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Evaluation of leap motion control for hand rehabilitation in burn patients: An experience in the dust explosion disaster in Formosa Fun Coast

Yah-Ting Wu [a], Kuo-Hu Chen [b,c], Shiun-Lei Ban [a], Kwang-Yi Tung [d], Li-Ru Chen [a,*]

[a] Department of Physical Medicine and Rehabilitation, MacKay Memorial Hospital, Taipei, Taiwan
[b] Department of Obstetrics and Gynecology, Taipei Tzu-Chi Hospital, The Buddhist Tzu-Chi Medical Foundation, Taipei, Taiwan
[c] School of Medicine, Tzu-Chi University, Hualien, Taiwan
[d] Division of Plastic and Reconstructive Surgery, Department of Surgery, MacKay Memorial Hospital, Taipei, Taiwan

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ABSTRACT

Hand burns cause functional impairment. Leap motion control (LMC), a kind of virtual reality games, employs a novel system that provides biofeedback and training of fine motor function and functional skills. In this study, we hypothesized that LMC would improve burned hand function.

Sixteen participants were allocated to either the LMC group or the control group. The LMC group played 20 min identical leap motion video games after 40 min traditional occupational therapy (OT). The control group received traditional OT for 60 min. Both groups received interventions 2 days a week for 4 months.

A series of questionnaires were administered, including BSHS-B, QuickDASH, iADL, and Barthel index. Data on baseline characteristics including joint range of motion (ROM), grip and pinch strength, and scar thickness were obtained. Furthermore, we used the Mann-Whitney U test and Wilcoxon signed-rank test for comparison, as appropriate.

We found improvements in BSHS-B, QuickDASH, and iADL in the LMC group (all $p < 0.05$) compared to those in the control group. In the LMC-trained hand, the ROM of the thumb IP joint and pinch strength increased, whereas the scar thickness over the first dorsal interossei muscle decreased ($p < 0.05$). In conclusion, leap motion training could help patients with hand burns to increase finger ROM, decrease scar thickness, and improve hand function.

Abbreviations: BSHS-B, Burn Specific Health Scale-Brief; QuickDASH, Quick Disabilities of the Arm, Shoulder and Hand; FDI, first dorsal interossei muscle; iADL, Instrumental Activities of Daily Living; LMC, leap motion controller; ROM, range of motion; TBSA, total body surface area.

* *Corresponding author at*: Department of Physical Medicine and Rehabilitation, MacKay Memorial Hospital, No. 92, Section 2, Zhongshan N. Road, Taipei City 10449, Taiwan.
E-mail address: gracealex168@gmail.com (L.-R. Chen).

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1. Introduction

Hand burns limit a survivors' ability to function and carry out daily activities. The dust explosion disaster in Formosa Fun Coast injured 499 people, and most of them were young. Sixty-nine patients were admitted to intensive care units of MacKay Memorial Hospital, Taipei branch, one of the largest medical centers in Taiwan, for resuscitation and acute burn care. Half of them returned to work or school 1 year after burn injury. The remaining patients with severe burn injuries received regular rehabilitation training in MacKay Memorial Hospital, Taipei branch. Disabilities after burns in these young patients bring tremendous burdens to themselves, their families, and the society [1]. Scar management and contractures are critical issues that induce poor body image and both physical and psychological complications [2]. Massage therapy, compression garments, and steroid injections help to reduce the formation of scar tissue and prevent contractures. Rehabilitation is an essential part of burn treatment [3]. However, there are some limitations to traditional rehabilitation, including political, financial, communication, and physical barriers [4,5]. Among these factors, LMC has the advantage of financial and physical barriers such as transportation and accessibility difficulties.

