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Human factor ergonomic analysis of cervical cancer intracavitary therapy transport process based on Jack virtual simulation technology

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Abstract: With the incidence of cervical cancer in women rising year by year, its impact on the physical and mental health of patients as well as their families is becoming more and more significant. At present, hospitals often use intracavitary radiation therapy, and intracavitary therapy transfer bed as a gynecological oncology intracavitary radiation medical auxiliary device plays an extremely important role. Therefore, for the design of intracavitary therapy transfer beds, the validation of man-machine adaptability can well help to optimize its structure. The paper firstly imports the three-dimensional model of intracavitary therapy transfer bed established in UG software into the ergonomics analysis software Jack; secondly, in the analysis environment, it establishes the human body model that conforms to the body dimensions of patients with cervical cancer as well as the human body model of healthcare workers; then, on this basis, it establishes the simulation model for the patient's posture of using the intracavitary therapy transfer bed as well as for different movements of the healthcare workers in the course of the treatment; finally, it analyzes the stresses of the patient's lower limbs, as well as the waist, back, and upper limbs of the healthcare workers through the simulation and analyzes the comfort of the patients and the healthcare personnel with respect to the different movements of the treatment task. The analysis of the simulation results can verify the rationality of the design of the intracavitary therapy transfer bed and the use of comfort, and at the same time, combined with the results of the analysis of the healthcare worker's working posture, to provide an analysis method for the structural optimization of the intracavitary therapy transfer bed.

1. Introduction

Cervical cancer, mainly caused by HPV virus infection, is a common gynecological malignancy, and its high incidence is mostly in women aged 30 to 55 years old. Current treatments for cervical cancer can be broadly categorized into four types: surgery, radiation therapy, chemotherapy, and other treatments[1]. Radiation therapy is the most widely used treatment for cervical cancer of different stages and caused by various pathologies[2]. Usually, cervical cancer patients are treated with radiation therapy on simple stainless steel transfer beds, which have a single function and cannot regulate the posture of patients' lower limbs or fix the patient's position, thus negatively affecting the therapeutic effect to some extent. Moreover, such transfer beds do not have the function of bed crossing, and it is necessary to rely on a large amount of manpower from healthcare workers to realize the transition of patients between CT scanners and transfer beds. therefore, an intracavitary therapy transfer bed with relevant functions is designed, and Jack software is used to establish digital human models of patients and healthcare workers, create application scenarios such as patient treatment and bed-crossing operation, and carry out static and dynamic simulation of the human-computer interaction process, and through the analysis of the simulation results, the human-computer suitability of intracavitary therapy transfer bed is verified, so as to propose improvement and optimization of the design.

2. Establishment of the simulation environment

2.1. Transfer bed ergonomics simulation experiment basic process

The ergonomics simulation experiment of the transfer bed for intracavitary therapy of cervical cancer is divided into two steps: firstly, prepare the three-dimensional model of the transfer bed, create the user's human body model, and construct the task environment; secondly, use the Jack analysis tool to get the results and analyze them. The basic flow of the experiment is shown in Figure 1.

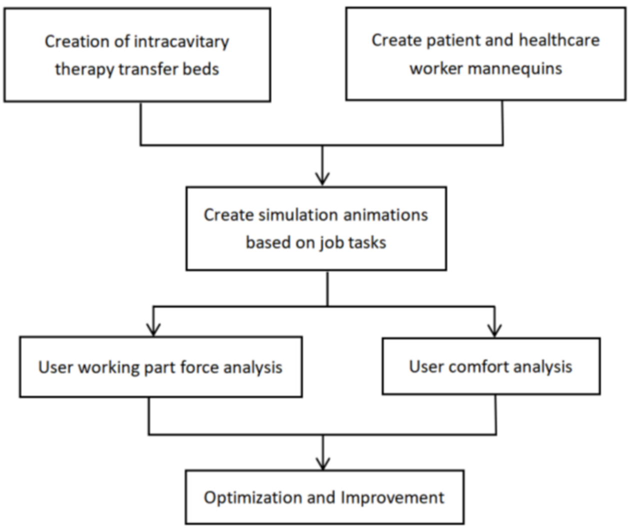


Figure 1: Flow of human factors efficacy analysis for transfer beds.

