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(54) PORTABLE INTELLIGENT STRETCHING DEVICE

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(57) ABSTRACT

A portable intelligent stretching device for use by patients suffering from spastic and contractured joints and limbs. The intelligent stretching device has a motor and a motor shaft for rotating the joint or limb. The variable velocity and stretch distance of the device is determined by a torque sensor on the joint or limb that communicates information to a controller which subsequently instructs the motor as to the variable velocity and stretch distance.

42 Claims, 3 Drawing Sheets

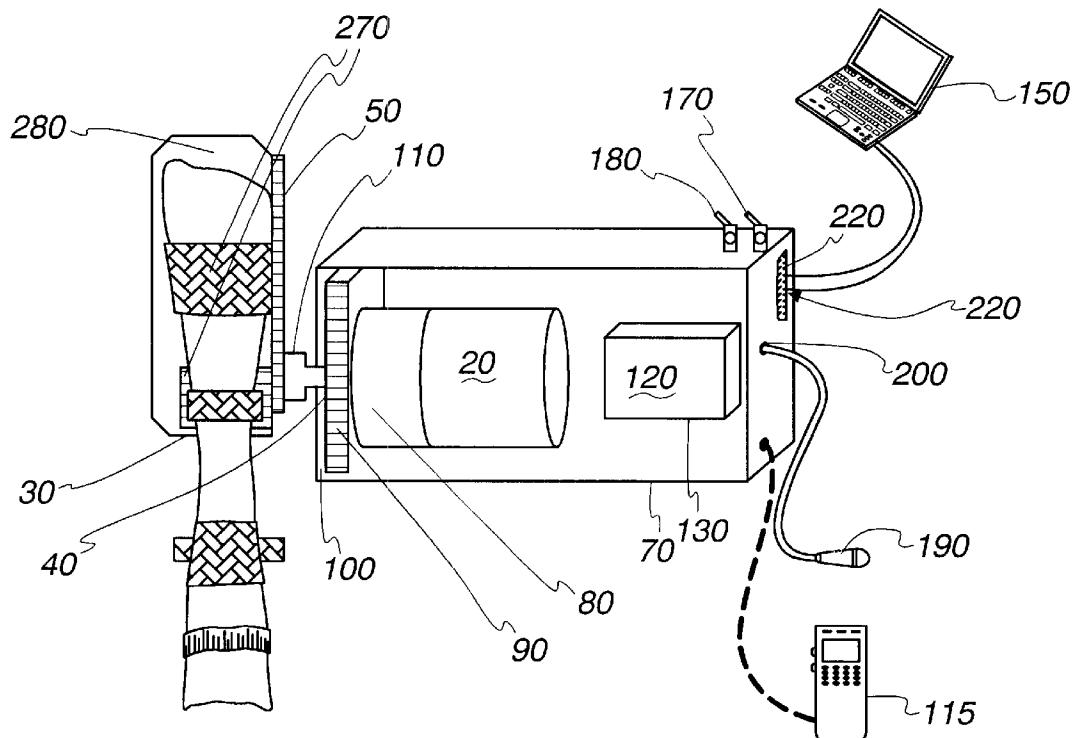


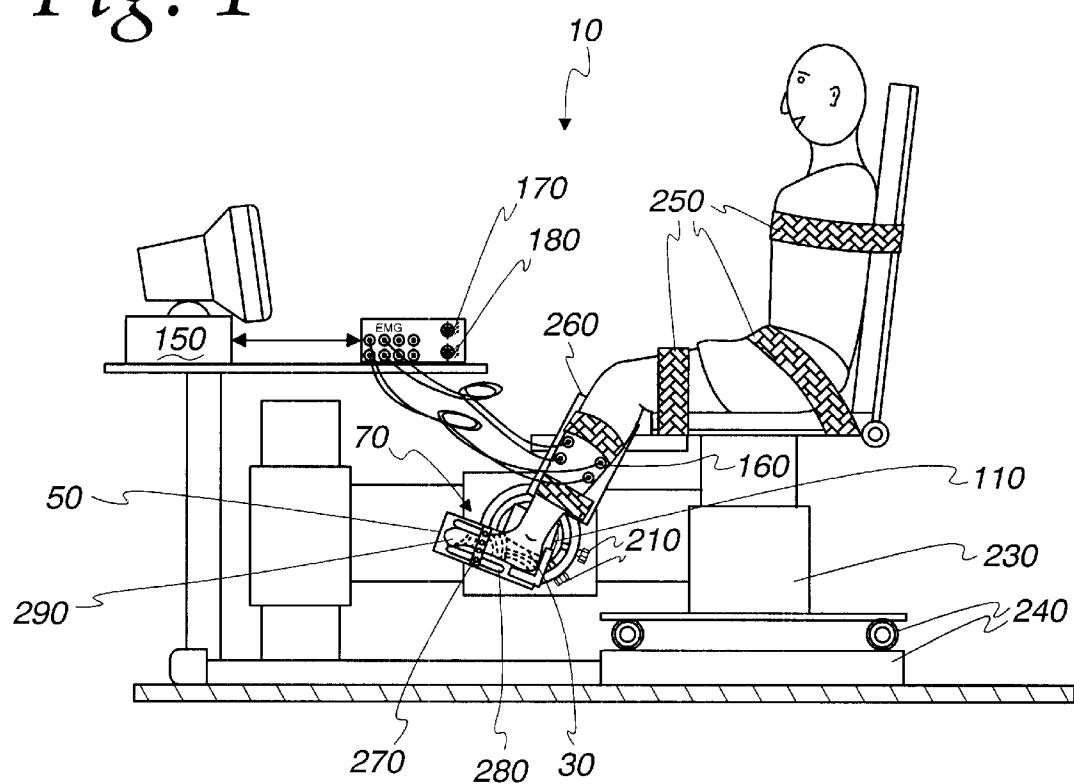
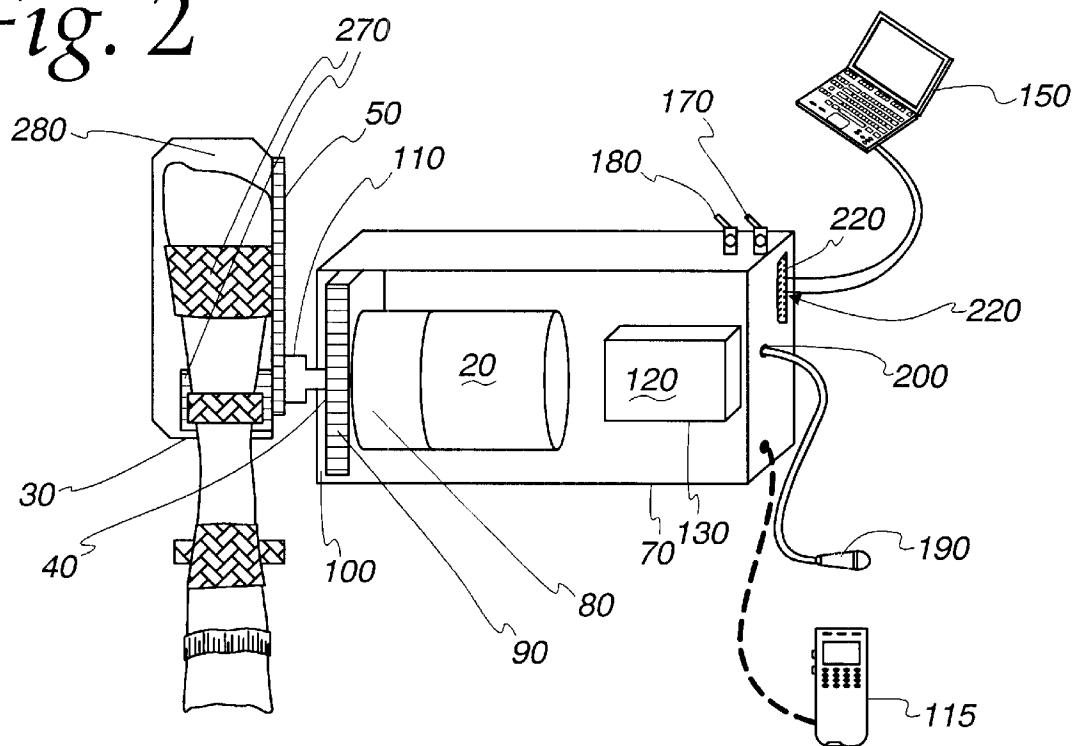
Fig. 1*Fig. 2*