Virtual reality (VR) generates an environment with stereo realistic images and sounds that are simulated through a three-dimensional infrared sensor device. In the last few years, an interest in VR technology for neurorehabilitation has increased with the use of commercially available systems such as PlayStation, Wii, and Xbox Kinect. Leap Motion Controller (LMC), developed in 2013, is a small, low-cost, portable, noninvasive motion capture device that is placed in front of the monitor and connected to a computer through a USB cable. As input data, this device tracks hand and finger positions and movements without contact with the real objects. While swiping, pinching, or grasping, it tracks the movement of users' hands and fingers and displays the interactions on the screen. Some researchers attempted to use the LMC device for motor training of surgeons and rehabilitation of patients with stroke [6,7].

LMC is a new device for fine motor rehabilitation and functional training, and it provides visual and auditory feedback. It promotes upper extremity motor function. Owing to the limitations of traditional rehabilitation, such as manpower demand for manual therapy and suffering from stretching exercise [8], we used LMC games to train and rehabilitate burn patients. Our research group assessed the extent to which LMC improved hand function, scar thickness, range of motion (ROM), and strength of grip and pinch by evaluating questionnaires administered to patients.

2. Materials and methods

Participants recruited were survivors of dust explosion disaster in Formosa Fun Coast; they had severe hand burns and received regular rehabilitation training in MacKay Memorial Hospital, Taipei branch. In total, 15 people died and 484 people were injured after the dust explosion disaster in Formosa Fun Coast. These 484 survivors underwent rehabilitation in different hospitals and institutions after acute burn care. Of them, 69 patients were admitted to intensive care units of MacKay Memorial Hospital, Taipei branch. All participants or their legal guardians read and signed the informed consent, and the institutional review board approved the current study.

Participants were eligible for study recruitment after having undergone surgical and medical treatment for their burns as well as occupational and physical therapy (OT/PT) specific to their impairments. The OT/PT rehabilitation programs were offered during both inpatient and outpatient care.

Additional inclusion criteria were as follows: clear consciousness; ability to sit independently for 30 min; and burns involving bilateral upper extremities resulting in dysfunction, with the need for self-care assistance. The included patients had moderate scar thickness, limited ROM, and impaired strength of grip and pinch. Participants were excluded if they were ventilator dependent; had a history of seizure or dementia, or the muscle power of the upper limbs was rated less than three with a Medical Research Council scale [3,9].

If the statistical power of the study was set at the 0.80 level (thus, β error equals to 0.20) and α error (significance level) was set at the 0.05 level, then the number of samples should be 18–20 according to the formula of sample size determination.

The eligible patients were allocated to either the LMC group or the control group after consents were obtained. The participants had the privilege to decide whether to undergo LMC group or control group therapies. We used the LMC device to train patients with burns on specific finger and hand movements. We instructed subjects of the LMC group to play three leap motion video games including cube grasping, flower petal removal, and balloon or bird shooting (Figs. 1–3). The key movement of the cube grasping game is finger flexion, the flower petal removal game is pinching, and the shooting game is finger abduction and adduction. The LMC group completed 20 min identical leap motion video games after 40 min traditional OT. The control group received traditional OT for

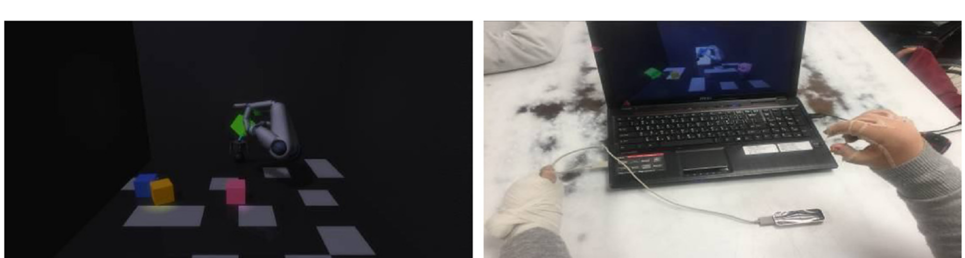

Fig. 1 – Cube grasping game.

