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Robotics in Massage: A Systematic Review

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Abstract

Background: Over the past few years, a growing number of studies have explored massage robots. However, to date, a dedicated systematic review focused solely on robot-assisted massage has not been conducted.

Objective: To systematically identify and summarize evidence from studies concerning robot-assisted massage in healthcare settings.

Methods: An extensive literature search, involving electronic databases Ovid and Scopus, was conducted from the inception of the databases up to March 2023. This systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement, and relevant papers were chosen based on the predefined inclusion criteria. Given the substantial methodological diversity among the included studies, a qualitative analysis was conducted.

Results: Seventeen studies met the inclusion criteria, comprising 15 preliminary trials, one quasi-experimental study, and one randomized controlled trial. Approximately 29% of the studies focused on the application of robotic massage for patients, 24% targeted both healthy volunteers and patients, and the remaining 47% were preclinical trials assessing the effectiveness of robotic massage solely on healthy volunteers. Primary interventions included robotic massage for oral rehabilitation, scalp massage, low back massage, shoulder massage, and full-body massage. All studies provided evidence that robotic massage interventions can enhance health and well-being, indicating a promising future for the integration of robotics in the field of massage therapy.

Conclusions: In general, robotic massage interventions offer physical and mental health benefits. Robot-assisted massage may be integrated into care provision as an adjunct to enhance human well-being. Nonetheless, further research is needed to confirm these findings.

Keywords

robotic massager, robot, massage, Tuina, review

Background

Massage therapy, which typically involves a range of manual techniques applied to soft and connective tissues, is widely adopted across the globe as an adjunct in the management of various diseases and the promotion of wellness and relaxation. It has been proven to be a highly effective noninvasive, nonpharmacological complementary therapy[1] across all age groups.[2] There are many proposed mechanisms behind how massage alleviates patient symptoms, the most accepted being its modulation of local blood flow and regulation of oxygenation.[3]

The manual manipulation of soft tissues and muscles by skilled practitioners has been the traditional approach to administering massage therapy. However, challenges such as the availability of trained therapists, the occurrence of overuse syndromes among therapists, inconsistencies in technique, and the need for personalized treatments have prompted the exploration of alternative methods for delivering massage therapy. Robot massage is performed by machines or devices with minimal human interaction.[4] This renders robot-assisted massage an attractive alternative when compared with traditional manual massage, which can be repetitive, labor-intensive,

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and time-consuming. Given the prevalent shortages of healthcare workers in the industry, it is worthwhile to explore the utilization of autonomous robots to supplement the role of therapists with autonomous robots, while bearing in mind that collaborative approaches between therapists and machines require strict adherence to safety and efficacy standards, within the healthcare industry.[5] The integration of robotics is gaining traction, alongside advancements in artificial intelligence, within the healthcare industry. This is particularly evident in the field of massage therapy, where specialized robotic devices have been designed to replicate the techniques used in manual massages. Beyond the increased convenience and efficiency they provide, these devices have the capability to deliver controlled, precise, and customizable mechanical stimulation to the body. This opens new possibilities for massage therapy.

Numerous studies have explored the application of robotics in massage therapy across various contexts and demographics. These studies have evaluated its effectiveness in delivering massage treatments, patient satisfaction, and impact on clinical outcomes. However, despite these findings, this technology is still not widely used in clinical practices in many countries and regions. Furthermore, a comprehensive review regarding the efficacy and safety of robot-assisted massage has not been reported. Hence, through a comprehensive analysis of the existing literature, this study aimed to examine the benefits and risks and benefits of robot-assisted massage. This will serve as a reference for future clinical decision-making and as a guide for further research in the field of robotic massage.

Methods

This review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 statement.[6] Electronic databases (i.e., EBM Reviews—Cochrane Central Register of Controlled Trials, EBM Reviews—Cochrane Database of Systematic Reviews, Embase, Ovid MEDLINE(R) and Epub Ahead of Print, In-Process, In-Data-Review and Other Non-Indexed Citations, Daily and Versions, and Scopus) were searched from their inception until March 2023.

The search strategy encompassed the use of specific phrases associated with both modern robotics and traditional Far East medicine. The following phrases were employed in the literature search: "Robotics," "robot," "telerobot," "haptic," "haptics," as well as terms rooted in Far East medicine such as "tuina," "Tui Na," "tui-na," "Chu na," "massage," and "An mo." It is noteworthy that these terms from Far East medicine, such as Tui Na and An Mo, are deeply embedded in traditional practices and contribute to the holistic understanding of massage therapies in Eastern cultures. No restrictions on study outcomes or geographic location of the publications were applied. Only articles published in English were included. In addition, the reference lists of all identified articles were examined to identify studies not captured by electronic searches. Reports of trials involving the use of robotic massage either in the management of health conditions or relaxation were included in this study. The results of the literature search were uploaded to EndNote X9.3.1. This qualitative review relied on summary data for analysis. The electronic search and the eligibility of the studies were assessed by two authors independently. Differences were discussed, and consensus was reached.