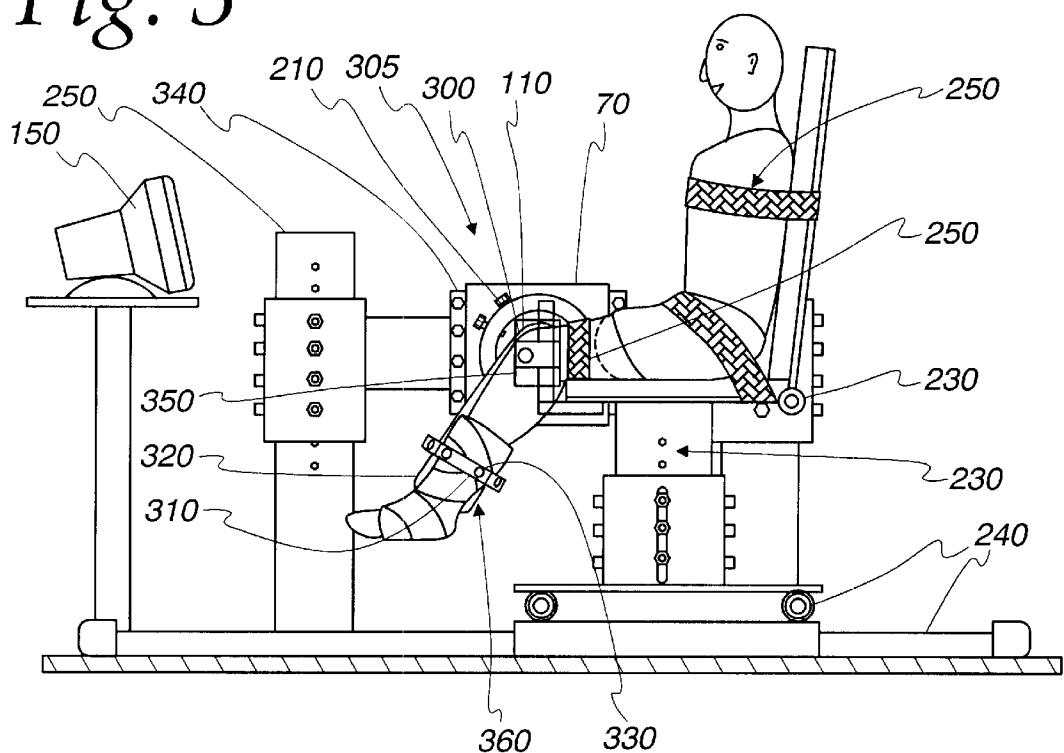
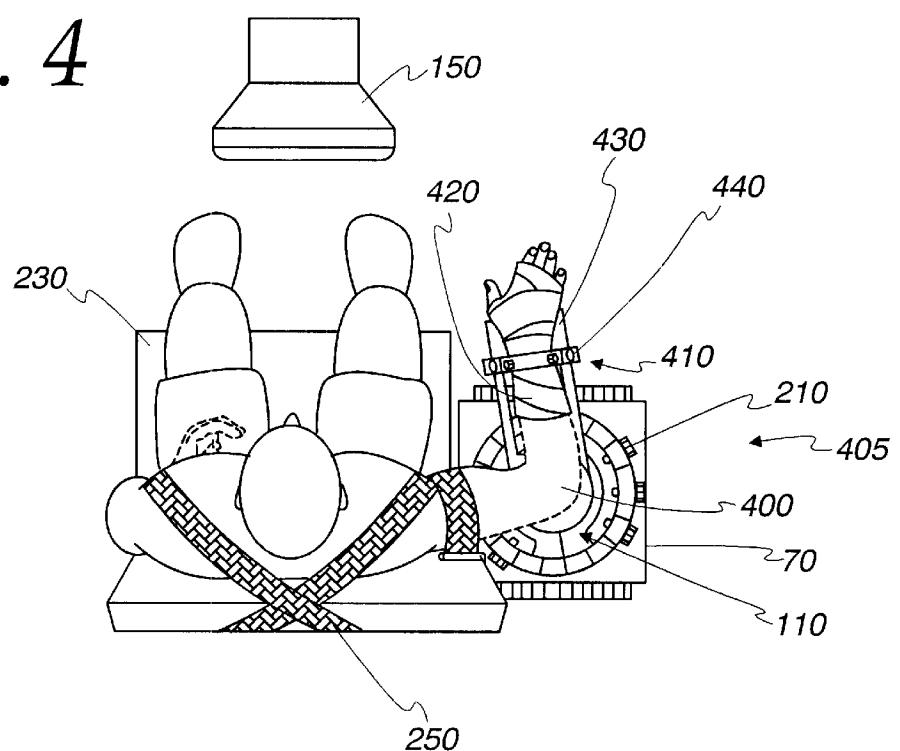
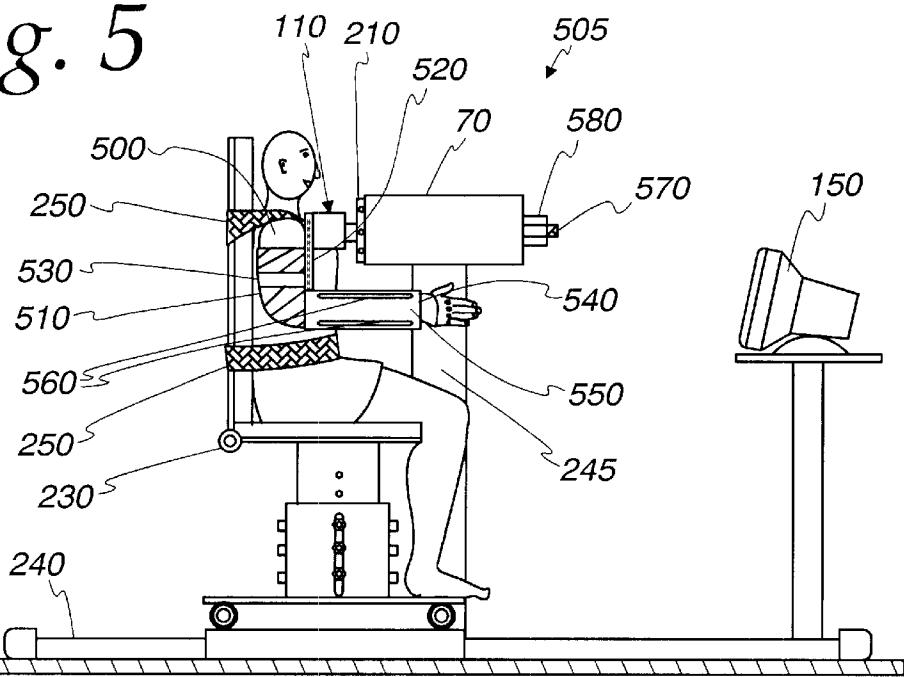
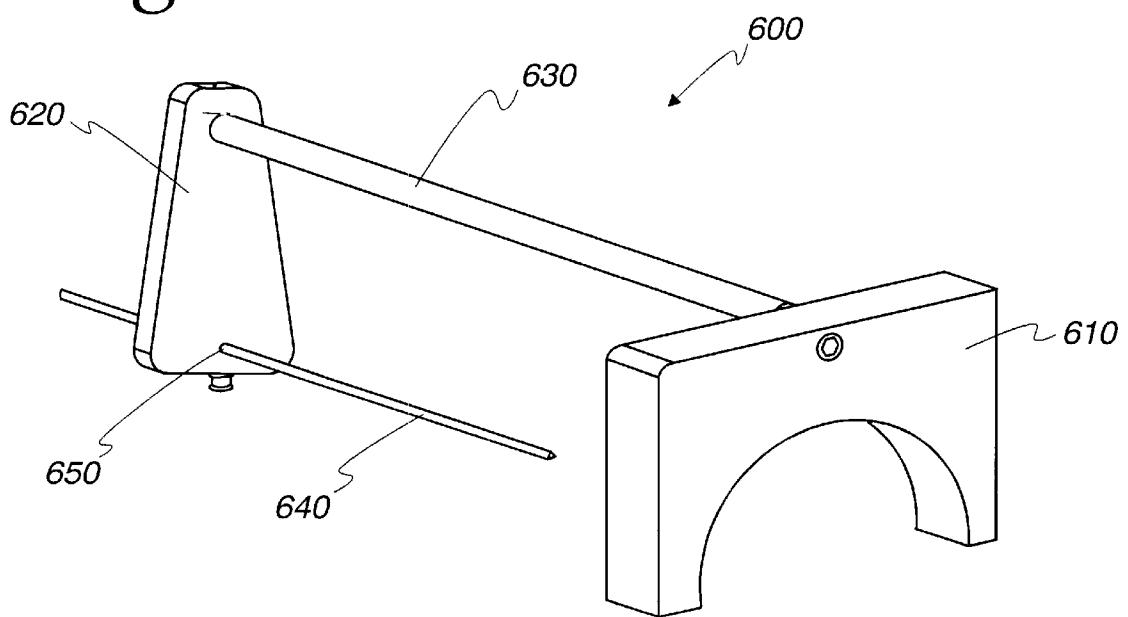
Fig. 3*Fig. 4*

Fig. 5*Fig. 6*

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PORTABLE INTELLIGENT STRETCHING DEVICE**FIELD OF THE INVENTION**

The present invention relates to a device for stretching limbs and joints. More specifically, to a stretching device that allows precise stretching throughout the joint range of motion including the extreme positions where spasticity and contracture are most significant.

BACKGROUND OF THE INVENTION

Neurological impairments including stroke, spinal cord injury, multiple sclerosis, and cerebral palsy are the leading causes of adult disability, resulting in spasticity and contracture as one of the largest lasting effects in patients. The hypertonus and reflex hyperexcitability disrupt the remaining functional use of muscles, impede motion, and may cause severe pain. Prolonged spasticity may be accompanied by structural changes of muscle fibers and connective tissue, which may result in a reduction in joint range of motion. For example, stroke patients may develop considerable ankle spasticity or contracture and walk with "drop-foot." An ankle-foot orthosis is often used to stabilize the ankle and correct the foot-drop. Though the ankle-foot orthosis helps support the ankle and provides toe clearance during the swing phase of a gait stride, it may force adaptive behavior on the patients by interfering with ankle plantarflexion and alter the need for muscles to contract at the appropriate time and intensity throughout the gait cycle. The latter may have significant adverse effects on the recovery of the patient's motor control capability. Lack of mobilization may also risk development of contracture, changes in connective tissue length and the number of sarcomeres in muscle fibers.

Physical therapy has long been in use as a mode of rehabilitation for treating persons with spastic limbs or contractured joints. Most often people are afflicted with these types of disabilities from strokes, as discussed herein, spinal cord injury, cerebral palsy, or multiple sclerosis, although affliction can be caused through other diseases and traumatic injuries as well.

Typically, a physical therapist uses physical modalities and physical manipulation of a patient's body with the intent of reducing spasticity and contracture, thereby restoring limb and joint function. Unfortunately, the effects may not be long-lasting, partly due to the limited and sometimes infrequent therapy a patient may receive. Furthermore, the manual stretching is laborious and the outcome is dependent on the experience and subjective "end feeling" of the therapists. Patients may try to restore function to the limbs and joints themselves. Unfortunately, most of the time it is difficult for the patient to have controlled movement without the assistance of a therapist. In addition, it may be difficult for a patient with an impaired limb or joint to maintain continuous motion and resistance to the limb for the treatment to be effective. Of large concern for patients who attempt to rehabilitate on their own is the potential for an increase in injuries due to lack of knowledge or from overexcessive rehabilitation.

For both patients and therapists, there is a need for a device that can stretch and mobilize the joint accurately, reliably and effectively. Furthermore, there is a need for a device to reduce spasticity and contracture that is portable and one that patients can conveniently use in the comfort of their own home such that treatment will be more frequent and provide longer-lasting improvement for the patients.

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A number of devices have been developed to exercise the joint and reduce joint spasticity and contracture. One example of the prior art, and one that is generally representative of such prior art devices, discloses serial casting which fixes the limb at a corrected position. This method has been used to correct and treat ankle plantar-dorsi-flexion contracture. Dynamic splinting and traction apply a continuous stretch to the joint involved through an adjustable spring mechanism. This continuous passive motion (CPM) device is widely used in clinics and in a patient's home to move the joint within a pre-specified range, to prevent postoperative adhesion and to reduce joint stiffness. However, existing devices like the CPM machine move the limb or joint at a constant speed between two preset joint positions. Because the machine must be set between two preset positions, normally between the flexible part of the joint range of motion, the passive movement does not usually stretch the extreme positions where contracture and spasticity are most significant. If a CPM machine is set too high, at a higher rate of speed or to stretch where the contracture and spasticity are most significant, there is an increased potential of risking injury to the joints because the machine operates at a constant velocity without incorporating the resisting torque generated by the soft tissues. Obviously, significant damage can be done to the joint or limb if the CPM is set too aggressively. Therefore, a need exists for a device that can safely stretch the joint to its extreme positions with quantitative control of the resistance torque and stretching velocity. In addition, there is a strong need for quantitative and objective measurements of the impairment and rehabilitation outcome.

What is needed is a limb and joint therapeutic device to stretch a spastic or contractual joint repeatedly to the extreme positions until a pre-specified peak resistance torque is reached with the stretching velocity controlled precisely based on the resistance torque.

