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Abstract

Purpose – For self-training of nursing students, this paper developed a mannequin to simulate and measure the movement of a patient's arms while nurses changed the patient's clothes on a bed. In addition, using the mannequin the purpose of this paper is to determine the difference in the handling of a patient's arms between nursing teachers and students.

Design/methodology/approach – The target patient was an old man with complete paralysis. Three-degrees-of-freedom (DOF) shoulder joints and one-DOF elbow joints were applied to the mannequin. The angles of all joints were measured using a potentiometer, and those angles were transmitted to a computer via Bluetooth.

Findings – In a preliminary experiment, the two nursing teachers confirmed that the mannequin arms simulated the motion of the arms of a paralyzed patient. In the experiment, two teachers and six students changed the clothes of the mannequin. The average joint angle of the left elbow and the moving frequency of the left elbow, right shoulder adduction/abduction and right shoulder internal/external rotation were lower in the case of teachers dressing the mannequin than when students were dressing it.

Originality/value – The proposed system can simulate a completely paralyzed patient that nursing students would normally be almost unable to train with. Additionally, the proposed approach can reveal differences between skilled and non-skilled people in the treatment of a patient's body.

Keywords Robotics, Education

Paper type Research paper

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1. Introduction

Today, as society ages, the need for nursing care is increasing. However, the training of nurses in nursing schools and universities is becoming more difficult for a number of reasons. First is the limited number of nursing teachers available to meet the social demand to train increasing numbers of nurses. Therefore, the teachers cannot teach nursing care skills to a sufficiently large number of students. Second is that nursing care skills have become more advanced over the years. Thus, nursing students need to learn increased numbers of higher level skills from their teachers than before. This problem also prevents the nursing students from mastering the skills.

One solution to these problems is constructing a self-training system with which the students can study and practice the skills by themselves repeatedly and appropriately. Such a system is considered to be especially effective for the acquisition of nursing skills such as how to move the body of a patient, because nursing students need repeated training to master these skills.

There are many self-training systems to teach trainees skills related to body movement in the areas of dance, sport and worker training, for example. In many previous studies, a camera system or motion capture system were often used to measure the body movement of experts or/and trainees (Chakravorti *et al.*, 2012; Chan *et al.*, 2011; Davcev *et al.*, 2003; Davis and Bobick, 1998; Hachimura *et al.*, 2004; Han *et al.*, 2012; Karliga and Hwang, 2006; Komura *et al.*, 2006; Leow *et al.*, 2012; Magnenat-Thalmann *et al.*, 2008; Nakamura *et al.*, 2005; Qian *et al.*, 2004; Ray and Teizer, 2012; Soga *et al.*, 2011; Urtasun *et al.*, 2005; Wilson, 2008). For example, Chakravorti *et al.* (2012) also used cameras along with placing light emitting diode markers on the trainee's body to extract a swimming tumble turn signature. Leow *et al.* (2012) measured 3-D body postures of Taichi trainees using a single camera and tried to compare the trainees' postures to those of experts, measured by a motion capture system in advance. Another approach is using motion sensors attached to trainees (Ghasemzadeh *et al.*, 2009; Ghasemzadeh and Jafari, 2011; Spelmezan *et al.*, 2009; Takahata *et al.*, 2004). Ghasemzadeh *et al.* (2009) and Ghasemzadeh and Jafari (2011) used wearable sensors, including a tri-axial accelerometer and a bi-axial gyroscope, to measure the motion during a golf and baseball swing, respectively, to quantitatively evaluate trainees' motions.

For some activities of nursing care, self-training systems have been developed. As shown in Table I, the nursing care activities are divided into four types by target, the target part of the activities, and whether the evaluation points are clear. First, the activities can be divided into two categories by the target handled by

Table I. Four types of nursing care activities divided by "target," "part/whole of patient's body" and "clarity of evaluation points"

Target	Part/whole of patient's body	Clarity of evaluation points	Example	Self-training system
Equipment	–	–	Bed making Transferring gurney	Nagata *et al.* (2013)
Patient	Part	–	Injection Dental care Checking vital signs	Laerdal; Takanobu *et al.* (2006, 2007)
Patient	Whole	Clear	Transferring patients Changing patient's position	Huang *et al.* (2013)
Patient	Whole	Not clear	Changing clothes Changing diapers	–

the nurses: equipment or patient (see Table I; target). The first type of activity includes activities whose target is equipment, such as making the bed. The self-training system for these activities needs to observe the trainee and equipment simultaneously. Nagata *et al.* (2013) developed a training system for making a bed. This system measures the trainee's movement as well as the equipment's position by cameras.