Results

A total of 284 articles were found during initial literature retrieval. After the removal of duplicates, 283 articles entered the next phase of preliminary screening on title, abstract, and main text. Ten conference abstracts, 15 review protocols, 146 device introductions, and 79 other irrelevant records were further removed. Of the remaining citations, 15 studies were excluded as they did not involve robotic massage trials. Finally, 17 publications met our inclusion criteria. The literature inclusion process is detailed in Figure 1.

The summary of each article has been presented in Tables 1 and 2. Fifteen preliminary studies, along with one quasi-experimental, and one randomized controlled trial study, involving a total of 841 adults, comprising 621 healthy volunteers and 220 patients, were included in this review. Geographically, these studies were conducted in various regions: Japan (10 studies),[7–16] China (2 studies),[17,18] Taiwan (2 studies),[19,20] and individual studies in New Zealand,[21] Vietnam,[22] and Spain.[23] Of the 17 studies, five studies[11,13,16–18] did not specify participants' age and gender. The remaining 12 trials detailed the inclusion of a total of 297 males and 361 females, with ages ranging from 18 to 83 years. The massage was applied to various focal points, including the oral ($n = 9$, 53%),[7,8,10–16] head ($n = 3$, 18%),[9,21,22] shoulder ($n = 1$, 6%),[20] lower back ($n = 3$, 18%),[17,18,23] and full body ($n = 1$, 6%).[19] Massage treatments were administered to both healthy volunteers[9,11,13,16,17,21,22] and individuals with various conditions such as temporomandibular joint (TMJ) dysfunction associated with myofascial pain,[7,8,10,12,14,15] muscular fatigue,[20] anxiety during menopause,[19] and lower back pain.[18,23] These interventions were administered over differing timeframes.

Notably, only one study documented muscle pain experienced by two healthy volunteers who underwent massages on the masseter and temporal muscles, using 6 N and 10 N forces respectively.[14] No mechanical adverse events were observed. Safety considerations were not addressed in the remaining studies. Approximately 59% of the studies received applicable ethics approval from the Institutional Review Board[7–9,11–15,21,23] or acquired informed consent from participants.[7–9,14,15,19,21,23]

Oral Rehabilitation Massage

Nine studies investigated the use of robot-assisted massage in the setting of oral massage therapy. In 2008, Koga et al[16] designed a novel rehabilitation robot, the Waseda-Asahi Oral-Rehabilitation Robot No.1 (WAO-1), to provide massage to the maxillofacial region of patients with xerostomia. They programed WAO-1 to provide massage to the parotid glands of 6 healthy volunteers

