≤ 4 weeks)	9	294	Mean difference (IV, Random, 95%CI)	4.24[1.56 to 6.93]	0.002	>50%
Medium-term intervention (>4 weeks and < 8 weeks)	5	268	Mean difference (IV, Random, 95%CI)	4.71[3.49 to 5.94]	<0.00001	40%
Long-term intervention (≥ 8 weeks)	8	333	Mean difference (IV, Random, 95%CI)	4.65[0.96 to 8.34]	0.01	>50%
Differences in intensities of intervention for the balance function with Berg balance scale scores						
Low-intensity intervention (≤ 120 minutes per week)	6	265	Mean difference (IV, Random, 95%CI)	4.31[2.70 to 5.92]	<0.00001	33%
Medium-intensity intervention (>120 minutes per week and < 240 minutes per week)	13	558	Mean difference (IV, Random, 95%CI)	4.71[2.63 to 6.79]	<0.00001	>50%
High-intensity intervention (≥240 minutes per week)	4	106	Mean difference (IV, Random, 95%CI)	4.92[1.85 to 8.00]	0.002	>50%
Robot-assisted therapy for the balance function with Fugl-Meyer balance assessment scores						
Fugl-Meyer balance assessment scores	3	180	Mean difference (IV, Fixed, 95%CI)	3.57[2.81 to 4.34]	<0.00001	0%
Robot-assisted therapy for the balance function with Timed-up-and-go test scores						
Timed-up-and-go test scores	3	68	Mean difference (IV, Fixed, 95%CI)	−5.60[-13.69 to 2.49]	0.18	16%

IV: Inverse Variance; **CI:** Confidence Interval;

8.00, *P* = 0.002] were higher in the intervention group than for those in the control group.

3.3.2. Evaluation of therapeutic efficiency with Fugl-Meyer balance scale

180 participants in three studies (Table 2) were measured for balance function by the Fugl-Meyer balance scale (FM-B). The pooled analysis showed that the FM-B scores in the intervention group were improved compared with those in the control group [fixed effects model, MD = 3.57, 95%CI = 2.81–4.34, *P*<0.01].

3.3.3. Evaluation of therapeutic efficiency with timed-up-and-go test

The balance function of 68 participants in three studies (Table 2) was measured by the Timed-up-and-go Test (TUG). The results of the meta-analysis showed that the TUG scores [fixed effects model, MD=-5.60, 95%CI=-13.69 to 2.49, *P* = 0.18] in the intervention group were not significantly improved compared with those in the control group.

3.3.4. Evaluation of therapeutic efficiency with Tinetti balance assessment

Tinetti balance assessment was performed to measure balance function in two studies involving 62 participants. One study (Giovanni et al., 2016) showed that the parameter effectiveness of the Tinetti balance assessment scores were higher in the intervention group than that in the control group. On the other hand, the study by Fisher et al, (2011) reported that the Tinetti balance assessment scores in the intervention group were not significantly improved in comparison with those in the control group.

3.3.5. Evaluation of therapeutic efficiency on SFRT, TIS, ABC, and postural sway tests

SFRT, TIS, ABC and Postural sway tests were applied as secondary outcome measures in three studies, of which Postural sway tests consisted of the static balance test (AP speed of COP and ML speed of COP), Dynamic balance trip as well as Dynamic balance time. Wang et al. (2016) showed that the SFRT and TIS

Table 3
Sensitivity analyses of rehabilitative effects of robot-assisted therapy on the balance function.

