American Journal of Case Reports

e-ISSN 1941-5923
© Am J Case Rep, 2019; 20: 1636-1642
DOI: 10.12659/AJCR.918521

Received: 2019.07.05
Accepted: 2019.08.27
Published: 2019.11.07

Effects of an Immersive Virtual Reality Environment on Muscle Strength, Proprioception, Balance, and Gait of a Middle-Aged Woman Who Had Total Knee Replacement: A Case Report

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

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Conflict of interest: None declared

Patient: Female, 62
Final Diagnosis: Knee joint osteoarthritis
Symptoms: Knee pain • range of motion limitation • swelling
Medication: —
Clinical Procedure: —
Specialty: Rehabilitation

Objective: Unusual or unexpected effect of treatment

Background: The purpose of this case study was to apply a training program using virtual reality to a middle-aged woman who had total knee replacement surgery and to investigate its effects on her muscle strength, proprioception, balance, and gait ability.

Case Report: The subject who participated in this study was a 62-year-old woman, who had been diagnosed with moderate osteoarthritis and had a total knee replacement. Post-operative treatment consisted of virtual reality training along with range of motion exercise of the knee joint, light quadriceps isometric exercise, and conventional physical therapy. This also included thermal and electric therapy for pain control conducted on 10 occasions (5 times a week for 2 weeks). Total treatment time, which included 30 min of conventional physical therapy, was 60 min. Measurement of the subject's lower extremity muscle strength after intervention decreased to 9.43 s, and the error in proprioception decreased to 1.5°. In addition, balance score increased to 56 points, and the time taken to measure gait ability decreased to 9.87 s.

Conclusions: The patient responded positively to rehabilitation using virtual reality, and her muscle strength, proprioception, balance, and gait ability improved. These results suggest that the application of rehabilitative training through virtual reality for total knee replacement patients warrants further study and consideration.

MeSH Keywords: Arthroplasty, Replacement, Knee • Case Reports • Virtual Reality Exposure Therapy

Full-text PDF: https://www.amjcaserep.com/abstract/index/idArt/918521

Indexed in: [PMC] [PubMed] [Emerging Sources Citation Index (ESCI)] [Web of Science by Clarivate]

Background

Degenerative osteoarthritis is a chronic disease in the elderly population and is a disease that not only causes physical problems such as pain and dysfunction but also significantly reduces the quality of life of the elderly [1]. The prevalence of degenerative osteoarthritis is 53% in the population aged over 65 years, and women are affected more than men. It occurs in all joints, with 82.6% of cases associated with the knee joint that bears more weight [2]. The knee joint is a complex structure that includes several joints. It is the joint between the femur and the tibia, which are two of the longest bones in the body. The bio-lever arm is long, resulting in great power and moment. It is a joint for which both stability and mobility are required. For example, bearing weight and helping to move through motions in multiple directions render it more vulnerable to degenerative injuries [3,4].

Total replacement of the knee joint is a surgical intervention conducted to resolve pain in the joint and to address the pathological cause of late-stage, degenerative osteoarthritis of the knee joint. This is done when conservation methods such as medication and physical therapy no longer effectively increase the range of motion of the joint and reduce pain [5,6].

Total knee replacement involves replacing the knee joint surface with an artificial metal substitute due to the aging of the knee joint surface. A number of complex issues make it difficult to choose the optimal time for surgery. For example, in older patients, early surgery is often performed if other underlying diseases such as hypertension and diabetes mellitus are present [7].

The strength of the lower extremity muscle of total knee replacement patients is often weak prior to surgery. As a result of surgery, their muscle strength decreases rapidly and muscle atrophy occurs, causing increased instability of the joint due to a lack of proprioception and balance. The risk of injuries, such as falling, increases [8,9]. Therefore, fast recovery and a return to daily life, along with safe and systematic rehabilitation training is essential for quickly restoring the muscular functions of these patients. Moreover, a delay in exercising after surgery has detrimental effects on the joint proprioception, muscle strength, and balance. This can cause joint malfunction, so it is imperative to prevent it from occurring [10].