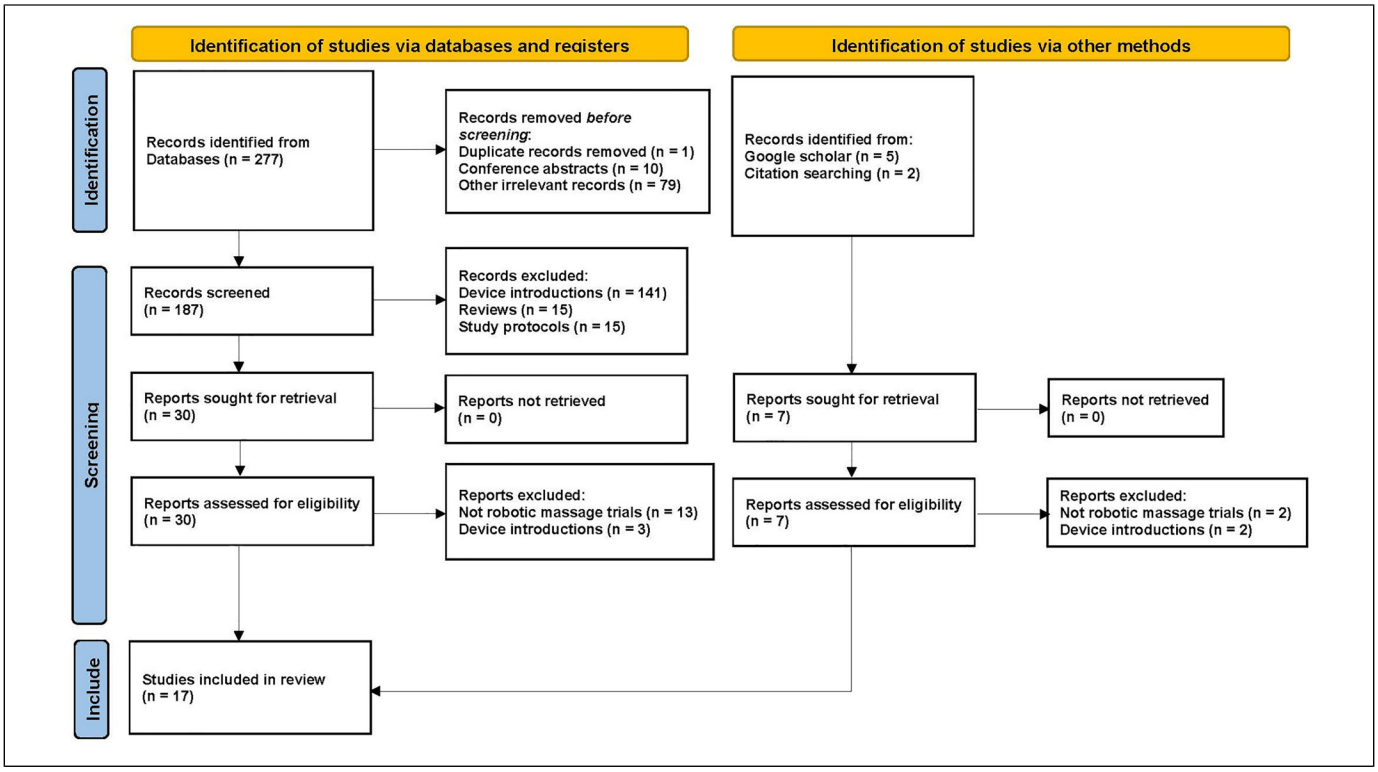

Figure 1. Flow chart of study selection.

and to the masseter muscle of 11 healthy volunteers without any maxillofacial disorders. They found that the massage therapies provided by WAO-1 could enhance the production of saliva. However, it is crucial to note that this study primarily focused on the technical aspects of the robot's development and did not include empirical data on its effectiveness in clinical settings or patient outcomes. Between 2009 and 2016, eight additional preliminary studies were conducted using WAO-1 robots to assess different massage techniques targeting the mouth and surrounding tissues. This included massaging the masseter and temporal muscles, as well as the parotid gland, to address myofascial pain and xerostomia respectively. Three studies were conducted on healthy volunteers,[11,13,16] 2 studies on patients with TMD with associated myofascial pain,[7,10] and 4 on both healthy and patients with TMD with associated myofascial pain.[8,12,14,15] In 2010, Ariji et al[10] utilized sonographic evaluation of the bilateral masseter and temporal muscles to evaluate the efficacy of WAO-1 massage treatment in 15 patients with TMD (10 with unilateral and 5 with bilateral muscle pain). Changes in sonographic features of the relevant muscles were found to be correlated with improvements in pain and range of motion following WAO-1 massage treatment. In 2016, Ariji et al[7] conducted further research to evaluate the use of sonographic features as predictors of the efficacy of robotic massage treatment in 37 patients with TMD with associated myofascial pain. A standard WAO-1 massage pressure of 10 N was applied to the masseter and temporal muscles for a duration of 16 min, over the course of 5 sessions every 2 weeks. The median total treatment duration was 9.5 weeks. Their findings revealed that sonographic features of the masseter and temporal muscles after the third treatment session could predict treatment efficacy. Specifically, patients with more pronounced changes in muscle features experienced more significant improvements following the treatment.

Additionally, in 2009, Jorge Solis et al[11] noted the development of the revised oral rehabilitation robot, known as the WAO-1 Refined (WAO-1R). This included the redesign of the arms of WAO-1 to enable precise massage therapy on maxillofacial regions and expand the range of massage techniques available for addressing oral motor dysfunction or facial muscle weakness. The authors verified the effectiveness of the improved mechanical design of WAO-1R in providing massage to 12 healthy volunteers. The study findings suggested that massages with WAO-1R increased the thickness of the masseter muscle on volunteers and the amount of mouth opening, compared to the previous robot model. However, this was also a study primarily focused on the technical aspects of the robot's development and did not include empirical data on its effectiveness in clinical settings or patient outcomes.

