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Research Article

Augmented reality-supported exercise therapy system improves physical frailty and musculoskeletal pain: a preliminary feasibility study

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Abstract

Objectives: Although the usefulness of exercise therapy for chronic musculoskeletal pain has been established, there are many challenges in introducing and continuing the therapy. We have developed a system that allows patients to exercise using instructional polygons so that they can exercise at home. In this study, we investigated the effect of exercise instruction using this system.

Methods: Consent was obtained from 14 patients (age 72.4±11.6, man/woman 7/7) with musculoskeletal chronic pain. The subjects used this system in our outpatient clinic once a week (for a total of 10 times), and exercised at an activity level of about 3METs for 30 minutes. They were also instructed to perform the same exercise at home six days a week without the system. Each clinical data was tested before and after treatment using the Wilcoxon Signed Rank test.

Results: All 14 patients have completed the exercise. Their walking speed improved significantly after using Kinect. (P = 0.019). We acknowledged the increase in muscle strength in hip, knee and ankle MMT. Good effects in lower limb functions such as lower limb pain (P = 0.035) and going out by train or bus (P = 0.037) were confirmed in each item of Locomo 25.

Conclusions: Exercise therapy with our system improved walking speed that affects life prognosis. It can be presumed that strengthening of lower limb function is related to the factor.

ABBREVIATIONS

QOL: health-related quality of life**;** **AR:** augmented reality; **ADL:** activities of daily living; **MMT:** manual muscle testing; **TUG test:** Timed Up & Go test

INTRODUCTION

Chronic musculoskeletal pain like as low back pain, neck pain, and osteoarthritis joint pain has been very common in the world's aging society despite numeral treatment options [1]. Pain is one of the most frequent causes for patients to seek medical care [2], and chronic pain remains health-related problems with a substantial impact on daily functioning [3]. Even worse, it is expected that the prevalence of musculoskeletal pain will further increase because of rapid aging in the near future. Therefore, chronic pain has been identified as a critical public health issue and a global health research priority [4]. There are urgent needs for novel treatments and prevention methodology for chronic musculoskeletal pain. We recognize that exercise therapy has been one of the most useful treatments for musculoskeletal pain disorders over the decades. Exercise therapy for musculoskeletal disorders can maintain and improve muscle strength and range of motion of osteoarthritis joints, and also analgesic and anti-inflammatory effects can be expected in osteoarthritis joints [5]. Exercise therapy for chronic low back pain like as aerobic exercise and strength training improves pain and dysfunction of the musculoskeletal system and health-related quality of life (QOL), compared with the non-treatment group [6]. However, despite such positive effects on both pain and disability, not all patients benefit from exercise therapy and the effect sizes are not necessarily moderate-to-high [7-8]. It is also known that merely increasing exercise intensity is not effective [9]. To assist exercise therapy for musculoskeletal pain, various technological systems have been developed. A recent systematic review could reveal that the technology-supported exercise therapy possibly improves pain, disability and QOL for patients with musculoskeletal pain and also revealed that a standard treatment combined with an additional technology-supported exercise therapy program might be superior to a standard treatment alone [10]. Here, we developed a novel technology-supported exercise therapy system, which help musculoskeletal pain patients exercise by themselves in the augmented reality (AR) space. The present pilot study sought to demonstrate the feasibility and acceptability of our AR-supported exercise therapy combined with standard self-exercise therapy for the provision of treating musculoskeletal pain and educating the patients on exercise habits.

MATERIALS AND METHODS

Participants

This study was approved by the ethics committee of The University of Tokyo Hospital, and written informed consent was obtained from each patient before participating in this study. This study was registered in the University Medical Information Network (UMIN trial ID: UMIN000017129) before starting. Fourteen patients (7 female; age 72.4±11.6 mean ± standard deviation; height 157.2±8.3cm; body weight 61.6±7.8kg) with some kind of the musculoskeletal disorder participated in this feasibility and acceptability study. All patients were outpatients in the Department of Anesthesiology and Pain Relief Center, The University of Tokyo Hospital, with a complaint of musculoskeletal pain.