What is further needed is a limb and joint therapeutic device that will evaluate changes in the mechanical properties of spastic joints including changes in passive joint range of motion, joint stiffness and viscosity, and energy loss.

SUMMARY OF THE INVENTION

The present invention satisfies the need for a device that can safely stretch the joint to its extreme positions with quantitative control of the resistance torque and stretching velocity. The present invention provides for a limb and joint therapeutic device that changes velocity in relation to the resistance torque throughout the joint range of motion corresponding directly to a patient's spasticity or contracture.

The present invention further satisfies the need for a limb and joint therapeutic device that is small and portable. Furthermore, the device satisfies the need for a stretching device that can stretch and mobilize the limb or joint accurately, reliably and effectively. Finally, the device satisfies the strong need for quantitative and objective measurements of the impairment of the patients' spasticity or contracture while providing a means for reliably detailing the rehabilitation outcome.

According to the embodiments of the present invention, there is a limb and joint therapeutic device for use by both therapists and patients, whether at home or at a clinic. The limb and joint therapeutic device has a limb support, the limb support securing a limb such that the limb is rotatable with respect to a joint. The device has a motor and a motor shaft, the motor and shaft rotating the joint at a variable

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velocity. A controller communicates with a torque sensor and the motor such that as the resistance torque from the limb increases, the controller communicates to the motor to decrease the variable velocity.

The above advantages, features and aspects of the present invention are readily apparent from the following detailed description, appended claims and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a limb and joint therapeutic device for stretching an ankle made in accordance with the principles of the present invention;

FIG. 2 is the limb and joint therapeutic device for stretching the ankle made in accordance with the principles of the present invention;

FIG. 3 is a limb and joint therapeutic device for stretching a knee made in accordance with the principles of the present invention;

FIG. 4 is a limb and joint therapeutic device for stretching an elbow made in accordance with the principles of the present invention; and

FIG. 5 is a limb and joint therapeutic device for stretching a shoulder made in accordance with the principles of the present invention.

FIG. 6 is an alignment pointer for aligning a joint with a motor shaft made in accordance with the principles of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Turning first to FIGS. 1-2, there is illustrated, in accordance with a first embodiment of the present invention, a limb and joint therapeutic device 10 having a motor 20 for stretching an ankle 30. The motor 20 has a motor shaft 40 extending in a lateral direction substantially parallel to the axis of rotation of the ankle 30, the motor shaft 40 being mounted to a rotatable side plate 50. The rotatable side plate 50 supports a limb such as a foot and is further secured to a foot plate 280 for resting the patient's foot during use of the device 10. The ankle 30 is then aligned with the motor shaft 40 such that the ankle 30 is rotatable with respect to the motor shaft 40 axis by the motor 20.

The motor 20 is encased within a motor housing 70, the motor housing 70 having an aperture through which the motor shaft 40 extends for rotation of the side plate 50 and the ankle 30. Also encased within the motor housing 70 is a gearbox 80 attached to the motor 20 for reducing speed and increasing the torque output. The gearbox 80 is attached to the motor 20 on one side and is mounted to a mounting frame 90 on the opposing side. The mounting frame 90 is mounted to an inner side 100 of the motor housing 70, the gearbox 80 and the mounting frame 90 having an aperture therethrough such that the motor shaft 40 extends to an outer portion of the motor housing 70. As the motor shaft 40 extends through the motor housing 70, a torque sensor 110 is mounted to the shaft 40 while the shaft 40 is mounted to the rotatable side plate 50. The torque sensor 110 measures the amount of resistance torque and communicates the information to a control box 120.

The motor 20 communicates with the control box 120 which may or may not be provided within the housing 70, the control box 120 having a controller 130. The control box 120 may also have an amplifier 140, the amplifier 140 adapted to communicate with the controller 130 for increasing the amount of electrical current and power to the motor

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20 such that velocity may be increased. The controller 130 may be any type of controller 130 including, but not limited to, a digital signal processor, a microprocessor or a microcontroller.

The controller 130 controls the amount of resistance torque as measured by the torque sensor 110, the position of the joint angle and the stretching velocity wherein the controller 130 will be set with a predetermined limit for each prior to the use of the device 10, these limits set by an operator using a computer 150 to communicate with the controller 130 to set the limits. For example, the controller 130 will be set with a maximum resistance torque limit. As this maximum torque limit is achieved, the motor 20 holds the ankle 30 in position for a predetermined amount of time and then reverses the direction of the motor shaft 40 such that the ankle 30 is moved in the opposite direction. In addition, the controller 130 determines the velocity of the movement, the velocity being inversely proportional to the resistance torque such that as the resistance torque increases, the velocity decreases. Conversely, as the resistance decreases, the velocity increases. This inverse relationship is described by the following algorithm:

$$V(t) = \begin{cases} 0, & \text{if } (M_{res}(t) \geq M_p \text{ or } \theta(t) \geq \theta_p + \theta_d) \\ & \text{and need to hold} \\ -V_{max}, & \text{if } (M_{res}(t) \geq M_p \text{ or } \theta(t) \geq \theta_p + \theta_d) \\ & \text{and have held long enough} \\ \max\left(\frac{C}{M_{res}(t)}, V_{min}\right), & \text{if } 0 < M_{res}(t) < M_p \\ \min\left(\frac{C}{M_{res}(t)}, -V_{min}\right), & \text{if } -M_p < M_{res}(t) < 0 \\ V_{max}, & \text{if } (M_{res}(t) \leq -M_n \text{ or } \theta(t) \leq \theta_n - \theta_d) \\ & \text{and have held long enough} \\ 0, & \text{if } (M_{res}(t) \leq -M_n \text{ or } \theta(t) \leq \theta_n - \theta_d) \\ & \text{and need to hold} \end{cases}$$

where $\theta(t)$ and $M_{res}(t)$ are the ankle 30 position and resistance torque at time t, respectively. M_p and M_n are the specified peak resistance torque at the positive and negative ends, respectively, although both are positive numbers. V_{min} and V_{max} are the magnitudes of the minimum and maximum velocity. C is a constant, scaling the $1/M_{res}(t)$ to the appropriate stretching velocity. θ_p and θ_n are the specified positive and negative end of the range of motion. θ_d represents the allowed further rotation beyond the position limits, thus allowing room for improvement in the range of motion. If θ_d is a very large number, thus allowing the device 10 to move beyond the position limits, or if θ_p and θ_n are set outside the range of motion, the stretching control will be dominated by the resistance torque. On the other hand, if M_p and M_n are large, the stretching will be restricted by the position limits. Generally, the stretching reaches the torque limits at both ends of the range of motion with the position limits incorporated into the control scheme as a safety measure and as an optional mode of stretching, thus θ_p and θ_n will be set to approximately match the range of motion and θ_d will be chosen as a positive number. In this manner, the torque limits will be reached while the position limits still restrict excessive ankle 30 movement.

As described herein, during the stretching exercise, the controller 130 controls the stretching velocity according to the resistance torque. In the middle range of motion where resistance is low, the motor 20 will drive the motor shaft 40, and stretch the relatively slack muscles quickly at higher rates of speed. Near the end of the range of motion, the gradually increased resistance torque is measured by the

controller 130 such that the controller 130 will then slow the motor 20 and subsequently the motor shaft 40 so that the muscle-tendons involved will consequently be stretched slowly. The result is a greater ankle 30 range of motion. Upon reaching the specified peak of resistance torque, the motor 20 will hold the joint at the extreme position for a period of time, which may range from about a few seconds to several minutes as will be appreciated by one skilled in the art. This improvement over the prior art allows for an increase in the range of motion of the stretch, yet, because of the variability in velocity of the motor 20, minimizes potential ligament and joint damage.

During movement of the limb and joint, the joint angle, resistance torque and Electromyogram (EMG) signals from the soleus, gastronemius and tibialis anterior muscles are recorded. The EMG signals are recorded via electrodes 160 attached to these muscles and subsequently connected to the computer 150 for recordation and further analysis. The electrodes 160 emit electronic signals to the computer 150 corresponding to those emitted by the muscles. The computer 150 can then communicate with the controller 130 to increase or decrease the limits of the range of motion or the variable velocity based upon the information provided by the electrodes 160 to better tailor the device 10 to a specific patient.

The preferred embodiment of the present invention has a number of built-in safety functions. An operator will enter the maximum amount of resistance torque and a position limit, the position limit indicating the maximum and minimum angular position of the ankle 30 during rotation such that the ankle 30 is stretched to extreme positions without causing further damage to the joint or limb. If the maximum resistance torque and/or position limits are reached, a torque limit light emitting diode (LED) 170 and position limit light emitting diode 180 positioned on the motor housing 70 will be illuminated. The LED indicators 170, 180 signal the operator that the maximum ranges have been achieved. The controller 130 continually monitors the joint position and resistance torque levels at a speed of approximately 2000 Hz, but speeds above or below that level may also be used as will be appreciated by one skilled in the art. If the controller 130 finds that either the position limit or resistance torque limit are out of their pre-specified range, the controller 130 may be enabled such that the device 10 is automatically shut off, thus preventing injury. Furthermore, at least one stop switch 190 will be provided such that an operator or patient may shut off the device 10 immediately. The stop switch 190 provides a back-up mechanism to shut off the device 10 if either the position limit, resistance torque limit or velocity are out of their pre-specified ranges. It further provides for automatic shutdown by the operator or patient at any time during use of the device 10 should the patient experience any pain or discomfort or for any other reason. The stop switch 190 is connected to the controller 130 through a hole 200 in the motor housing 70 for shutting off the device 10. The operator can also include a certain amount of further rotation beyond the position and resistance torque limits to provide room for improvement in the range of motion of the patient's ankle 30.

Further provided in the preferred embodiment are stopping screws 210 attached to the rotatable side plate 50 supporting the limb. As the rotatable side plate 50 rotates with respect to the motor shaft 40, the screws 210 provide an additional safety mechanism such that as the rotatable side plate 50 reaches the screw 210, the screw 210 stops the side plate 50 from further rotation. The stopping screws 210 are removable and the position of the screws 210 along the

side plate 50 may be varied to provide for a greater or lesser range of motion, the range of motion dependent on the patient's individual needs.

The motor housing 70 also has provided a computer interface 220, the computer interface 220 for communication between the controller 130 and a computer 150. The controller 130 communicates information to the computer 150 for further data analysis. The information sent from the controller 130 to the computer 150 includes the joint angle or position or both, the resistance torque and the velocity of the device 10 or any combination of two or more of these including, but not limited to other joint or limb information as well.

The device 10 has an adjustable seat 230 movable along an adjustable track 240 for positioning of a patient. The adjustable seat 230 is movable in both a lateral and a longitudinal direction for aligning the ankle 30 with the motor shaft 40 of the motor 20. The device 10 has a plurality of straps 250 or seat-belts for securing the patient to the seat 230 once alignment of the ankle 30 and the motor shaft 40 has been achieved.