Head Massage

Three studies shed light on the potential of robot-assisted scalp massages. The efficacy of a head-care robot was evaluated using biosignal, reflecting the direct biological impact of massage therapy on user relaxation.[9] Fifty-four healthy subjects were randomized to receive scalp massage with shampooing from either a nurse with head care experience, the earlier

Table 1. Characteristics of the Included Studies.

Author/year	Country	Study type	Population	Age	Gender (female/male)	Condition targeted by robot
Koga et al., 2008[1]	Japan	Preliminary study	17 healthy volunteers	/	/	Oral health problems
Ariji[a] et al., 2009[2]	Japan	Preliminary study	16 healthy volunteers/2 patients with TMD	25-64	8 F/10 M	TMD associated with myofascial pain
Ariji[b] et al., 2009[3]	Japan	Preliminary study	22 healthy volunteers/12 patients with TMD	19-68	16 F/18 M	TMD associated with myofascial pain
Ishii, 2009[4]	Japan	Preliminary study	24 healthy volunteers	/	/	TMD and xerostomia
Obokawa et al., 2009[5]	Japan	Preliminary study	29 healthy volunteers/26 patients with TMD	21-77	33 F/22 M	TMDs
Solis et al., 2009[6]	Japan	Preliminary study	12 healthy volunteers	/	/	Oral health problems
Ariji et al., 2010[7]	Japan	Preliminary study	15 patients with TMD	19-68	11 F/4 M	TMD associated with myofascial pain
Luo et al., 2011[8]	Taiwan	Preliminary study	5 healthy volunteers	23-32	5 M	Muscular fatigue
Ando et al., 2013[9]	Japan	Preliminary study	54 healthy volunteers	20-31	27 F/27 M	Relaxation
Hiraiwa et al., 2013[10]	Japan	Preliminary study	24 healthy volunteers/16 patients with TMD	24-69	24 F/16 M	TMD associated with myofascial pain
Walker et al., 2013[11]	New Zealand	Preliminary study	18 healthy volunteers	18-49	7 F/11 M	Relaxation
Hu et al., 2013[12]	China	Preliminary study	30 patients with lumbar muscle strain	/	/	Lumber muscle strain
Huang et al., 2015[13]	China	Preliminary study	100 healthy student volunteers	/	/	/
Ariji et al., 2016[14]	Japan	Preliminary study	37 patients with TMD	19-83	31 F/6 M	TMD associated with myofascial pain
Lai et al., 2020[15]	Taiwan	Quasi-experimental study	40 menopausal patients with anxiety	45-55	40 F	Menopausal anxiety
Hai et al., 2021[16]	Vietnam	Preliminary study	300 healthy volunteers	18-75	136 F/164 M	Bedboundness/immobility
Marin-Mendez, 2021[17]	Spain	Randomized controlled trial	42 patients with non-specific low back pain (NSLBP)	18-60	28 F/14 M	NSLBP

Note: TMD, temporomandibular disorder.

Table 2. Characteristics of the Included Studies.

Author/year	Robot	Location	Massage type	Treatment	Outcome evaluation	AE	IRB	Consent	Results
Koga et al., 2008[1]	WAO-1	Parotid gland and masseters	Effleurage and petrissage	Massage of parotid gland was performed for 2 min. Massage of masseter muscle was performed for 2 min.	Saliva production by Saxon test after parotid massage. Facial skin temperature and masseter size after masseter massage.	/	/	/	WAO-1 massage significantly increased the production of saliva.
Ariji[a] et al., 2009[2]	WAO-1	Masseter and temporal muscles	Effleurage and petrissage	1-min massages were administered alternately on the masseter and temporal muscle. Each treatment session consisted of 5 massages for healthy volunteers and 7 massages for patients. Three massage pressures (1-2 N, 6-8 N, and 10 N) were evaluated.	Amount of mouth opening, muscle pain and impediments to the activities of daily life (VAS). Relationship between the right masseter stiffness index and the most comfortable massage pressure.	/	Yes	Yes	The masseter stiffness index could serve as a measure to determine the appropriate massage pressure for comfort.
Ariji[b] et al., 2009[3]	WAO-1	Masseter and temporal muscles	Effleurage and petrissage	Phase-1 (healthy volunteers only): 1-min massages were alternately performed on the masseter and temporal muscles of both healthy volunteers and patients. Each treatment session consisted of 5, 7, or 10 repeated massages. A dose-escalation study was performed with three massage pressures (1-2 N, 6-8 N, and 10 N). Phase-2 (patients only): 1-min massage was performed alternately for the masseter and temporal muscles and each treatment session consisted of 7 repeated massages. Sessions were conducted 3 times a week every 2 weeks. The massage pressure was set arbitrarily.	Maximal mouth opening, along with comfort, warmth, and ease of mouth opening across different massage pressures in both groups. Muscle pain, impediments to the activities of daily life additionally evaluated in patients (VAS).	Yes	Yes	Yes	The administration of 7 repeated 1-min massages per muscle at a pressure of 6-10 N every 2 weeks was safe and effective for most TMD patients with associated myofascial pain.

