Can mobilising specialists be relieved by a robotic system for the early mobilisation of intensive-care patients? A quantitative longitudinal study at three data collection points at a German university hospital

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Abstract

Immobility in intensive-care patients can lead to significant health risks and costs for the health system. Reasons for this include the shortage of specialist staff in nursing and physiotherapy who typically handle mobilisation activities for intensive-care patients. The use of robotic systems aims to facilitate early mobilisation and thereby counteract prolonged immobility. Whether this can also alleviate the workload for staff has not yet been sufficiently investigated. To examine the psychological stress and behaviour of mobilising specialist during conventional and robot-assisted mobilisations of intensive-care patients and to draw conclusions regarding the impact on and relief for the mobilising staff due to the robotic system, a quantitative longitudinal study was conducted with two data collection points (T1, T2). Aspects of body posture, the perceived stress of mobilising staff, as well as the time and personnel required for mobilisation were collected through non-participatory standardized observations. Descriptive statistics were used for data analysis of the observations of 35 conventional mobilisations (T1) and 55 robot-assisted mobilisations (T2). Additionally, a follow-up was conducted for nine robot-assisted mobilisations to assess the routine use of the robotic system.

The duration of robot-assisted mobilisation had significantly longer process times in preparation, follow-up and execution phases compared to conventional mobilisation.

A significant correlation was found between the subjectively assessed feasibility of mobilisation and psychological stress (PSaR) experienced by the specialist staff during robot-assisted mobilisation. The more confident users felt in robot-assisted mobilisation, the less psychologically stress they perceived it.

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Background

Patients treated in an intensive care unit (ICU) can experience prolonged immobility (1). However, initiating early patient mobilisation within 72 hours of admission to the ICU, as stipulated by the German S3 guideline "Positioning therapy and mobilisation of critically ill patients in intensive care units" (2), can help mitigate potential long-term damage, such as the development of ICU-acquired weakness (3). This approach may also reduce costs for the healthcare system (4) . The primary reasons for delayed or omitted early mobilisation include a shortage of resources among specialist staff and inadequate equipment (5, 6). Additionally, caring for patients in the ICU entails significant physical and psychological stress for specialist staff. These stress factors not only affect job satisfaction but also private well-being (7). Moreover, high levels of stress can affect self-esteem and contribute to burnout (8). Robotic systems can be utilised, some of which can even assist or take over mobilisation activities to counteract patients' prolonged immobility and alleviate the workload of the mobilising specialist staff (9). One such robotic system is the adaptive robotic assistance system VEMOTION® developed by ReActive Robotics.

The system comprises a specialised intensive care bed with a docking point at the foot end for the robotic system (see figure 1). It can then be controlled via an associated monitor and generate a gait movement. Consequently, the hospital bed, with the robotic system docked, functions as a therapy device without the need to transfer the patient. To commence therapy with the robotic system, the patient must first be securely fastened to their bed using special securing units. For this purpose, a seat adapter is positioned under the ischial tuberosities of the patient and attached and secured to the bed with a snap hook system. Fastening straps are also placed across the patient’s chest and hips. Subsequently, the robotic system is docked following the instructions displayed on the monitor. The feet and thighs are also connected to the robotic system there. In-bed gait training can then be initiated, during which the bed can be vertically adjusted to 70 degrees. The monitor allows for configuring the step frequency and activity level of the robot, among other settings. This enables the robotic system to facilitate passive or assisted mobilisation.

The quantitative longitudinal study described here focuses on the stress perception of mobilising specialist staff during conventional and robot-assisted mobilisation of patients requiring intensive care. Mobilising specialist staff are understood to mean the professions of nursing and physiotherapy, as it can be shown that these are the main mobilising professional groups (10, 11) .

To establish the best possible comparability with the movements of the VEMOTION®, mobilisations of intensive-care patients to sitting, walking, or standing are observed during the data collection of the conventional mobilisation. The primary objective of observing only early mobilisations could not be fully realised due to staff turnover caused by the pandemic and reduced familiarity with the VEMOTION® robotic system among the mobilising specialist staff. Therefore, the results report only refers to “mobilisation” as a whole.

The study description is based on the checklist for observational studies “STrengthening the Reporting of OBservational studies in Epidemiology” (STROBE) (12).

Objectives

The study aims to test the VEMOTION® robotic system during mobilisation in an intensive care unit (ICU) setting.

The following research questions served as the guiding principles:

1. What differences can be observed in terms of the psychological strain or relief experienced by mobilising specialist staff during conventional mobilisation compared to mobilisation with the VEMOTION® robotic system?
2. What are the effects on patient-, user-, and process-related aspects of testing the robotic system VEMOTION® for mobilising patients in the intensive care unit?

Methods

Study design

This is a prospective observational study conducted at a single center, with data collected at two time points. The study was conducted from August 2021 to April 2022 in two anaesthesiologically managed intensive care units of a German university hospital that treats approximately 500,000 patients per year in two locations (13). The range of the anaesthesiological intensive care units includes follow-up treatment after urological, gynaecological, general, and trauma surgery, as well as following organ transplants.

A total of 100 standardised non-participant observations of mobilisations were carried out (14), distributed across the two data collection points T1 and T2 (see figure 2). Ten of these observations had to be excluded in the course of the study (see table 2). The observations were analysed using descriptive statistics (15).

In addition, a follow-up consisting of nine mobilisations performed by routine users could be observed.

Sample/study participants

Mobilising specialist staff

Nurses and physiotherapists with a minimum of three years of professional experience in an intensive care unit, along with nurses with specialist further training in anaesthesia and intensive care (in accordance with the specifications of the Deutsche Krankenhausgesellschaft; DKG), were included. Additionally, all participants had to be employed at the University Hospital LMU Munich, Germany, working in the project wards, and had to consent to the observation.

Group composition (T1, T2 and Follow Up group)

At both T1 and T2, study participants were selected based on their shifts and mobilisation activities and asked to consent to participate. After consenting, the mobilising professionals were then observed during conventional or robot-assisted mobilisations. Participants who were already familiar with the use of the robotic system and had previously consented to participate in the study during the T2 observation were observed again during a follow-up.