2.2. Building patient mannequins

The Jack human model database contains body size measurements from several countries, such as China, the United States, and Germany. Since cervical cancer patients are mostly middle-aged women, only the body size characteristics of middle-aged women in China need to be considered to build a virtual digital human model. According to the Chinese Adult Body Size GB/T 10000-1988[3], female body sizes selected close to the age of onset are shown in Table 1.

Table 1: Body size of middle-aged women.

Item	Middle-aged women/mm		
	P5	P50	P95
height	1477	1560	1646
weight，kg	44	55	70
maximum shoulder width	368	405	449
upper arm length	260	282	306
forearm length	192	213	233
thigh length	399	434	472
calf length	311	341	373
girth	704	836	998
hip measurement	843	926	1021

Where the waist-hip ratio can be expressed as:

$$WHP = WC/HC \tag{1}$$

WHP(Waist to Hip Ration)Indicates waist-to-hip ratio, WC(Waist Circumference) Indicates waist circumference, HC(Hip Circumference) Indicates hip circumference. To accommodate the body dimensions of most patients, the 95th percentile measurements were chosen to build the patient mannequins. In the [Anthropometric Scaling] dialog box of Jack software, a Chinese female with a height of 1646 mm, a weight of 70 kg, and a waist-to-hip ratio of 0.97 was created, as shown in Figure 2. Compared to the 95th percentile female numerical model in the system, the female numerical model in the diseased age group has a larger waist-to-hip ratio and a fuller body shape.

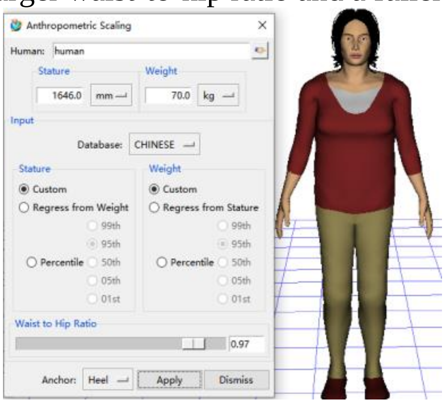


Figure 2: Digital human model of a patient.

2.3. Establishment of healthcare worker mannequins

When healthcare workers are performing tasks such as inserting and treating patients, transferring them across beds, etc. They often feel soreness in the upper limbs and lower back due to poor working postures or inconveniently operated medical equipment. Over time, this substantially increases the risk of musculoskeletal disorders (MSDs) in healthcare workers [4]. Therefore, in order to improve the comfort of healthcare workers, a healthcare worker mannequin was created for simulation analysis.

The treatment process generally requires the collaborative work of two or more healthcare workers and there is some physical work involved. Therefore, a digital human model of a male and female healthcare worker was created separately, and the 50th percentile human data was chosen as the healthcare worker model, considering that human body sizes are normally distributed. In addition, in order to highlight the characteristics of the healthcare workers, the use of Jack software to create the human body dialog box in the [Material Properties] function, the healthcare workers digital model of the dress code is set to white, and then create a good mask as well as the nurse cap and other CAD models imported, and wear with the healthcare workers, as shown in Figure 3.

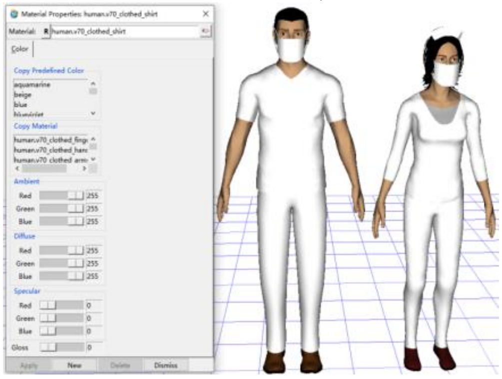


Figure 3: Digital human model for healthcare workers.

2.4. Modeling of intracavitary therapy transfer beds

Siemens ergonomics simulation software Jack also has a powerful interactivity, can directly import STL, IGES, VRML and other 3D graphics data [5]. Therefore, the 3D software UG is used for modeling, and the model is exported to STL format and then imported into Jack software, as shown in Figure 4. According to the patient's human body size, the length of his bed is set to 1080mm and the width is 500mm.