(continued)

Table 2. (continued)

Author/year	Robot	Location	Massage type	Treatment	Outcome evaluation	AE	IRB	Consent	Results
Ishii et al., 2009[4]	WAO-1	Parotid gland and duct, and masseters	Effleurage and petrissage	2-min massage of the parotid gland, including rubbing of the parotid duct, was performed by a doctor and 1-2 min by the WAO-1. Massage to masseter muscle (pressing and rubbing) for 2 min was performed by either a doctor or the WAO-1.	Saliva production by Saxon test after parotid gland and duct massage. Fascial skin temperature and width of masseter muscle after masseter massage.	/	Yes	/	WAO-1 could be effective for patients with oral disorders. WAO-1 massages applied to the parotid gland and duct, as well as the masseters, increased the production of saliva, and the width of the masseter muscle and fascial skin temperature respectively.
Obokawa et al., 2009[5]	WAO-1	Masseter and temporal muscles	Effleurage	Healthy volunteers: Robotic massage with 1-2 N, 6-8 N, and 10 N massage pressures. Patients with TMD: 10-min massage around the masseters and musculus temporalis at a massage pressure between 6 and 10 N.	Feeling, thermal sensing, and ease of mouth opening in healthy volunteers. Amount of mouth opening and subjective lameness of masseter muscle in patients.	/	Yes	/	WAO-1 massage helped relieve TMD symptoms.
Solis et al., 2009[6]	WAO-1, WAO-1R	Masseter and temporal muscles	Effleurage and kneading	The WAO-1 Refined (WAO-1R) massage was delivered at a force of 0.8 kg-f during a period of 4 min (two minutes for each target organ).	Massage time, masseter thickness, mouth opening (pain-free and maximal) and facial skin temperature.	/	Yes	/	WAO-1R massage increased the thickness of masseter muscle and the amount of mouth opening in volunteers compared with WAO-1.
Ariji et al., 2010[7]	WAO-1	Bilateral masseter and temporal muscles	Effleurage and petrissage	1-min massages were performed alternately on the bilateral masseter and temporal muscles. Each treatment session consisted of 7 or 10 repeated massages. The individual pressures were set arbitrarily, ranging from 8-12 N, with 10 N as a standard. The treatment was performed every 1 or 2 weeks.	Maximal mouth opening, muscle pain, impediments to activities of daily life, their impression of the massage (comfort, warmth, ease of mouth opening) (VAS), muscle thickness and intramuscular appearance on the sonography.	/	/	/	Sonographic features, such as the decrease in masseter thickness and disappearance of intramuscular anechoic areas, might be related to the therapeutic efficacy of muscle pain.
		Shoulder		Isometric 50% MVC	Trapezius surface	/	/	/	The multifinger robot hand

(continued)

Table 2. (continued)

Author/year	Robot	Location	Massage type	Treatment	Outcome evaluation	AE	IRB	Consent	Results
Luo et al., 2011[8]	Multifinger robot hand (IRA-Hand I)		Grasp-kneading massage	(maximum voluntary contraction) was performed for 90 s to induce fatigue of the volunteers' trapezius muscles. Then, volunteers either underwent a 10-min grasp-kneading shoulder massage by the robot hand, a specialist, or they were instructed to simply rest. These three options were conducted on three separate days.	electromyographic (SEMG) parameters: electrical activity (EA) and median frequency (MF)				was comparable or even more effective as compared to a specialist in delivering massage and aiding the recovery of the trapezius muscle from fatigue.
Ando et al., 2013[9]	Head-care robot	Head	Pressing and extension	Each participant was shampooed by either a nurse with head care experience, Proto 0 (swinging and pressing movements), or Proto 1 (pressing and extension movements). Constant shampoo amounts (10 ml) and shampoo time (1-min rinse, 2-min wash, and a 1.5-min rinse) were reinforced.	Accelerated plethysmography (SDNN, HF/TP, LF/HF), heart rate (HR), blood pressure, salivary amylase (sAA) and peripheral skin temperature (PST)	/	Yes	Yes	The head-care robot's massage provided satisfactory physical and psychological relaxation in just 5 min of use by decreasing sympathetic activity and increasing parasympathetic activity.
Hiraiwa et al., 2013[10]	WAO-1	Bilateral masseter and temporal muscles	Effleurage and petrissage	1-min massages were performed alternately on the bilateral masseter and temporal muscles. The individual pressures were set arbitrarily, ranging from 6-14 N, with 10 N as a standard. Each session consisted of 7 or 10 repeated massages, and the treatment was performed every 1 or 2 weeks.	Masseter muscle hardness and asymmetry index, maximal mouth opening, subjective evaluations (VAS) regarding muscle pain, impediments to the activities of daily life and their impression of the massage (comfort, warmth, and ease of mouth opening).	/	Yes	Yes	The masseter hardness, which decreased post-WAO-1 massage alongside right-and-left difference, may be an index for determining the massage pressure in TMD patients with associated myofascial pain.

