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Impact of Using a Robot Patient for Nursing Skill Training in Patient Transfer

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Abstract—In the past few decades, simulation training has been used to help nurses improve their patient-transfer skills. However, the effectiveness of such training remains limited because it lacks effective ways of simulating patients' actions realistically. It is difficult for nurses to use the skills learned from simulation training to transfer an actual patient. Therefore, we developed a robot patient that could simulate the behavior of patients' limbs for patient-transfer training. This study examined the performance of the robot used in training and evaluated its training effectiveness. Four nursing teachers individually transferred the robot patient and then scored the robot patient's ability to simulate patients' actions and its suitability for skill training. An experiment using pre-post control group design was carried out to examine the robot patient's training effectiveness compared with the human simulated patient. The participants were 20 nursing students and one nursing teacher who was responsible for scoring the students' skills in the pre-test and post-test. All of the students were assigned to train with either the proposed robot patient or a healthy person simulating the patient. The results show that all four nursing teachers regarded the robot patient's actions as realistic. In addition, all four teachers agreed that the robot patient was suitable for skill training. The results also show that the proposed robot patient is more challenging than the current method, which employs a healthy person to simulate the patient. Significant skill improvement ($p < 0.01$) was observed in the experimental group when transferring the robot patient.

Index Terms— Computer uses in education, Educational technology, Training, Robot patient.

1 Introduction

Interacting with a patient's limbs is a major challenge for nurses transferring patients from, for example, a bed to a wheelchair. These tasks involve many complicated interaction procedures, and because many patients suffer from mobility problems, cognitive disorders, or skeletal deformations, they may not fully cooperate during patient transfer. A patient's actions (e.g., swaying while standing, hugging a nurse's shoulder weakly) could increase the difficulty of the task. In order to ensure patient comfort and safety, before undertaking patient transfer in hospitals, nurses must be familiar with likely patient actions and must improve their ability to deal with the behavior of patients' limbs. Clinical practice certainly helps to improve patient transfer skills. However, when unskilled nurses perform the task, there is a high risk of injury for patients. In addition, the inappropriate operation also raises the risk of injury, in particular lower back pain, to the nurses [1], [2], [3]. Therefore, it is necessary to develop an effective way to simulate patients' actions in training and to enable nurses to practice patient transfer skills.

A stationary mannequin [4] is a common means of simulating a patient during training. Stationary mannequins have been successfully used in medical training, including cardiac assessment training [5], trauma resuscitation training [6], and airway skills training [7]. These simulated patients mimic a real patient's physical characteristics, such as heartbeat, sphygmus, breath, and bleeding. Previous studies confirm that using such mannequins to simulate a patient's performance during training enhances the effectiveness of the training [8], [9], [10], [11], [12]. However, none of these stationary mannequins is able to simulate the actions of patients' limbs. As a result, existing stationary mannequins cannot be effectively used for patient-transfer training.

Currently, patient-transfer training employs healthy people to play the role of patients [13], hereafter referred to as *human simulated patients*. Each student is often paired with another student, one assuming the role of the nurse and the other assuming the role of the patient during patient transfer. However, the effectiveness of this kind of training remains limited [13], [14] as the students cannot simulate patients' actions appropriately [15], [16]. Based on discussion with the nursing teacher, several disadvantages of this form of training are summarized. First, it

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is difficult for healthy people to simulate the strength of actual patients suffering from muscle weakness. As a result, simulation training cannot make nurses fully familiar with likely patient behavior. Second, human simulated patients usually provide extra strength to support their body weight (when standing up, for example). As a result, the training is insufficient because it does not allow a novice nurse to develop the strength and appropriate posture necessary to support a patient's body weight. Third, the human simulated patient may unconsciously assist the trainees to complete the tasks. For example, when trainees perform inappropriate postures or actions that might lead a real patient to fall down, the human simulated patient may provide additional support instinctively. Trainees therefore may have difficulty recognizing their inappropriate performance and correcting it during the simulation training. In summary, the current methods hinder trainees' abilities to develop skills for real patient transfers. If the training conditions are easier than the real task, then trainees do not receive sufficient training to improve these skills. In addition, inappropriate simulation makes it difficult for trainees to become familiar with patients' likely actions.

Therefore, there is immense potential in using robotics to develop effective alternative ways to simulate patient actions. A robot can be programmed to simulate the required actions in a way that can be objectively and quantitatively measured. In the past few decades, many studies have proposed robotics-based methods of simulating a patient's performance to support medical training. However, the effectiveness of using robotics in training has not yet been fully evaluated.

In some studies, a haptic simulator was designed to simulate the feeling of touching a patient's real tissue. Inoue et al. [18] developed a haptic device using flexible sheets to simulate the softness of an abdomen for abdominal palpation training. Sutherland et al. [19] proposed an augmented reality haptic training simulator for spinal needle procedures. Spillmann et al. [20] used adaptive space warping to enhance passive haptic in an arthroscopy surgical simulator. Yu et al. [21] designed a haptic interface for a gastrointestinal endoscopy simulation. Tokuyasu et al. [22] proposed a device to simulate the feeling of touching cardiac muscle. Gerling et al. [23] proposed a training simulator for clinical prostate exams.

Other researchers have focused on simulating a patient's facial expression for medical diagnosis training [24], [25]. In another study, a visual servo system was introduced into a robot to simulate the patient's acts of gazing at the nurses or turning away during injections [26]. Furthermore, several studies have designed robot joints to simulate the behavior of a patient's limb joints when struck [27], [28], [29], [30], whereas in [31], wearable robot joints were developed to help a healthy person to simulate crepitus. In another work [32], a robot patient was used to simulate the behaviors (e.g., moving tongue, salivation) of a patient's oral cavity for dental training. In addition, Takanishi et al. [33] developed a robot patient for airway management training.

However, among these previous studies, little attention has been paid to simulate the behavior of patient's limbs, while other works have only focused on the action of a single joint [26], [27], [28], [29], [30], [31]. The use of robots to simulate the behavior of patients' limbs in nursing training remains limited, and its effectiveness still lacks empirical evidence.

Therefore, this study focuses on the potential of using robots to simulate patients' actions to enhance the effectiveness of nursing training. We improved the robot patient's hardware over that of the former version [34] and then examined the effectiveness of using the robot patient in patient-transfer training.

In our previous works [34], we developed a robot patient for patient-transfer training. The robot was designed to simulate the actions of the patients' limbs, including actively hugging, continuous standing, passively standing up, and sitting down. We have proved that the nursing teacher could apply their nursing skill on the robot during patient transfer. However, we have not yet examined the effectiveness of using the proposed robot patient for the purposes of training. Nursing teachers' attitudes towards the robot patient have also not yet been evaluated.

According to the nursing teachers' comments in the previous study [34], we designed the new upper limbs of the robot patient and improved the robot patient's performance in simulating the patient's act of hugging. In addition, one degree of freedom (DOF) was added to the trunk in order to improve the patient's performance in bending back.

The main contribution of this paper is to provide the first evaluation of the effectiveness of using a robot patient in patient-transfer training.

In this study, we conducted experiments to explore the impact of using a robot patient in patient-transfer training, including the robot's performance and its training effectiveness.

The remainder of the paper is structured as follows. Section 2 describes the process of the patient transfer. Section 3 details the functions of the robot patient and the newly designed upper limbs, including the mechanical structure and control methods. Section 4 describes the experiment design and the evaluation methods employed in this study, and then outlines the results. Section 5 discusses the results in detail. Section 6 concludes the paper.