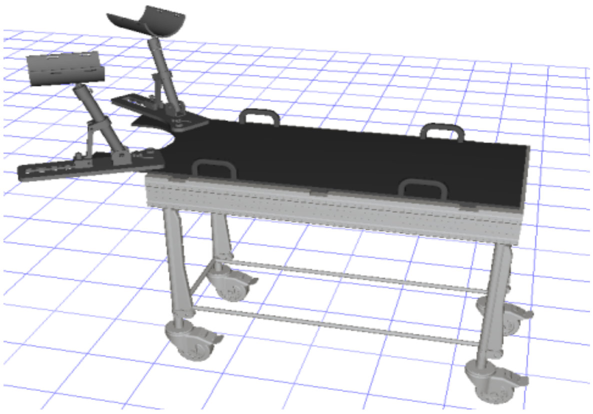


Figure 4: Three-dimensional model of intracavitary therapy transfer bed.

3. Patient human-machine simulation modeling and human factors analysis

3.1. Creating patient ergonomics simulation models

For the patient, the main function of the transfer bed is to fix the patient's lower limbs and realize the posture adjustment of the patient's lower limbs, when using the patient needs to lie flat on the bed board, the lower leg is placed in the leg rest, the palm of the foot against the bottom plate of the leg rest. The posture mainly involves the motion biomechanics of the patient's hip, knee and ankle joints. The motion of the hip joint is similar to that of a ball bearing, which can be broken down into three mutually perpendicular movements, i.e. Flexion and extension in the sagittal plane, abduction and adduction in the coronal plane, and internal and external rotation in the transverse plane. In general, the maximal hip flexion and extension ranges are 0~140° for forward flexion and 0~15° for backward extension, the maximal abduction and adduction ranges are 0°~30° for abduction and 0°~25° for adduction, and the maximal internal and external rotation ranges are 0°~70° for internal rotation and 0°~90° for external rotation. The motion of the knee is not only a flexion-extension motion but a multi-degree-of-freedom motion pattern that includes flexion-extension, sliding, axial rotation, and lateral translation, with flexion-extension ranging from 0° to 145°, internal rotation ranging from 0° to 10°, and external rotation ranging from 0° to 20°. The movements of the ankle joint are mainly dorsiflexion, plantarflexion, rotation, and flipping of the foot, with dorsiflexion ranging from 0° to 25°, plantarflexion ranging from 0° to 45°, internal rotation ranging from 0° to 30°, and external rotation ranging from 0° to 35°[6].

As the intracavitary therapy transfer bed has multiple adjustment stops, the patient's lower limb posture can be adjusted for a variety of situations, the range of motion of the patient's three lower extremity joints is also taken into account. Therefore the gears of the intracavitary therapy transfer bed are set to maximum, that is, the patient's maximum lower extremity joint mobility during use of the device, to create a patient human-machine simulation model. Using the human joint adjustment function in Jack software is to adjust the posture of the created digital mannequin of the patient, so that the digital mannequin and the intracavitary therapy transfer bed can be coordinated. The simulation model is created as shown in Figure 5.

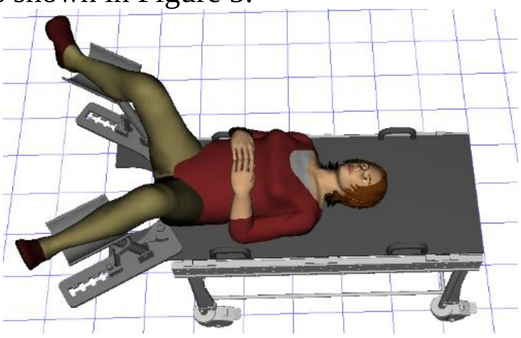


Figure 5: Patient man-machine simulation model.

3.2. Static strength analysis of the patient's body

[Task Analysis Toolkit]Task Analysis Toolkit is the most important human factors analysis tool in Jack's software, which contains ten major human factors analysis tools, of which "Static Strength Prediction" can analyze the ability of a digital person to complete the work in a specific position and the bending angle, torque and strength of the body's joints [7]. The established patient task model was analyzed using Static Strength Prediction (SSP) and the analysis results shown in Figure 6 were obtained.

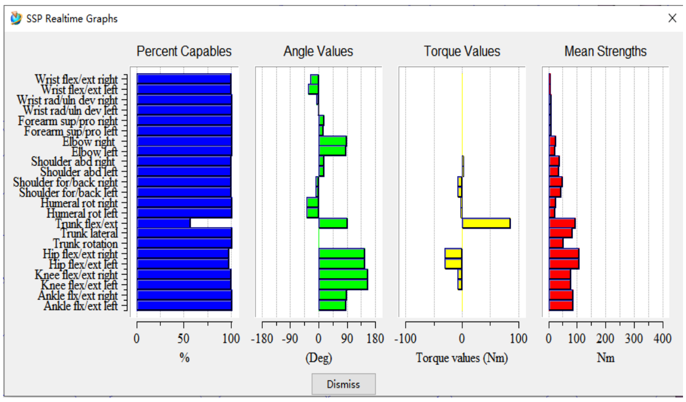


Figure 6: Patient static strength analysis results.