Attached to the adjustable seat 230 is a leg support 260 for stabilizing the leg. Further attached to the leg support 260 and adjustable seat 230 is the rotatable side plate 50 for stabilizing the foot. The seat 230 and leg support 260 are adjustable in multiple degrees of freedom to align the ankle 30 with the motor shaft 40. As additional support for the foot, there is provided a foot clamp 270 for securing the foot against the side plate 50 once the ankle 30 has been aligned with the motor shaft 40. A foot plate 280 is mounted to the side plate 50 for added stabilization of the foot. The foot plate 280 may be adjustable relative to the side plate in the toe-heal, medio-lateral or dorsi-plantar positions, as well as other positions as will be appreciated by one skilled in the art, to achieve the appropriate alignment and stabilization of the ankle 30. Once the adjustment has been completed, the seat 230 and leg support 260 will be secured into the selected position. A cast 290 may be used to enclose the foot, heel and leg for further stabilization of the limb yet allowing movement of the joint. It will be understood by those skilled in the art that movement during the stretching of the ankle 30 could result in further damage and significant pain to the patient, therefore the ankle 30 must be aligned with the motor shaft 40 and the leg must be secured to the leg support 260 such that the leg is immobilized, while the foot is stabilized and only rotational with respect to the ankle 30.

As an additional safety feature for aligning the joint, there is provided an alignment pointer 600 as illustrated in FIG. 6. The pointer 600 has an arc 610, the arc 610 for aligning the pointer 600 with an outer surface of the torque sensor 110. The pointer 600 also has a block 620, the block 620 substantially parallel to the plane of the arc 610, the arc 610 and block 620 secured to one another at a top end by a pole 630. The pointer 600 has a pointer pin 640, the pointer pin 640 slidably through on aperture 650 in a bottom end of said block 620 and extending substantially parallel to the pole 630 and along the same axis as the motor shaft 40 such that the pointer extends toward the center of the torque sensor 110, the pointer pin 640 aligning the joint with the motor shaft thereby preventing injury.

In the preferred embodiment of the present invention, the patient will sit upright in the seat 230 with the knee flexed at about a 60 degree angle as measured between an upper and lower part of the leg. The ankle joint will be manually rotated back and forth several times to check the alignment between the ankle axis and the motor shaft 40. After adjusting the alignment, the limb and joint therapeutic

device 10 will be rotated manually by the operator or patient to the ends of the ankle 30 range of motion, thus setting the two extreme positions or, alternatively, the extreme positions may be entered into the computer 150 and subsequently communicated to the controller 130. Once these values have been set, the stretching device 10 will rotate the ankle 30 about its axis throughout its range of motion, the controller 130 controlling the stretching velocity based on the resistance torque via the motor 20 and motor shaft 40.

As discussed herein and embodied in the present invention, EMG electrodes 160 may be attached to the patient's leg to provide specific muscular information to the computer 150. The computer 150 can then analyze the data to show increases in the range of motion, muscular activity and provide recommendations for future stretching. The computer 150 will evaluate changes in the intrinsic properties of contractured and spastic ankles 30 of neurologically impaired patients, including, but not limited to changes in the passive range of motion, joint stiffness, joint viscous damping, energy loss or any combination of those or other intrinsic properties.

One example of the motor 20 used in the present embodiment is an Industrial Drives Goldline B806 servomotor, although other motors 20 may be utilized. The controller 130 controls the velocity and the range of motion of the motor shaft 40. Texas Instruments' TMS320 digital signal processor (DSP) is an example of a type of controller 130 which may be used. As can be appreciated by one skilled in the art, any known controller 130 can be used to control the motor 20.

In an alternate embodiment of the present invention, the torque sensor 110 may be eliminated. This is accomplished by measuring the motor 20 current wherein the current has an approximate linear relationship with the motor torque. This enables the device 10 to be more portable, lightweight and less expensive. In this embodiment, a gearhead 80 may be used with the motor 20 to reduce speed and increase the torque output as necessary. A separate computer 150 is not required as the motor 20 may be controlled by a stand-alone controller 130 or a portable computer or hand-held device 115 having a controller 130, which also aids in reducing the size and expense of the present invention. Electric stops or limits within the motor 20 may be provided as an additional safety mechanism as described herein and known by those skilled in the art.

In the preferred embodiment of the present invention, the controller 130 will monitor the joint position and torque signals at least 2000 times per second and will shutdown the system if either one of these signals are out of the pre-specified ranges. Mechanical and electrical stops may be used to restrict the motor range of motion. Both the evaluator and the patient may each hold a stop switch 190 attached to the motor 20, providing a mechanism by which either the evaluator or the patient may shut down the motor 20 by pressing the switch 190.

In an alternate embodiment of the present invention as described in FIG. 3, there is provided a limb and joint therapeutic device 305 for stretching a knee 300. Like the first embodiment, the second embodiment includes a height adjustable seat 230 and adjustment tracks 240 for aligning the knee 300 with the motor shaft 40 of a motor 20. Seat belts 250 and straps are provided for immobilizing the patient and an upper portion of the patient's leg once the knee 300 has been aligned. Further provided is a knee clamp 350 for securing the knee 300 to the leg support 360, the leg support 360 having a beam 320, preferably made of aluminum, extending from the knee 300 to the ankle 30 and

mounted to the motor shaft 40 and torque sensor 110 such that the knee 300 is only rotatable with respect to the motor shaft 40. Also provided herein are a pair of half rings 310. The half rings 310 secure a lower part of the leg to the leg support 360 having the beam 320 and are secured with tightening screws 330. The tightening screws 330 are adjustable to support various sizes of legs.

In this embodiment of the present invention there is provided a motor housing 70 containing a motor 20, a gearhead 80 and a motor shaft 40, the motor shaft 40 extending through an aperture of the motor housing 70 and through a torque sensor 110. The motor shaft 40 is mounted to the leg support 360 such that as the shaft 40 rotates, the leg support 360 and beam 320 rotate with respect to the knee 300. The motor housing 70 is secured to an adjustable track 250, the housing 70 movable along the adjustable track 250 in a vertical direction for aligning the motor shaft 40 with the knee 300. Like the device 10 for use with the ankle 30 as described herein, the motor 20 communicates with the control box 120 which may or may not be provided within the housing 70, the control box 120 having a controller 130. The control box 120 may also have an amplifier 140, the amplifier 140 adapted to communicate with the controller 130 for increasing the amount of electrical current and power to the motor 20 such that velocity may be increased.

The controller 130 controls the amount of resistance torque, the position of the knee and the stretching velocity and the controller 130 will be set with a predetermined limit for each prior to the use of the device 305 for stretching the knee 300, these limits set by an operator manually or by using the computer 150 to communicate with the controller 130 to set the limits. Like the device 10 for use with an ankle 30, the controller 130 will be set with a maximum resistance torque limit. As this maximum torque limit is achieved, the motor 20 holds the knee 300 in position for a predetermined amount of time and then reverses the direction of the motor shaft 40 such that the knee 300 is moved in the opposite direction. In addition, the controller 130 determines the velocity of the movement, the velocity being inversely proportional to the resistance torque such that as the resistance torque increases, the velocity decreases. Conversely, as the resistance decreases, the velocity increases as determined by the algorithm set forth above.

As described herein, during the stretching exercise, the controller 130 controls the stretching velocity according to the resistance torque. In the middle range of motion where resistance is low, the motor 20 will drive the motor shaft 40, and stretch the relatively slack muscles quickly, at higher rates of speed. Near the end of the range of motion, the gradually increased resistance torque is measured by the controller 130 such that the controller 130 will then slow the motor 20 and subsequently the motor shaft 40 so that the muscle-tendons involved will consequently be stretched slowly. The result is a greater range of motion for the knee 300. Upon reaching the specified peak of resistance torque, the motor 20 will hold the joint at the extreme position for a period of time, which may range from about a few seconds to several minutes as will be appreciated by one skilled in the art. This improvement over the prior art allows for an increase in the range of motion of the stretch, yet, because of the variability in velocity of the motor 20, minimizes potential ligament and joint damage.

During movement of the limb and joint, the joint angle, resistance torque and EMG signals from the leg muscles may be recorded. The EMG signals are recorded via electrodes 160 attached to these muscles and subsequently connected to the computer 150 for recordation and further

analysis. The electrodes 160 emit electronic signals to the computer 150 corresponding to those emitted by the muscles. The computer 150 can then communicate with the controller 130 to increase or decrease the range of motion for movement of the knee 300 or the variable velocity based upon the information provided by the electrodes 160 to better tailor the device 305 to a specific patient.

The joint and limb therapeutic device 305 for stretching the knee 300 provides the same safety mechanisms as those for use with an ankle 30. In addition, the device 305 provides a rotation adjustment disk 340 attached to the motor housing 70, the adjustment disk 340 for rotating the motor shaft 40 such that the knee 300 can be aligned with the motor shaft 40. The adjustment disk 340 is further attached to the height adjustment track 245 such that it moves in concert with the motor housing 70 in a vertical direction.

In an alternate embodiment of the present invention there is provided a joint and limb therapeutic device 405 for use with an elbow 400, as illustrated by FIG. 4, having a motor 20, motor shaft 40 and a gearhead 80 supported within a motor housing 70. The motor housing 70 has an aperture therethrough such that the motor shaft 40 extends in a vertical direction outward of the motor housing 70 and is mounted to a torque sensor 110. The motor shaft 40 and torque sensor 110 are further mounted to an arm support 410, the arm support 410 comprising an aluminum beam 430, although the beam 430 may be made of other materials, the support substantially perpendicular to the motor shaft 40. The arm support 410 therefore holds a lower portion of the arm 420 in substantially a horizontal position. The arm support 410 has a coupling 440 for securing the lower part of the arm to the arm support 410, such that the lower arm is movable only with respect to the elbow 400 and the motor shaft 40. Thus, the motor shaft 40 rotates the elbow 400 at a variable velocity to stretch the joint and therefore improve rotation of the elbow 400.

Similar to the device 305 for use with the knee 300, this embodiment of the present invention includes a height adjustable seat 230 and adjustment tracks 240 for aligning the elbow 400 with the motor shaft 40 of a motor 20. Seat belts 250 and straps are provided for immobilizing the patient and the lower portion of the patient's arm once the elbow 400 has been aligned.

In this embodiment of the present invention the motor housing 70 is secured to a height adjustment track 245, the housing 70 movable along the adjustable track 245 in a vertical direction for aligning the motor shaft 40 with the elbow 400. Like the device 10 for use with the ankle 30 as described herein, the motor 20 communicates with the control box 120 which may or may not be provided within the housing 70, the control box 120 having a controller 130. The control box 120 may also have an amplifier 140, the amplifier 140 adapted to communicate with the controller 130 for increasing the amount of electrical current and power to the motor 20 such that velocity may be increased.