(continued)

Table 2. (continued)

Author/year	Robot	Location	Massage type	Treatment	Outcome evaluation	AE	IRB	Consent	Results
Walker et al., 2013[11]	NA0 robot	Head	Up and down movements, with circular movements in the down position	Head massages were performed by the masseur, robot, or oneself, each lasting around 45 s.	Negative Attitude Towards Robots Scale (NARS), the "Massage as Pleasant" subscale of the Attitudes Toward Massage (ATOM) scale.	/	Yes	Yes	Although participants in the robot group reported less enjoyment compared to massages by human masseurs, they displayed more happy facial expressions. Their attitudes toward robots remained unchanged after the experience, highlighting the potential of robots in the realm of human–robot interaction.
Hu et al., 2013[12]	Novel Chinese massage robot	Lower back	Rolling, thumb kneading, vibrating, pinching, and pressing	The robotic massage system acted on acupuncture points based on the traditional Chinese massage therapy theory and integrated 5 manipulation techniques into 3 stages, namely (1) relaxation massage (2) carding physique massage, and (3) follow-up massage.	Subjective pain intensity (VAS)	/	/	/	Robotic massage based on the traditional Chinese massage therapy theory was effective in lumbar muscle strain treatment.
Huang et al., 2015[13]	Anthropomorphic robotic arm with integrated elastic joints	Lower back	Pressing, kneading, and plucking	Robotic massages were performed on 100 student volunteers in sitting and lying postures.	Questionnaire on satisfaction of robot massage and similarity between robot and human massages.	/	/	/	The developed robotic arm could effectively replicate the taditional Chinese medicine remedial massage techniques, with good quality and high safety.
Ariji et al., 2016[14]	WAO-1	Masseter and temporal muscles	Effleurage and petrissage	Massage was performed alternately on the bilateral masseter and temporal muscles. The standard massage pressure was at 10 N, and massages lasted 16 min. The standard treatment protocol was set at 5 sessions every 2 weeks.	Maximal mouth opening, muscle pain, daily life impediments (VAS) and the intramuscular echogenic bands and elasticity index ratios of masseter muscles on sonography.	/	Yes	Yes	Sonographic features after the third session of robotics massage could serve as predictors of WAO-1 massage efficacy.

(continued)

Table 2. (continued)

Author/year	Robot	Location	Massage type	Treatment	Outcome evaluation	AE	IRB	Consent	Results
Lai et al., 2020[15]	Robotic arm	Whole body	Aromatherapy massage with essential oils	Intervention: 2-h aromatherapy massages using essential oils were performed weekly for 3 months. Control: participants lay in a resting position without interventional aromatherapy massage.	State-Trait Anxiety Inventory	/	/	Yes	The use of essential oil massage over 3 months resulted in a significant decrease in both trait and state anxiety in menopausal women.
Hai et al., 2021[16]	Robotic autonomous scalp massage	Head	Rotation	Human scalp massages targeting the acupuncture points of the scalp were administered using water jets, with their trajectories predicted by machine learning based on physical factors.	Pain threshold of water impact on human scalp.	/	/	/	Robotic autonomous scalp massage and shampoo combined with traditional Vietnamese's acupuncture massage would enhance treatment efficacy and resilience, benefiting patients requiring care.
Marin-Mendez et al., 2021[17]	ADAMO robot	Lower back	Air pressure massage	Robot-controlled air pressure massage was administered for 10 min for 10 sessions.	Subjective pain intensity (VAS), ODI	/	Yes	Yes	The ADAMO robot was at least on par with or even surpassed the regular treatment's efficiency in reducing low back pain and could provide even greater benefits to overweight patients.