Recent advances in technology have provided new methods that may have an effect on rehabilitation exercise by enabling various tasks to be accomplished in virtual reality. Virtual reality refers to a user's interaction with images on a screen while performing a variety of motions by moving or operating virtual objects in a simulated environment [11,12]. Through the use of virtual reality, patients can feel interested and motivated. Thus, it is a novel intervention method that can increase access to and control over exercise with feedback through visual, auditory, and tactile senses [13–15].

Previous studies using virtual reality have only been done in patients with a damaged central nervous system and in the elderly. There are no reported studies of subjects with diseases of the musculoskeletal system and those who have had surgery. In this study, we applied a training program using virtual reality with a middle-aged woman who had total knee replacement surgery, and we investigated its effects on her muscle strength, proprioception, balance, and gait ability.

Case Report

History and systems review

The subject of this study was a 62-year-old woman. Her height was 152.4 cm, her weight was 62.10 kg, and her BMI was 26.74. She has been maintaining her weight for 20 years. She has been dominantly using the right upper and lower extremities.

Due to knee joint pain on both sides beginning 10 years ago, she was diagnosed with osteoarthritis at a private clinic. She had received intermittent physical therapy as a conservation method and injections into the knee joint. As her knee pain grew worse 7 to 8 years ago, she was diagnosed with moderate right knee joint osteoarthritis (K-L grade II) at B Hospital and received a total knee replacement. Figure 1 shows radiographic images of her knee before and after the operation (Figure 1). She was referred to physical therapy.

The subject did not have any previous issues with nerves or psychological disorders, no musculoskeletal system diseases other than degenerative osteoarthritis, no neurological system diseases such as dizziness, and no previous total knee replacement procedures.

The patient's goal was to reduce pain, be able to walk without any gait assistance device, and recover mobility in order to return to her previous level of housework.

The subject understood the study purpose and method and signed the participation agreement. This study was approved by the Institutional Review Committee of Kyungnam University (1040460-A-2019-010).

Tests and measures

Virtual reality training was applied to the subject on 10 occasions, with 5 sessions per week for 20 min each session over the course of 2 weeks. Following each intervention,