The controller 130 controls the amount of resistance torque, the position of the elbow 400 and the stretching velocity and the controller 130 will be set with a predetermined limit for each prior to the use of the device 405 for stretching the elbow 400, these limits set by an operator manually or by using a computer 150 to communicate with the controller 130 to set the limits. Like the device 10 for use with an ankle 30, the controller 130 will be set with a maximum resistance torque limit. As this maximum torque limit is achieved, the motor 20 holds the elbow 400 in position for a predetermined amount of time and then reverses the direction of the motor shaft 40 such that the

elbow 400 is moved in the opposite direction. In addition, the controller 130 determines the velocity of the movement, the velocity being inversely proportional to the resistance torque such that as the resistance torque increases, the velocity decreases. Conversely, as the resistance decreases, the velocity increases as determined by the algorithm set forth above.

As described herein, during the stretching exercise, the controller 130 controls the stretching velocity according to the resistance torque. In the middle range of motion where resistance is low, the motor 20 will drive the motor shaft 40, and stretch the relatively slack muscles quickly, at higher rates of speed. Near the end of the range of motion, the gradually increased resistance torque is measured by the controller 130 such that the controller 130 will then slow the motor 20 and subsequently the motor shaft 40 so that the muscle-tendons involved will consequently be stretched slowly. The result is a greater range of motion for the elbow 400. Upon reaching the specified peak of resistance torque, the motor 20 will hold the joint at the extreme position for a period of time, which may range from about a few seconds to several minutes as will be appreciated by one skilled in the art. This improvement over the prior art allows for an increase in the range of motion of the stretch, yet, because of the variability in velocity of the motor 20, minimizes potential ligament and joint damage.

During movement of the limb and joint, the joint angle, resistance torque and EMG signals from the arm muscles may be recorded. The EMG signals are recorded via electrodes 160 attached to these muscles and subsequently connected to the computer 150 for recordation and further analysis. The electrodes 160 emit electronic signals to the computer 150 corresponding to those emitted by the muscles. The computer 150 can then communicate with the controller 130 to increase or decrease the range of motion for movement of the knee 400 or the variable velocity based upon the information provided by the electrodes 160 to better tailor the device 405 to a specific patient. In addition, the joint and limb therapeutic device 405 for stretching an elbow 400 provides the same safety mechanisms as those for use with an ankle 30 including safety screws 210 and stop switches 190.

In yet another embodiment of the present invention, there is provided, as shown in FIG. 5, a joint and limb therapeutic device 505 for use with a shoulder 500. In this embodiment, like those for use with other joints, there is provided a motor 20, motor shaft 40 and gearhead 80 encased within a motor housing 70, the motor shaft 40 mounted to a torque sensor 110 and an upper arm 510 support such that the motor shaft 40 rotates the shoulder 500. The upper arm support 510 has an aluminum beam 520 and a ring 530, the ring 530 securing the upper arm to the beam 520, thus forming the upper arm support 510. In addition the upper arm may have a cast for additional immobilization of the upper arm. The upper arm support 510 is further attached to a lower arm support 540. The lower arm support 540 has a pair of arm beams 550 and forearm ring screws 560 securing the lower arm to the lower arm support 540. The upper arm support 510 and lower arm support 540 are mounted to one another such that the arm is movable only with respect to the rotational movement of the shoulder 500 about the motor shaft 40.

The motor housing 70 is mounted to a height adjustment track 245 and is movable in a vertical direction such that the motor shaft 40 can be aligned with the shoulder 500. Furthermore, the device 505 may have an adjustable seat 230 that is movable along an adjustable track 240, such as those discussed herein, for aligning the shoulder with the

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motor shaft 40. Also provided are position 570 and velocity sensors 580 to provide additional information regarding position and velocity to the controller 130.

Like the other embodiments the controller 130 is connected to a computer 150, the controller 130 communicating with the motor 20, thus controlling the variable velocity, position and resistance torque of the device 505 for stretching a shoulder 500. The controller 130 controls these variables according to the algorithm set forth herein.

While only a few embodiments of the portable intelligent stretching device of the present invention have been described and illustrated in detail herein, it will be evident to one of ordinary skill in the art that other embodiments may be possible for use with a variety of joints and limbs, such as, but not limited to use with fingers and wrists, without departing from the scope of the following claims.

What is claimed is:

1. A portable intelligent stretching device comprising:
a limb support, said limb support securing a limb such that
said limb can be rotated at a joint;
a motor having a motor shaft, said motor shaft rotatable
at a variable velocity and mounted to said limb support,
said joint rotatable with respect to said motor shaft, said
joint aligned with said motor shaft;
a torque sensor, said torque sensor positioned between
said motor and said limb support, said torque sensor
measuring an amount of resistance torque exerted by
said joint; and
a controller connected to said torque sensor and to said
motor, the motor adapted to decrease said velocity as
communicated by the controller in response to an
increase in resistance torque as communicated to said
controller from said torque sensor.
2. The device of claim 1 wherein said joint reaches at least
one predetermined torque or position limits, said controller
communicates to said motor to reverse the rotational direc- 35
tion of said motor shaft.
3. The device of claim 1 further comprising a torque limit
light-emitted diode indicating a maximum allowable amount
of resistance torque.
4. The device of claim 1 further comprising a position 40
limit light-emitted diode indicating a maximum and a mini-
mum allowable limb position.
5. The device of claim 1 further comprising a computer,
said computer communicating with said controller, said
controller providing resistance torque data, velocity data and 45
position data to said computer.
6. The device of claim 1 further comprising an amplifier,
said amplifier increasing said variable velocity of said
motor.
7. The device of claim 6 further comprising a gearhead 50
mounted to said motor, said gearhead reducing said variable
velocity of said motor and increasing the torque output of
said motor.
8. The device of claim 7 further comprising a mounting
frame, said gearhead and motor fixed to said mounting
frame, said mounting frame having an aperture
therethrough, said motor shaft extending through said aperture
thereby connecting to said limb support.
9. The device of claim 8 further comprising a housing,
said housing enclosing said motor, mounting frame, gear- 60
head and amplifier.
10. The device of claim 9 further comprising a height
adjustment track for movably adjusting the height of said
housing for aligning said motor shaft with said joint.
11. The device of claim 1 further comprising at least one
stop switch, said stop switch disconnecting power to said
motor wherein rotation of said motor shaft is stopped.

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12. The device of claim 1 further comprising Electromyogram sensors connected to a limb of said patient, said Electromyogram sensor transmitting Electromyogram information to said computer.

13. The device of claim 12 wherein said controller communicates with said motor and computer, said computer displaying said Electromyogram information, velocity, position and resistance torque wherein said computer is selected from the group consisting of handheld devices, laptops and desktop computers.

14. The device of claim 1 further comprising a height adjustable seat, said adjustable seat for aligning said motor shaft with said joint.

15. The device of claim 14 further comprising an angular backrest adjustment, said backrest adjustment for further aligning said joint with said motor shaft.

16. The device of claim 14 further comprising seat adjustment position tracks, said tracks positioning said seat proximate or distal said motor shaft further aligning said joint with said motor shaft.

17. The device of claim 16 further comprising a base plate, said base plate securing said adjustment tracks to a surface.

18. The device of claim 1 further comprising a rotation adjustment disk, said disk rotating said shaft for alignment with said limb and having safety screws, said screws limiting the amount of rotation of said motor shaft.

19. The device of claim 1 further comprising at least one safety screw, said at least one safety screw attached to said motor shaft such that said shaft cannot rotate past said at least one screw.

20. The device of claim 1 further comprising at least one clamp and a plurality of screws, said plurality of screws securing said clamp to said limb support for additional stabilization of said limb.

21. A portable intelligent stretching device comprising:
a limb support, said limb support securing a limb such that
said limb is rotatable with respect to a joint;
a motor having a motor shaft mounted to said limb
support, said joint rotatable with respect to said motor
shaft by said motor shaft;
a torque sensor, said torque sensor measuring an amount
of resistance torque exerted by said joint; and
a computer remotely connected to said motor and said
torque sensor, said computer having a controller, said
controller controlling the velocity of said motor
inversely proportional to the amount of resistance
torque measured by said torque sensor.

22. The device of claim 21 wherein said joint reaches at
least one predetermined position, said controller communi- 50
cates to said motor to reverse the rotational direction of said
motor shaft.

23. The device of claim 21 further comprising a torque
limit light-emitted diode indicating a maximum allowable
amount of resistance torque.

24. The device of claim 21 further comprising a position
limit light-emitted diode indicating a maximum and a mini- 55
mum allowable limb position.

25. The device of claim 21 wherein said computer having
the controller receives resistance torque data, velocity data
and position data.

26. The device of claim 21 further comprising an
amplifier, said amplifier increasing said variable velocity of
said motor.

27. The device of claim 26 further comprising a gearhead
mounted to said motor, said gearhead reducing said variable
velocity of said motor and increasing the torque output of
said motor.

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28. The device of claim **27** further comprising a mounting frame, said gearhead and motor fixed to said mounting frame, said mounting frame having an aperture therethrough, said motor shaft extending through said aperture thereby connecting to said limb support.

29. The device of claim **28** further comprising a base plate, said base plate securing said adjustment tracks to a surface.

30. The device of claim **21** further comprising at least one stop switch, said stop switch disconnecting power to said motor thereby stopping rotation of said motor shaft.

31. The device of claim **21** further comprising Electromyogram sensors connected to a limb of said patient, said Electromyogram sensor transmitting Electromyogram information to said computer.

32. The device of claim **21** wherein said computer is a hand-held device for communicating with said motor.

33. The device of claim **32** further comprising a housing, said housing enclosing said motor, mounting frame, gearhead and amplifier.

34. The device of claim **21** further comprising a height adjustable seat, said adjustable seat for aligning said motor shaft with said joint.

35. The device of claim **34** further comprising an angular backrest adjustment, said backrest adjustment for further aligning said joint with said motor shaft.

36. The device of claim **34** further comprising seat adjustment position tracks, said tracks positioning said seat proximate or distal said motor shaft for further aligning said joint with said motor shaft.

37. The device of claim **21** further comprising a rotation adjustment disk, said disk adjusting the rotation of said shaft.

38. The device of claim **21** further comprising at least one safety screw, said at least one safety screw attached to said

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motor shaft such that said shaft cannot rotate past said at least one screw.

39. The device of claim **21** further comprising at least one clamp and a plurality of screws, said plurality of screws securing said clamp to said limb support for additional stabilization of said limb.

40. The device of claim **21** further comprising a height adjustment track for movably adjusting the height of said housing for aligning said motor shaft with said joint.

41. The device of claim **21** further comprising an alignment pointer, said pointer aligning said joint with said motor shaft comprising:

an arc, said arc aligned with an outer surface of said torque sensor;

a block, said block parallel to a plane of said arc, said arc and said block secured by a pole at a top end of said arc and said block; and

a pointer pin, said pin slidable through a bottom end of said block extending along the same axis as the center of said arc and said torque sensor, such that said pin is on the same axis as said motor shaft.