2 Patient Transfer

Patient transfer is one of the most difficult nursing tasks [35] because it includes complicated procedures for interacting with patients' limbs. Fig. 1 depicts the process of patient transfer [36], [37]. There are six steps: preparing the wheelchair and adjusting the patient's sitting position, assisting the patient in hugging, assisting the patient in standing up, assisting the patient in turning, assisting the patient in sitting down, and adjusting the patient's sitting position in the wheelchair. All the steps are related to limb interactions between the nurses and the patients.

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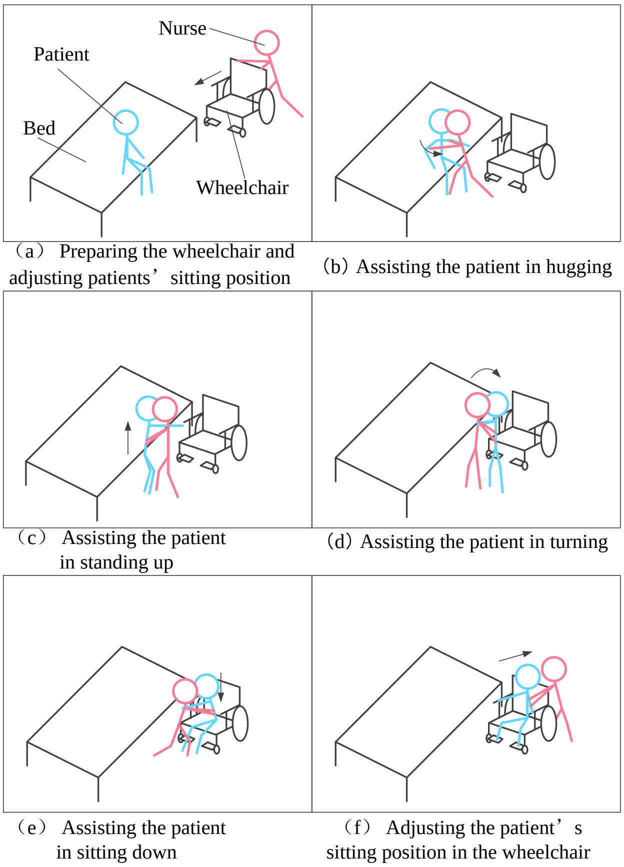

Fig. 1. Steps of patient transfer

3 ROBOT PATIENT

3.1 Joint Configuration of the Robot Patient

The robot patient was developed from a previous version [27]. This new version included newly designed upper limbs and an increase of one DOF in the trunk.

The robot patient has 17 DOFs. Each limb has four DOFs, and the trunk has one DOF. The rotation ranges of all of these joints are the same as those in human joints [38].

The upper limbs' DOFs were increased to four, so that all of the joints were able to rotate actively using the RC servo, whereas the former version [34] had three DOFs and only one active joint.

The remaining joints of the lower limbs and the trunk were passive joints. All of these joints were installed without an actuator, except for the knee joints, which were installed with electromagnetic brakes.

The height of the robot patient is 160 cm, and its weight 30 kg.

3.2 Hardware of the Robot Patient

3.2.1 Upper limbs

In order to simulate the active hugging action, the shoulder joints and the elbow joint have to be able to rotate actively. Therefore, an RC servo (Futaba Co., Ltd.) was installed in each joint of the upper limbs (Fig. 2). The RC servo was able to work in position because there is an angle sensor inside the RC servo. Each joint can be controlled in order to maintain position or to rotate to the required position with the necessary speed (the maximum speed is 60 °/s). We planned each joint's position such that the robot patient was able to simulate the action of hugging. The control method is detailed in Section 3.3.

To simulate the strength of the patient when hugging, the continued output torque of the RC servo was carefully selected. In our design, we set the torque at 3.2 N m. This is approximately 10% of the average level of a healthy human and is just sufficient for the upper limbs to oppose gravity in order to actively hug.

3.2.2 Lower limbs

The lower limbs of the robot patient have to be able to simulate a weak patient's tendency to passively extend and fold their lower limbs when standing up and sitting down with the nurse's assistance. The robot patient also has to simulate a patient's standing instability during assisted turning. Therefore, all joints of the robot's lower limbs were designed to be passive joints. The knee joints were installed with electromagnetic brakes (Miki Pulley Co., Ltd.) (Fig. 2), whereas the other joints were installed without actuators. As the robot patient stood up or sat down with the assistance of a nurse, the electromagnetic brakes were released and the lower limbs passively extended or folded. The body weight of the robot patient was therefore loaded onto the nurse. When the robot patient turned to the wheelchair with the nurse's assistance, the electromagnetic brakes were applied and the knee joints of the robot remained straight owing to the torque provided by the brakes. The remaining joints of the lower limb rotated passively. When a nurse helped the robot patient to turn towards the wheelchair, the robot swayed and its standing position became unstable. In this way, the robot patient simulated a patient's instability while standing and turning (Fig. 1 (d)).

In order to enable a robot patient to automatically judge when to apply the electromagnetic brake, an angle sensor was installed in each knee joint (Fig. 2). The brakes were released at the beginning of the patient transfer to allow the nurse to help the robot patient to stand up. When both knee joints expanded to a pre-determined angle, the process of standing up was recognized as complete, and the brakes were applied to keep the robot patient standing.

3.2.3 Voice recognition module

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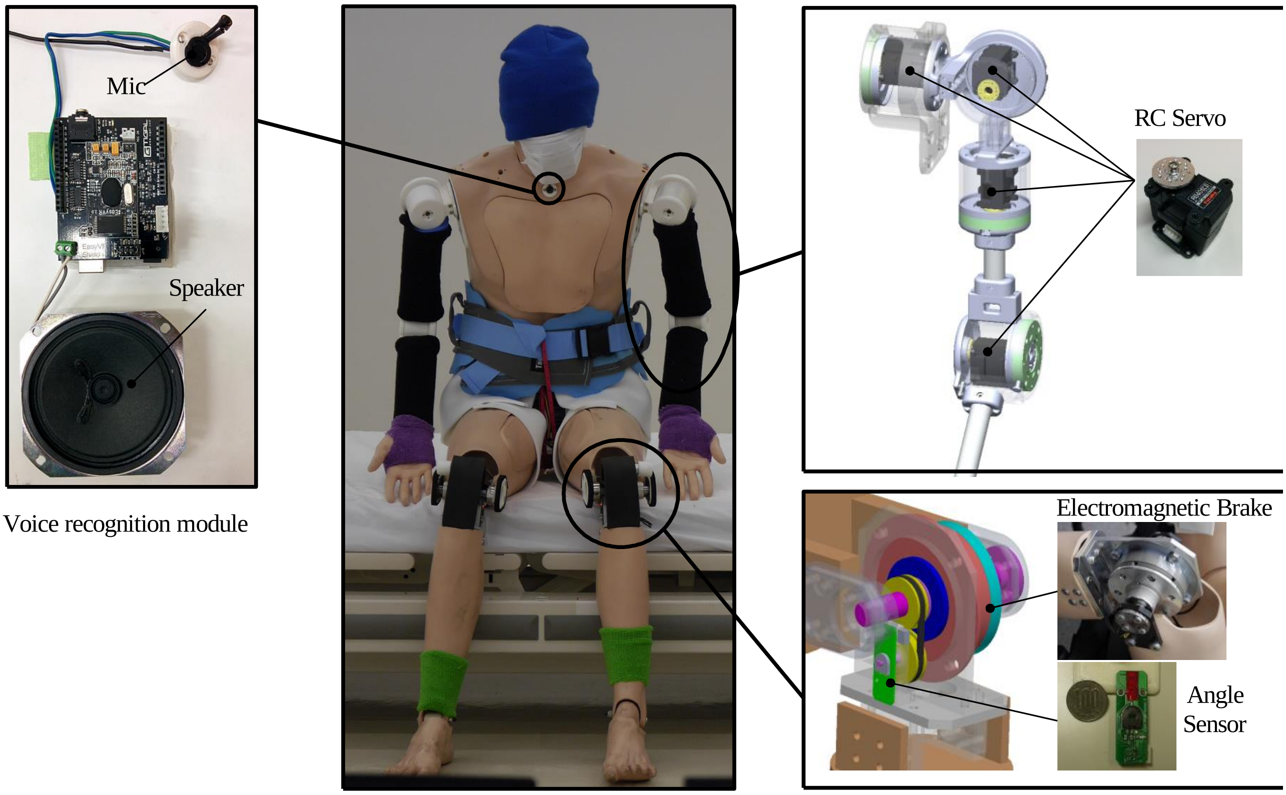