Patients

The study included only adult patients aged eighteen years and above who were scheduled for an intensive care stay after surgery, as this was the most suitable time for planning and obtaining informed consent. A homogeneous composition with regard to the surgical intervention was considered, and further inclusion criteria included an expected duration of ventilation of at least 48 hours, a height between 1.50 m and 1.95 m, and a weight between 45 kg and 135 kg.

Data collection and evaluation

Data collection was carried out using standardised, non-participant observations during different mobilisation methods by mobilising specialist staff in the intensive care setting. This enabled the observation of participants in their working environment (field observation) (16). Observers were visible and present at all times for the mobilising specialist staff and explicitly acted as researchers during data collection (17) .

In the process of operationalising the phenomena “perception of psychological and physical stress”, the standardised observation sheet was initially created. Preparation was based on a previously conducted systematic literature research and evaluation of the preliminary studies performed within the framework of the MobiStaR project (9, 11, 18) . The relevant variables and their variations were identified before designing the observation sheet. The observation sheet was designed with explanatory illustrations for quick and uncomplicated use and uniform documentation (16). The primary focus of the observation was always on the person who took the leading role in mobilisation. This role was determined before mobilisation was performed and documented in the observation sheet.

The observation sheet was designed directly by the researchers. It was reviewed and adapted to the questions in collaboration with other researchers from the field of intensive care and physiotherapy. The observation sheet was subjected to a pretest in the context of operationalising the relevant variables and the respective variations (16). Two researchers applied the survey instrument in parallel, using the same sample drawn from the population of interest, and then reflected on the perspectivity, selectivity, and constructedness of the observation process.

The same results were obtained when the pretest was conducted on the same observed sample by the two independent researchers. Interrater reliability was checked and accepted without further testing.

Furthermore, the designed observation sheet was tested by five persons from the fields of nursing science and nursing practice as well as physiotherapy, within the scope of an expert validation and consent for the first form of content validity, or apparent validity (19). In addition, the observations in the pretest could be practicably documented on the survey form, and the two initial researchers rated the contents of the observation sheet as comprehensible and appropriate. Due to the standardisation of the questionnaire, the quality criterion of objectivity of implementation was considered to be fulfilled, and further adaptation of the observation sheet was not necessary (19). No further psychometric tests for validity and reliability were conducted within the scope of this study.

Description of the observation sheet

The standardised data collection form comprises basic data, anonymised data of the test persons, process-related data on mobilisation duration and work organisation as well as variables on body postures of the mobilising specialist staff, their subjective assessment of psychological stress and relief, and feasibility of robot-assisted mobilisation. Table 1 lists the constructs, the respective variables, and their characteristics.

(Table1)

The time of the survey defined the start of the observation and was assigned to the nursing shift (morning shift: 6:00 AM - 2:00 PM and afternoon shift: 2:00 PM - 10:00 PM).

The professional qualification of the mobilising specialist staff (users) was differentiated into “nursing service (PD) with and without specialist further training in anaesthesia and intensive care (FWB)” and “physiotherapy (PHYS)”.

Patient-related variables included height in centimetres and body weight in kilograms, from which the “Body Mass Index” variable was calculated. In a further step, a categorical variable was formed, based on the WHO classification (20):

- Underweight (BMI <18.5 kg/m^2)
- Normal weight (BMI 18.5 - 24.9 kg/m^2)
- Overweight (BMI 25.0 - 29.9 kg/m^2)
- Obesity (summarising classes 1-3) (BMI >30 kg/m^2)

In addition to recording the type of ventilation and access as well as medication, drains and catheters were documented, completing the picture of the patient ´s situation within the framework of the research question.

One focus of the study was to capture differences based on user- and process-related criteria. Process times for the duration of mobilisation (preparation, execution, and follow-up), the use of mobilisation aids, and the involvement of additional persons, as well as the body posture of the mobilising specialist staff during mobilisation, were documented for this.

The subjective assessment of psychological stress (PSaR) was recorded using a 10-point numerical scale with the variations of 0= “no stress”, 10=“very severe stress”.

Additionally, the subjective assessment of the mobilising specialist staff for the feasibility of the robot-assisted mobilisation was surveyed using a 7-point numerical scale (1=“not feasible at all”, 7=“highly feasible”).

Data analysis was performed with the IBM statistical software SPSS® version 29. Microsoft Excel® for MAC version 16.72 was used for the graphical preparation.

Statistical methods

The information collected in writing from the observation sheet was transferred into an analysable, digital format, coded and converted for data analysis. For this purpose, a raw data set was created in tabular form in Microsoft Excel for MAC®, the variables and their numerical coding were defined in a code plan. Missing or implausible values were cleaned up and then imported into the statistics programme SPSS® (21). On enhance data quality, two independent

researchers entered the data, verifying each other's entries. The measurement level of the variables is predominantly nominal-scaled. Socio-demographic and process variables have a metric level of measurement, while numerical scale surveys have an ordinal level of measurement.

Subsequently, the data set was described based on absolute and relative frequencies, as well as position measures such as the arithmetic mean, median, minimum, and maximum, range, and standard deviation (22). The data were checked for normal distribution as a prerequisite for statistical procedures (21). For this purpose, the data were graphically examined using a histogram and boxplots, and finally confirmed using the Kolmogorov Smirnov test (15) . None of the test procedures indicated a normal distribution of the metric data.

The Mann-Whitney-U test and the Kendall-Tau-b correlation coefficient were employed to analyse possible differences and correlations between conventional and robot-assisted mobilisation. The Mann-Whitney-U test serves a non-parametric alternative to the *t*-test for two unrelated samples, comparing two medians (23) . Ordinally scaled data, which may not necessarily have an equivalent distance between categories but can be arranged in a natural order, can be assessed for correlations using Kendall's rank correlation coefficient (23). A 95% confidence interval with a p-value <0.05 was chosen for the data analysis (15).

Results

Basic data

Table 2 displays the survey points' duration and the corresponding mobilisation methods, along with the absolute and relative frequencies of the observations. It also highlights the cases excluded due to missing inclusion criteria.