The activity including patient handling can be subdivided into two categories by whether the activities relate to part of the patient's body or the whole of the patient's body (see Table I; part/whole of patient's body). For example, infection, dental care and checking vital signs are typical activities in which nurses need to handle part of the patient's body (Takanobu *et al.*, 2006, 2007; Laerdal). For training these nursing activities, a commercial mannequin that imitates vital signs and blood vessels is available (Laerdal).

The nursing activities relating to the patient's whole body are further divided into two categories by clarity of the evaluation points for the activities (see Table I; clarity of evaluation points). For example, patient transfer from a bed to a wheelchair is an activity in which the nurse handles the patient's entire body and the evaluation points are clear. The procedure of transferring the patient is clearly divided into fixed steps, and in each step nurses should move the patients in a certain way. Huang *et al.* (2013) constructed a self-training system for transferring a patient from a bed to a wheelchair. In each step, this system measures the movements of the patient and trainee by cameras, checks the evaluation points of those movements and provides feedback (for example, the movement is acceptable or does not correspond to predetermined evaluation items).

The last type of activity is similar to the previous type in that the target is the same and the nurse handles the entire patient's body. However, for these activities, the way to move the patient's body is not clearly defined. The changing of clothes is an example of this type of activity. In this activity, the movement of the patient's body, especially movement of the arms, is important in that no harm comes to the patient. For example, if part of the patient's body exceeds the limit of its joint, the patient experiences pain and risks fractures. In other words, the nurses should not move the patient's body in the wrong way. However, how to actually move the patient's arm is not clearly defined.

In nursing school, some students practice changing clothes with a student imitating the patient. That makes the practice less effective for improving their skills because the student mock patient cannot perfectly imitate the patient. When the trainee moves the body of the mock patient, the student patient sometimes moves so that the student nurse can easily perform the activity. Additionally, when the trainee moves the mock patient improperly, the student patient tends to move their body consciously/subconsciously to avoid pain. However, real patients needing to have their clothes changed are often unable to move their body like a healthy mock patient. Therefore, it is necessary to construct a mannequin which can imitate real patients and enable the measurement of body movement for the self-training of this type of activity.

However, previous systems for the self-training of nurses have not taken the patients' movements into account. Also, from the standpoint of other self-training systems described above, there has not been any research to measure the patient movement caused by the trainee. Therefore, this study developed a mannequin system that can measure the movement of a patient. Specifically, the present study focussed on the changing of clothes, proposed a mannequin that can imitate human performance, and measured the movement during the changing of clothes.

The remainder of this paper is structured as follows. Section 2 describes the skills needed in the changing of clothes. Section 3 presents the proposed approach, design and construction of the mannequin. Section 4 describes the experiment, which confirms that the developed mannequin is appropriate for self-training. In addition, the difference between nursing students and nursing teachers are showed. Section 5 provides the discussion. Finally, Section 6 is the conclusion.

2. Skills for the changing of clothes and problem setting

2.1 Skills for the changing of clothes

The changing of clothes is an activity that involves the nurse helping the patient remove their dirty clothes and putting on clean ones. In this paper, the clothes mean Japanese-style night wear, the yukata, made of cotton, which makes it less stretchy. The yukata is used in most Japanese hospitals and nursing homes as well as stretchy pajamas. Although the yukata and pajamas present the same difficulties in the changing of clothes, the less stretchy yukata is harder to change than the pajamas.

The skills in the changing clothes can be approximately divided into the postural changing of the patient's body, and the movement involved in dressing/undressing the patients' arms; putting them through or pulling them from the sleeves.

The procedure can be described as follows. First, the nurse removes the clothes from the right hand of the patient. The nurse gets the part of the clothes off their right shoulder. Then, holding the elbow joint, the nurse pulls the right arm of the clothes off the patient (Figure 1(a)).