Content of AR-supported exercise therapy

In our AR-supported exercise therapy system, the participant exercised in front of a video monitor equipped with an infrared camera (Kinect ®, Microsoft, USA). By capturing their physique using the infrared camera, two skeletal doppelganger polygons were simultaneously displayed in the AR space on the monitor (Figure 1A). One was the patients' doppelganger polygon, which accurately replicates real-time movements of the patient's skeleton in the AR-space. The other was the teaching polygon which demonstrates a total of 48 types of exercises (i.e., 12 types of anti-gravity muscle training, 24 types of left-and-right balance exercises, 12 types of whole-body exercises). The exercise speed presented by the teaching polygon could be adjusted in 30 steps, so a total of 1440 exercise programs could be demonstrated for the participant imitating the movements. While imitating the teaching polygon's movements, the participants could visually check their self-movements by watching the doppelganger polygon abreast of the teaching polygon in the main window of the AR space. Additionally, the front and lateral views of the doppelganger polygon hovering the teaching polygon were displayed in the sub-windows. The system automatically detected movement errors of the participant from the teaching polygon, and then it alerted and instructed the participant the errors and precise exercise contents (Figure 1B). Thus, the participants easily recognized how different their execute movements were from the movements being instructed by the teaching polygon. Using these AR-supported exercise therapy system once a week (30 minutes once a session for a total of 10 sessions), the participant continued to exercise at a daily activity level of about 3 METs for the purpose of establishing exercise habits. They were also instructed to execute almost same contents of the exercise therapy being instructed by the teaching polygon at home six days a week without the AR-supported system. The study periods were set for 3 months.

Evaluation

We collected several clinical data before and after the study periods to determine the usefulness of our AR-supported exercise therapy system. To systemically evaluate the musculoskeletal disorders, we used the Locomo25 questionnaire. The Locomo25 was developed as a screening tool for impaired activities of daily living (ADL) by the musculoskeletal disorders, which can foresee the future risk of being recipient of care [11]. The Locomo25 contains of 25 questions, and evaluates 5 subcategories of musculoskeletal pain, indoor activities, personal work, anxiety, and social participation. We investigated items related to sarcopenia [i.e., muscle mass measured by the bioelectrical impedance analysis (InnerScan 50V, Tanita inc., Japan), grip strength and the lower limb muscular strength tested by manual muscle testing: MMT]. We also investigated their balance adjustment ability such as gait speed, Timed Up & Go (TUG) test and one-leg standing, that were reported to be associated with musculoskeletal degeneration by aging [12-13]. Each clinical data were recorded twice before and after the study period, and statistically analyzed using the Wilcoxon Signed Rank test.

RESULTS AND DISCUSSION

Fourteen patients gave their informed consent and participated in the protocol. All of them had no experience of rehabilitation using such an AR system. An experimental physiotherapist accompanied them when using this system once a week. Patients achieved the protocol for 3 months without feeling any difficulty in using the AR system. There were no obvious adverse events such as falls or discomfort during the study periods. The results are shown in (Table 1). There were no significant changes in body weight, body mass index, muscle mass (%) and fat mass (both visceral and subcutaneous fat: %). In terms of sarcopenia-related items for which lower limb function can be evaluated, there was no clear significant difference in TUG (P=0.075), but there were significant improvements in one-leg standing time (P=0.007) and walking speed (P=0.019). In a survey using Locomo25 to evaluate motor dysfunction, there was no change in the total score. In the evaluation of each questionnaire item of Locomo25, the item relate to lower limb motor function such as lower limb pain (P= 0.035) and going out by train or bus (P= 0.037) was significantly improved (Figure 2). There were no significant differences in other questionnaire items of Locomo25. The results of lower limb muscle strength evaluation are shown (Table 2). Effective results were observed in MMT muscle strength of hip (Left Extension: P= 0.014, Abduction: P= 0.011), knee (Left Extension: P= 0.029) and ankle (Plantar flexion: P=