(Table 2)

In total, the observed mobilisations were exclusively carried out by nurses (62.2% female, 37.8% male). Physiotherapists did not participate in the observed mobilisations. Five observations were excluded at each of the survey points T1 and T2 due to the inclusion criteria “specialist training in anaesthesia and intensive care” or “nurse with at least three years of experience in intensive care”, as the users did not meet these criteria (see also table 2).

The observations occurred more frequently during the afternoon shift (70.0%) than in the morning shift at both survey points regarding the time of mobilisation.

Socio-demographic data of the users

The relative proportion of nurses with specialist training (PD with FWB) was 58.9%, and the overall average age was 33.2 years (±24.8/13.2; SD=7.14). The nurses without further training were younger on average (=31.9 ±13.1/11.9; SD=5.83) and had a shorter intensive care experience (=6.5 ± 13.5/3.5; SD=3.67) than those with further training.

Table 3 reflects the socio-demographic data of the users, including specialist training, age, and intensive care experience, differentiated by the time of survey and gender.

(Table 3)

Socio-demographic data of the patients

Patients were, on average, 56.3 years old (±/11.7/20.3) and 50.0% female (n=45).

The mean BMI in survey T2 was with 22.9 kg/m^2 slightly higher than in survey T1 (22.6 kg/m^2). Normal-weight patients represented the largest group overall (52.2%) and were differentiated by observation time points T1 (n=20: 57.1%) and T2 (n=27: 49.1%). There were more underweight subjects during robot-assisted mobilisation at survey time T2 (n=13, 20.3%) than during conventional mobilisation (n=4, 11.4%). At the survey time point T2, ten (18.2%) overweight patients were mobilised with the assistance of the VEMOTION®, compared to eight (22.9%) patients with a BMI between 25.0 - 29.9 kg/m^2 during conventional mobilisation.

With regard to medication, only the documentation of medication for analgesia, catecholamines, and simultaneous administration of both groups of medication was observed. 33 patients (60.0%) were analgosedated at T2, while only four patients (11.4%) were analgosedated during conventional mobilisation. Half of the patients (n= 28, 50.9%) mobilised with the VEMOTION® received circulatory support with catecholamines. This was necessary for only thirteen patients at the survey point T1 (37.1%). During conventional mobilisation, however, more than half of the patients (n= 18, 51.4%) did not receive

any analgosedation or catecholamine. At the time of robot-assisted mobilisations, only thirteen patients (23.6%) were neither analgosedated nor did they need any catecholamine.

Eleven (84.6%) of the thirteen invasively ventilated patients in T1 had a tracheostomy and only two (15.4%) had a tube. During robot-assisted mobilisation (T2), significantly more of the 32 invasively ventilated patients (n=24, 75.0%) were fitted with a tube than with a tracheostomy.

Table 4 shows the absolute and relative distribution of the variables ventilation mode and ventilation access differentiated by T1 and T2.

(Table 4)

There were a total of 28 mentions of ingoing and outgoing tubes in T1 and 71 in T2. Table 5 shows the absolute frequencies sorted by drains, ingoing catheters, and extracorporeal therapy devices.

(Table 5)

Work organisation

The process-related data on the organisation of work were documented based on the time required in the process steps of preparation, execution, follow-up, and the calculated total duration of mobilisation, the number of specialist staff mobilising, and the aids used as well as the application of kinaesthesia.

Significant differences were evident in the time required between conventional and robot-assisted mobilisation in all sub-steps of mobilisation. Figure 3 shows the median time required in minutes, differentiated by preparation, execution, follow-up, and total duration of mobilisation.

The Mann-Whitney-U test was used to demonstrate significant and high effect sizes (in accordance with Cohen) (23) between the times required for conventional and robot-assisted mobilisation. The greatest difference between T1 (n=35) and T2 (n=55) was seen in the preparation time (see table 6).

(Table 6)

A bed sheet was used as a support during conventional mobilisation (n=7), and a slide board was used in two cases, while the users did not use any other aids besides the VEMOTION® during robot-assisted mobilisation. These aids were used to transfer patients in bed or to transfer them to another therapy device, such as a mobilisation or therapy chair. In three observations, patients were assisted in walking by a forearm walker.

In terms of staffing, two nurses were involved in most mobilisation cases at all survey points (T1 n=20: 57.1%; T2 n=42: 76.4%). In twelve cases (34.3%), a nurse mobilised the patients conventionally without the VEMOTION® (T1) without further staff support. By comparison, seven robot-assisted mobilisations (12.7%) were performed by a nurse without further staff support at survey point T2. Three or more persons were rather the exception during conventional (n=3, 8.6%) and robot-assisted mobilisation alike (n=6, 10.9%).

The use of kinaesthetic techniques during mobilisation was also examined as well. There were no major differences between the mobilisation methods. Use of kinaesthesia was observed in six (17.6%) nurses during conventional mobilisation. Eight (15.4%) nurses used kinaesthetic techniques for mobilisation with the VEMOTION®.

Posture of the mobilising specialist staff

The most frequent variation of each posture of the mobilising person was documented when observing the postures of the mobilising nurse.

Table 7 shows the flexion in the lumbar spine and thoracic spines of the users during survey points T1 and T2. Only a marginal difference in flexion in the lumbar spine was found between conventional (n=14, 40.0%) and robot-assisted mobilisation (n=25, 45.5%). Upper body inclination in the thoracic spine to 20-60 degrees was also nearly unchanged in T1 (n=19) with 54.3% and in T2 (n=32) with 58.2%. The lowest tilt of the upper body of <20 degrees was observed in 38.2% of robot-assisted mobilisations (n=21), which was similary frequent to that during conventional mobilisation (n=12, 34.3%).

(Table 7)

In the observation sheet, evasive movements of the upper body were defined as lateral flexion of the upper body, rotation at the waist, their combined movement, or no evasive movement. During fourteen conventional mobilisations (40.0%) and eighteen mobilisations with the VEMOTION® (33.3%), a combined evasive movement to the side and rotating at the waist was observed. Whereas in ten of the robot-assisted mobilisations (18.5%) an evasive movement was observed rotating exclusively at the waist, this movement was evident in six of the conventionally performed mobilisations (17.1%). No evasive movements were performed in twenty robot-assisted mobilisations (37.0%) and in nine conventional mobilisations (25.7%).