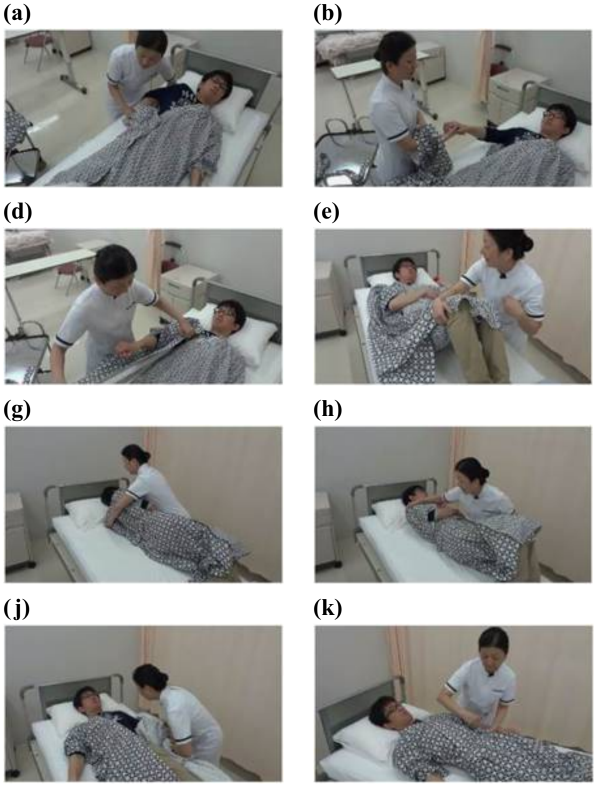
Next, the nurse rolls the removed half of the clothes under the patient's back and puts the new clothes onto the patient from the right hand. The nurse puts their hand in the sleeve (Figure 1(b)), holds the elbow and forearm of the patient, pulls the patient's arm through the sleeve (Figure 1(c)) and tidies the front part of the clothes (Figure 1(d)).

Then the nurse makes the patient lie on their side (Figure 1(e)), and puts the dirty clothes under the patient's back (Figure 1(f)). The nurse adjusts the new clothes and puts them under the patient's body (Figure 1(g)). The nurse helps the patient to lie on their back (Figure 1(h)) and pulls the dirty clothes from under them (Figure 1(i)).

They then put the patient's arm through the sleeve of the new clothes by taking the patient's hand (Figure 1(j)). Finally, the nurse tidies the clothes and ties the sash/belt of the yukata (Figure 1(k)).

2.2 Problem setting

There are no descriptions of how to move the limbs or parts of the body of patients, including how much a nurse is able to move or twist a patient's forearm. It is difficult to determine the evaluation points for this activity. However, it is clear that the nurse should not inflict pain by exceeding the limit of the elbow joint. Thus, this study constructed a mannequin system to reproduce and measure the movement of the patient. As mentioned before, the skills in the changing of clothes can be approximately divided into two parts: postural changing and arm handling. From discussion with nursing teachers, it was found that nurse students often failed to handle the patients' arms while putting them through or pulling them from the sleeves of hospital clothing. This failure would cause severe injury to the patient, such as a fracture. Therefore, this study designed a model of a human arm for the training of the changing of clothes.



Note: The nurses need to follow the procedure from (a) to (k) to change the patient's clothes

Figure 1. Procedure to change the clothes of a patient on a bed

The present study targeted on an old man with complete paralysis. Such patients cannot help a nurse to change their clothes because they cannot move their bodies at all. Therefore, a completely paralyzed patient is one of the most difficult persons for nurses to treat.

3. Design and construction of mannequin

3.1 Mannequin design

From discussion with the nurse teachers, joints to reproduce the patient's arm movement and the associated degrees of freedom of the joints needed for the mannequin were determined. The elbow of the mannequin should have one degree of freedom: that of extension/flection. Three degrees of freedom are needed for the shoulder joint: internal/external rotation, adduction/abduction and extension/flection.

With regards to the range of freedoms, this study concentrated on the extension/flection freedom of the elbow joint and internal/external rotation of the shoulder joint, because these freedoms are most related to severe injuries.