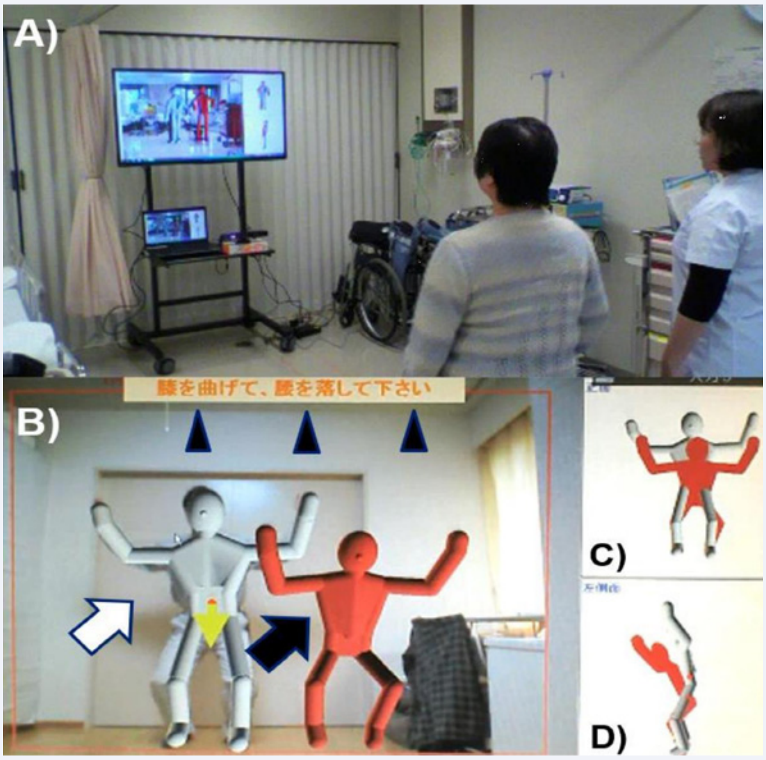

Figure 1 Scenes using our AR-supported exercise therapy system
(A) The participant exercises in front of a video monitor equipped with an infrared camera.
(B) Two skeletal polygons are displayed in the augmented reality (AR) space on the monitor [teaching polygon, white arrows; the patient's doppelganger polygon, black arrow]. The patient practices exercises taught by the teaching polygon, and visually confirms the difference between exercise postures of them on the main monitor. They can real-timely check precautions, which were presented if the differences of exercise postures are large, during exercising at the top of the monitor [Dark blue arrow heads indicate "Bending knees, and stoop down" in Japanese].
(C) To easier understand the differences of the participant's postures during practicing exercises from the teaching polygon, two sub-windows (C) and (D) are also presented in the monitor. In these sub-windows, the polygons are superimposed in the front (C) and lateral (D) views.

Table 1: Data comparing pre and post of our AR-supported exercise therapy.

	AR-supported exercise therapy		
	Pre	**Post**	*P-value*
BMI	25.4±3.1	25.0±2.9	*0.48*
Locomotive 25	31.6±15.7	25.7±11.4	*0.13*
Body fat [%]	31.6±9.9	30.7±10.2	*0.21*
Muscle mass [%]	40.6±7.7	40.5±7.2	*0.94*
Grip strength: Right [Kgw]	24.3±8.4	25.4±7.8	*0.16*
Grip strength: Left [Kgw]	21.6±8.8	22.8±8.0	*0.13*
TUG [sec]	8.5±3.6	7.5±2.7	*0.075*
one-leg standing time [sec]	17.3±15.2	29.8±23.3	*0.0069**
5m walking speed [sec]	5.1±0.8	4.4±1.1	*0.019**

All items were compared before and after using the Kinect system, using the Wilcoxon Signed Rank test. P-value less than 0.05 is significant.
BMI, Body Mass Index; TUG, Timed Up & Go Test

0.025). There were no clear significant differences in MMT of other muscles.