Fig. 2 – Flower petal removal game.

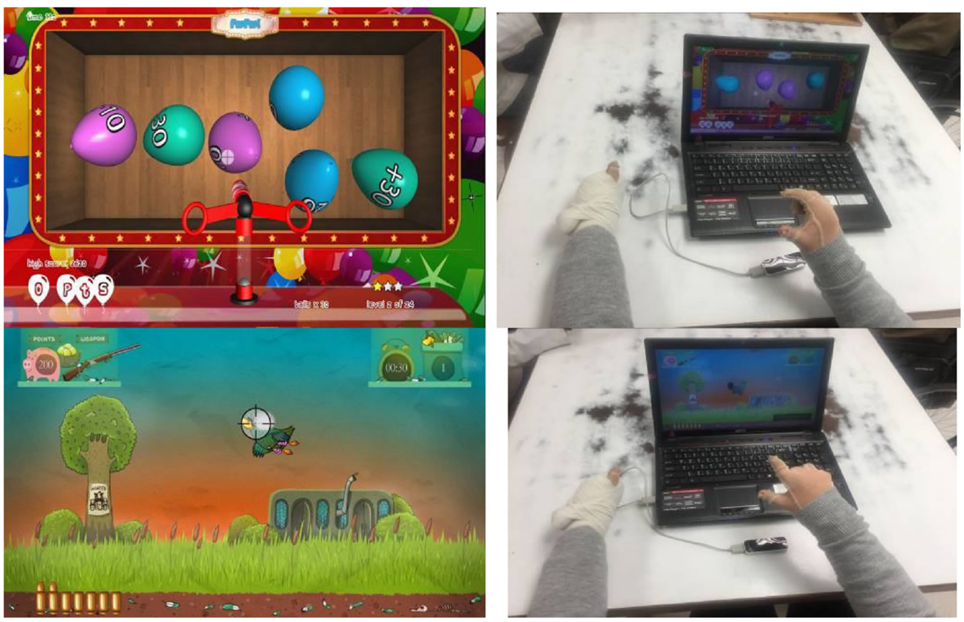

Fig. 3 – Balloon or bird shooting game.

60 min. Both groups received interventions 2 days a week for 4 months in hospitals.

Hand function was evaluated with the following tools: Burn Specific Health Scale-Brief (BSHS-B), Quick Disabilities of the Arm, Shoulder and Hand (QuickDASH), Instrumental Activities of Daily Living (iADL), and Barthel index [10]. These questionnaires were administered to both groups before and after group-specific training. BSHS-B was used to assess for psychological and environmental problems after burns [11]. QuickDASH was used for measuring physical function [12]. iADL was used for assessing the daily function. The BSHS-B is a valid self-rating scale consisting of 40 items in nine domains, namely, heat sensitivity, affect, hand function, treatment regimens, work, sexuality, interpersonal relationships, simple abilities, and body image to evaluate psychological and environmental problems and quality of life after a burn. The QuickDASH score questionnaire contains 11 items and is scored from 1 to 5 on the basis of the symptoms and ability to perform certain functional activities [13]. The iADL questionnaire was used to assess personal care, mobility, and eating.

The treatment subjects had LMC therapy for the right hand and traditional therapy for the left hand. Pre-tests were performed in both hands of participants in the LMC group. Baseline characteristics included ROM (degrees), strength of grip and pinch (pounds), and scar thickness (millimeters). Scar thickness was evaluated at the dorsal wrist, over the first dorsal interossei (FDI) muscle, and on metacarpophalangeal (MCP) joints of the index finger. Post-tests were performed 1 week after the 4 month training. Joint ROM was assessed using an ergometer. Grip and pinch strength were measured using hydraulic dynamometers and pinch gauges. The scar thickness was evaluated by ultrasonography.