The “Percent Capables” table in the Static Strength Prediction results indicates the percentage of women who are able to withstand the forces placed on the muscles of each joint in the current position. The percentage of capacity of the trunk in the analyzed results is lower than the set standard value of 75% due to the fact that the patient is lying flat and the lower limbs are flexed and raised in this position, so that the patient's self-weight is mainly concentrated in the trunk position. "Angle Values" refers to the angle of bending of the elbows, shoulders, hips, knees, and ankles, and the results showed that the patient's lower extremities had large angles of bending in all areas, but were within the acceptable range of motion. "Torque Values" and "Mean Strengths" represent the joint torque and the average strength of each part, respectively. This calculation is based on the results of the three-dimensional static force strength experiments conducted by Prof. Anderson and Prof. Chaffin of the Human Factors Engineering Center of the University of Michigan [8].

3.3. Patient comfort analysis

The level of comfort of the patient's body joints when using the transfer bed is an important reference for evaluating as well as improving this designed device. Joint comfort can be expressed as the ratio of the current joint moment to the maximum joint moment, which is expressed as[9]:

$$C_j = 1 - I_{cj}\ ,\ j = 1,2,3 \ldots n \tag{2}$$

where j denotes each joint and n denotes the number of joints, I_{cj} is the discomfort of the joint, which can be described as the ratio of the joint moment M_j to the maximum joint moment M_{jmax} , namely

$$I_{cj} = \frac{M_j}{M_{jmax}} \tag{3}$$

$$C_j = 1 - \frac{M_j}{M_{jmax}} \tag{4}$$

Jack provides the [Comfort Assessment] comfort analysis tool, which has six types of comfort experimental data as a reference, of which the single joint comfort usually refers to the Dreyfuss 2D experimental data, which is Henry Dreyfuss Associates through a large number of men and women experimental measurements[10]. This data study shows that it can be comfortable in most cases and is more suitable for analyzing the comfort of human lower limb movements than other comfort reference data. Therefore, Dreyfuss 2D was utilized to analyze the patient's current postural comfort and the results are shown in Figure 7.

The analysis shows the flexion of each of the patient's joints, and when the joints are flexed beyond the comfort range, the color of the data bar is yellow. It can be seen that the hip and knee joints connecting the trunk and thighs of the patient in this position are flexed too much, and the patient will feel a certain degree of discomfort if the position is maintained for a long period of time. However, since the entire treatment process takes about thirty minutes and each treatment is spaced out over a long period of time, it does not cause any harm to the patient's body, although there is some discomfort during the treatment. Through the comfort analysis, consideration should be given to prototype manufacturing with additional soft padding at the foot rest to improve patient comfort.