Although the most effective exercise therapy for chronic musculoskeletal pain patients has still remained controversial, there was no specific exercise therapy with clear evidence [14-15]. Important factors affecting the effectiveness of exercise therapy are how to select appropriate exercise intensity for individual patients and how to keep and improve patients' adherence to exercise therapy. It was reported that 50-70% of patients with chronic low back pain failed to comply with home exercise prescriptions [16-17]. Good exercise compliance is essential for maximizing the effectiveness of exercise therapy for

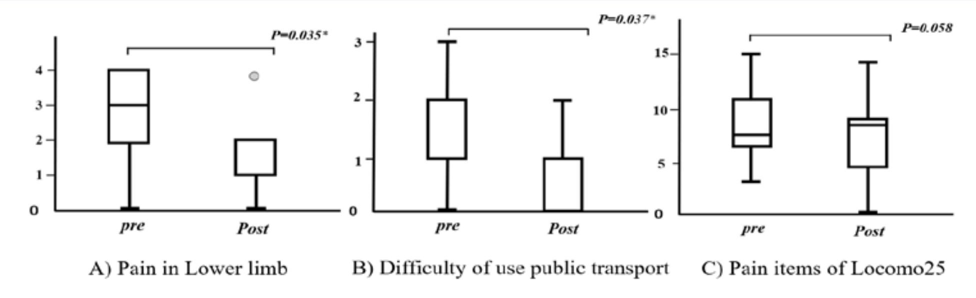

Figure 2 Changes before and after AR-supported exercise therapy: Effects evaluated for each item of the Locomo 25 questionnaire
Augmented reality-supported exercise therapy demonstrated improved lower limb functions such as lower limb pain (P = 0.035) and going out by train or bus (P = 0.037) were confirmed in each item of Locomo 25.

pain, and proper feedback to the patients is required to achieve high adherence rates. However, feedback from physiotherapists would be largely due to individual abilities of the attendant physiotherapists and have significant differences in reliability and results [18-19]. Therefore, it is recognized that developing more accurate feedback by using novel technologies could improve treatment outcomes. In our AR-supported exercise therapy, the patients could select the individualized exercise intensity appropriate to their musculoskeletal disorder and physical functioning. By watching the AR polygons, the patients could easily recognize their own movement errors and correct them promptly. Such prompt feedback, which are real-timely presented in the AR space, might contribute to improving patients' adherence to exercise therapy. Since adequate exercise guidance to patients requires profound manpower of physiotherapists and exercise trainers, exercise therapy-assisting systems which have a property to offer adequate exercise guidance automatically and real-timely would be beneficial particularly in the medical field where manpower is limited. The patients who participated in this AR-supported exercise therapy program significantly improved both their balance ability such as standing on one leg and the walking speed. Several lines of evidence suggest that walking speed is directly linked to life prognosis [20-21]. Considering not only the current super-aged society in Japan but also rapidly aging societies all over the world, significant improvement of walking speed by conducting the AR-supported exercise therapy might contribute to extend healthy life expectancy. The AR-supported exercise therapy program successfully demonstrated a wide range of improvements in lower limb muscle strength. Muscle strength of the lower limb was improved of not only proximal muscles but also distal muscles. Distal muscle strength especially affects the ability to adjust gait [22-23], and thereby this would bring improvements of balance ability. Apart from motor function, the AR-supported exercise therapy demonstrated to improve chronic musculoskeletal pain. Since this was a single-arm study with very small numbers of subjects, these findings should be interpreted in a cautious manner. This study successfully demonstrated the feasibility and acceptability of our AR-supported exercise therapy for elderly patients with musculoskeletal pain, and therefore its effectiveness on musculoskeletal disorders and pain should be verified to compare standard exercise alone in the future.

CONCLUSION

We developed the AR-supported exercise therapy system that visually presents contexts of the exercise program and thereby users understand their posture during the exercise therapy. In this feasibility and acceptability study, the elder participants with musculoskeletal disorder successfully accumulated moderate exercise activity on most days of the week and such exercise habits with our AR-supported exercise therapy improved lower limb muscle strength and ability to adjust balance. Improvements in lower limb function might increase walking speed and patients' opportunities for social participation in a future time.

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