Fig. 2. Hardware of the robot patient

When a nurse helped the robot patient to turn towards the wheelchair, the robot patient released the electromagnetic brakes so that the lower limbs could passively rotate to simulate the patient sitting down. A voice recognition module (TIGAL KG Co., Ltd.) was applied to enable the robot patient to receive nurses' commands (Fig. 2). The voice recognition module was able to recognize the instruction "please sit down." Upon receiving this command, the robot answered "I understand" via a speaker (Fig. 2) and then released the brakes on both knees.

3.3 Actions in active hugging

In order to enable the robot patient to automatically hug a nurse's shoulder, two issues had to be resolved. First, the robot has to be able to determine when to perform the hugging action. Second, each joint's rotation angle and timing has to be planned.

To solve the first issue, we used the angle sensor inside the RC motor of Joint J-2 (Fig. 3 (a)) to detect whether the nurses had raised the robot patient's upper limbs. When the angle of Joint J-2 was greater than the preset threshold (40°), the robot patient started to actively hug. Each upper limb was controlled independently. The robot patient hugged using only the upper limb that the nurse lifted, which is typical of real patients in hospitals. Before the nurse asked the patient to hug their shoulder, the nurse held the patient's upper limbs and helped the patient to raise them.

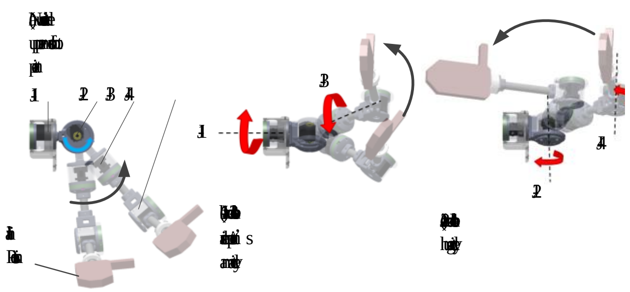

Fig. 3. Plan of hugging actions

The robot patient performed a hugging action by rotating its joints J-1, J-2, J-3, and J-4. Based on video-recorded observations of the patients' actions, we determined the rotation angle and duration of each joint. The hugging action was divided into three steps. First, the upper limb remained in the initial position, as shown in Fig. 3(a). The torque of J-2 was turned off so that the nurse could raise the upper limbs. When J-2 was expanded to 40° from its initial position, the robot patient recognized the movement and started to hug the nurse. Next, Joints J-1 and J-3 rotated actively to continue to raise the upper limbs. J-1 and J-3 rotated from their initial position to 130° and 90°, respectively (Fig. 3 (b)). The duration of rotation was set to 1.5 s. Finally, J-1 and J-3 maintained their positions, while J-2 and J-4 started to rotate to move the upper limb to the nurses' shoulders. J-2 and J-4 rotated from their position to 10° and 30°, respectively. The duration was set to 1 s. By means of the three steps above, one upper limb of the robot patient completed the action of hugging. The other upper limb was controlled in the same way.

4 Experiment and Result

In order to examine the impact of using a robot patient in patient-transfer training, two factors should be evalu-

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TABLE I. RESULT OF QUESTIONNAIRE

Questions	Level [a] [b]	
	Action simulation	Suitable for training
Adjusting the patient's sitting position in the bed	4.50 SD 0.58	4.25 SD 0.96
Assisting the patient in hugging	3.75 SD 0.96	4.25 SD 0.96
Assisting the patient in standing up	4.75 SD 0.50	4.75 SD 0.50
Assisting the patient in turning to the wheelchair	4.50 SD 0.58	4.75 SD 0.50
Assisting the patient in sitting down	4.75 SD 0.50	4.75 SD 0.50
Adjusting the patient's position in the wheelchair	4.75 SD 0.50	4.25 SD 0.50
Is the robot patient useful for the nursing students to improve their skills?	4.8 SD 0.4	
Would you recommend that the nursing students train with the robot patient?	4.8 SD 0.4	

[a] *Levels：1-Strongly disagree, 2-Disagree, 3-Normal, 4-Agree, 5-Strongly agree)*
[b] *Number of respondents：4*

ated carefully. One is the performance of the robot used in patient-transfer training, including the ability to simulate patient's action and its applicability to skill training. The other is training effectiveness. It is important to examine whether the robot patient can help the nurses improve their skills. Therefore, a pre-study and an experiment using pre-post control group design were carried out in this study, as follows.

4.1 Pre-study regarding nursing teachers' subjective evaluations

4.1.1 Purpose

A pre-study was conducted to examine the performance of the robot patient used in patient-transfer training. It sought to answer the following two research questions:

- Can the robot patient simulate a patient's actions during a patient transfer?
- Is the robot patient suitable for patient-transfer training?

4.1.2 Participants

The participants were four nursing teachers with up to ten years of experience in nursing education.

4.1.3 Procedures

Each nursing teacher was asked to transfer the robot patient three times and then complete a questionnaire to evaluate the robot patient's performance.

4.1.4 Evaluation methods

The validity of using the robot patient in patient transfer training was examined by the nursing teacher's subjective evaluation. We designed the questionnaire to survey the nursing teacher's evaluation of the robot patient. The questionnaire consisted of three parts. The first part measured the overall attitude of the nursing teacher to the robot patient. This part contained two questions: 1) Did the nursing teacher consider the robot patient to be useful for improving the skills of nursing students? and 2) Would the nursing teacher recommend that their students train with the robot patient?

The second part consisted of questions regarding the robot patient's ability to simulate a real patient's actions. Six questions corresponded to the six different steps of patient transfer.

The third part consisted of questions regarding the applicability of the robot patient used in patient-transfer training. As in the second part, six questions corresponded to the six steps.

All of the questions were measured using a five-point Likert scale, on which the items were ranked from 1 (strongly disagree) to 5 (strongly agree).