Outcomes	Before sensitivity analyses			Method of sensitivity analyses	Outcomes	After sensitivity analyses		
Number of studies	Mean difference 95%CI	*P*	I^2		Number of studies	Mean difference 95%CI	*P*	I^2
Sensitivity analyses of Berg balance scale scores								
23	4.64[3.22 to 6.06]	<0.00001	88%	Removing Jun Zhang 2016 & Jun Wang 2015 & Zhigu Yao 2016 & Huawei Liu 2013	19	4.46[3.97 to 4.95]	<0.00001	48%
Sensitivity analyses of Berg balance scale scores in Lokomat device subgroup								
8	4.25 [3.11 to 5.39]	<0.00001	70%	Removing Jun Wang 2015 & Kelly 2009	6	4.36 [3.77 to 4.94]	<0.00001	43%
Sensitivity analyses of Berg balance scale scores in Lokohelp device subgroup								
5	7.95[3.53 to 12.37]	0.0004	95%	Removing Jun Zhang 2016 & Zhigu Yao 2016	3	4.85 [3.63 to 6.07]	<0.00001	11%
Sensitivity analyses of Berg balance scale scores in other robotic devices subgroup								
8	3.19 [0.25 to 6.13]	0.03	77%	Removing Huawei Liu 2013 & Larry W. Forrester 2014	6	2.92 [1.11 to 4.72]	0.002	0%
Sensitivity analyses of Berg balance scale scores in only robot-assisted therapy subgroup								
5	4.78[-1.93 to 11.49]	0.16	95%	Removing Zhigu Yao 2016	4	2.44 [0.67 to 4.21]	0.007	0%
Sensitivity analyses of Berg balance scale scores in robot-assisted therapy combine with another intervention subgroup								
18	4.49[3.41 to 5.57]	<0.00001	88%	Removing Jun Zhang 2016 & Jun Wang 2015 & Huawei Liu 2013 & Larry W. Forrester 2014	14	4.28 [3.38 to 5.19]	<0.00001	35%
Sensitivity analyses of Berg balance scale scores in short-term intervention subgroup								
9	4.24[1.56 to 6.93]	0.002	72%	Removing Jun Zhang 2016 & Jun Wang 2015	7	2.27 [0.58 to 3.96]	0.009	0%
Sensitivity analyses of Berg balance scale scores in long-term intervention subgroup								
8	4.65 [0.96 to 8.34]	0.01	95%	Removing Zhigu Yao 2016 & Huawei Liu 2013	6	4.05 [3.04 to 5.06]	<0.00001	12%
Sensitivity analyses of Berg balance scale scores in medium-intensity intervention subgroup								
13	4.71[2.63 to 6.79]	<0.00001	92%	Removing Westlake and Patten, 2009 & Jun Zhang 2016 & Jun Wang 2015 & Huawei Liu 2013 & Zhigu Yao 2016	8	4.34[3.37 to 5.30]	<0.00001	17%
Sensitivity analyses of Berg balance scale scores in high-intensity intervention subgroup								
4	4.92[1.85 to 8.00]	0.002	76%	Removing Larry W. Forrester 2014	3	3.60[1.36 to 5.85]	0.002	32%

scores in the intervention group were higher than those in the control group. Bang and Shin (2016) reported that the ABC scores in the intervention group were observably improved in comparison with that in the control group. Peurala et al. (2005) indicated that the static balance test parameters were not noticeably improved after the gait trainer training compared with those in the control group, but the parameters of dynamic balance trip test and dynamic balance time test in the intervention group were significantly changed in comparison with that in the control group.

3.4. Sensitivity analyses

The results of the sensitivity analyses showed that five dubious studies (Forrester et al., 2014; Liu et al., 2013; Wang et al., 2015; Yao and Xi, 2016; Zhang et al., 2016) contributed most to the heterogeneity among the groups of the sensitivity analyses in the present study. After sensitivity analyses and the removal of dubious studies, the I^2 values were reduced and the results remained comparatively stable, except for those concerning the sensitivity analyses in the only robot-assisted therapy subgroup. The sensitivity analyses of the BBS scores in this subgroup had a major change that varied from non-significant differences [random effects model, MD = 4.78, 95%CI=-1.93 to 11.49, P = 0.16] to significant differences [random effects model, MD=2.44, 95%CI=0.67 to 4.21, P<0.01] between the intervention group and the control group. The summary of the sensitivity analyses is shown in Table 3.

3.5. Publication bias analyses

The potential publication bias for the 23 studies using BBS was evaluated by funnel plot analyses. The results showed that publication bias might exist as the graph of the funnel plot analyses was not symmetrical. The graph is shown in Fig. 3.

4. Discussion

Thirty-one RCTs, involving a total of 1249 patients with stroke, were reviewed concerning the rehabilitative effects of robot-assisted therapy on balance function. The review indicated that robot-assisted therapy could generate positive effects on balance function among stroke patients compared with routine physical treatment. However, due to the majority of the included studies having methodological problems, more large-scale, high-quality and rigorously conducted randomized controlled trials are needed to generate scientific evidence for robot-assisted therapy.

The pooled analyses indicated that robot-assisted therapy had significantly beneficial effects on balance function among stroke patients compared with those not using these devices, as showed by an increase in BBS scores (MD = 4.64) and FM—B scores (MD = 3.57). The results of the present study further verified a conclusion of a previous systematic review (Swinnen et al., 2014) that robot-assisted therapy improved balance function among stroke patients. Furthermore, the present systematic review conducted a systematic review and meta-analysis in comparison to the descriptive analysis in the previous systematic review (Ibid.). The result of the meta-analysis concerning TUG scores (MD=-5.60, 95%CI=-13.69 to 2.49, P = 0.18) showed there was no significant improvement for robot-assisted therapy on balance function compared with conventional therapy. One reason for this might be the small sample size (68 people in three RCTs) in comparison with the sample for FM—B scores (180 people in three RCTs) in this study. Moreover, a descriptive analysis illustrated that there was an