SPSS version 22.0 statistical software was used to analyze the data. Demographic data were represented as mean and standard deviation for continuous variables. Baseline demographic data were evaluated using the Fisher exact test for sex and occupational status, whereas the Mann–Whitney U test was used for evaluating age and %TBSA. Comparisons of baseline characteristics between the LMC group and the control group were assessed using the Mann–Whitney U test. Comparisons of differences in outcome between the LMC and control groups were evaluated using the Wilcoxon signed-rank test. The level of statistical significance (alpha) was set at $p < 0.05$. As face-to-face physical measurements were obtained, no data were missing for these 16 participants who completed the study.

3. Results

The participants were allocated to either the LMC group or the control group. The former had LMC trained for the right hand and traditional therapy for their left hand. A CONSORT diagram to describe enrolment as well as recruitment and assessment is shown in Fig. 4. We examined 20 patients for whom both hands were assessed. Four people were excluded from the study. One patient was left because of not meeting inclusion criteria, and the others refused to participate (Fig. 4). Only 16 eligible patients were allocated to either the LMC group (n=8) or the control group (n=8). The 16 participants (10 women and 6 men, aged 18–30 years, >30% TBSA, and a second-to-third degree depth of burns), mean age of 22.8 years, completed the study. Most of the participants were women (n=10, 62%), right-handed (n=15, 94%), and without any chronic illness. The average TBSA of burns was 63% (57.75% ±13.38% in the LMC group and 68.50%±14.90% in the control group, $p>0.05$), and the depth of burn was mostly partial to full thickness. All the participants underwent skin grafts on the burn wounds including both hands, and the difference between burn area and grafting area on the hands of every participant was less than 1% TBSA. Table 1 summarizes the demographic characteristics of patients in the LMC group and the control group, including age, sex, dominant hand, %TBSA, and occupation status. There were no significant differences between the two groups ($p>0.05$), except for age and sex. In the LMC group, seven participants were right-handed and one participant was left-handed. The burn %TBSA of the LMC-trained right hand and the LMC-untrained left hand is also shown in Table 1.

Comparisons of the baseline data between the LMC group and the control group showed no significant differences in BSHS-B, QuickDASH, iADL, and Barthel index ($p>0.05$) (Table 2). After 4 month training, the LMC-trained side demonstrated statistically significant improvement, whereas the LMC untrained side did not show improvement for BSHS-B, QuickDASH, and iADL ($p<0.05$). Barthel index improved in both groups (Table 3).

Paired statistical analysis (using the Wilcoxon signed-rank test) was performed for comparisons between the left and right hands in the same subject of the LMC group. p values (pre-training and post-training) for the right hand (with LMC training) and the left hand (without LMC training) in the same subject after comparisons are listed in Table 4. The measurements included changes in pinch and grip strength (pounds), ROM of thumb IP (degrees), and scar thickness (millimeters). The thumb IP joint ROM and pinch strength increased significantly ($p<0.05$), and the scar thickness above the FDI of the right hand (trained with the LMC device) decreased significantly ($p<0.05$). However, there was no significant improvement in scar thickness on the dorsal wrist and MCP joints of the index finger ($p>0.05$) (Table 4).