There has been some previous research in producing simulation models or mechanical structures to reproduce the arm of a human. For example, a model of a human shoulder joint with a ball joint manipulated by wires has been developed (Sakai *et al.*, 2006; Sodeyama *et al.*, 2008). Kinoshita *et al.* (2014) developed a humanoid electric arm with three degrees of freedom for the shoulder joint and manipulated it by servo motors.

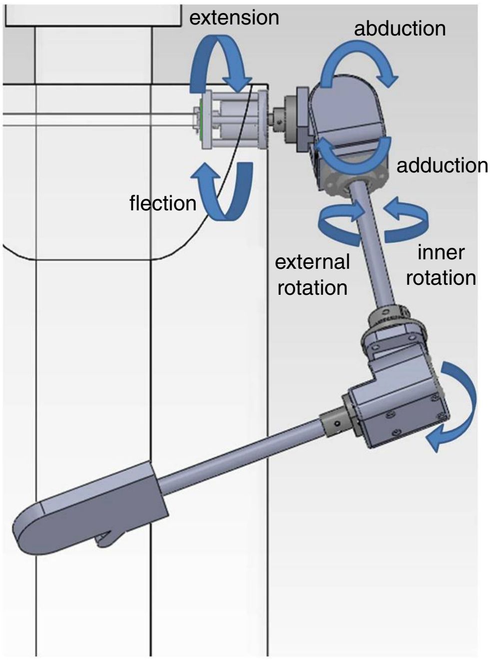
From the practice viewpoint of nursing students, the shoulder with a ball joint has two problems: the design is complicated, and it is not strong enough to stand up to long-term practice. The shoulder with three degrees of freedom also has two problems: the mannequin cannot reproduce the freedom that results from the shoulder blade bone; and the reproduction of the limited ranges of the joints is not sufficient.

The durability of a model is important for practice. Although the shoulder blade bone is needed for the mannequin to naturally lie on its side, this movement is not significant during the changing of clothes, so, it is less important. Therefore, shoulder joints with three degrees of freedom were constructed.

From the discussion above, we designed the arm of the mannequin. Figure 2 shows a computer-aided design image of the designed arm. The elbow joints and extension/flection, adduction/abduction and internal/external rotation of shoulder joints were applied to the mannequin. The length of the upper arm and forearm including hand and the rotation limits of each joint were generated from a database of old Japanese men (National Institute of Technology and Evaluation, 2013), as listed in Table II.

3.2 Measurement system design

To measure the angle of joints, we fitted potentiometers in all left and right rotation axes of the mannequin (adduction/abduction, flection/extension and internal/external



Notes: The shoulder had three DOFs and the elbow had one. The left arm had the same DOFs

Figure 2.
CAD image of the mannequin right arm

rotation of shoulder and elbow). To avoid interfering with the handling of the mannequin by trainees, the measurement system should be compact and installed inside the mannequin. This study used an Arduino (RDC506002A, Arduino Software) microcontroller board (based on the ATmega 2560) to gather the measurement data of the potentiometers. Bluetooth was used to transfer the data from the Arduino microcontroller to the computer.

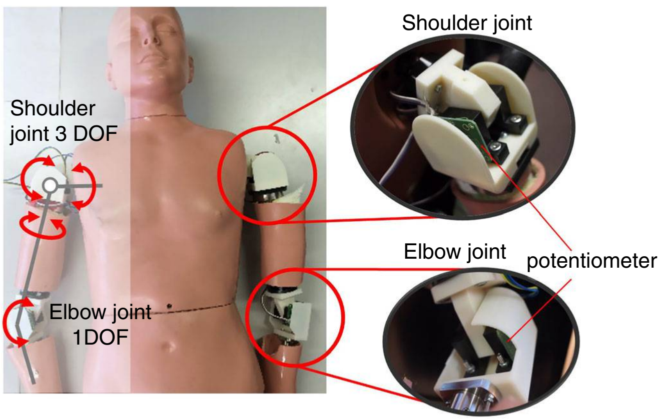
3.3 Construction of the mannequin

Figure 3 shows the developed mannequin based on a mannequin produced for rescue training (W44512, Avice Inc.). The original height was 165 cm and the body weight was 48 kg. Weight was removed from inside the mannequin and the arms were replaced with arms developed for this study. After construction, the mannequin height was unchanged, while the body weight was reduced to 17.8 kg. However, the arm weight of the mannequin was adjusted to reproduce that of a target patient.