Note. TMD, temporomandibular disorder; AE, adverse events; WAO-1, Waseda-Asahi oral-rehabilitation robot No.1; VAS, visual analog scale; ODI, oswestry disability index; IRB, Institutional Review Board.

head care robot prototype, or the latest head care robot model. Participants in each arm received 5 min of head massage with the same amount of shampoo. The study results revealed that the robotic head massage provided physical and psychological relaxation as evidenced by decreased sympathetic activity and increased parasympathetic activity, highlighting the potential of robots to provide relaxation and stress relief. The subjective experience of receiving a head massage from a robot compared to that of a human masseuse was also evaluated among 18 healthy volunteers.[21] Although the experience of a robotic massage was reportedly less enjoyable and relaxing, participants receiving a robotic massage expressed significantly more happiness compared to being served by a human masseuse. In 2021, a combination of robotic scalp massage, shampooing, and reflexology (Vietnamese traditional medicine) was administered to 300 healthy volunteers. The robotic scalp massage, which used water jets with trajectories predicted by machine learning based on physical factors to meet the desired position on the human scalp, enhanced the recovery of bedbound patients and thereby reduced the risk of bedsores-related infection.[22] These studies collectively suggest that robots are capable of providing pleasurable and relaxing experiences that are comparable to those provided by human touch and can also be tailored to promote rehabilitation.

Shoulder Massage

The role of electromyography (EMG) in evaluating the therapeutic effects of massage was demonstrated with a multifinger robot hand on the upper trapezius muscle, which is commonly associated with muscle tension and pain. The robot hand resulted in a significant decrease in EMG activity, signifying muscle relaxation under the simulated fatigued conditions, which was comparable to the effect achieved by a human therapist. However, it is worth noting that the study had a limited number of healthy participants and did not assess the robot hand's efficacy in treating specific health conditions. More research is necessary to validate these results and assess the potential effectiveness of robot-assisted massage therapy across a broader range of health conditions.[20]

Lower Back Massage

A single-blinded, two-arm randomized controlled trial showed encouraging results with the use of a robot to treat nonspecific low back pain (NSLBP). In this trial, 44 participants were assigned to either the conventional physical therapy plus robot-assisted therapy group or the conventional physical therapy group. The conventional physical therapy group received 10 sessions of standard treatment, involving thermotherapy and rehabilitation exercises, for NSLBP at the Rehabilitation Service. The robot-assisted therapy group received 10 sessions of robot-controlled air pressure massage for 10 min in addition to the standard physical treatment. The study found that both groups experienced significant improvements in functional disability after the intervention ($p < .05$). Uniquely, only pain improvement was statistically significant in the robot arm ($p = .0001$). Patients of both sexes obtained similar benefits from either treatment. Overweight patients (body mass index ≥ 25 kg/m^2) in the robot arm benefited more from the treatment ($p = .008$) than patients with normal weight. The researchers concluded that robot-assisted therapy could be a feasible and effective alternative for treating NSLBP, especially for patients with excessive weight.[23]

Two other studies incorporating robot-assisted massage into Chinese massage (Tuina) therapy were also reviewed. In 2013, Hu et al[18] designed a robotic system that replicated the key movements and techniques used in Chinese massage therapy. While demanding less manual effort, the massage robot was still found to have been able to integrate the experience and skills of professionals into reproducing expert techniques with individualized manipulation parameters and improved safety measures. Furthermore, in 2015, Huang et al[17] developed an anthropomorphic robotic arm with integrated elastic joints specifically designed for Traditional Chinese Medicine (TCM) massage. The anthropomorphic robotic arm showed promise in simulating human-like massage techniques, providing more stable pressure distribution and accurate manipulation as compared to human therapists. These massage robots have the potential to offer advantages such as consistent performance, extended treatment duration, and improved availability of TCM massage therapy.

Full Body Massage

The use of artificial intelligence and robotic arms in combination with aromatherapy was explored in menopausal women to study its effects on anxiety. Forty menopausal women were randomly divided into the aromatherapy robot massage group or control group without aromatherapy robot massage. The interventions were provided weekly for 3 months. Anxiety levels were measured before and after the interventions using a standardized questionnaire. Study results indicated that aromatherapy robot massage reduced anxiety levels of menopausal women significantly. However, the small sample size highlights the need for further research to confirm these findings and evaluate the effectiveness of the intervention across diverse populations and health conditions.[19]

In summary, while the field of robotics in massage therapy is still in its nascent stages, it shows significant promise. Future research could benefit from larger and more comprehensive clinical trials to better ascertain the efficacy and acceptability of robotic massage.