42. The device of claim **1** further comprising an alignment pointer, said pointer aligning said joint with said motor shaft comprising:

an arc, said arc aligned with an outer surface of said torque sensor;

a block, said block parallel to a plane of said arc, said arc and said block secured by a pole at a top end of said arc and said block; and

a pointer pin, said pin slidable through a bottom end of said block extending along the same axis as the center of said arc and said torque sensor, such that said pin is on the same axis as said motor shaft.

* * * * *



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Nashner

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(45) **Date of Patent:** Feb. 20, 2007

(54) **APPARATUS AND METHOD FOR CHARACTERIZING CONTRIBUTIONS OF FORCES ASSOCIATED WITH A BODY PART OF A SUBJECT**

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(52) **U.S. Cl.** **600/595; 600/587**

(58) **Field of Classification Search** **600/587, 600/595**

See application file for complete search history.

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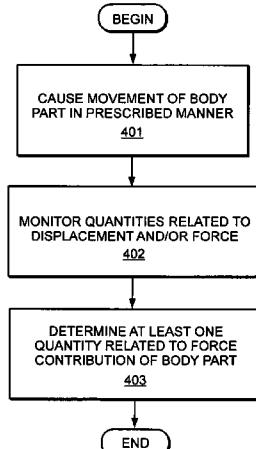
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ABSTRACT

A method and apparatus for characterizing contributions of forces associated with a body part of a subject when the body part is involved in movement is provided. The method includes causing movement of the body part in a prescribed manner and monitoring quantities related to at least one of displacement of the body part and external force on the body part. At least one quantity related to a force contribution associated with the body part is determined from the quantities measured.

13 Claims, 4 Drawing Sheets



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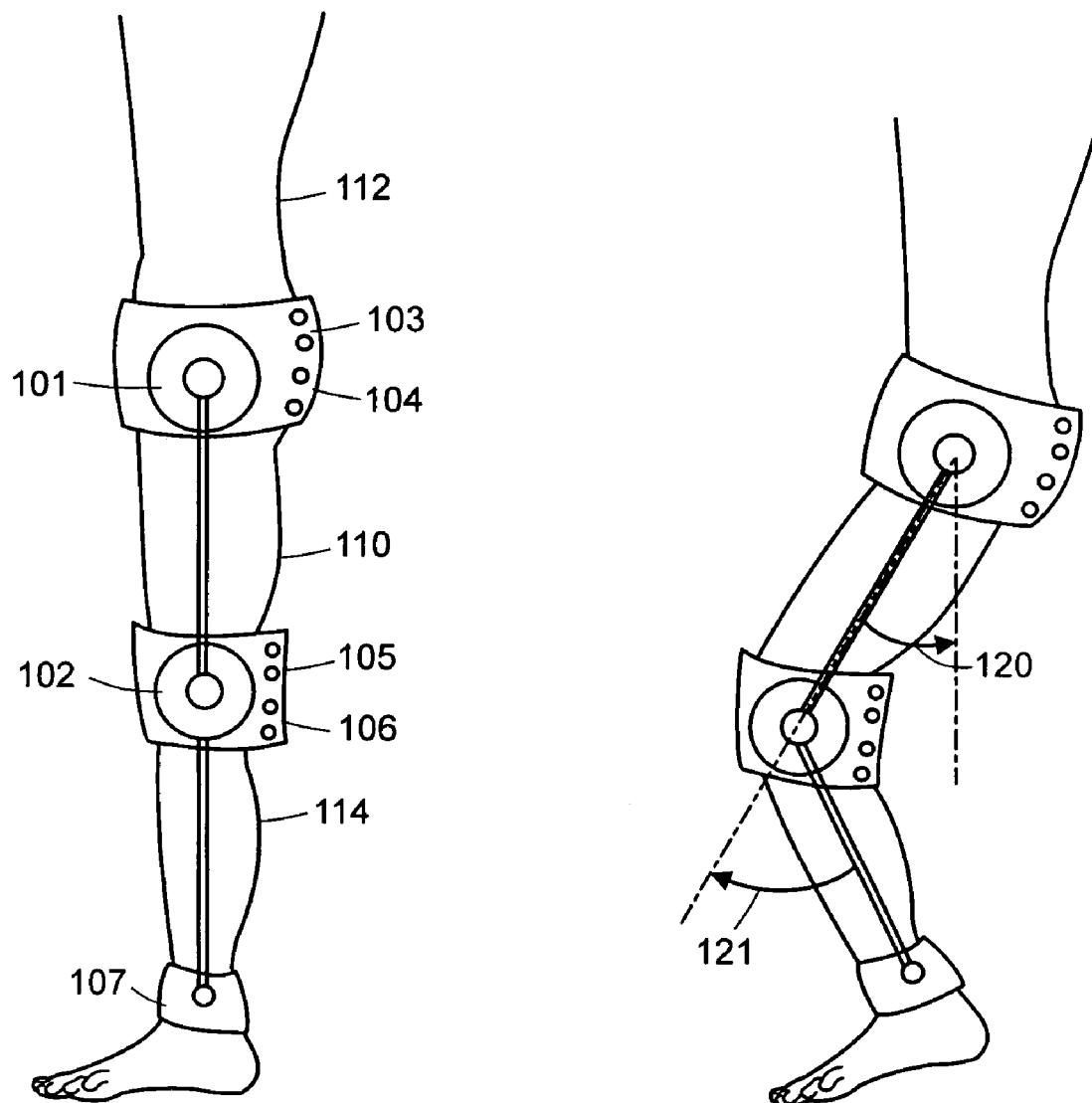