Joint	Target patient	Mannequin
Elbow (degrees)	137	140
Shoulder adduction (degrees)	41	10
Shoulder abduction (degrees)	115	160
Shoulder flection (degrees)	150	Unlimited
Shoulder extension (degrees)	56	Unlimited
Shoulder internal rotation (degrees)	97	Unlimited
Shoulder external rotation (degrees)	34	Unlimited
Upper arm (mm)	300	300
Forearm+hand (mm)	421	420

Note: Target patient data were referred to the National Institute of Technology and Evaluation (2013)

Table II. The joint limits and length of the upper arm and forearm of the target patient and mannequin



Notes: The RHS upper and lower pictures show the detail of the shoulder and elbow joints, respectively. Potentiometers were fitted to all joints for the measurement of angles

Figure 3. The constructed mannequin

In Table II, the limits of each of the joints of the mannequin are shown. The range of the shoulder adduction of the mannequin is much smaller than that of the target patient, because the shoulder blade bones were not reproduced for the mannequin. Due to this limited range of shoulder adduction, the mannequin could not lie on its side like a human. However, as mentioned in Section 3.1, this movement is not important for the training of the changing of clothes. Therefore, it was decided that the difference in the shoulder adduction range between that of a real patient and the mannequin did not in any way influence the trainees in learning the skill of the changing of clothes.

Before the evaluation experiment by nursing students, two nursing teachers performed the changing of clothes operation using the mannequin as a preliminary experiment. The purpose of this experiment was to evaluate the arm movement of the mannequin during the pulling of the arm from the sleeves and getting it into the clothes. In addition, the teachers checked whether or not the small adduction range of the shoulder affected the training. They recognized that the movement of the mannequin's arm was similar to that of a completely paralyzed patient during the changing of clothes. In addition, they explained that the shoulder adduction range of the mannequin would not prevent the students from training. The mannequin was assessed to be completely suitable for the training of the changing of clothes. Therefore, we considered that the skill of the changing of clothes could be assessed through the mannequin and decided to perform the evaluation experiment in the next session.

4. Experiment and results

The purpose of the evaluation experiment was to elicit the difference in clothes-changing skills between nursing teachers and students using the mannequin we constructed.

Two nursing teachers and six nursing students (the first- and second-year students) from the Tokyo Ariake University of Medical and Health Sciences (TAU) took part in this experiment. All the students had learned about changing clothes in classroom lectures but did not have any practical experience of the procedure. The teachers knew very well how to change a patient's clothes. All participants gave written informed consent prior to the experiment. The study was approved by the ethics committee of TAU.

The task was to change the clothes on the mannequin four times. Figure 4 shows the image of the mannequin during the changing of clothes by a nursing student. Before

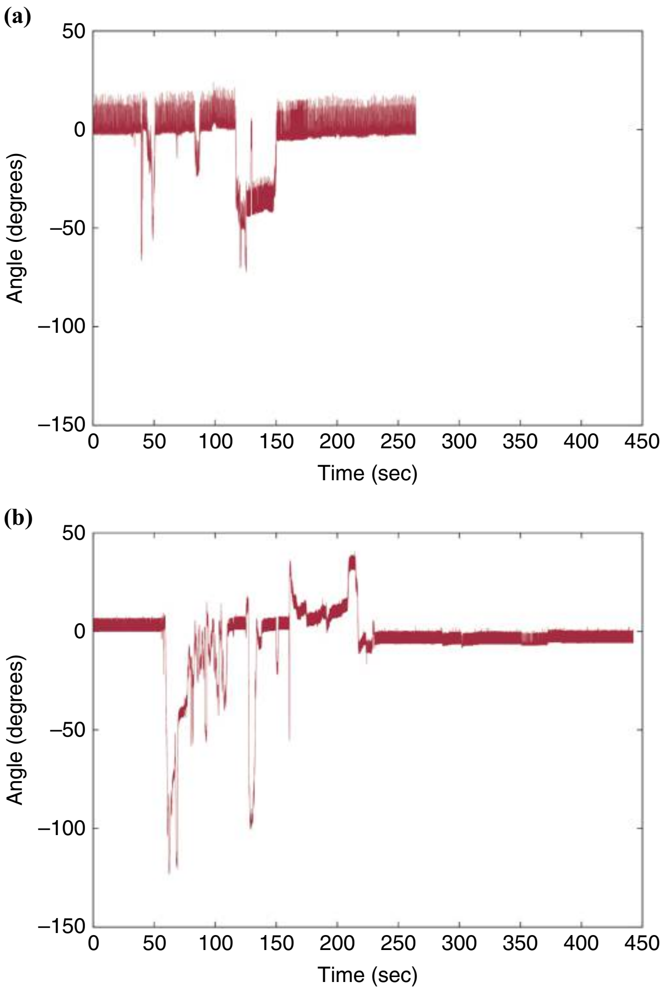
Note: The student nurse is trying to remove the clothes from the right arm of the patient