The observation of the leg posture was recorded based on the flexion or extension of the knees, the position of the feet in relation to each other, and the angle at which the mobilising specialist was standing in relation to the bed. The nurses stood at an angle of more than 90 degrees to the bed only once during both conventional and robot-assisted mobilisation (T1: 2.9%; T2: 1.9%). A position parallel to the bed was documented most frequently in 45 robot-assisted mobilisations (83.3%). This parallel position to the bed was also chosen most frequently by the nurses during conventional mobilisation (n=26) with 74.3%.

In both forms of mobilisation, the knees of the mobilising persons were rather extended than bent, but in T1 (n=26) to a higher proportion (78.8%) than during mobilisation with the VEMOTION® (n=36, 65.5%). The fencer stance was recorded only once at T1 (2.9%), and during six robot-assisted mobilisations in T2 (11.1%). Most frequently, a parallel stance could be observed among the nurses during mobilisations (T1 n=26, 74.3%; T2 n=41: 75.9%).

The most noticeable difference in the observation of the postures was recorded in the position of the shoulders. Shoulder elevation was observed significantly less frequently in the users during robot-assisted mobilisation (T2). Figure 4 below shows that users pulled their shoulders upwards in two-third of cases during conventional mobilisation (n=24), while users' shoulders remained in a neutral position in nearly 70% of robot-assisted mobilisations (n=37).

Users' subjective assessments of psychological stress

The subjective assessment of psychological stress (PSaR) by the mobilising specialist staff during mobilisation was conducted using a 10-point numerical scale (0=no stress, 10=very severe stress). There are no significant deviations between the survey points (T1 n=35: =3.09 ±3.9/3.09, Md=3.0, SD=1.884; T2 n=55: =3.35 ±6.65/3.35, Md=3.0, SD=2.503).

Figure 5 displays the distribution of the subjectively assessed psychological stress (0= no stress, 10= very strong stress) differentiated based on the professional qualification of the nurses with and without additional training at survey points T1 and T2.

When differentiating based on the professional qualification of the nurses, the position measures in T2 showed marginal differences in robot-assisted mobilisation between the groups of nurses with and without specialist training. The Mann-Whitney-U test shows no statistical significance here (see table 8).

(Table 8)

The correlation between years of intensive care experience and the age of the nurses and their subjective assessment of psychological stress and relief (PSaR) was tested using the Kendall-Tau-b correlation coefficient. There were no significant results in T1 during conventional mobilisation. However, at the point of the survey T2, a weak negative correlation was found between the nurses' time of experience in an intensive care unit and their perception of psychological stress. The observed nurses with a longer period of experience in intensive care showed subjectively lower psychological stress during robot-assisted mobilisation. Table 9 displays the results of the correlation coefficient Kendall Tau b of the variable "Subjective assessment of psychological distress and relief" (PSaR) with age and years of intensive care experience for the mobilising nursing staff (users) at both survey points.

(Table 9)

Furthermore, the subjective assessment of the feasibility of the mobilisation was additionally requested using a 7-point numerical scale (0=not feasible at all, 7=very feasible) at the point of the survey T2 to detect any changes in the psychological stress during robot-assisted mobilisation with the VEMOTION®.

When considering all users without differentiation in professional qualification, it was found that individuals who predominantly rated the feasibility of mobilisation with the VEMOTION® as high assessed themselves as less psychologically stressed than individuals who felt less able to perform mobilisation with the VEMOTION® (PSaR/feasibility: Kendall Tau b=-0.435, p=<0.01, n=54).

Regarding assessment of the feasibility of robotic mobilisation with the VEMOTION® in survey T2 between the groups of nurses with and without specialist training (PD with FWB: n=36; PD without FWB: n=18), however, the Mann-Whitney-U test showed no significant differences (U=313.500, z=-0.197, p=0.844).

Results of the follow-up

The opportunity was taken to conduct nine observations of routine users of the robotic system as part of a follow-up. A total of nine robot-assisted mobilisations of routine users could be observed. Despite the small number of cases, the results will nevertheless be reported for selected variables in the following descriptive and in comparison with the observations of survey point T2.

Patients in the follow-up group had an average age of 56.2 years (±/11.8/20.2), predominantly female (n=77.8%), and an average BMI of 22.9 (±/3.1/1.9).

Three out of nine (33.3%) nurses had specialist training (PD with FWB), with an overall average age was 31.6 years (±4.4/4.6). Notably, nurses with further training were slightly younger on average (=31.0 ±4.0/5.0) than nurses without training in ICU (=32.7 ±1.3/1.7) but had longer intensive care experience (=9.0 ± 3.0/3.0) compared to those without further training (=4.3 ± 1.7/1.3).

Regarding medication, seven patients were analgosedated (77.7%), two of whom required catecholamines and two patients (22.2%) required no medication. All four invasively ventilated patients were on a tube. Four patients received no ventilatory therapy and one patient was ventilated noninvasively with an NIV mask.

There were a total of 22 mentions of inflow and outflow drains or catheters. In all cases of the follow-up, hemodialysis and two or more chest drains were documented.

There were nearly no differences between the follow-up group and the observations in the T2 group regarding time for preparation, implementation, follow-up and total duration (total duration: T2: 47 min vs. follow-up group: 46 min).

Regarding the number of mobilising specialists, in 77.8% (n=7) only one person without further support performed the mobilisation with the VEMOTION®. This was the case for non-routine users in only seven mobilisations (12.7%) at the time of the survey T2. Kinaesthetic techniques were also not used in the follow-up group (n=6, 75.0%).

An upright back position was observed more frequently in the postures during the follow-up compared to the survey time point T2. Table 10 shows the flexion in the lumbar and thoracic spine of the users during the survey times T2 and follow-up.

(Table 10)

Regarding the position of the shoulders, a neutral shoulder position was observed most frequently among the experienced users in the follow-up, as at the time of the T2 survey. This was even the case for eight out of nine experienced users in the follow-up (88.9%).