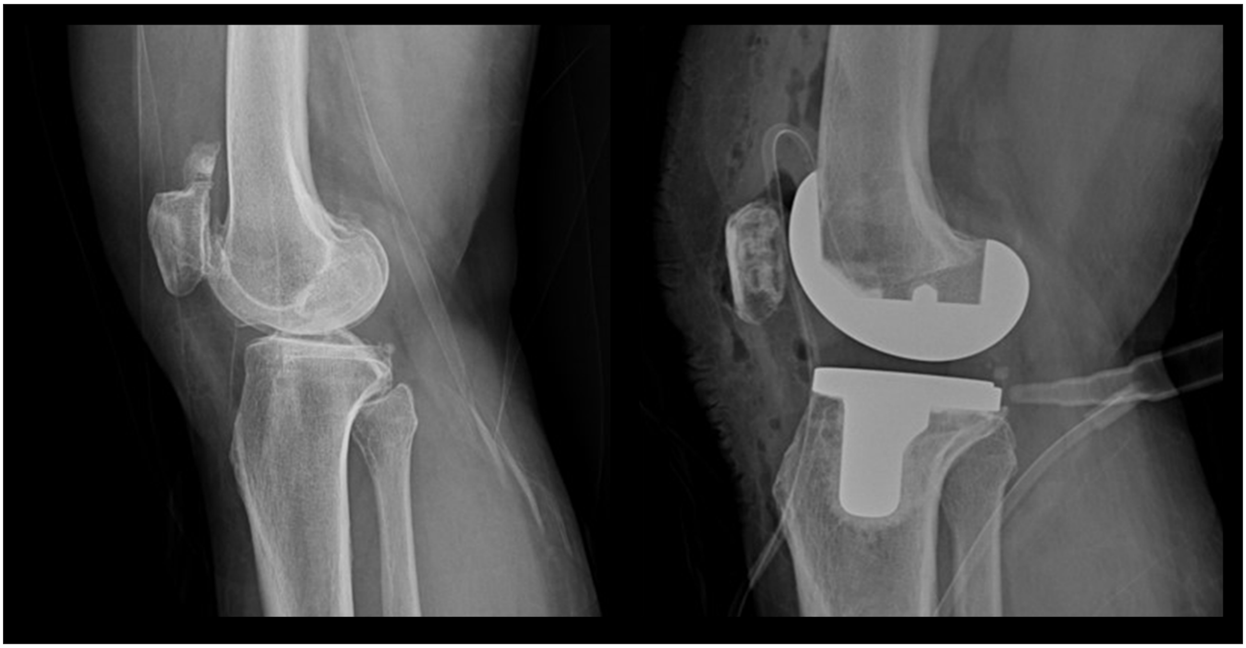

Figure 1. Radiologic imaging of the subject's knee.

tests and measurements were conducted on muscle strength by: 1) the Sit-To-Stand (STS) test, 2) proprioception by measuring the difference in sensing knee joint position using a smartphone angle meter application, 3) balance using the Berg Balance Scale (BBS), and 4) gait ability using the 10-m walking test (10MWT).

In the first preoperative STS test, used to assess the lower extremity muscle strength, a value of 12.45 s was recorded. This test measures the time required for completely sitting and standing 5 times, using a chair with standard height (46 cm) and without armrests. This method is used mainly for evaluating the lower extremity muscle strength and balance ability [16,17]. This means that the shorter the time required for completely sitting and standing 5 times, the greater the strength of the lower extremity. In a study of the STS's test-retest reliability with arthritis patients, the ICC was 0.96 [18].

The deficit of angle error measurement for proprioception was 3.3°. This test is an angle reproduction test method used to measure the lower extremity's proprioception, in which the subject makes an unassisted flexure angle of the knee joint and holds it for 3 s. The examiner records the joint angle and measures the error when the patient reproduces the joint angle. A decrease in the measured angle error means that the joint position sensation has increased. To record an accurate angle, a smartphone protractor application (protractor and angle gauge, Toolkit, Korea) was used [19]. The reliability of the measurements of this smartphone protractor application is ICC=0.76–96 [20].

BBS scores were used to assess balance, based on the performance of 14 common tasks and functional movements experienced in daily life. These tasks are regarded as the primary outcome measure and each task is rated on a 5-point scale (0–4), with the maximum score of 56 indicating that balance function is within the normal range [21,22]. The intra- and inter-tester reliability are r=0.98 and r=0.97, respectively [23].

The 10MWT test was used to measure gait speed while walking. This is a functional assessment tool commonly used in clinical practice. A 14-m straight-line distance was marked between 2 points, and the subject walked with assistance at a comfortable speed. The first 2 m and the last 2 m of the walk were excluded from measurement so as not to consider acceleration and deceleration. The gait time for the 10-m distance was measured 3 times with a stop watch to obtain the average. The average time was 9.24 s. The test-retest reliability of this test is ICC=0.95–0.96 [24].

Clinical impression

The subject that participated in this study had been diagnosed with moderate right knee osteoarthritis (K-L grade III) and had a total knee replacement. She had pain and swelling due to the surgery and a limited range of motion of flexion and extension of the treated knee joint. In addition, she did not have normal weight bearing, so she did not have an independent gait and required a walker. Her sense of balance decreased in a one-legged stance test. In a comparison of muscle strength prior to surgery, her post-surgery muscle strength decreased (from 12.45 s before surgery to 25.63 s after surgery), and her

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Figure 2. PlayStation virtual reality game (Fruit Ninja).

proprioception also decreased (from 3.3° before surgery to 4.3° after surgery). In addition, her balance after surgery decreased (from 56 points before surgery to 44 points after surgery), and her gait ability also decreased (from 9.24 s before surgery to 18.74 s after surgery).

Interventions

The VR equipment used as intervention in this study consisted of a PlayStation 4Pro (CUH-7117B, Sony, Japan), USB Connection-type Motion Tracking Camera (CUH-ZEY2, Sony, Japan), Head-mounted display (CUH-ZVR2, Sony, Japan), and Motion Controller (CECH-ZCM2G, Sony, Japan). For display, a 42" LCD TV video display terminal was used.