4.1.5 Results of nursing teachers' evaluations of the robot patient's performance

Table 1 depicts the results of the pre-study. According to the preset levels, in the results of the questionnaire, a score of ≥4 indicates that the teachers agree. Regarding the robot patient's ability to simulate the patient's action, the average score of six related questions was 4.5 (SD = 0.39). With the exception of the question relating to the hugging action, all of the questions achieved a score of over 4.5, which is higher than the agreement level. Regarding the applicability of skill training, the average score of related questions was 4.5 (SD = 0.27). A score of over 4.25 was calculated for each question. Regarding the overall feeling about the robot, all of the nursing teachers agreed that the proposed robot patient was useful in helping nursing students to improve their skills (Avg. = 4.8, SD = 0.4). The nursing teachers also expressed that they would recommend the robot patient to their students (Avg. = 4.8, SD = 0.4).

The result of the questionnaire (Table 1) indicates that the nursing teachers regarded the robot patient to be able to simulate patients' actions. They were satisfied with the robot patient's passive actions of standing up and sitting down, as well as the robot's simulation of standing instability during assisted turning.

The results of the questionnaire further revealed that the proposed robot patient was suitable for patient-transfer skill training. With the exception of the action of hugging, all teachers assigned scores of over 4, indicating their agreement that the robot is suitable for skill training.

The nursing teachers held different opinions regarding

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the hugging action. Two nursing teachers agreed that the robot was able to simulate patients' hugging action effectively, while the other teachers were neutral. In addition, regarding the steps of assisted hugging, three teachers agreed that the robot patient was suitable for skill training, while one teacher was neutral. According to the comments of the teacher who remained neutral, the differing opinions might have arisen because the robot patient sometimes could not hug the teacher's shoulder closely due to the interference of the robot patient's hands.

In general, all of the nursing teachers agreed that the robot patient was useful for skill training and that they would recommend the robot patient to their students in future.

4.2 Experiment regarding nursing students' evaluations of training effectiveness

4.2.1 Purpose

An experiment using pre-post control group design was carried out to examine the training effectiveness of using the robot patient in patient-transfer training.

There were two evaluation criteria, as follows

- Compared with the current method, which uses a human simulated patient, does the robot patient offer a more challenging experience in patient-transfer training?
- Could the robot patient help the nursing students to improve their skills?

4.2.2 Participants

The participants were 20 nursing students (15 female and 5 male) who served as the trainees. All of the students had learned the skills of patient transfer and were able to perform the steps (Fig. 1) in order. All students were randomly assigned to either the control group or experimental group, each of which consisted of 10 nursing students.

A woman acted as a human simulated patient to simulate the current training method for the control group. The height of the human simulated patient is 160 cm, equal to the height of the robot patient.

In addition, a nursing teacher with more than 10 years of experience in nursing education was employed in order to evaluate the trainees' skill performances in the experiment.

4.2.3 Procedures

Fig. 4 depicts the procedures of this study's four-stage experiment.

In Stage 1, both groups had seven minutes to watch the demonstration video to review the skills of patient transfer. The video, which was used in nursing school as learning material, introduces each step of patient transfer and the corresponding skills. After the students watched the video, they received ten minutes of instruction introducing them to the functions of the robot patient, including the hugging action of the upper limbs, the electromagnetic brake in the knee joints, and the voice recognition module.

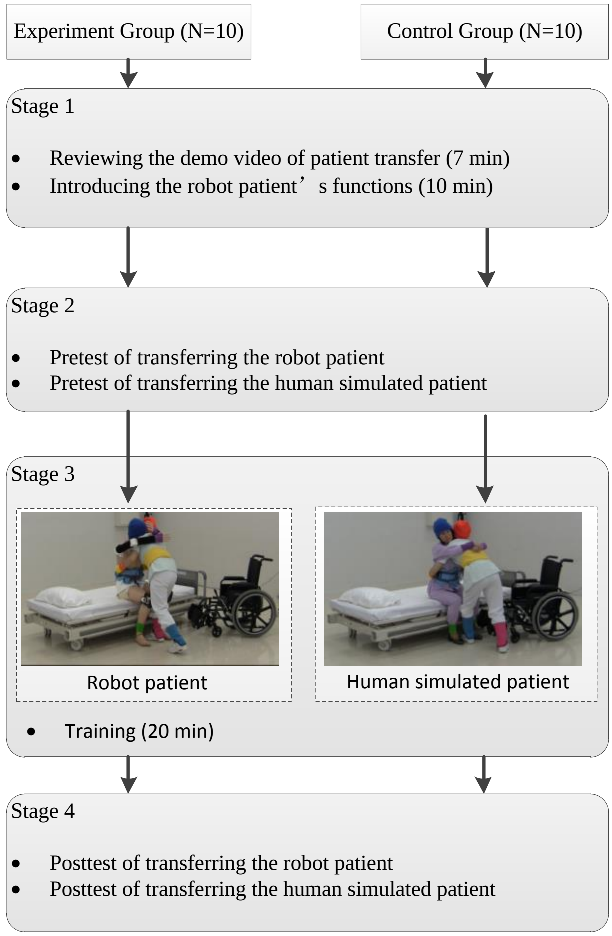

Fig. 4. Procedures of the experiment using pre-post control group design

In Stage 2, a pre-test was carried out for both groups to evaluate the trainees' initial performance prior to training. In each group, the student's skill performance was evaluated for two patient conditions, that of the robot patient and the human simulated patient. Each student was asked to individually transfer the robot patient and the human simulated patient. This pre-test process was recorded on video camera for the nursing teacher to evaluate later.

After the pre-test, in Stage 3, the students in each group were asked to participate in the patient-transfer training. In the experimental group, the students trained with the proposed robot patient, while in the control group, the students trained with the human simulated patient. The duration of the training was 20 minutes, which enabled the trainees in each group to perform the patient transfer at least three times. In order to avoid the effects of other factors during the training, trainees in both groups were not provided with any supervision, feedback, or learning material. Trainees were given the choice to either undergo the training or to have free time.

Finally, in Stage 4, the post-test was conducted in both groups to examine whether the students' skills had improved after training. In each group, each student was asked to transfer both the robot patient and the human

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simulated patient individually. This post-test process was recorded by video camera.

4.2.4 Evaluation methods

This study referenced a checklist that is used in nursing schools to evaluate the skill performance of nursing students (Table 2). The validity of the checklist was approved by the nursing teachers. The checklist consists of 20 items, and each item corresponds to one skill in patient transfer. The nursing teacher selected "right" or "wrong" to evaluate a student's performance for each item. A correct behavior was assigned 1 point, while an incorrect behavior was assigned 0 points. Therefore, each student could receive a maximum score of 20 on the test, which would indicate that the student had performed correctly on all items.

In order to prevent bias, a single-blind skill evaluation was conducted, meaning that the nursing teacher did not know which group the student belonged to, or if it was a pre-test or post-test when evaluating the skill performance of the students. The evaluation was performed after all of the students had finished the post-test. The nursing teacher evaluated the students' skill performance by watching the video recordings. To prevent the nursing teachers from missing any small step of trainee's performance, the tape could be slowed down and rewound. In order to prevent the nursing teacher from knowing which video was the pre-test and which was the post-test, the order of the videos was randomly arranged.

The reliability of the teacher scoring was examined. Another two nursing teachers were asked to evaluate 16 videos which were randomly selected from 80 videos (2 Group x 10 student x 2 types of patient x (pretest+ post-test) = 80) in our experiment. In each video, there were 20 items that required evaluation. In total, the sample size was 320. Light's kappa [39], which is a non-parametric statistic for the situation of three evaluators, was carried out to examine the agreement among the nursing teachers' evaluation. The level of agreement was considered to represent the reliability of the nursing teacher's evaluation result.