In the subjective assessment of the routine and nurses on their psychological stress during mobilisation with the VEMOTION®, only marginal deviations in the scatter measures were noticeable compared to group T2 (T2 n=55: =3.35 ±6.65/3.35, Md=3.0, SD=2.503; follow-up group n=9: =3.22 ±6.78/3.22, Md=2.0, SD=3.073). Regarding the subjective assessment of feasibility in connection with psychological stress, there was a higher correlation measure among the routine users in the follow-up (Kendall Tau b =-0.743, p= <0.01) than among the non-routine users in group T2 (Kendall Tau b=-0.435, p= <0.01).

Discussion

This article provides an overview of the possible physical and psychological burdens and reliefs for the mobilising specialist staff in conventional and robot-assisted early mobilisation.

There was a significant correlation between the psychological stress perceived by the mobilising personnel and the feasibility of robot-assisted early mobilisation. Psychological stress perception was lower when early mobilisation was assessed as feasible (PSaR/feasibility: Kendall Tau b = -0.435, p=<0.01, n=54). This seems to remain unchanged even when routine use of the robotic system has already begun (follow-up group: Kendall Tau b =-0.743, p=<0.01). This can be explained based on the secondary evaluation of a stress stimulus in the sense of the transactional stress model in accordance to Lazarus (24). The model describes that whether a specific stimulus leads to a stress response or not depends on the individual’s evaluation using three processes (primary, secondary, and tertiary evaluation). Secondary assessment involves evaluating one's own coping skills and opportunities, where self-efficacy, i.e., confidence in one's abilities, plays a relevant role (25) . Applied to the use of robot-assisted early mobilisation, this means that individuals who feel confident in using the robotic system or perceive its application as feasible rate themselves as less psychologically stressed.

The implementation of conventional early mobilisation seems to be hindered by factors such as tube or ventilator access or excessive analgosedation, among other things (26). These barriers did not apply to robot-assisted early mobilisation investigated in this study. Significantly more patients in the robot-assisted early mobilisation group were ventilated invasively with a tube (75.0%) in this study than in conventional early mobilisation (15.4%). In addition, significantly more robot-mobilised patients were analgosedated (T2: 60.0%; T1: 11.4%). Furthermore, significantly more patients with drains and special accesses, such as a pulmonary catheter, chest drains, or extracorporeal therapy devices (ECMO, hemofiltration) were mobilised with the robotic system than with the conventional method (T1: n=28; T2: n=71). In the follow-up group, all patients had at least one drainage and one haemodialysis.

It stands out that most mobilisations, both conventional and robot-assisted, took place during the afternoon shift in this study. This result is in contrast with other study findings that show that early mobilisation being performed during both morning and afternoon shifts (11).

An average of two specialists were involved in each mobilisation in both conventional and robot-assisted early mobilisation. This need for personnel, which, in the context of a possibly existing personnel shortage, has already been examined as a barrier to the implementation of conventional early mobilisation, should also be critically assessed for robot-assisted early mobilisation (26).

The study situation, with only nurses performing the mobilisations, does not correspond to the results of studies that have investigated responsibilities in the performance of early mobilisation. Nydahl et al. (10) and Mehler-Klamt et al. (11) show that both nurses and physiotherapists share equally responsibility for the mobilisation of critically ill intensive-care patients.

Compared with robot-assisted early mobilisation, the times for preparation, performance, and follow-up, as well as the total duration of conventional early mobilisation, were each significantly shorter than robot-assisted early mobilisation (total duration: T1: =16min; T2: =47min). The large amount of time required, in particular in relation to the preparation of robot-assisted early mobilisation (T1: =3min; T2: =17min), is attributed to securing the safety belts and docking the robot to the hospital bed. However, the fact that robot-assisted mobilisation took an average of twenty minutes can be considered positive for the patients since it adhered to the time specified by the S3 guideline (2).

The lack of statistical effects of qualifications or competence levels on the perception of stress by care staff is consistent with other research studies (27). However, the professional experience of specialist staff appears to influence their psychological stress perception. For instance, this study revealed that nurses with more extensive intensive care experience rated themselves as less psychologically stressed when using robot-assisted mobilisation than nurses with less intensive care experience (intensive care experience/PSaR: Kendall Tau b= -0.270, $p<0.01$).

The literature often reports a lack of aids for patient mobilisation, which is perceived as a major obstacle by mobilising specialist staff (11, 28). This study demonstrated that mobilisation with the VEMOTION® did not require the use of any additional aids. In contrast, different devices were used to transfer patients to mobilisation chairs in conventional mobilisation. This can be challenging not only due to a potential lack of available aids but also because transferring to a therapy device can pose a safety risk to all involved parties (specialist staff and patients) (29, 30). The postures adopted during the transferring to the therapy device are often performed incorrectly, which can lead to back pain and, subsequently, to musculoskeletal disorders (29, 30).

There were few relevant differences between robot-assisted and conventional mobilisations in terms of posture of the mobilising specialist staff. During robot-assisted mobilisation, the upper body was bent less than 20 degrees in the thoracic spine region with similar frequency compared to conventional mobilisation (T1: 34.3%; T2: 38.2%). An upper body tilt can increase strain on the back muscles and is, therefore, a potential risk factor for back pain (31). Rotation from the waist was also observed with a similar frequency in robot-assisted and conventional mobilisation (T1: 17.1%; T2: 18.5%). Notably, robot-assisted mobilisation exhibited fewer evasive movements overall compared to conventional mobilisation (T1: 25.7% vs. T2: 37.0%). This is remarkable because the robotic system is controlled, especially during preparation and follow-up, via a monitor that requires repeated turning for the next step of execution. Evasive movements such as rotation can exert additional strain on the lumbar region. This strain can lead to lower back pain and lumbar conditions such as herniated discs and other musculoskeletal disorders (32–34). Therefore, it is positive that robot-assisted mobilisation is often performed without evasive movements.

In general, care staff are at an increased risk of work-related musculoskeletal disorders (WMSD), which can be caused by incorrect movement patterns, among other factors. In addition, mental pressure, such as stress, appears to have a positive effect on the development of musculoskeletal disorders (MSD) (35). The shoulder area, neck, and lower back are particularly susceptible (35) . A risk for manifestation in the shoulder area, aside from the basic physical strain, is particularly associated with mobilisation methods involving patient transfers (29). Therefore, incorrect movements, such as rotation or shoulder elevation, should be avoided at all costs in work processes. Shoulder elevation occurred less frequently during robotic mobilisation in this study than during conventional mobilisation (Shoulder protrusion in T1: 68.6% vs. shoulder protrusion in T2: 32.7%), which can be viewed positively in relation to the development of WMSD. In general, kinaesthesia can support the avoidance of incorrect movements and thus reduce the risk of MSDs (36). Kinaesthesia was rarely used within this study, both in robotic and conventional mobilisation (T1: 17.6%; T2: 15.4%).