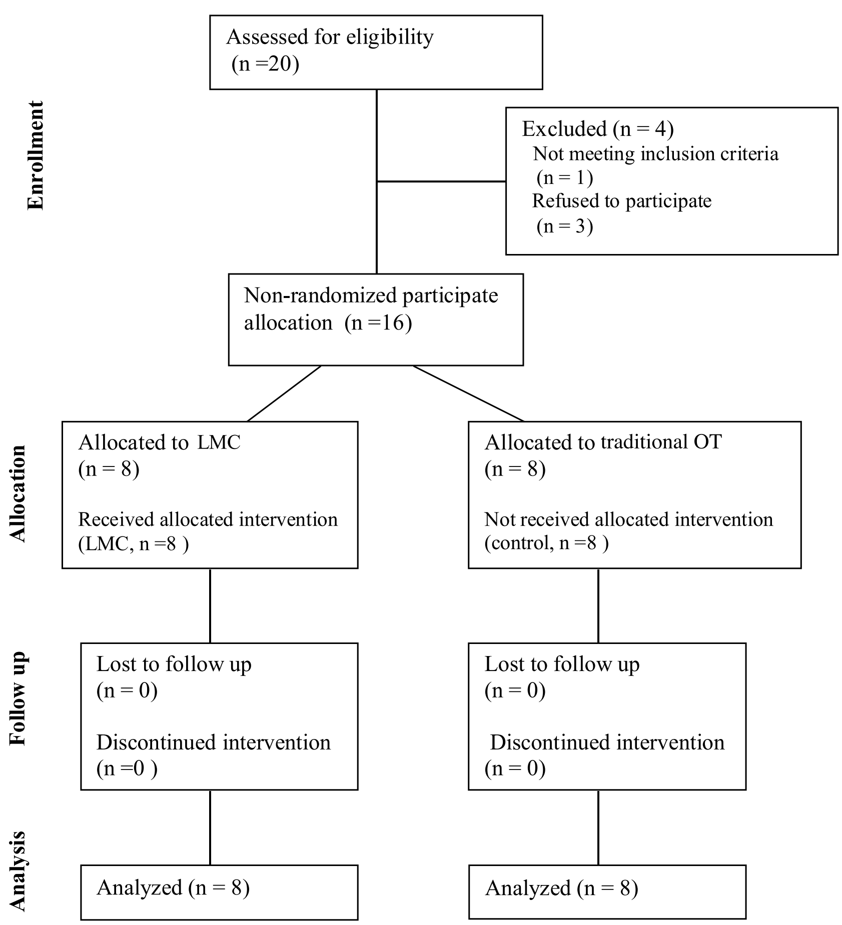

Fig. 4 – A CONSORT diagram showing the flowchart of recruitment, group allocation, and analysis of participants in the study.

Table 1 – Baseline characteristics of the leap motion controller (LMC) and control (traditional occupational therapy) groups.

	LMC group (mean±SD)			Control group (mean±SD)	*p* Value
Age (mean±SD)	21.00±2.93			24.63±3.25	0.040[*,a]
Sex (F:M)	8:0			2:6	0.007[*,b]
Dominant hand (R:L)	7:1			8:0	
Burns					
% TBSA (whole body)	57.75±13.38			68.50±14.90	0.141[a]
% TBSA (upper extremities) (R: LMC-trained side, L: untrained side)	No.	R	L		
	1	8[c]	8		
	2	7[c]	7		
	3	4[c]	3		
	4	2[c]	3		
	5	8[c]	8		
	6	1[c]	3		
	7	5[c]	5		
	8	8[c]	8[c]		
Occupation (student:working)	4:4			2:6	0.608[b]

TBSA: total body surface area; SD: standard deviation.
[a] Mann–Whitney U test.
[b] Fisher exact test.
[c] Dominant hand.
[*] $p < 0.05$.

Table 2 – Baseline comparison of the leap motion controller (LMC) and control (traditional occupational therapy) groups.

	LMC group (mean±SD)	Control group (mean±SD)	*p* Value[a]
QuickDASH	54.29±16.14	44.90±18.27	0.429
BSHS-B	79.50±23.78	80.88±25.08	0.958
iADL	9.25±1.58	13.00±4.87	0.078
Barthel	68.75±22.64	78.75±25.88	0.185

BSHS-B, Burn Specific Health Scale-Brief; QuickDASH, Quick Disabilities of the Arm, Shoulder and Hand; iADL, Instrumental activities of daily living; Barthel, Barthel index.
[a] Mann–Whitney U test.

Table 3 – Comparisons of *p* values obtained from questionnaires within the leap motion controller (LMC) and control (traditional occupational therapy) groups after 4 months of therapy.