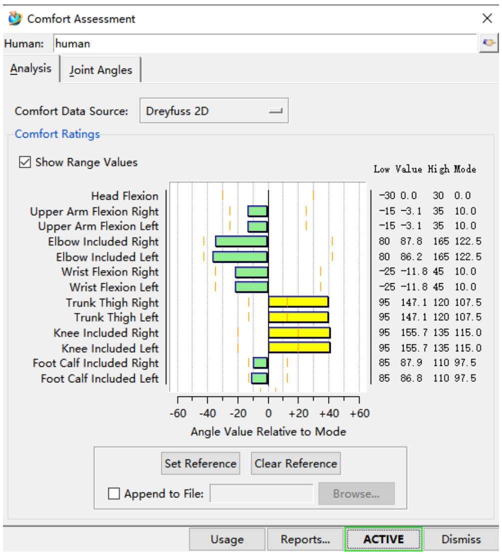


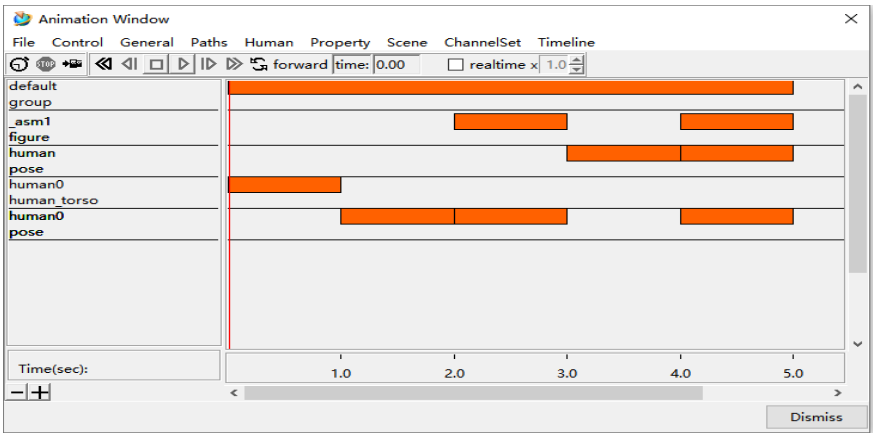
Figure 7: Results of patient comfort analysis.

4. Establishment and ergonomic analysis of working model of healthcare workers

4.1. Establishment of patients' cross-bed task model

To facilitate the transfer of patients to the CT scanner by healthcare workers, the design's intracavitary therapy transfer bed has a detachable bedpan and bed frame, and the bedpan can be mated with the override bracket on the CT scanner to enable patient override by means of the override bracket rails. Import the assembled transfer frame and CT scanner model into Jack, use [Animation] animation to create a dynamic simulation, use[Human]to edit the poses of the healthcare workers and save them in[Pose], call these poses and set the start time to generate animation in the dynamic simulation window[Human]. The dynamic simulation of the healthcare worker pushing the patient across the bed, as shown in Figure 8. After the dynamic task scene is created, it is also necessary to apply loads to the upper limbs of the healthcare workers. Since the healthcare workers is mainly subjected to friction in the horizontal direction during this task, the friction force can be expressed as:

$$F = \mu \times F_n \tag{5}$$



(a)

(b)

Figure 8: (a) Transport patient animation simulation editor; (b) Transport patient animation simulation.

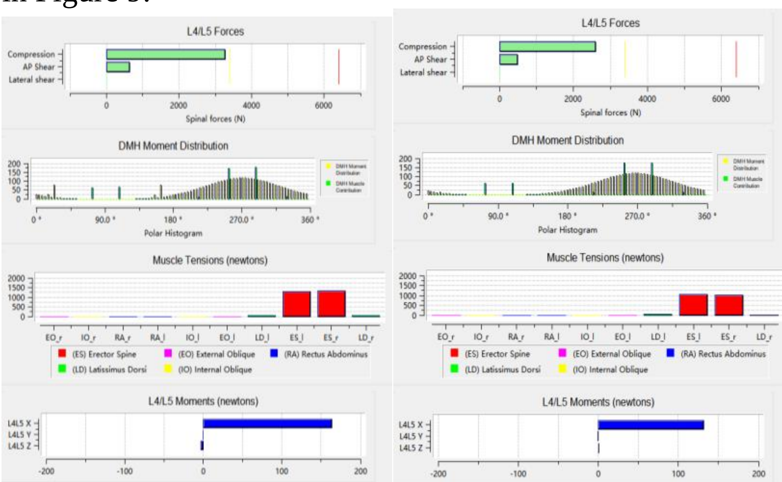
where μrepresents the kinetic friction factor and$F_n$is a positive pressure. Use [Loads&Weights] in Jack to apply loads to the arms of the healthcare workers.

4.2. Human factors ergonomics analysis of healthcare workers

4.2.1. Lower back analysis results

The [Lower Back Analysis] tool in Jack's software can analyze the impact of spinal force on the lower back of healthcare workers during patient transportation. This analytical tool utilizes a physiological lower back model to calculate the pressure at the L4/L5 vertebrae, which exceeds the NIOSH (National Institute for Occupational Safety and Health) standard, which indicates that the human body is at a higher risk of lower back damage from prolonged exposure to this work posture [11].

Lower back analysis was performed on the dynamic work process of the two healthcare workers respectively, and their lower back force, torsional moment distribution, muscle force, and torque were obtained, as shown in Figure 9.