More ergonomic patient handling can be achieved in the step or fencer stance by shifting one`s weight, thereby reducing back strain (30). The fencer stance was more frequently observed at observation points T2 than at T1 (fencer stance T1: 2.9%; T2: 1%). However, it cannot be definitively concluded from the results of this study whether this is directly related to the robotic system. The foot position should generally be chosen to prevent rotation in the lumbar region, as mentioned above. Additionally, bending the knees during mobilisation helps alleviate strain on the back (30). This was observed less frequently than knee extension in both conventional and robot-assisted mobilisation.

Overall, robot-assisted mobilisation was more ergonomic and less stressful for the musculoskeletal system.

Limitations

The original goal of exclusively observing early mobilisations starting within the first 72 hours after admission to the intensive care unit (37) could not be consistently achieved due to the restrictions caused by the Covid-19 pandemic. Teams experienced increased turnover as nurses from other areas, who were working on a limited basis due to the pandemic, were deployed to the project ICUs in a supportive capacity. This resulted a lack of consistency in the introduction to the VEMOTION® robotic system and within the nursing team.

Furthermore, it was not possible to instruct physiotherapists in the robotic system and thus include them in the observations for staffing reasons. Thus, only nurses could be instructed and observed, which contradicts the fact that both nurses and physiotherapists are considered mobilising specialist staff (10, 11).

Additionally, this is a monocentric study conducted in a university hospital. The perspective of several university hospitals as well as hospitals with different levels of care could not be considered.

Due to use of non-participant observation, it cannot be ruled out that the study participants adapted their behaviour to the research situation, potentially affecting the results. However, obtaining informed consent within the ethical framework necessitated this approach.

The observation sheet underwent checks for initial content validity and intercoder reliability based on a systematic literature search, pretest, and consensus by a panel of experts. Therefore, further research is required to conduct psychometric tests on the quality and reliability of the data collection instrument.

Comparability between conventional and robot-assisted mobilisation also cannot be fully illustrated, as the movements generated by the robotic system cannot comprehensively replicate conventional mobilisation. Therefore, mobilisation to sitting, walking, or standing were chosen because the robotic system can perform verticalisation with leg movement and these conventional mobilisations are closest to the movement of the robot.

In comparison to survey point T1, feasibility was only additionally queried for point T2 in the form of a 7-level scale in order to evaluate testing of the new device in terms of feasibility from the users' perspective.

Recommendations for further research and practice

Based on the results regarding physical stress, it is recommended to continuous training in kinaesthesia for mobilising specialist staff. This training helps to manage muscle work, which is a relevant concern both in conventional and robot-assisted mobilisation. Furthermore, when introducing a robotic system, attention should be given to regular use to establish a routine in handling the system. Routine seems to reduce psychological stress and increase user acceptance of robotic systems. Apart from this, all mobilising occupational groups, including physiotherapists, should be familiar with the use of the robotic system for early mobilisation to promote multi-professional cooperation. This is because mobilising intensive-care patients can be viewed as a multi-professional task and thus requires the perspective of physiotherapy, which can assess movement patterns much better than the nursing staff.

In this study, a follow-up with nine observations of routine users of the robotic system was conducted. This yielded promising initial results that should be further investigated with a larger sample.

A multicentric study would also provide a broader perspective on the burden and relief experienced. Furthermore, examining the experiences in a qualitative design should be reconsidered to make the experiences of VEMOTION® users more transparent and to better understand the reasons for non-acceptance or acceptance.

Conclusion

The fact that the VEMOTION® robotic system serves as both a hospital bed and a therapy device offers numerous advantages that positively impact the workload of the care staff. There is no need for patient transfer to a therapy device, which is associated with high safety risks, and eliminates the related movement sequences, often performed incorrectly and linked to back pain. Moreover, neither a ventilator tube nor patient analgesia appears to pose obstacles to robot-assisted mobilisation. Additionally, mobilisation with the VEMOTION® requires no use of additional aids, which are typically in short supply on the wards.

Robotic early mobilisation with the VEMOTION® seems to reduce physical strain since many physically demanding movements are eliminated, and the mobilising specialist staff only need to assist with mobilisation before and after. However, the lengthy preparation and follow-up times for robotic mobilisation can be seen as an additional effort that complicates integration into the daily routine. This may lead to reduced usage of the system and can impact user acceptance.

Abbreviations

ECMO= Extracorporeal membrane oxygenation

FWB=Further training in intensive care and anaesthesia

ICU=Intensive care unit

MSD= musculoskeletal disorders

NIV= Non-invasive ventilation

PD= Nursing service

PHYS=physiotherapy

PSaR= subjective assessment of psychological stress

WMSD=work-related musculoskeletal disorders

WHO= World Health Organisation

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Declarations

Ethics approval and consent to participate

Before the study was performed, the responsible ethics committee of the LMU university hospital (21-0355), the data protection officer of the LMU university hospital, and the hospital's staff council approved the study. Patients and mobilising specialist staff consented to participate in written form in the sense of informed consent (37). Patients consented to participate before a planned intensive care stay after surgery. We confirm that all methods were performed in accordance with the relevant guidelines and regulations as set out in the Declaration of Helsinki.

Consent for publication

Patients and mobilising specialist staff consented for publication in written form in the sense of informed consent (37).

Data availability

The datasets utilized for this study are not publicly available due to IRB agreements; however, they are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Contributions to the conception: AMK, NK, JH, IE

Contributions design of the work: AMK, NK

Acquisition (Mobilising specialist staff): AMK, NK, JH, AW, IR

Acquisition (Patients): LH, CS, IS, MZ

Analysis: NK

Interpretation of data: AMK, NK, JH

Drafted the work: AMK, NK, JH, CO, IE

Substantively revised the work: JH, AW, MG, JTB, LH, IS, CS, CO, EK, MZ, UF, IE

All authors read and approved the final manuscript and agreed both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature.