Since the experiment was a three-factor 2x2x2 mixed design, ANOVA was used to identify the significance of the factors' effect. As mentioned above, in the pre-test and post-test, we evaluate the student's skill performance in transferring both the robot patient and the human simulated patient. Therefore, in the experiment, there were two within-subject factors and one between-subject factor, as follows.

1) *within-subject factors*
- Time conditions: Pre-test VS Post-test (Pre vs. Post);
- Patient conditions: Transferring robot patient VS Transferring human simulated patient (R vs. H);

2) *between-subject factors*
- Training conditions: Training with robot patient VS Training with human simulated patient (Expt. vs. Ctrl.).

The main effect of *patient conditions* (R vs. H) indicated the different levels of difficulty involved in transferring a robot patient and a human simulated patient. Therefore, an alternative hypothesis *H1* was raised to examine the difference in difficulty, as follows.

H1: There is a significant effect of patient conditions.

If a significant difference was found, it might reveal that one type of simulated patient was more difficult than the other.

A significant *time conditions × training conditions* interaction was expected, as it was considered to indicate a significant difference in training effect between the two groups. In detail, it was expected to see the experiment group's trainees improve their performance in transferring both the robot patient and human simulated patient. On the other hand, for the control group, the trainees were expected to improve their skill performance only when transferring the human simulated patient. R-Expt.-post was expected to be higher than R-Ctrl.-post, since this indicates that training with the robot patient might improve learning beyond the control conditions. The alternative hypothesis *H2* was raised as follows.

H2: There is a significant effect of the interaction of time conditions × training conditions.

In order to further analyze the result of the experiment in detail, another four alternative hypotheses were raised. *H3* and *H4* were used to examine the training effectiveness of both types of patient, while *H5* and *H6* were used to investigate the learning transfer in the two groups. In each hypothesis, if a significant difference was found, the null hypothesis could be rejected and the alternative hypothesis would be accepted. Each alternative hypothesis and corresponding compared dataset is described as follows:

H3: There is a significant difference in the score between the pre-test and post-test when the experimental group's trainees transferred the robot patient.

Compared datasets: Expt.-R-pre VS Expt.-R-post

H4: There is a significant difference in the score between the pre-test and post-test when the control group's trainees transferred the human simulated patient.

Compared datasets: Ctrl.-H-pre VS Ctrl.-H-post

H5: There is a significant difference in the score between the pre-test and post-test when the experimental group's trainees transferred the human simulated patient.

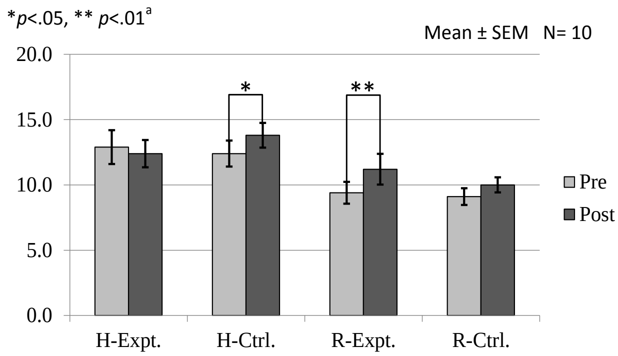
Compared datasets: Expt.-H-pre VS Expt.-H-post

H6: There is a significant difference in the score between the pre-test and post-test when the control group's trainees transferred the robot patient.

Compared datasets: Ctrl.-R-pre VS Ctrl.-R-post

4.2.5 Result of experiment

In both groups, all of the trainees finished the pre-test, training, and post-test. In the experimental group's training process, the average number of patient-transfer train-



H-Expt. : Experiment group transfer human simulated-patient
H-Ctrl. : Control group transfer human simulated-patient
R-Expt. : Experiment group transfer robot patient
R-Ctrl. : Control group transfer robot patient
[a] *The brackets indicated the significant effect found in simple main effect test*

Fig. 5 Average skill performance in the pre-test/post-test of each group

ing was 6.3 (SD = 0.9), while in the control group the average was 4 times (SD = 2.9). In addition, a significant difference (p<0.05) was found between the two groups by t-test.

The result of Light's kappa (0.537) indicates a moderate level of agreement among the nursing teachers. Based on this result, the reliability of the nursing teacher's scoring employed in our experiment was considered to be acceptable.

Fig. 5 depicts the results of the experiment using pre-post control group design. The pre-test score of experimental group (M=12.4, SD=3.3) in transferring the human simulated patient did not significantly differ from that of the control group (M=12.9, SD=4.1). In addition, when transferring the robot patient, the pre-test score of the experimental group (M=9.4, SD= 2.6) did not significantly differ from that of the control group (M=9.1, SD=2.0). The two groups exhibited a comparable degree of performance in patient transfer prior to training.

The ANOVA result is as follows. For the main factor of patient conditions (R VS H), there is a significant effect at the p<0.001 level [F (1, 18) =43.66, p<0.0001]. Therefore, *H1* can be accepted, as there was a significantly different level of difficulty between the two types of patient. The comparison result in Fig. 5 reveals that transferring the robot patient was more challenging than transferring the human simulated patient.

For the factor of time conditions (Pre VS Post), there is a significant effect at the p<0.05 level [F (1, 18) =6.55, p=0.020]. However, no significant *time conditions* × *training conditions* interaction is observed [F(1,18)=0.505,

TABLE II.- CHECKLIST FOR EVALUATING PATIENT TRANSFER SKILLS AND NUMBER OF CORRECT PERFORMANCE IN EACH ITEM UNDER DIFFERENT CONDITIONS [a]

Item No. and Description	Control group transferred human simulated patient			Experimental group transferred robot patient		
	Pre[b]	Post	Diff.	Pre	Post	Diff.
*1.Place the wheelchair near the patient	9	9	0	5	6	1
2.Place the wheelchair at the bedside and adjust the included angle to 20–30 degrees	7	9	2	7	7	0
3.Apply the wheelchair brakes	9	10	1	10	10	0
4.Place your right foot behind you	2	5	3	4	4	0
5.Place your left foot between the feet of the patient	2	5	3	3	3	0
*6.Grip the bottom of the patient	7	5	-2	2	4	2
7.Make the patient sit on the edge of the bed by shuffling the patient's bottom	3	6	3	3	8	5
8.Adjust the patient's leg posture	7	6	-1	5	6	1
9.Place both of the patient's arms on your shoulders	9	10	1	9	9	0
10.Grip the lower back of the patient	5	6	1	2	4	2
11.Place your right foot behind you	6	7	1	5	6	1
12.Place your left foot between the feet of the patient	6	7	1	4	5	1
13.Lower your waist to assist the patient	6	8	2	3	6	3
14.Help the patient to lean down before starting to stand	4	2	-2	2	4	2
15.Use your left foot as a pivot axis to help the patient to turn to sit in the wheelchair	9	10	1	8	9	1
*16.Lower your waist	7	6	-1	2	3	1
*17.Help the patient to lean down before sitting down	5	5	0	1	1	0
18.Grip the patient's forearms with your arms passing under the patient's armpits	7	7	0	6	6	0
19.Help the patient to lean over before adjusting their sitting position	4	5	1	3	1	-2
20.Place the patient's feet on the wheelchair's footrests	10	10	0	10	10	0

[a] *The number of trainees -in each group was 10.*

[b] *The number indicated the total number of trainees who performed correctly in each item.*

**Significant difference in pretest between two groups was found by Chi square test. (* p<0.05)*

p=0.486]. As a result, *H2* cannot be accepted. We cannot say that there is a significant difference between the two groups' training conditions. The score of R-Expt.-post (M=11.2, SD=3.5) is higher than that of R-Ctrl.-post (M=10.0, SD=1.7). However, a significant effect is not found in the simple main effect test [F (1, 72) =0.769, p=0.383].