	LMC group (mean±SD)	*p* Value[a]	Control group (mean±SD)	*p* Value[a]
QuickDASH	32.38±10.99	0.017[*]	36.00±17.93	0.262
BSHS-B	104.75±24.24	0.036[*]	104.00±15.77	0.069
iADL	18.63±1.85	0.011[*]	15.38±3.54	0.056
Barthel	94.38±6.78	0.012[*]	95.63±4.96	0.042[*]

BSHS-B, Burn Specific Health Scale-Brief; QuickDASH, Quick Disabilities of the Arm, Shoulder and Hand; iADL, Instrumental activities of daily living; Barthel, Barthel index.
[a] From baseline to post-treatment within group.
[*] $p < 0.05$, Wilcoxon signed-rank test.

4. Discussion

As listed in Table 4, The LMC-trained hand demonstrated statistically significant improvement in function and scar status, including scar thickness, ROM, and strength. The scar thickness on the FDI decreased in the LMC-trained hand. The thumb IP joint ROM and pinch strength increased in the LMC-trained hand. In addition, the results shown in Table 3 (with associated *p*-values) indicate that there was a statistically significant difference in Barthel index between pre-training and post-training for the LMC group and for the control group. The changes from pre-training to post-training were statistically significant in QuickDASH, BSHS-B, iADL, and Barthel index for the LMC group. For the control group, only Barthel index showed statistically significant changes. Grossly, the LMC training showed better hand function improvement than only traditional OT. In fact, the control group showed clinical improvement, although it did not show a statistically significant difference.

Table 4 – Comparisons of *p* values of changes (pre- and post-training) in the right hand (with LMC training) and the left hand (without LMC training) for the same patient in the LMC group, after 4 months of intervention.

Groups	Pinch	Grip	Thumb IP ROM	Scar on wrist	Scar on FDI	Scar on index MCP
p Value of the right (trained) hand	0.011*	0.012*	0.016*	0.233	0.011*	0.107
Pretraining mean value	8.875	17.625	50.000	4.375	4.638	3.700
Post-training mean value	11.750	30.750	63.125	4.150	4.075	3.350
p Value of the left (untrained) hand	**0.228**	**0.012***	**0.059**	**0.888**	**0.866**	**0.674**
Pretraining mean value	9.125	13.500	53.125	3.663	4.725	3.600
Post-training mean value	11.125	31.000	60.000	3.375	4.500	3.475

The measurements included changes in degrees for ROM (thumb IP) and changes in millimeters for scar thickness.
Mean values assessed were rounded off to three decimal places.
IP ROM, interphalangeal joint range of motion.
FDI, first dorsal interossei muscle.
MCP, metacarpophalangeal joints.
* $p < 0.05$, Wilcoxon signed-rank test.

In this study, we could not include a large number of patients as the sample in clinical practice in spite of enrolling all patients as possible as we could. The number of potential participants was not adequate because the patients must survive the catastrophic event, pass the acute stage of burns, and then be willing to participate in the study.

However, participants in the current study had the privilege to decide whether to undergo LMC or not. Finally, younger girls were more willing to undergo LMC training and tended to play LMC games regularly for better functional results or some other unknown reasons. It resulted in the significant differences in age and sex between the two groups ($p < 0.05$), and these differences may affect our results.