(a) (b)

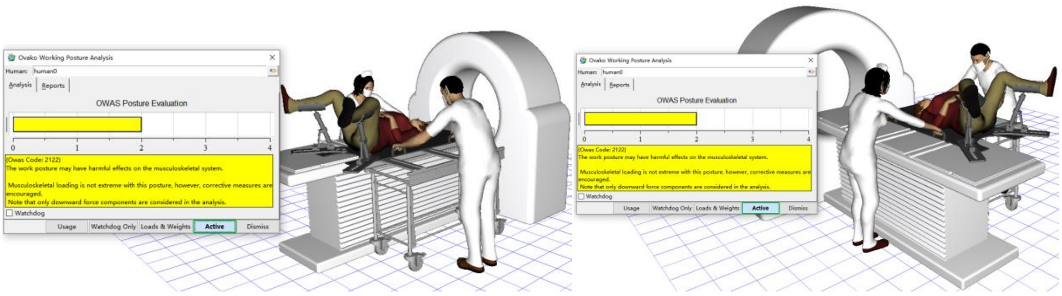
Figure 9: (a) Results of the analysis of the maximum force on the lower back of male healthcare workers; (b) Results of the analysis of the maximum force on the lower back of female healthcare workers.

This result shows that the force on the spine of both healthcare workers was less than the recommended force of 3400N given by NIOSH, and the histogram is green. [DMH Moment Distribution] Histogram of torsional moment distribution, mainly showing the effect of each joint moment on each muscle. The histogram of muscle force shows that the vertical spine muscles on the left and right sides of the healthcare worker have the greatest force. From the L4/L5 torque diagram, it can be seen that the L4/L5 joints of the healthcare worker are mainly subjected to the torque in the X direction.

4.2.2. Results of work posture analysis

The Working Posture Analysis tool [Ovako Working Posture Analysis] is an important dynamic simulation and analysis tool in Jack, which evaluates the working posture based on the human back, arm and leg loading requirements[12]. According to the necessity of correcting the working posture, the correction level is divided into four levels: level 1 indicates that the working posture is normal and does not need to be corrected; level 2 represents that there is some adverse effect of the working posture, and appropriate adjustments can be taken; level 3 is that there is an adverse effect of the working posture, and it needs to be corrected as soon as possible; and level 4 indicates that the working posture is very harmful, and it needs to be corrected immediately.

Throughout the dynamic simulation process, the working posture correction level changed from level 1 to level 2 when the healthcare worker moved to the working posture shown in Figure 10 respectively. Since the lower back force of the healthcare worker in the lower back analysis was within the NIOSH recommended value, it was considered that the healthcare worker's arm was subjected to larger force resulting in certain adverse effects on the working posture.



(a) (b)

Figure 10: (a) Results of the analysis of the work posture of male healthcare workers; (b) Results of the analysis of the work posture of female healthcare workers.

5. Conclusions

In this paper, the human-computer interaction of the intracavitary therapy transfer bed was studied by using Jack software, and digital human models of patients and healthcare workers were established to simulate the scene of using the intracavitary therapy transfer bed for cervical cancer, focusing on the analysis of patients' lower limbs and torsos, as well as the upper limbs and backs of the healthcare workers. According to the results of the static strength and comfort analysis of the patients, it can be seen that when the lower limb immobilization device of the transfer bed is adjusted to the maximum gear, the patient's hip joint flexion is larger, which not only reduces the patient's comfort, but also leads to the patient's torso muscles to be more stressed, so that the percentage of their ability is lower than the standard value of 75%. Therefore, when designing the lower limb immobilization device, the height of the tripod adjustment should be appropriately lowered, so that the range of inward and outward adduction in the horizontal direction can be convenient for the doctor to insert the implant treatment. Adjusting the height and angle of the foot rest in the lower limb immobilization device, the patient's knee range of motion is roughly 90°~180°, while the comfort analysis results of the patient's knee bending angle of 155°, the patient's knee bending angle is too large due to the patient's discomfort has begun to occur, Jack gave the recommendation that the knee bending angle is within 135°. Therefore, the height of the footrest should also be lowered and tilted as far upward as possible to minimize the patient's knee flexion angle. By analyzing the dynamic simulation results of healthcare workers, it is known that the way of transferring patients with the help of track translation can reduce the amplitude of bending of healthcare workers, so as to reduce the force on their lumbar backs and reduce the risk of lumbar muscle strain, but the results of the analysis of the working posture show that there is still a certain adverse effect on the working posture of the healthcare workers, and it is considered to be that the arm is subjected to too great a force. Therefore, when researching and designing transfer beds, consideration should be given to using materials with a lower friction factor or changing from sliding to rolling to reduce friction and reduce the force on the arms of healthcare workers.

Acknowledgements

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