A significant effect at the p<0.05 level is found in the interaction of the three factors above [F (1, 18) =7.62, p=0.013]. Therefore, the test of the simple main effect with Bonferroni correction was carried out and the results are shown in Fig. 5. The post hoc test was carried out according to four alternative hypotheses raised in Section 4.2.4.

H3, which was used to check, after training, whether the trainees of experimental group could improve their skills in transferring robot patient. There is a significant effect at the p<0.01 level in the time conditions (Pre-test vs Post-test) when the trainees of the experimental group transferred the robot patient [F (1, 36) =8.61, p=0.006]. The mean score of post-test (M=11.2，SD=3.7) is higher than that of pre-test (M=9.4, SD=2.6).

H4, which was used to check, after training, whether the trainees of control group could improve their skills in transferring human simulated patient. The situation was the same as that of the experimental group. In the control group, when transferring the human simulated patient, a significant difference at the p<0.05 level is found between the score of pre-test (M=12.4, SD=3.1) and post-test (M=13.8, SD=3.0) [F (1, 36) =5.211, p=0.029].

Therefore, both hypothesis *H3* and *H4* could be accepted.

H5 and *H6* were used to investigate whether there was learning transfer in each group. However, these two alternative hypotheses could not be accepted, since there were no significant differences. In the experimental group, when transferring the human simulated patient, the mean score of post-test (M=12.4, SD=3.3) does not significantly differ from that of pretest (M=12.9, SD=4.1). On the other hand, in the control group, when transferring the robot patient, the mean score of post-test (M=9.1, SD=2.0) does not significantly differ from that of pretest (M=10.0, SD= 1.8).

In order to investigate the degree of difficulty in each item under different patient conditions, in addition to observing the trainees' improvement in different items under different training conditions, we counted the number of trainees who performed correctly for each item. We focused on investigating the pre-test and post-test results of the control group when transferring the human simulated patient and the experimental group when transferring the robot patient, as the improvement was only observed in these two conditions according to the statistical analysis (see *H3* to *H6*). The data was categorized according to different conditions and is presented in Table 2. Since there were ten trainees in each group, in each item under each condition, the maximum value is 10, which indicates that all the trainees performed correctly in the item. The difference between the post-test and pre-test was shown in column 4 and 7.

5 Discussion

The results of the pre-study reveal that the nursing teachers' attitude towards the proposed robot patient was positive. They agreed that the robot has the ability to simulate patient's actions and considered the robot to be suitable for training the nursing students to have the required skills for patient transfer.

According to the result of H1, the effect of patient conditions (R VS H) is considered to be significant in the trainees' performance. The significant differences in pre-test scores between the robot patient transfer and the human simulated patient transfer reveal that the former was more challenging than the latter. In both groups, compared with the human simulated patient transfer, the nursing students committed more errors in the robot patient transfer. In the pre-test of the robot patient transfer, the number of items that more than half of trainees performed incorrectly increased to 14 in the experimental group and to 13 in the control group. However, in the pre-test of the human simulated patient transfer, for both groups, the number is only 7. As shown in columns 2 and 5 of Table 2, the main difference of difficulty is in Items 1 (wheelchair near bed), 6 (grip patient's bottom), 10 (grip patient's lower back), 13 (lower nurse's back before standing assistance), 16 (lower nurse's back before sitting assistance), and 17 (help patient to lean down). In each of these items, the number of trainees who performed correctly when transferring the robot patient was at least three less than for transferring the human simulated patient. In addition, significant difference at the level of p<0.05 are found in Items 1, 6, 16 and 17 by the Chi Square test.

Different training attitudes between the two groups in the training process were observed. Since there was no supervision during the training stages for both groups, the difference in practice times might be due to the difference in difficulty between the two simulated patients. The robot patient was more difficult than the human simulated patient and might stimulate the trainees to continue practicing to improve their skills. However, in the control group, some trainees satisfied with their performance stopped practicing.

No significant effect is found in the interaction of *time conditions* $\times$ *training conditions*. As a result, *H2* cannot be accepted. This result disagrees with our expectation claimed in Section 4.2.4. In order to explain this result, the significant effect in the interaction between the three factors should be noted. This reveals that the score of the trainees between the two groups was affected by the interaction of three factors, rather than only the interaction of *time conditions* $\times$ *training conditions*. A further sample main effect test confirms this viewpoint. According to the results of *H3* to *H6*, no learning transfer occurred. In other words, in both groups, the trainees only improved their performance in transferring the simulated patient that they practiced with during the training process.

The post hoc test result accepts the alternative hypotheses of *H3* and *H4*. Combined with the comparison of the mean score between the pre-test and post-test, the training effectiveness of both the robot patient and human simulated patient is observed (see the result of hypothesis *H3* and *H4* in Section 4.2.5). Training with the robot patient assisted the trainees in improving their skills of transferring robot patients. On the other hand, training with the human simulated patient assisted the trainees in improving their skills of transferring human simulated patients. The items which were observed to have improved are different in each group. In Table 2, for the experimental group that trained with the robot patient, the improvement (Diff. ≥2) is observed in Item 6 (grip patient's bottom), 7 (move patient closer to the bed edge), 10 (grip patient's lower back), 13 (lower nurse's back before standing assistance), and 14 (help patient to lean down); whereas for the control group which trained with the human simulated patient, the improvement (Diff. ≥2) is observed in Item 2 (wheelchair's parking direction), 4 (nurse's right foot position), 5 (nurse's left foot position), 7 (move patient closer to the bed edge), and 13 (lower nurse's back before standing assistance). In addition, for the control group, Item 14 (help patient to lean down) was considered to be difficult, as only two trainees performed correctly in the post-test. This result reveals that trainees in the experimental group might tend to improve their skills relating to operations that require strength to move the patient's body, such as Item 7 (related to moving the patient closer to the edge of the bed), and Items 13, and 14 (related to assisting the patient in standing up). The challenges of using the robot patient might motivate trainees to improve their skills. Most of these items are related to heavy physical exertion, such as the task of supporting the patient's body weight. For example, Items 10-14 are related to helping the patient to stand up. Because the robot did not provide any assistance, if the trainees performed a step incorrectly (e.g., had inappropriate posture or grip position), the task might feel more laborious, making the trainees more aware of their error. This experience might inspire the trainees to continue to improve their skills. However, due to the limitation of sample size, the current experiment still cannot provide statistical results to support the conjecture regarding how the patient's conditions affect the trainees' performance in each item. In future work, in order to prove such conjecture, the sample size of the experiment will be expanded.

Alternative hypotheses *H5* and *H6* could not be accepted in the post hoc test. The result revealed that there was no learning transfer occurred in either group. In other words, the robot patient trained nurses to transfer the robot patient, and human simulated patient trained the nurses to transfer the human simulated patient. However, there was no learning transfer of the training in either direction. It seems that the trainees could not improve their skill in transferring the human simulated patient, even after they trained with the robot patient, which was more challenging. Different patient conditions might contribute to this situation. However, in this study, our purpose is to evaluate the proposed robot patient's training effectiveness, but not the effect of learning transfer. Considering the limitation of the sample size and duration of training in the current experiment, it is difficult to conclude whether learning transfer exists. In order to examine the learning transfer, the current sample size and the duration of training should be expanded. The work will be carefully considered in future.