With regard to the mechanisms of VR, previous studies found that VR visual-motor tasks activate the ventrolateral prefrontal cortex [14]. While performing LMC, early attention components increase latencies in the occipital lobe for visual sensory, whereas latencies decrease in the frontal lobe for attention and action planning [15]. The LMC device detects hand motion, which is proven to encourage patients in rehabilitation to cooperate and perform therapeutic exercises [16]. VR promotes the recovery of proprioception in patients with stroke [17] and enhances upper limb movements and skills in children with cerebral palsy [18]. By performing activities in VR, patients can improve their driving skills for powered wheelchairs maneuvers [19]. The VR system is suitable for home-based hand or finger rehabilitation [20]. In neurology, three LMC algorithms are proposed for characterizing tremor amplitudes [21]. In surgery training, the LMC device captures the movement of fingers using instruments in a laparoscopic box simulator [22]. State-of-the-art LMC training systems are already available for training for surgeons, with simulated natural interactions in a surgical intervention [23]. However, there remain some challenges for the configuration of the LMC device to adapt to the user's requirements [24]. Among numerous studies on VR technology for surgery training for surgeons and motor training for stoke rehabilitation, there are few studies about the application of LMC for burn patients. Additionally, LMC takes advantage of noncontact between the user's hands and the device for fine motor training, which is critical in the training of burn patients with unhealed wounds on their hands.

Focusing on the traditional rehabilitation of burn patients, we emphasize scar managements with splinting, stretching, and motor training to improve ROM and hand function [25]. Splinting is an essential feature of acute burn care to maintain functional position and protect wounds, and it also contributes to joint contracture. LMC games encourage burn patients to move their hands and fingers as early as possible. Without direct body contact, the LMC device has the advantage to avoid contact contamination at the burn wounds and is easy to use during the subacute and chronic periods of burn management.

The traditional measurements of hand function for burn patients are ROM as well as grip and pinch strength [26]. Several hand motor exercises can improve ROM and grip and pinch strength. LMC is a new device to capture and record hand movements, with validation of wrist flexion and extension and radial and ulnar deviation [27]. The LMC is reliable for assessing motor performance in pointing tasks [28]. Moreover, the reachable space from fingertip positions with the LMC device may be deduced by a computer [29]. We proposed that patients with burn injuries would improve their hand function after LMC training. In our study, the LMC-trained hand showed improved thumb IP ROM and grip and pinch strength. A previous study showed better ROM of shoulder flexion and abduction and elbow flexion while playing a VR game with Microsoft Xbox [30]. Yeh et al. used a robot-assisted VR training system for pinch-grip training to assess its therapeutic effect in patients with chronic stroke [31]. Our study is the first research using VR interventions to train small joints such as finger joints of patients with burn injuries. Three leap motion games were applied in our study, namely, cube grasping game, flower petal removal game, and balloon or bird shooting game. These games underscore thumb and index finger flexion–extension and abduction movement. After LMC training, with the video game simulation, the ROM of thumb IP joint improved. We found that the scar thickness decreased at the FDI of the LMC-trained hand, thereby allowing more abduction and adduction of the first web space. Nonetheless, scar thickness at the wrist and MCP joints of the index finger showed no statistically significant improvement after LCM training. The reason for the nonimprovement may be due to other essential factors that cause progressive scar formation and lack movements in these injured regions during their activities of daily living [32].

The BSHS-B and QuickDASH questionnaires include hand function evaluations and reveal improvement after LMC training. As shown in Table 3, the implication is that the LMC-trained hand demonstrated a statistically significant improvement, whereas the untrained hand did not show improvement. When performing activities of daily living with Microsoft Xbox, Adams et al. also validated the measures of upper extremity motor function [33].

Indeed, most of our participants were right-handed. The hand dominance might have a confounding effect. Ideally, the best way to conduct this study is that half the participants should be trained in the dominant hand and another half trained in the nondominant hand. Although there were some limitations to our study, such as small sample size and nonrandom patient allocation, this is the first report of the use of LMC training for patients with severe hand burns. One advantage of our study was the homogeneity of the participants.

5. Conclusion

In conclusion, patients with severe hand burns who undergo leap motion training would have better improvement in ROM, scar management, and hand function. LMC creates a natural noncontact interface for motor rehabilitation, which could provide an application in a new era of research in the field of burn rehabilitation. However, quality training and individualized software designs are essential, depending on practitioner demand. Future validation studies of LMC motion tracking are needed.

Acknowledgments

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