FIG. 1

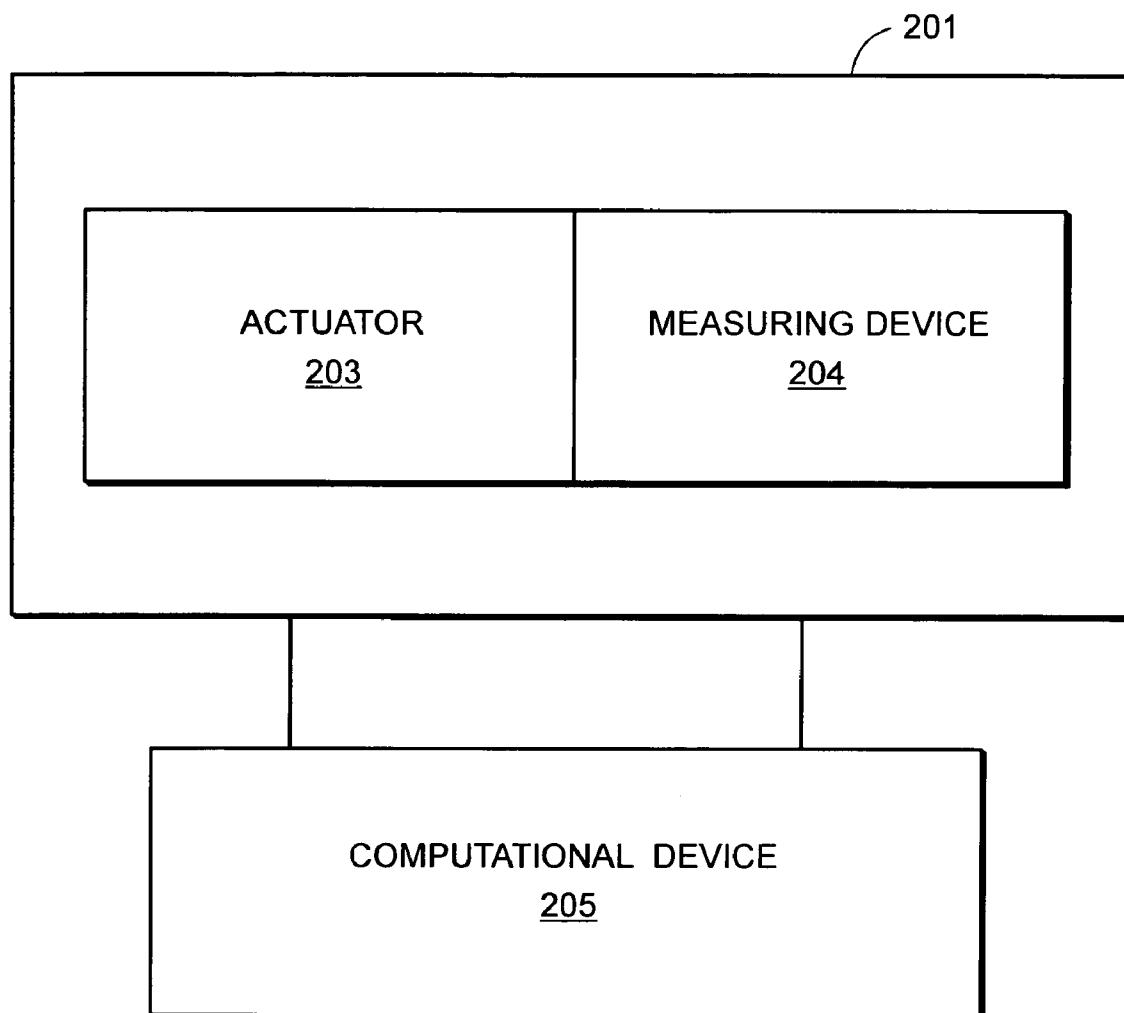


FIG. 2

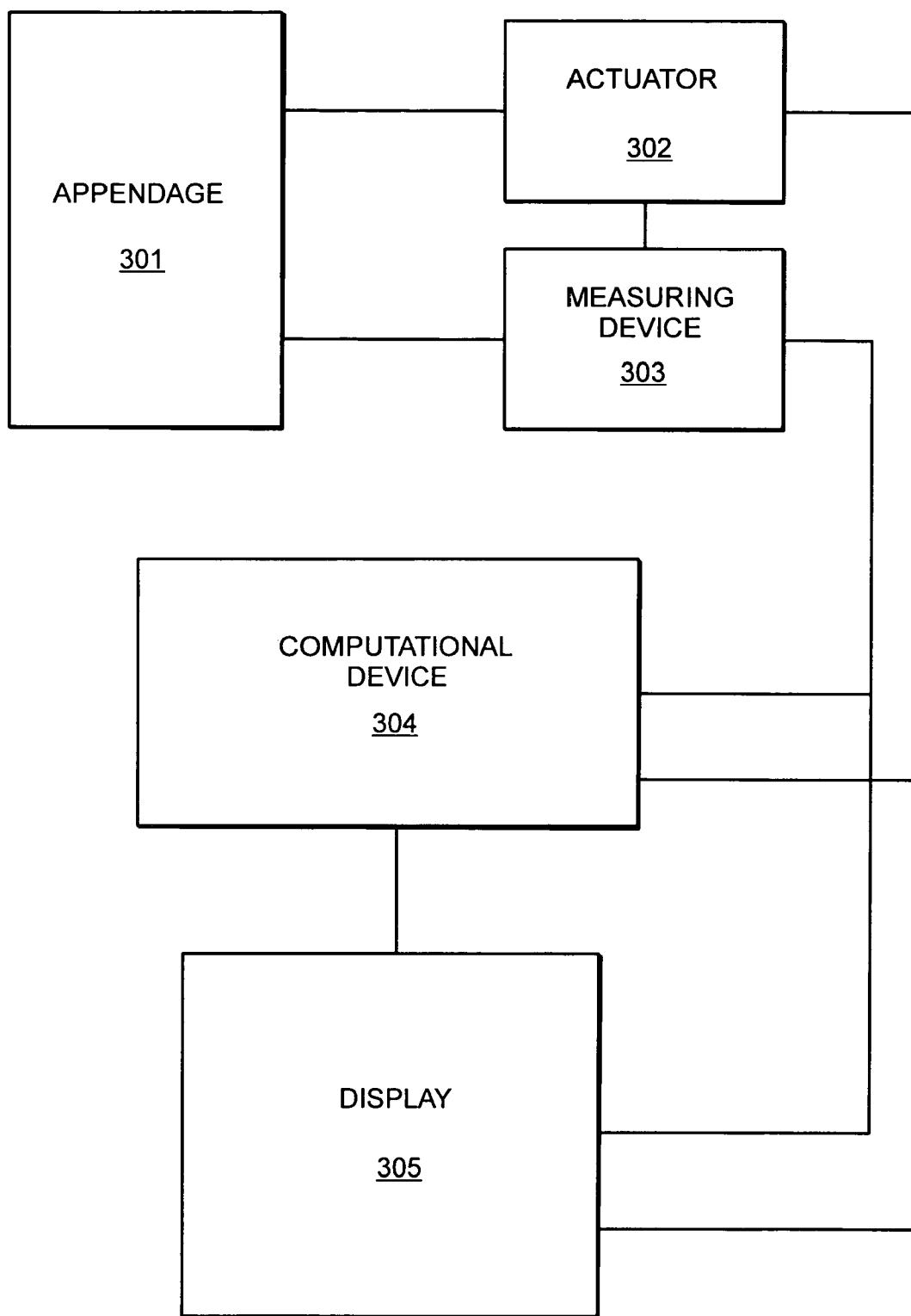


FIG. 3

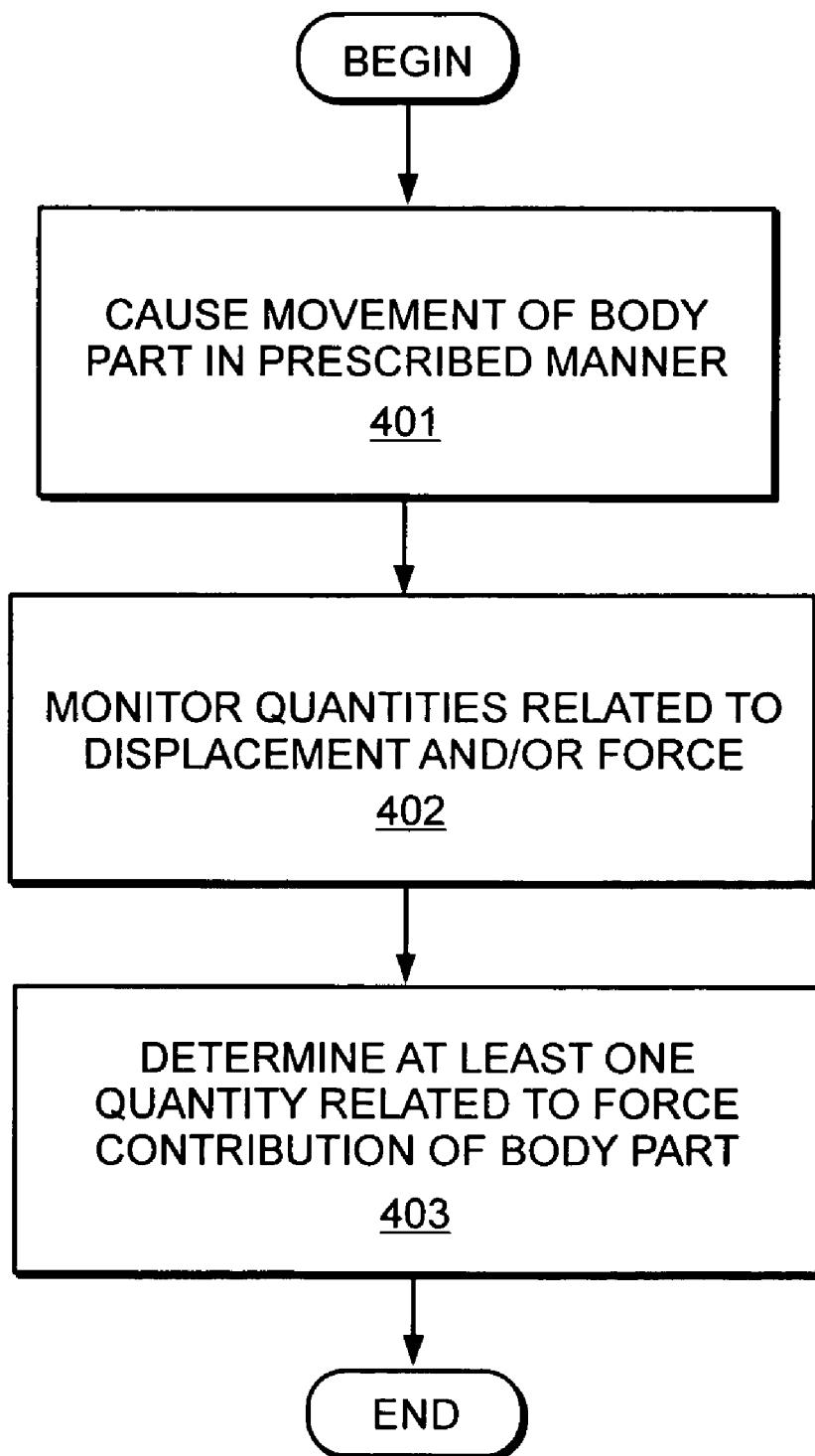


FIG. 4

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**APPARATUS AND METHOD FOR
CHARACTERIZING CONTRIBUTIONS OF
FORCES ASSOCIATED WITH A BODY PART
OF A SUBJECT**

The present application claims priority from U.S. Provisional Application No. 60/486,055, filed Jul. 10, 2003, which is hereby incorporated herein, in its entirety, by reference.

TECHNICAL FIELD

The present invention relates to stimulation of neural tissue and, in particular, to methods and apparatuses for causing prescribed movement of a portion of a subject's body using a mechanical device.

BACKGROUND ART

In individuals with substantial damage to the central nervous system ("CNS"), the traditional understanding has been that the damaged CNS tissue cannot readily regenerate. As a consequence, it has been further understood that the possibility of substantial recovery of daily life functional capabilities is highly unlikely in individuals with severe paralysis of the legs and/or arms caused by CNS diseases such as strokes, spinal cord injuries, and traumatic brain injuries.

New hope for individuals with CNS damage has been provided by recent research studies demonstrating regeneration of substantially damaged CNS pathways controlling the sensory and motor activities of the limbs (Taub Edward, PhD; Gitendra Uswatte, MA; Rama Pidikiti, MD. Constraint-Induced Movement Therapy: A New Family of Techniques with Broad Application to Physical Rehabilitation—A Clinical Review. *Journal of Rehabilitation Research and Development* 1999; 37). Frequent stimulation of damaged neural pathways has been cited as a critical factor to CNS tissue regeneration. For individuals with paralysis concentrated in the limbs on one side of the body, one approach to providing the necessary stimulation therapy is to force the subject to use the impaired limbs by constraining use of the unimpaired ones while the patient performs simple tasks. For individuals with incomplete bilateral paralysis, including paraplegic and quadriplegic injuries, spastic paralysis, multiple sclerosis, stroke, and traumatic brain injuries, locomotion therapy using a treadmill and a partial weight bearing harness has become an accepted standard of care (Rossignol IS, Barbeau H. New approaches to locomotor rehabilitation in spinal cord injury. *Annals of Neurology* 1995;37(5):555–556). In this type of therapy, the overhead harness system supports the patient sufficiently such that the motion of the treadmill belt assists the patient in moving the legs in a locomotor-like pattern. Such partial weight bearing treadmill methods are of proven clinical value in restoring the ability to move and walk in patients with unilateral paralysis and/or with sufficient residual function to generate a minimum level of limb movement in response to the treadmill belt motion (Dobkin BH. An overview of treadmill locomotor training with partial body weight support: a neurophysiologically sound approach whose time has come for randomized trialy. *Neurorehabilitation and Neuronal Repair* 1999; 13(3): 157–164).

For individuals with more severe bilateral paralysis involving the two legs, forced use of the impaired limbs and treadmill-based locomotion therapies are impractical and potentially unsafe. The patient is too impaired to move the

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legs independently while either freely standing or suspended over a moving treadmill belt. In these cases, stimulation therapy can be provided only by externally imposing movements of the legs in repetitive patterns resembling daily life activities such as walking.

The effectiveness of providing stimulation to individuals with bilateral paralysis by externally imposed movements of the impaired limbs has been dramatized in popular press descriptions of Christopher Reeves' medical situation. Reeves, an actor famous for his film portrayal of Superman, suffered a complete section of his spinal cord resulting in total paralysis and loss of sensation below the neck. Despite the conventional belief that his paralysis was permanent and complete, Reeves has undergone imposed movement stimulation therapy as administered by a team of clinicians for several hours per day, resulting in measurable recovery of sensory and motor function in the legs.

There are practical and technical barriers to widespread treatment of severe stroke, spinal cord injury, and traumatic brain injury patients using externally imposed movement therapy similar to that used with Reeves. When the movement therapy is provided manually, the therapy requires multiple clinicians for multiple hours per day to manipulate the limbs, making the cost of such therapy prohibitive. Even with the patient suspended on a moving treadmill belt, the assistance of multiple clinicians to manually move the legs is required, since movement of the treadmill belt alone does not result in stepping-like leg motions.

In response to increased interest in the use of imposed movement therapy, two manufacturers have developed partial weight bearing treadmill systems that include mechanically powered appendages that can automatically move the legs through pre-programmed patterns of movement. One of these devices, the "AutoAmbulator" manufactured by HealthSouth Corporation of Birmingham, AL, is described at www.healthsouth.com/medinfo/home/app.

The HealthSouth website describes the AutoAmbulator as including an overhead harness system able to fully or partially support a subject's weight, two mechanically motorized braces to move each of the subject's legs, computerized sensors to track the subject's vital signs, leg motions and speed of leg movements, devices that permit automatic belt speed adjustments based on leg movement speed, and emergency controls that permit the subject or therapist to stop the machine. The site further describes the ability of the machine to mimic the proper human gait as well as to provide the clinician with the above described data to monitor patient progress.