Discussion

The collective data compiled from the seventeen observational studies that fulfilled the inclusion criteria in this systematic review suggests that robot-assisted massage is feasible and can be performed safely for health and well-being enhancement. The interventions primarily encompassed oral rehabilitation and included head, shoulder, back, and full-body massages. The robotic massage interventions not only improved health

conditions but also alleviated pain and stress, enhancing overall wellness in the process.

Robot-assisted massage in the setting of oral rehabilitation has been the most explored. The oral rehabilitation robot WAO-1R demonstrated substantial potential in providing relief to patients with oral disorders, such as TMJ disorders with associated myofascial pain. Moreover, the use of sonographic elastography to optimize massage pressure and the evaluation of masseter muscle sonographic features to assess treatment efficacy emphasizes the strong interplay between robotics and imaging technologies in the field of massage therapy.

The existing literature is mainly centered on the capability of robotic interventions in executing various massage techniques on humans. However, the psychological aspects of robotic massage therapy should not be overlooked. As indicated by Ando et al.,[9] patients' experiences and psychological acceptance of a robot-assisted massage were generally marked by positive reactions. This finding suggests that the lack of the "human touch" element of traditional massage therapy may not be a limiting factor in the acceptance and effectiveness of robotic massages. Furthermore, the incorporation of robots to perform culturally specific techniques such as Tuina (Chinese massage therapy) highlights the robots' versatility and extends their potential applications.

Of note, the literature search identified numerous publications, that though related to robot-assisted massage, were regarding study designs, study protocols, reviews of mechanical and electrical concepts, and robotic engineering designs. These studies did not fit into the predefined inclusion criteria and thus were not included in this systematic review.

The potential for integration of robot-assisted technology into massage therapy is noteworthy. However, based on the review of the existing literature, future studies employing rigorous methodologies are needed. Future prospective studies should focus on robot-assisted massage effectiveness, safety, and cost-efficiency. Additionally, future studies should delve into comprehending and enhancing the psychological experiences and interactions between users and robots to amplify the comprehensive impact of robotic massage therapy. Furthermore, additional studies should be performed in various healthcare settings (inpatient, outpatient, home-based) as well as for numerous different medical conditions.

Strengths

As demonstrated in this review, the field of robotic massage therapy is both diverse and expanding. This systematic review represents the first comprehensive synthesis of trials within this domain. This systematic review followed a rigorous, predefined protocol with multiple independent reviewers. The thorough examination of data is crucial as the growing amount of evidence supporting the effectiveness of robotic-assisted massages could raise ethical and medicolegal considerations in the future.

Limitations

While the available evidence indicates several potential advantages, it is imperative to acknowledge several limitations of this systematic review. A considerable number of the trials encompassed within this review are of a preliminary nature, characterized by small participant cohorts and limited follow-up periods. Most of these trials lacked randomization or blinding, thereby diminishing the overall credibility of the findings.

It appears that robotic massages, categorized as electric massagers, were not subject to 510 K regulations.[24] Despite the many trials, only 29% of studies targeted patients,[7,10,18,19,23] while 24% involved both healthy volunteers and patients[8,12,14,15] and, 47% comprised preclinical trials focused on healthy volunteers assessing the viability of robotic massage[9,11,13,16,17,21,22] in this review. Primarily, these trials featured preliminary investigations on healthy volunteers. Considering the early stage of published reports, the potential costs and accessibility barriers of these technologies could pose challenges to their widespread adoption. The sample size examined in this review was relatively modest, which could potentially impact the robustness of its findings due to the limited literature available. Additionally, the variability in robot design, massage techniques, and assessment protocols complicates the applicability and generalizability of the study outcomes. The lack of standardized norms for robotic massage interventions might undermine the accuracy of results. Notably, only English-language publications were included, potentially introducing a language bias by overlooking articles in other languages.

Conclusions

In conclusion, the potential physical and mental benefits brought about by the integration of robotic technology into massage therapy are evident. However, caution is warranted when processing the evidence due to limitations in existing literature such as the small sample sizes, nonrandomized trials, and heterogeneity in methodologies. Despite these challenges, robot-assisted massage may be incorporated into care provision as an adjunct to enhance human well-being. Nonetheless, further research is required to validate these findings.

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Author Contributions

BAB contributed to the study conceptualization, investigation, and funding acquisition. JY, KHL, and DEJ curated and analyzed the data. JY and AD developed the study methodology. BAB contributed to project administration and supervision. JY contributed to software. JY and ABM wrote the original draft of the manuscript. SCF, JJC, MRM, TYC, and BAB reviewed and edited the manuscript. All authors approved the final manuscript.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declaration of Conflicting Interests

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