Figure 4.
Picture of the mannequin during the changing of clothes experiment

the task, the students were shown a film/video/DVD in which a nursing teacher changes the clothes of healthy mock patients for review.

The data for three students were eliminated because they were unable to complete four trials due to insufficient skill. Thus we used the results of the remaining three students and the two teachers for the analysis.

We measured the left and right joint angles of the elbow, shoulder adduction/abduction, extension/flection and internal/external rotation. Figure 5(a)-(b) show the samples of the extension/flection angle of the right shoulder during the changing of clothes by the teacher and student nurses, respectively. The teacher completed the changing of clothes before the students. The joint angles measured in the case of the students were greater than those in the case of the teachers. In addition, when the



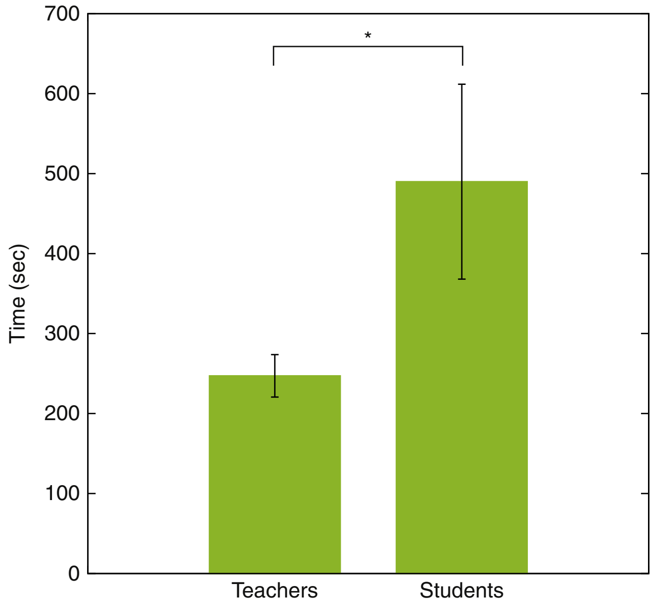
Notes: Time 0 is the start of the trial. The end of the time series means the finish of the trial

Figure 5. The extention/flection angle time series of the right shoulder in (a) the nursing teacher case and (b) the student nurse case

students were performing, the frequency of the large angles measured was higher than in the case of the teachers. To exclude these different points between the nursing teachers and students, the total time it took to change the clothes, average joint angle and number of peak angles were calculated.

Figure 6 shows results of the average total time it took for the teachers and students to change the clothes. The average times of the teachers and students were 247 and 490 seconds, respectively. The *t*-test showed a significant difference between the teachers and the students ($p = 0.043$).

Table III shows the average of the joint angles and number of peaks in the teacher and student cases. There were significant differences in the average joint angles on the



Notes: The error bars represent the standard deviations between all trials. *Significant difference $p < 0.05$

Figure 6. Comparison of time taken to change the clothes of the mannequin

Table III. Average angles of the joints

Joint	Teachers mean ± SD (degrees)	Student mean ± SD (degrees)	*p*-value
Right elbow	−8.31 ± 6.02	−13.82 ± 13.37	0.436
Left elbow	−7.20 ± 4.72	−21.81 ± 7.80	0.003**
Right shoulder adduction/abduction	4.10 ± 3.84	3.14 ± 27.68	0.902
Left shoulder adduction/abduction	−4.77 ± 7.57	−9.76 ± 13.58	0.645
Right shoulder extension/flection	−4.50 ± 6.20	−17.39 ± 36.03	0.503
Left shoulder extension/flection	−5.25 ± 11.15	−25.88 ± 24.07	0.332
Right shoulder internal/external rotation	4.94 ± 14.68	−11.55 ± 28.10	0.241
Left shoulder internal/external rotation	8.84 ± 13.33	−13.17 ± 25.41	0.154