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Not applicable

Tables

Table 1: Variables of the observation sheet with variations (own presentation)

Construct	Variables	Variations
Basic data	Survey point	T1, T2, Follow up
	Time	6:00 AM - 2:00 PM 2:00 PM - 10:00 PM
Socio-demographic data of the users	Gender	Female, male, other
	Professional qualification	PD with / without FWB, physiotherapy
	Age and experience in ICU	In years
Socio-demographic data of the patients	Gender	Female, male, other
	Weight	In kilograms
	Size	In centimetres
	Medication	Catecholamines, analgesia, catecholamines and analgesia, no medication
	Form of ventilation	Invasive, non-invasive, no ventilation
	Ventilation access	Tube, tracheostomy, NIV mask, high-flow therapy, no ventilation access
	Inlet and outlet drains/catheters	Number and location
Work organisation	Preparation, execution, follow-up time	In minutes
	Mobilisation aids	Anti-slip mat, slide mat, bed gallows, slide board, bed sheet, mobilisation chair, bed bicycle, forearm walker, commode chair, VEMOTION®
	Persons involved	Number of mobilising specialist staff
	Application of kinaesthesia	Yes/no
Posture of the mobilising specialist staff	Back flexion lumbar spine	Bent, straight
	Upper body forward tilt in the cervical spine/thoracic spine	< 20°, 20 - 60°, > 60°
	Knee	Bent, straight
	Foot position	Parallel stance, step stance, fencer stance
	Foot position in relation to the patient bed	Parallel (0°), oblique (< 90°), lateral (> 90°)
	Shoulder posture	Shoulder elevation, neutral position
	Evasive movements upper body	Lateral, rotation, lateral rotation
Subjective assessments of the users	Psychological stress (PSaR)	Numerical scale 0-10
	Feasibility	Numerical scale 1-7

Table 2: Absolute and relative frequencies of the observations in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

Survey point	Number of observations Absolute /relative frequency
T1 (conventional mobilisation)	n=35/32.1%
T2 (robot-assisted mobilisation	n= 55/50.5%
Follow up (robot-assisted mobilisation – with routine)	n= 9/8.2%
T1 excluded	n=5/4.6%
T2 excluded	n=5/4.6%
Total	n=109/100%

Table 3: Age, gender, professional qualification, and intensive care experience of the users in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

			Age in years	ICU experience in years
T1	female PD with FWB n=9 PD without FWB n=13	Mean value	31.23	7.09
		Median	31.50	6.00
		Std. deviation	4.730	4.128
		Minimum	24	3
		Maximum	45	20
	male PD with FWB n=7 PD without FWB n=6	Mean value	33.00	7.38
		Median	31.00	6.00
		Std. deviation	9.469	2.873
		Minimum	20	3
		Maximum	58	12
T2	female PD with FWB n=28 PD without FWB n=6	Mean value	33.21	7.24
		Median	31.50	6.00
		Std. deviation	7.001	5.377
		Minimum	24	2
		Maximum	54	25
	male PD with FWB n=11 PD without FWB n=18	Mean value	35.19	11.14
		Median	33.00	8.00
		Std. deviation	7.941	8.940
		Minimum	25	3
		Maximum	55	33

Table 4: Type of ventilation and ventilation access of the patients in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

		Ventilation access			
Date of survey	Form of ventilation	Tube	Tracheostomy	NIV mask	Total
T1 n=14	Invasive	n=2/15.4%	n=11/84.6%	n=0/0.0%	13
	Non-invasive	n=0/0.0%	n=0/0.0%	n=1/100%	1
T2 n=33	Invasive	n=24/75.0%	n=8/25.0%	n=0/0.0%	32
	Non-invasive	n=0/0.0%	n=0/0.0%	n=21100%	1

Table 5: Inlet and outlet drains, catheters, and extracorporeal therapy devices in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

Inlet and outlet drains and catheters	Number/type	Survey point T1	Survey point T2
Chest drains	1	2	8
	2	2	8
	>2	2	32
Pulmonary catheter	yes	1	14
Extracorporeal devices	ECMO	1	0
	Haemodialysis	5	0
Other drains	1	3	13
	2	4	6
	>2	8	0

Table 6: Results of the Mann-Whitney-U test for process times (own presentation)

	Preparation time	Execution time	Follow-up time
Mann-Whitney-U test	24.500	128.500	140.000
Z	-7.778	-7.002	-6.841
Asymp. sig. (2-sided)	<0.001	<0.001	<0.001
Effect severity r	0.82	0.74	0.72

Table 7: Back flexion in the thoracic and lumbar spine, absolute and relative frequencies in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

		Absolute/relative frequencies	
Variable	Variation	Survey point T1 n=35	Survey point T2 n=55
Flexion Thoracic spine area	<20 degrees	n=12/34.3%	n=21/38.2%
	20-60 degrees	n=19/54.3%	n=32/58.2%
	>60 degrees	n=4/11.4%	n=2/3.6%
Flexion Lumbar spine area	straight	n=19/54.3%	n=30/54.5%
	bent	n=14/40.0%	n=25/45.5%
	missing values	n=2/5.7%	n=0/0.0%

Table 8: Results of the Mann-Whitney-U test for subjective assessment of psychological stress and relief in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

	T1 PD with FWB (n=16) PD without FWB (n=19)	T2 PD with FWB (n=37) PD without FWB (n=18)
Mann-Whitney-U test	143.000	291.000
Z	-0.303	-0.760
Asymp. Sig. (2-sided)	0.762	0.502

Table 9: Correlation coefficient Kendall Tau b of PSaR with age and ICU-experience of users in years in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

Survey point	Age in years of user	ICU experience of user
T1	-0.141	-0.204
T2	-0.040	-0.270**

**. The correlation is significant at the 0.01 level (two-sided).

Table 10: Back flexion in the thoracic and lumbar spine, absolute and relative frequencies in T2 (robot-assisted mobilisation) and follow-up (own presentation)