Fruit Ninja was selected as a game for virtual reality training (Figure 2). In this game, the subject wears a head-mounted display and the motion recognition sensor detects his or her head movements. The range of vision on the screen moves as the subject shakes his or her head. Using a controller that simulates a knife, the subject performs the task of cutting fruits flying from the left and right of the screen while barefoot under the care of a therapist. This motion enabled: 1) training of the subject's lower extremity using the shapes of weight bearing and 2) weight shifting, using the lower extremities on the left and the right. As the overall experiment progressed, the subject was allowed to adapt to virtual reality training with 10 min of practice and description before the experiment. Virtual reality training was conducted for 20 min, and dizziness and fatigue was prevented by providing 2-min breaks.

The total time required, including 30 min of conventional physical therapy, was 60 min. The conventional physical therapy was conducted for 30 min by the same therapist, and it consisted of knee joint range of motion exercises, light quadricep isometric exercise, and thermotherapy and electrotherapy for pain control.

Results

Changes in muscle strength, proprioception, balance, and gait are shown in Table 1. In the preoperative STS test, the subject had a score of 12.45 s. It was 25.63 s after the initial intervention and decreased to 21.96 s at the second session, 19.47 s at the third session, 19.40 s at the fourth session, 17.60 s at the fifth session, 14.42 s at the sixth session, 11.95 s at the seventh session, 9.76 s at the eighth session, and 9.43 s at the ninth session. Muscle strength in the lower extremity increased by approximately 32% from the start of the intervention to the end of the study. In the preoperative proprioception test, the mean error value between the target angle and measurement angle was 3.3° for 3 sessions. It was 4.3° after the first intervention and decreased to 3.3° at the second session, 2.3° at the third session, 2.3° at the fourth session, 2° at the fifth session, 1.3° at the sixth session, 1.3° at the seventh session, 2° at the eighth session, and 1.5° at the ninth session. The difference between lower extremity proprioception before starting the intervention and proprioception at the end of the intervention increased by approximately 45%. In the BBS test,

Table 1. Outcome on the muscle strengthening, proprioception, balance, and gait.

Variables/sessions	Pre-Op	1	2	3	4	5	6	7	8	9
STS (sec)	12.45	25.63	21.96	19.47	19.40	17.60	14.42	11.95	9.76	9.43
% Value (%)		–105	–83	–56	–55	–41	–15	4	22	25
Proprioception (°)	3.3	4.3	3.3	2.3	2.3	2	1.3	1.3	2	1.5
% Value (%)		–30	0	30	30	39	60	60	39	55
BBS (score)	56	44	51	53	51	52	53	54	54	56
% Value (%)		–22	–9	–5	–9	–7	–5	–4	–4	0
10 m walking test (s)	9.24	18.74	13.01	12.87	15.04	12.48	12.23	10.34	10.71	9.87
% Value (%)		–103	–40	–39	–38	–35	–32	–11	–12	–6

Op – operation; STS – sit-to-stand; BBS – Berg Balance Scale.

the preoperative score was 56 points. It was 44 points after the first intervention and increased to 51 points at the second session, 53 points at the third session, 51 points at the fourth session, 52 points at the fifth session, 53 points at the sixth session, 54 points at the seventh session, 54 points at the eighth session, and 56 points at the ninth session. Balance ability at the end of the study recovered to that prior to surgery. Using 10MWT as a preoperative gait test, the subject scored 9.24 s. The score was 18.74 s after the initial intervention, decreased to 13.01 s at the second session, 12.87 s at the third session, 15.04 s at the fourth session, 12.48 s at the fifth session, 12.23 s at the sixth session, 10.34 s at the seventh session, 10.71 s at the eighth session, and 9.87 s at the ninth session. Gait ability at the end of the study had recovered to a level similar to that prior to surgery.

Discussion

This is the first case study to investigate the effects of an immersive virtual reality environment on muscle strength, proprioception, balance, and gait in a middle-aged woman who underwent total knee replacement. The immersive virtual reality environment used in this study was conducted for 2 weeks, and as the number of interventions increased, muscle strength and proprioception improved, along with balance and gait ability.