Notes: SD means the standard deviation between all trials. **Significant difference $p < 0.01$

left elbow joint in the *t*-test. Table IV shows the results of the number of joint peaks in the teacher and student cases. The number of joint peaks was calculated as follow. First, a 50-interval moving average of the time series of each angle was calculated. Then, the number of joint peaks whose absolute values were greater than five degrees was counted. The number of peaks shows the movement frequency of the arm. With respect to the number of peaks, the left elbow joint, adduction/abduction freedom and rotation freedom of the right shoulder joint displayed significant differences between the teachers and students in the *t*-test.

5. Discussion

The evaluation experiment performed by the teacher and student nurses confirmed that our developed mannequin enabled nurses to change the clothes of the mannequin and that the mannequin was able to reproduce the movement of the patient arms.

In addition, some differences in the way of changing clothes between the teachers and students were found. The average total time to change the clothes was shorter for the teachers than the students. This result shows that teachers changed the clothes more efficiently than the students.

Both the average angle and the number of peak angles of the left elbow showed significant differences. These results demonstrated that there is a difference between how the nursing teacher and students move the patient's left arm. The left arm of the patient is moved a great deal when the nurse pulls the patient's left arm from the sleeve. Therefore, the results of the left elbow showed that the students bent the patient's arm to a greater extent and more frequently than the teachers. That is, the handling of the left elbow is one important point of the changing of a patient's clothes.

The other point is the right shoulder. The peak numbers of the right shoulder internal/external rotation and adduction/abduction showed significant differences between the students and teachers. The right shoulder moved to a great extent while pulling the right arm from the sleeves and getting it into the clothes. That is, the handling of the right shoulder is a point of difficulty in the changing of clothes.

In the future, it is necessary to develop a feedback system to evaluate the trainee's movements during self-training. For the training of transferring a patient from a bed to a wheelchair, Huang *et al.* (2013) developed a system that can inform the trainee whether the movement is correct depending on given check points. However, as mentioned in the introduction, it is uncertain yet as to how to move the patient's body during the changing of clothes. To construct the feedback system for such a procedure,

Joint	Teachers mean ± SD	Student mean ± SD	*p*-value
Right elbow	0.38 ± 0.52	3.83 ± 3.07	0.140
Left elbow	0.88 ± 0.64	4.33 ± 2.15	0.047*
Right shoulder adduction/abduction	0.38 ± 0.52	3.17 ± 2.41	0.010*
Left shoulder adduction/abduction	0.25 ± 0.46	4.00 ± 4.55	0.268
Right shoulder extension/flection	0.38 ± 0.52	2.50 ± 2.32	0.166
Left shoulder extension/flection	0.38 ± 0.52	2.67 ± 1.97	0.097
Right shoulder internal/external	1.38 ± 1.51	3.92 ± 2.43	0.013*
Left shoulder internal/external	1.63 ± 1.41	4.17 ± 2.67	0.116

Notes: SD means the standard deviation between all trials. *Significant difference $p < 0.05$

Table IV. The number of joint peaks

it is necessary to establish methods to evaluate students, including their skills. The results of the differences between the nursing students and teachers suggest that the mannequin system has the potential to identify key points or to extract some mathematical model of the way to move a patient's body.

6. Conclusion

The purpose of this paper was to report on the development of a mannequin system to simulate patients' movements and to measure their arm movements during the changing of clothes for the training of nursing students. This study developed a mannequin that reproduced a human shoulder joint and elbow joint as well as measuring the angles of those joints. In the evaluation experiment, it was confirmed that both the teachers and students were able to successfully change the clothes of the mannequin and that the reproduction of the mannequin was satisfactory for the training of the changing of clothes. In addition, it was found that the key difficulties in changing clothes are in removing the left arm from the clothes and getting the right arm into the clothes.

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