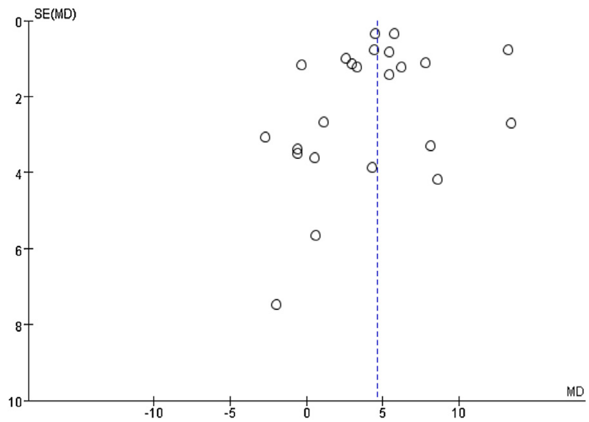

Fig. 3. Funnel plot for robot-assisted therapy on balance function with Berg balance scale.

inconsistency in the results, concerning whether Tinetti balance assessment scores in the intervention group were significantly improved compared with those in the control group or not. There were only two included studies (62 participants) using the Tinetti balance assessment, and the robotic devices in the two included studies differed.

After subgroup analyses, the effects of robot-assisted therapy on balance function remained positive. In terms of the BBS scores for different robotic devices, the results of subgroup analyses indicated that Lokomat (MD = 4.25), LokoHelp (MD = 7.95) and other robotic devices (MD = 3.19) had a significant effect on the recovery of balance function, while Gait Trainer (MD = 5.10, 95% CI=-4.66 to 14.87, $P = 0.31$) did not improve balance function compared with the control group. This might be due to the fact that there were only two RCTs in the meta-analysis of the Gait Trainer subgroup, and that the greatest advantage of the Gait Trainer was to improve gait rather than balance function (Morone et al., 2017). Chang and Kim (2013) illustrated that physical therapy could not be replaced by Lokomat and Gait Trainer for improving gait function among stroke patients; Lokomat and Gait Trainer were thus recommended for use combined with physical therapy. The BBS scores for the subgroup with only robot-assisted therapy (MD = 4.78, 95%CI=-1.93 to 11.49, $P = 0.16$) revealed that this intervention did not improve the balance function, however, robot-assisted therapy combining with another intervention (MD=4.49) had a noticeable effect on improving balance function. When one dubious study (Yao and Xi, 2016) was removed after sensitivity analyses, the I^2 values decreased from 95% to 0 and the effect of the only robot-assisted therapy intervention was increased to a moderate level (MD = 2.44, 95%CI = 0.67 to 4.21, $P<0.01$) on the recovery of balance function. However, according to Jakobsen et al. (2014), there could be a risk for bias in the result if the sensitivity analyses differ substantially from the primary meta-analysis results. The increase in BBS scores in short-term robot-assisted therapy (MD = 4.24), medium-term robot-assisted therapy (MD = 4.71) and long-term robot-assisted therapy (MD = 4.65) illustrated that robot-assisted therapy had a positive short-term, medium-term and long-term effect on improving the balance function among stroke patients. The BBS scores, for low-intensity (MD = 4.31), medium-intensity (MD = 4.71) and high-intensity (MD = 4.92) robot-assisted therapy, indicated that robot-assisted therapy had a cumulative dose effect on the rehabilitation of balance function.

In the study of the sensitivity analyses, the findings showed that the I^2 values significantly decreased after excluding the dubious studies and the results of the present study were still comparatively stable except for the subgroup of BBS scores in only robot-assisted therapy. Five dubious studies (Forrester et al., 2014; Liu et al., 2013; Wang et al., 2015; Yao and Xi, 2016; Zhang et al., 2016) contributed most to the heterogeneity due to allocation concealment, blinding of outcome assessment, and quality of study.

The emergence of rehabilitation robots has recently brought rehabilitation medicine into a modern and automatic era. The functional recovery of stroke patients is based on the mechanism of neural plasticity (Pekna et al., 2012), and therapists thus aim at the effective use of neural plasticity for stroke rehabilitation (Chang and Kim, 2013). Meanwhile, it is very important for stroke patients to have both high-dosage training and repetitive task-oriented training, which the present study indicates. Robot-assisted therapy is well suited for providing both these training methodologies for stroke patients (Poli et al., 2013), which can enhance muscle strength and movement coordination for nerve injuries (Sale et al., 2012).