The results of the experiment regarding the training effect are negative. It is difficult to conclude that the training effect of the proposed robot patient is better than the effect of the human simulated patient. The pre-test results shown in Table 2 reveal that the conditions between the two simulated patients were different. This difference might prevent learning transfer from occurring in a relatively short period of training (20 minutes).

There are two possible contributions to this difference. One is the limitations of the proposed robot patient, which might prevent the trainee from performing some skills. It might be difficult to grip the robot patient (see Item 6 and 10) due to the robot being naked and covered by hard material. Difficulty in gripping the robot patient might also make it difficult for the trainees to perform some skills related to support the patient's body (e.g. Item 16, 17). In addition, the limits of the DOFs of the robot's waist and the occasional failure of the hugging action might also make it difficult for the trainee to perform Items 16 and 17.

The other reason for the difference in performance is the difference in difficulty of the simulated patients. The design of the robot patient might contribute to difficulty in the items that require trainees to have significant strength. Compared with the human simulated patient, the proposed robot patient did not provide extra strength to support its body weight when standing up or sitting down because its lower limbs rotated only passively. In addition, when the nurses performed incorrect procedures, the robot did not provide additional assistance, as a human simulated patient might. Therefore, the nursing students had to use more strength to support the robot patient's body weight and be more careful during transfer. Without the assistance of the human simulated patient, it was more difficult for the trainees to perform these skills appropriately. This situation is clearly shown in Item 13, which is related to assisting the patient in standing up, and in Item 16 and 17, which are related to assisting the patient in sitting down.

We also note that trainees do not show improvement in some of the items. Two factors contribute to this lack of improvement. One is that such items involved little physical exertion (e.g., Items 4 and 5), making it difficult for trainees to notice their errors. Providing feedback might be one solution. The other contributing factor is the limitations of the robot patient. For Items 17, 18 and 19, as a result of the limits of the DOFs of the robot's waist, the trainees might have found it difficult to practice the skill.

The value of the proposed robot patient in improving the conditions of nursing simulation training in patient transfer should not be overlooked, although the result of the experiment regarding the training effect did not completely meet the expectation set in Section 4.2.4. There are three results that support the value of applying the robot patient to simulation training of patient transfer. Firstly, according to the questionnaire result in Table 1, the nursing teachers have positive attitude regarding the robot patient's performance. The nursing teachers regarded the robot patient's ability to simulate patients' actions. They further agree that the proposed robot patient is suitable for patient-transfer skill training. All nursing teachers were in firm agreement that the robot patient was useful for nursing students to improve their skill. In addition, they have high intentions to recommend the robot patient to the students. Secondly, the improvement in transferring the robot patient in the experiment group after training was observed. Combined with the nursing teacher's positive attitude, the improvement is considered to be meaningful and further supports the robot patient's value in simulation training. Finally, compared with the human simulated patient, the robot patient brought positive challenges to the simulation training of patient transfer. Owing to the design, the robot patient's low limbs did not provide any additional support when the trainee performed standing and sitting assistance. As a result, the trainees' ability to use appropriate strength and posture to support the patient's body during patient transfer can be trained.

6 Conclusion and Future Works

In this study, we conducted experiments to examine the performance and training effect of the proposed robot patient used in nursing simulation training of patient-transfer. The result of the experiment regarding nursing teacher's subjective evaluation revealed that the robot was able to simulate the patient's action during patient transfer, including active hugging, passive standing up/sitting down, and unstable standing. In addition, nursing teachers agreed that the robot patient was suitable for patient-transfer skill training. On the other hand, an experiment using pre-post control group design was used to evaluate the training effect of the robot patient by comparison with current training conditions, which employ a healthy person to act as the patient. The results revealed that the robot patient was more challenging than current training conditions. However, for both groups, significant improvement was only observed when the trainees transferred the simulated patient that they trained with. According to the results, although it was still hard to conclude that the proposed robot patient can displace current training conditions, the value of using a robot patient in nursing simulation training of patient transfer should be noted.

This research is the first to examine the effectiveness of using a robot patient in patient-transfer training. The results will hopefully motivate and inspire the use of robotics to improve the effectiveness of nursing education.

In future works, experiments will be conducted to obverse the trainees' improvement in transferring real patients after training with the robot patient. The effectiveness of using robot patients in patient transfer will be specific to each item by expanding the size of the experiment. The further potential of using robot patients to improve nursing education will be explored. For example, using the robot patient to simulate different patients' actions will provide a variety of training opportunities to help nurses improve their skills and practical experiences. In addition, the robot patient will be improved based on the experimental results of this study. The action planning of hugging will be upgraded to avoid the interference of the robot's hands. In addition, the DOFs of the robot patient's waist will be increased to ensure trainees can practice the skills required to adjust a patient's sitting position in a wheelchair.

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References

[1] J. Smedley, P. Egger, C. Cooper, and D. Coggon, "Manual handling activities and risk of low back pain in nurses," *Occupational and Environmental Medicine*, vol. 52, pp. 160–163, Mar. 1995.

[2] S. Hignett, "Work-related back pain in nurses," *Journal of Advanced Nursing*, vol. 23, pp. 1238–1246, Jun. 1996.

[3] A. Karahan and N. Bayraktar, "Determination of the usage of body mechanics in clinical settings and the occurrence of low back pain in nurses," *International Journal of Nursing Studies*, vol. 41, pp. 67–75, Jan. 2004.

[4] J. B. Cooper, and V. R. Taqueti, "A brief history of the development of mannequin simulators for clinical education and training," *Quality and Safety in Health Care*, vol. 13, no. suppl 1, pp. i11–i18, Oct. 2004.

[5] W. Maidhof, N. Mazzola, and M. Lacroix, "Student perceptions of using a human patient simulator for basic cardiac assessment," *Currents in Pharmacy Teaching and Learning*, vol. 4, no. 1, pp. 29–33, Jan. 2012.

[6] R. L. Marshall, J. S. Smith, P. J. Gorman, T. M. Krummel, R. S. Haluck, and R. N. Cooney, "Use of a human patient simulator in the development of resident trauma management skills," *Journal of Trauma and Acute Care Surgery*, vol. 51, no. 1, pp. 17–21, Jul. 2001.

[7] T. Moodley, and D. Gopalan, "Airway skills training using a human patient simulator," *Southern African Journal of Anaesthesia and Analgesia*, vol. 20, no. 3, pp. 147–151, Jul. 2014.

[8] G. M. Tan, L. K. Ti, S. Suresh, B. S. Ho, and T. L. Lee, "Teaching first-year medical students physiology: Does the human patient simulator allow for more effective teaching?," *Singapore Med J*, vol. 43, no. 5., pp. 238–242, May. 2002.

[9] G. Alinier, B. Hunt, R. Gordon, and C. Harwood, "Effectiveness of intermediate-fidelity simulation training technology in undergraduate nursing education," *Journal of Advanced Nursing*, vol. 54, no. 3, pp. 359–369. May. 2006.

[10] R. E. Hall, J. R. Plant, C. J. Bands, A. R. Wall, J. Kang, and C. A. Hall, "Human patient simulation is effective for teaching paramedic students endotracheal intubation," *Academic Emergency Medicine*, vol. 12, no. 9, pp. 850–855, Sep. 2005.