In a study of 50 total knee replacement patients, Alice et al. [25] found a lack of extension and flexion muscle in the knees, and proposed the need for an efficient exercise program to recover the normal function of the knees. Comparison with previous studies may be difficult as our study deals with the effects of an immersive virtual reality environment with total knee replacement patients on the improvement of muscle strength. There are few studies on lower extremity muscle strengthening using virtual reality training; however, one study showed that such training in a home care setting resulted in increased lower extremity muscle strength in incomplete spinal cord injury patients [26]. Another recent report demonstrated that virtual reality training increased lower extremity muscle strength in a local community of the elderly [27]. These results support the concept that virtual reality training has a positive effect on lower extremity muscle strength.

According to Torres et al. [28], joint position sense plays a very important role in inducing and stimulating voluntary and involuntary motions by transmitting basic information to the motor control area like balance or vestibular sense. However, osteoarthritis patients have decreased joint position sense. Moreover, total knee replacement patients had further decreased joint position sense after surgery than before total knee replacement [29]. This study found proprioception may be improved in the total knee replacement patient through an immersive virtual reality environment. This result is similar to that of Deblock-Bellamy et al. [30], who showed that virtual reality training improves proprioception in patients with peripheral nerve system injury. It is evident that this positive result may arise from prompt feedback through the vision's activation of proprioception [31].

In this study, there was an increase in balance in the total knee replacement patient through an immersive virtual reality environment. In other studies, Duque et al. [32] reported that balance ability significantly increased in elderly subjects who completed a virtual reality training program, and Song et al. [33] reported that virtual reality training using visual feedback resulted in significant differences in sensing weight shifting and balance in healthy adults. These results suggest that virtual reality training produces a dynamic motion that can increase muscle strength due to trunk and lower extremity motion control and weight shifting through upper extremity motion. Likewise, the speed of weight shifting increased, as did the number of times deviation occurred from the center body of the stable support base [34]. Increased activity of the body induces an increase in joint proprioception in addition to muscle strength and an increase in corresponding balance control capability [35].

Using 10MWT to examine changes in gait, there was an improvement after each intervention. Elderly patients that receive total knee replacement have about a 69% lower gait speed than a healthy elderly person [36], and most total knee replacement patients exhibit a slow speed gait and have a limitation in knee flexion in all sections of stance and swing phase [37]. They have a temporally shorter swing phase gait pattern during gait cycle and an excessive flexion moment in stance phase relative to swing phase [38]. This is the body's adaptation to prudent gait pattern to increase gait stability and decrease the risk of falling [39,40]. Baram and Miller [41] reported that virtual reality training noticeably increased gait speed in multiple sclerosis patients and that it could decrease the limitation of daily life motions. Lamontagne et al. [42] and Yang et al. [43] administered a virtual reality training program to stroke patients and also reported that gait speed significantly increased in all of them. This supports the result of our study that virtual reality training has a positive effect on gait ability. Furthermore, as shown in the results of our study, muscle strength and balance increased through virtual reality training and increased the ability to support the motion of weight falling on the lower extremity while walking [44,45]. The results of this study are consistent with a study reporting that there was a significant correlation between balance and gait speed [46].

In the present study, we found that training using an immersive virtual reality environment brought about positive changes

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in muscle strength, proprioception, balance, and gait speed of a total knee replacement patient. However, the results of this study cannot be generalized since this study is a case report involving a single patient. However, this study is important in that it is the first study using an immersive virtual reality environment as an intervention tool for a total knee replacement patient with moderate osteoarthritis. Although the positive potential is evident, a follow-up study should be done to analyze the effects of training using an immersive virtual reality environment in a larger cohort of patients.

Conclusions

The results of this case report suggest that virtual reality training may be an effective intervention for muscle strength, proprioception, balance, and gait of middle-aged women who had total knee replacement surgery. However, this case report has several limitations. Therefore, future studies to investigate the use of a virtual reality environment for total knee replacement patients are warranted.

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