		Absolute/relative frequencies	
Variable	Variation	Survey point T2 n=55	Follow-up n=9
Flexion Thoracic spine area	<20 degrees	n=21/38.2%	n=5/55,6%
	20-60 degrees	n=32/58.2%	n=3/33.3%
	>60 degrees	n=2/3.6%	n=1/11.1%
Flexion Lumbar spine area	straight	n=30/54.5%	n=7/577.8%
	bent	n=25/45.5%	n=2/22.2%

Figures

Figure 1

The VEMOTION® robotic system (ReActive Robotics, 2021)

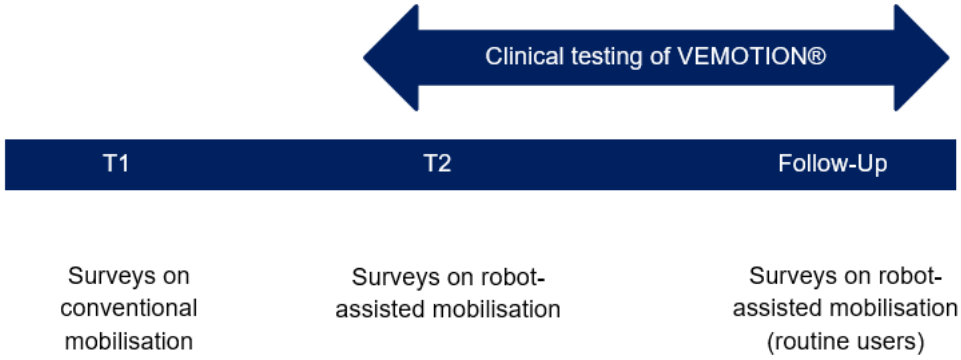

Figure 2

Study design of the longitudinal study (own presentation)

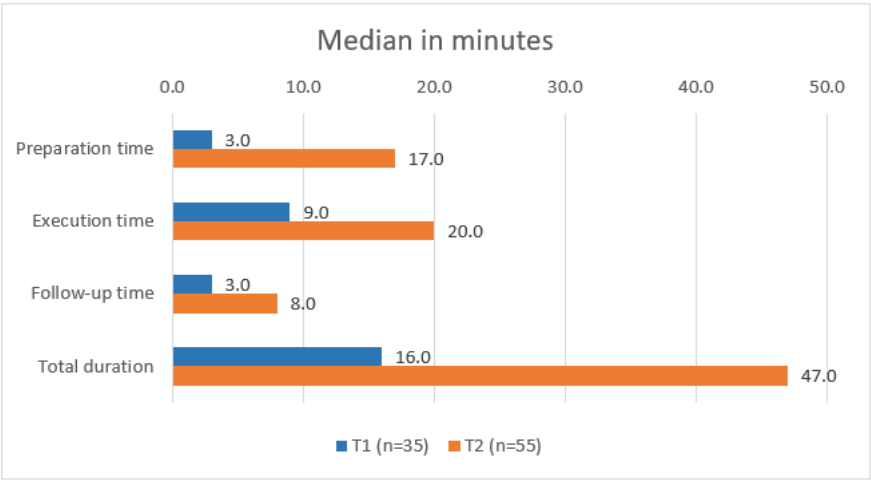

Figure 3

Median of preparation, execution, follow-up, and total duration in minutes in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

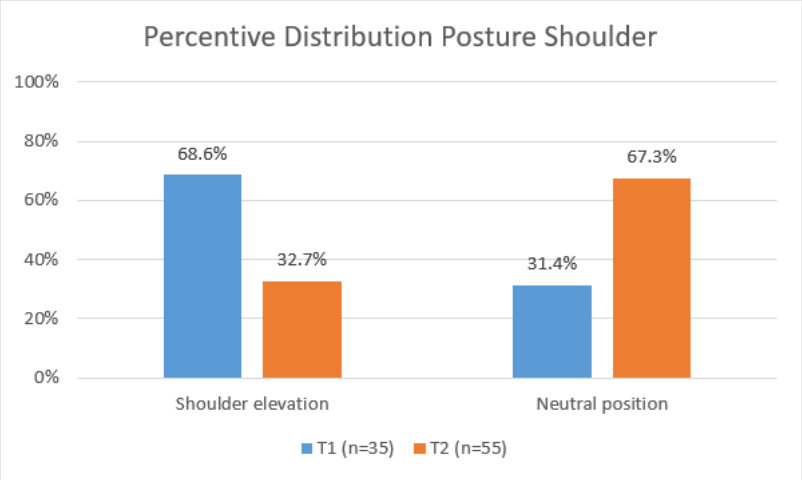

Figure 4

Percentage distribution of the variable “shoulder elevation/neutral position” in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

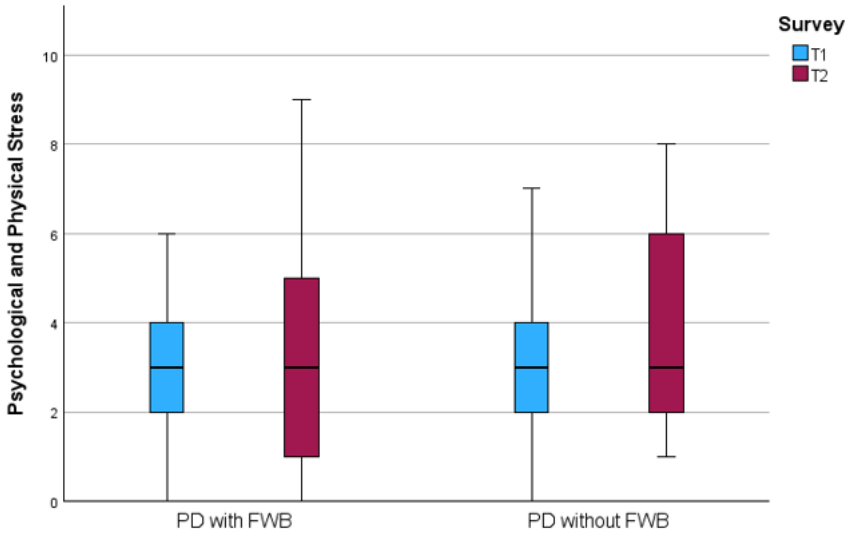

Figure 5

Distribution of subjective psychological stress and relief sorted by occupational qualification in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)