[11] J. F. Crofts, C. Bartlett, D. Ellis, L. P. Hunt, R. Fox, and T. J. Draycott, "Training for shoulder dystocia: a trial of simulation using low-fidelity and high-fidelity mannequins," *Obstetrics & Gynecology*, vol. 108, no. 6, pp. 1477–1485, Dec. 2006.

[12] J. Cioffi, N. Purcal, and F. Arundell, "A pilot study to investigate the effect of a simulation strategy on the clinical decision

making of midwifery students," *Journal of Nursing Education*, vol. *44*, no. 3, pp. 131–134, Mar. 2005.

[13] J. Swain, E. Pufahl, and G. R Williamson, (2003). "Do they practise what we teach? A survey of manual handling practice amongst student nurses," *Journal of clinical nursing*, vol. 12, no. 2, pp. 297-306, Mar, 2003.

[14] S. A. Clemes, C. O. Haslam, and R. A. Haslam, "What constitutes effective manual handling training? A systematic review," Occupational medicine, vol. 60, no. 2, pp. 101-107, Sep. 2010.

[15] C. C. Clark, *Classroom skills for nurse educators*. Jones & Bartlett Learning, 2008, ch. 3.

[16] K. H. E. Kroemer, "Personnel training for safer material handling," *Ergonomics*, vol. 35, no. 9, pp. 1119-1134, Aug. 1992.

[17] A. C. E. Johnsson, A. Kjellberg, and M. I. Lagerström, "Evaluation of nursing students' work technique after proficiency training in patient transfer methods during undergraduate education," *Nurse Education Today*, vol. 26, no. 4, pp. 322–331, May. 2006.

[18] K. Inoue, K. Ujiie, and S. Lee, "Development of haptic devices using flexible sheets for virtual training of abdominal palpation," *Advanced Robotics*, vol. 28, no. 20, pp. 1331–1341, Oct. 2014.

[19] C. Sutherland, K. Hashtrudi-Zaad, R. Sellens, P. Abolmaesumi, and P. Mousavi, "An augmented reality haptic training simulator for spinal needle procedures," *Biomedical Engineering, IEEE Transactions on*, vol. 60, no. 11, pp. 3009–3018, Nov. 2013.

[20] J. Spillmann, S. Tuchschmid, and M. Harders, "Adaptive space warping to enhance passive haptics in an arthroscopy surgical simulator," *Visualization and Computer Graphics IEEE Transactions on*, vol. 19, no. 4, pp. 626–633, Apr. 2013.

[21] I. S. Yu, H. S. Woo, H. I. Son, W. Ahn, H. Jung, D. Y. Lee, and S. Y. Yi, "Design of a haptic interface for a gastrointestinal endoscopy simulation," *Advanced Robotics*, vol. 26, no. 18, pp. 2115–2143, Sep. 2012.

[22] T. Tokuyasu, S. I. Oota, T. Tokuyama, K. I. Asami, T. Kitamura, G. I. Sakaguchi, and M. Komeda, "Mechanical modeling of a beating heart for a cardiac palpation training system," *Advanced Robotics*, vol. 17, no. 6, pp. 463–479, Apr. 2003.

[23] G. J. Gerling, S. Rigsbee, R. M. Childress, and M. L. Martin, "The design and evaluation of a computerized and physical simulator for training clinical prostate exams," *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on*, vol. 39, no. 2, pp. 388–403, Mar. 2009.

[24] T. Hashimoto, K. Morita, N. Kato, H. Kobayashi, and H. Nakane, "Depression patient robot for diagnostic training in psychiatric education," *Proc. AIM*, pp. 134–139, 2011.

[25] C. Wang, Y. Noh, C. Terunaga, M. Tokumoto, I. Okuyama, M. Yusuke, H. Ishii, and S. Shoji, "Development of a face robot for cranial nerves examination training," *Proc. ROBIO*, pp. 908–913, 2011.

[26] Y. Kitagawa, T. Ishikura, W. Song, Y. Mae, M. Minami, and K. Tanaka, "Human-like patient robot with chaotic emotion for injection training," *Proc. ICROS-SICE*, pp. 4635–4640, 2009.

[27] C. Wang, Y. Noh, K. Ebihara, C. Terunaga, M. Tokumoto, I. Okuyama, M. Yusuke, H. Ishi, A. Takannishi, K. Hatake, and S. Shoji, "Development of an arm robot for neurologic examination training," *Proc. IROS*, pp. 1090–1095, 2012.

[28] H. S. Park, J. Kim, and D. L. Damiano, "Development of a haptic elbow spasticity simulator (HESS) for improving accuracy and reliability of clinical assessment of spasticity," *Neural Systems and Rehabilitation Engineering, IEEE Transactions on*, vol. 20, no. 3, pp. 361–370, May. 2012.

[29] T. Fujisawa, M. Takagi, Y. Takahashi, K. Inoue, T. Terada, Y., Kawakami, and T. Komeda, "Basic research on the upper limb patient simulator," *In Rehabilitation Robotics, 2007. ICORR 2007. IEEE 10th*, pp. 48–51, 2007.

[30] N. A. Cz, T. Komeda, and C. Y. Low, "Design of upper limb patient simulator," *Procedia Engineering*, vol. 41, pp. 1374–1378, 2012.

[31] S. Ishikawa, S. Okamoto, Y. Akiyama, K. Isogai, and Y. Yamada, "Simulated crepitus and its reality-based specification using wearable patient dummy," *Advanced Robotics*, (ahead-of-print), 1–8, 2015

[32] H. Takanobu, A. Omata, F. Takahashi, K. Yokota, K. Suzuki, H. Miura, M. Madokoro, Y. Miyazaki, and K. Maki, "Dental patient robot as a mechanical human simulator," *Proc. ICM*, pp. 1–6, 2007.

[33] Y. Noh, K. Ebihara, M. Segawa, K. Sato, C. Wang, H. Ishii, J. Solis, A. Takanishi, K. Hatake, and S. Shoji, "Development of the airway management training system WKA-4: For improved high-fidelity reproduction of real patient conditions, and improved tongue and mandible mechanisms," *Proc. ICRA*, pp. 1726–1731, 2011.

[34] Z. Huang, T. Katayama, M. Kanai-Pak, J. Maeda, Y. Kitajima, M. Nakamura, N. Kuwahara, T. Ogata, and J. Ota, "Design and evaluation of robot patient for nursing skill training in patient transfer." *Advanced Robotics*, (ahead-of-print DOI:10.1080/01691864.2015.1052012), pp. 1–17.

[35] A. Garg, B. D. Owen, and B. Carlson, "An ergonomic evaluation of nursing assistants' job in a nursing home," *Ergonomics*, vol. 35, no. 9, pp. 979–995, 1992.

[36] P. A. Potter and A. G. Perry, *Basic Nursing: Essentials for Practice*, Mosby Elsevier, 2003, ch. 25.

[37] C. B. Rosdahl and M. T. Kowalski, *Textbook of Basic Nursing*, Lippincott Williams & Wilkins, 2008, ch. 48.

[38] I. P. Herman, *Physics of the Human Body*, Springer, pp. 16–20, 2007.

[39] K. A. Hallgren, "Computing inter-rater reliability for observational data: an overview and tutorial. Tutorials in quantitative methods for psychology," vol. 8, no. 1, pp. 23-34, Jul. 2012.

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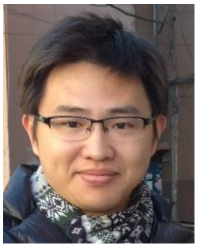

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