Robot-assisted therapy can be said to be an ideal choice to train balance function. The end-effector-type robots can provide a significant opportunity for stroke patients to perform walk training in a weight-supported state, thus facilitating them in transferring their center of gravity and controlling their pelvis (Luo et al., 2014). They help stroke patients readjust to hold the trunk upright and their brain receives the input of cinesthesia, topesthesia and balance information; the motion control of preliminary dynamic balance is thus established step by step (Combs et al., 2010; Luo et al., 2014). Moreover, the bilateral spinal muscles can become more symmetrical and functional and help stroke patients maintain their balance function (Zhang et al., 2016). The mechanism of the exoskeleton-type robots improves balance function; these robots have a body weight support system, a gait corrector system and an intelligent control system. The hip and knee joints are trained in a preset motion mode where patients receive near-normal proprioceptive input during the gait cycle under the drive of the exoskeleton system and the control of body weight support system (Zhao et al., 2012; Molteni et al., 2017). The proprioceptors of the lower tendons muscles are stimulated and thus the recovery of the proprioceptive sensation is promoted (Zhao et al., 2012) as well as the symmetry and coordination of stroke patients is improved (Swinnen et al., 2010). Moreover, exoskeletons devices are equipped with legs on both sides of the device, which can avoid abnormal patterns of foot varus, foot prolapse, and internal rotation of limbs when the whole body moves during the training (Zhao et al., 2012). Based on the above, robot-assisted therapy can be seen to be an ideal choice for training balance function among stroke patients.

4.1. Limitations

Firstly, the included studies showed substantial heterogeneity in a number of aspects: including different types of robotic devices, robot-assisted therapy combined with another intervention or not, or by differences in duration and intensity of intervention. Secondly, there is still some bias in the results due to the diverse designs for each included study (Chang and Kim, 2013), even though subgroup analysis and sensitivity analyses of BBS were conducted based on different types of robotic devices, and robot-assisted therapy combined with another intervention or not. Thirdly, we are based on our clinical knowledge to justify for short-term intervention ($\leq$ 4 weeks), middle-term intervention (>4 weeks and <8 weeks) and long-term intervention ($\geq$ 8 weeks) by using Mean ± SD. It could cause some bias in results since different intervention duration would have produced different results. Fourthly, some bias in the results could also be accounted for due to us not analyzing the different control conditions in the control groups as different control conditions could generate different effect sizes (Higgins and Green, 2011). Fifthly, from the clinical point of view, the selection of databases may lead to bias on the estimation of meta-analysis effect; even though thirteen electronic databases were systematically searched, there might be a reporting bias (Ibid.). Sixthly, subjective judgments were used to evaluate data, which could generate observer bias (Yang et al., 2018). Seventhly, the included studies were only published in the English and Chinese languages and there is a possibility that studies with negative results remain unpublished and are not retrievable, which might thus indicate language and publication biases (Higgins and Green, 2011). Finally, the study design, execution of each included study and the selection for publication by authors can also contribute to publication bias (Thornton and Lee, 2000), and as the funnel plot analyses of the BBS scores revealed, there might be a publication bias in the present study. In addition, the majority of the included studies had methodological problems concerning the processes of randomization, allocation concealment or blinding. This might result in a risk for bias concerning the outcomes of the studies (Higgins and Green, 2011).

4.2. Practical implications

Several implications from this review, taking the aforementioned limitations into consideration, are presented for future clinical research and practice. Firstly, the standardized training scheme of robot-assisted therapy and for the control groups should be rigorously designed, including types of interventions or treatments, training duration and intensity. Secondly, the methodological quality related to the research about robot-assisted therapy should be further improved, with rigorous study designs and correct random allocation. Thirdly, a valid and subjective assessment should be utilized to assess the effect, apart from the objective outcomes in the included studies. Fourthly, a correct estimation of the sample size should be performed, and the intention-to-treat analysis and a specific explanation should be applied to describe the drop-out samples. Finally, based on the positive effects of robot-assisted therapy on improving balance function among stroke patients, nurses as the patients' caregivers throughout the course of the disease could recommend stroke patients to use robot-assisted therapy and could also assist physiotherapists during the robot-assisted procedure in order to obtain positive rehabilitation effects. Furthermore, the application of robot-assisted therapy would also reduce the workload of therapists and nurses since the functional recovery care of stroke patients is a labor-intensive process. This therapy method should thus be more frequently utilized for stroke patients, therapists, nurses and doctors.

5. Conclusion

Robot-assisted therapy may have a significant effect on improving balance function among stroke patients compared with those without using these devices, as indicated by increases in BBS score and FM—B score, as well as by subgroups of different types of robotic devices, robot-assisted therapy combined with another intervention or not, and differences in duration and intensity of intervention. These findings suggest that robot-assisted therapy could be a complementary or alternative approach for balance function rehabilitation among stroke patients. Nevertheless, due to the heterogeneity of the robotic devices and the diversity of the study designs in each included study, as well as the participants' characteristics, it is very essential for us to consider both research data and expert opinions to draw the best conclusions (Chang and Kim, 2013). Considering the limitations of quantity and quality of the included studies, more high-quality, large-scale, and multi-center RCTs which rigorously follow the guidelines of CONSORT are necessary to generate high-quality scientific evidence in the future.

Conflicts of interest

None.

Acknowledgments

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ijnurstu.2019.03.015.

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