The HealthSouth website also provides two studies. The first study describes a normal subject walking on the AutoAmbulator system with partial weight support while wearing a tight nylon suit fitted with reflectors. The positions of the reflectors over time are recorded by a computer-video based motion analysis system. The purpose of the first study is to measure the subject's leg motions during robotic patterning and to compare the patterned motions to those produced by the same subjects during normal unassisted walking on the treadmill. The second study uses x-ray imaging techniques to analyze the position of the lower back while normal subjects are suspended in the harness six inches above the treadmill and while wearing the harness with the feet on the treadmill. The purpose of the second study is to assure that the harness system does not cause potential harm to the lower back.

A second partial weight bearing treadmill device incorporating a robotic appendage to provide patterns for movement of the legs is the LOKO System® manufactured jointly by Woodway GmbH of Weil am Rhein, Germany, and Hocoma AG of Zurich, Switzerland. The LOKO System, as described at the website www.woodway.com/LOKO_new.htm, is an open treadmill and partial weight bearing harness in which the patient can be led through locomotion therapy either with the clinician manipulating the patients leg movements or with the leg movements imposed automatically by an motorized appendage.

A number of devices and methods for measuring the forces and motions of the legs during free walking and walking on a treadmill have been described in the prior art. Examples of devices for recording the motions of the legs and body using computer-video techniques include systems manufactured by MotionAnalysis Corporation of Santa Rosa, Calif. and Vicon Ltd. of Oxford, United Kingdom, Lake Forest, Calif. and Hong Kong. Advanced Mechanical Technology, Inc. of Watertown, Mass. markets forceplates that can be mounted in the surface over which a subject walks to document the forces of the feet during human balancing and walking. The Balance Master system manufactured by NeuroCom International, Inc. of Clackamas, Oreg. uses a five-foot long forceplate to record the timing and positions of successive foot placements during locomotion. U.S. Pat. No. 5,474,087, U.S. Pat. No. 5,623,944, and U.S. Pat. No. 6,010,465 (each of which are hereby incorporated herein by reference) describe a treadmill device incorporating at least two forceplates under the moving belt to record the forces of the two legs independently during treadmill walking. GaitRite, a pressure sensitive mat manufactured by CIR Systems Inc. of Clifton, N.J. can measure the locations and timing of the successive steps of a walking subject.

SUMMARY OF THE INVENTION

In a first embodiment of the invention there is provided a method for characterizing contributions of forces associated with a body part of a subject when the body part is involved in movement. The method includes causing movement of the body part in a prescribed manner and monitoring quantities related to at least one of displacement of the body part and external force on the body part. At least one quantity related to a force contribution associated with the body part is determined from the quantities measured.

In accordance with related embodiments, the method may also include monitoring activity of a muscle associated with the body part in relation to displacement of the body part. Additionally, causing movement of the body part may include causing a large slow displacement of the body part. Similarly, causing movement of the body part may include causing a small rapid displacement of the body part. In accordance with other related embodiments, activity of a muscle associated with the body part may be monitored when the muscle is relaxed and/or activity of a muscle associated with the body part may be monitored when the muscle is active. The body part may include a limb or a set of limbs.

In accordance with further related embodiments, monitoring quantities related to displacement of the body part may include monitoring the displacement of a joint associated with the body part and the joint may be a knee. Monitoring quantities related to the displacement of the knee may include monitoring displacement along a knee-flexion-extension axis and/or monitoring displacement along a knee

pronation-supination axis. Similarly, monitoring quantities related to the displacement of knee may include monitoring displacement along an eversion-inversion axis. In accordance with another related embodiment, the joint may be a hip. In addition, causing movement of the body part by the application of external force may include causing cyclic movement typical of walking.

In accordance with another embodiment of the invention, an apparatus for characterizing contributions of forces associated with a body part of a subject when the body part is involved in movement includes means for causing movement of the body part in a prescribed manner, means for monitoring quantities related to at least one of displacement of the body part and external force on the body part and means for determining at least one quantity related to a force contribution associated with the body part from the quantities measured. In accordance with related embodiments, the apparatus may include means for monitoring activity of a muscle associated with the body part in relation to displacement of the body part. Additionally, the means for causing movement of the body part may include a mechanical arm. Similarly, the means for causing movement of the body part may include an actuator. In accordance with other related embodiments, the means for monitoring displacement of the body part may include means for accepting signals for controlling the position of the body part. Further, the means for monitoring displacement of the body part may include means for generating signals for related to the position of the body part and forces generated by the body part.

In accordance with a further embodiment of the invention, an apparatus for characterizing contributions of forces associated with a body part of a subject when the body part is involved in movement includes an appendage coupled to the body part for causing movement of the body part in a prescribed manner, a measurement device that measures quantities related to at least one of displacement of the body part, external forces on the body part and forces generated by the appendage. A computational device is in communication with the measurement device for determining at least one quantity related to a force contribution associated with the body part. In accordance with a related embodiment, the apparatus may also include surface electromyographic recorder for monitoring the activity of a muscle associated with the body part. In accordance with additional related embodiments, the computational device may calculate forces necessary to move the body part when no muscle activity is detected. Further, the body part may be a leg and the appendage attaches to the leg and causes knee and hip joints of the leg to move in patterns similar to those generated when walking. The measurement device may measure angular displacement of the knee and hip joints and/or the measurement device may measure forces generated by the appendage in rotating the knee and hip joints.

In accordance with further related embodiments, the appendage may include an actuator. Additionally, the measurement device may include an input for receiving and an output for transmitting signals related to displacement of the appendage and of the body part and forces generated by the appendage and the body part. Further, the appendage may include the measurement device. Similarly, the measurement device may be integrated with an actuator. In accordance with another related embodiment, the apparatus may include a display for displaying the at least one quantity related to a force contribution associated with the body part to a clinician. Similarly, the apparatus may include a display for displaying the at least one quantity related to a force contribution associated with the body part to the subject.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing features of the invention will be more readily understood by reference to the following detailed description, taken with reference to the accompanying drawings, in which:

FIG. 1 is graphical illustration of a mechanical device for moving knee and hip joints in a prescribed pattern in accordance with an embodiment of the invention;

FIG. 2 is a block diagram illustrating an apparatus for characterizing contributions of forces associated with a body part of a subject in accordance with an embodiment of the invention;

FIG. 3 is a block diagram illustrating an apparatus for characterizing contributions of forces associated with a body part of a subject in accordance with a further embodiment of the invention; and

FIG. 4 is a flow chart illustrating a method for characterizing contributions of forces associated with a body part of a subject in accordance with a further embodiment of the invention.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

When a portion of a subject's body, for example a limb, is moved by an externally attached mechanical device or appendage, the force required to impose a movement on the limb is related to the combined effects of the physical mass of the limb, the passive visco-elastic properties of the limb, and any active muscular forces generated by the limb either in support of or opposition to the imposed motion. Given knowledge of the physical dimensions and mass of the limb, the external force required to move a passive limb (i.e., a limb displaying no active muscular forces) may be calculated using classical Newtonian mechanics. Thus, with knowledge of the masses of the limb segments, the positions and degrees-of-freedom of the joints linking the limb segments, Newtonian mechanics, and the forces generated by a motorized mechanical device driving the limb motion, it is possible to determine the passive inertial, elastic, viscous components of the driving force. Any additional component of force not attributable to the above three components may be attributed to the active muscular force component.

It is further possible to differentiate between the contributions of the passive elastic, viscous, and non-visco-elastic active muscular components of the musculoskeletal force using principles of classical Newtonian mechanics. Specifically, it is known that the forces related to the elastic properties of a moving mass are in opposition and proportional to the displacement of the mass from a neutral rest position, whereas force contributed by the viscous property is also in opposition and proportional to rate of displacement.

The force generating properties of individual human muscles and pairs of muscles acting in opposition to one another about a body joint, termed antagonist pairs, are well described in the prior art (Principles of Neural Science. Kandel & Schwartz, editors. Elsevier/North Holland, N.Y., 1981). When one of an antagonistic pair of muscles is neurally activated, a muscular driving force is generated tending to move the joint in the direction of the active muscle, with the driving force proportional to the level of the neural activation. When both muscles of an antagonistic pair are simultaneously and equally activated, termed co-activation, no driving force tending to move the joint is generated.

During the co-activation state, however, the elastic resistance of the joint to an externally imposed displacement increases, with the active component of the elastic resistance proportional to the level of co-activation. Finally, when an antagonistic pair of muscles undergoes unequal co-activation, the result is combination of a muscular driving force tending to move the joint in the direction of the more active muscle and an increased active elastic component. In this case, the muscular driving force is related to the difference in levels of activation of the two antagonist muscles, while the active elastic component is related to the activation level of the muscle undergoing the lesser activation.

By imposing movements about the joint of a limb using an attached mechanical device or attached appendage and measuring the forces required to generate such imposed movement, it is possible to isolate the effects of the passive elastic, passive viscous, active elastic, and muscular driving force components. For example, by moving the limb through large displacement amplitudes at very slow displacement rates it is possible to maximize the effect of the passive elastic component of force while minimizing the inertial and passive viscous components. Under this condition of imposed motion, the elastic component is the force directly related to limb position, while the muscular driving force component is unrelated to position. Then, small, rapid displacements of the limb are used to maximize the viscous component and minimize the elastic. Now, the viscous component is the force directly related to limb displacement rate while the muscular driving force component is the force unrelated to displacement.

By combining the above methods with additional methods for measuring the level of activation of individual muscles, it is further possible to isolate the effects of the passive elastic forces from the active elastic forces generated by the co-activation of antagonist muscles. One quantitative method for measuring the level of neural activation of a muscle uses surface electromyographic ("EMG") recording techniques well-known in the prior art. A second method for measuring the activation level of a muscle is for a trained clinician to manually press on the belly of the muscle and then observe the degree of muscle hardness. One method of recording the passive elastic and viscous forces is to move the limb according to the above described methods, monitor the EMG activity level of the muscle, or the degree of muscle belly hardness, to assure that the antagonistic muscles are not active, and record the passive elastic and viscous components. During subsequent movements of the limb, differences in recorded elastic forces are related to the active elastic force, while the force component unrelated to the limb displacement is related to the muscular driving force component.

Using the above described methods, it is possible to cause a multi-segmented limb to move about several joints at the same time and to determine the passive, elastic, viscous, and active muscle components of force acting about each of the moving joints separately. For example, an appendage such as that described for the AutoAmbulator may be used to move the knee and hip joints in a cyclic pattern resembling normal walking. The above described measurements may be performed with the limb moving while suspended or while moving in contact with the moving belt of a treadmill.

Since the typical human limb joint can move about more than one axis at a time, the above described methods can be further used to determine the passive, elastic, passive viscous, active elastic, and active force components acting about different axes of limb joint motion. Using the example of cyclic knee and hip joint motions typical of walking, the

inertial, elastic, viscous, and active muscular force components acting at the knee joint may be determined for not only the normal axis of bending (the knee flexion-extension axis) but also for the axis of lateral twisting motion (knee pronation-supination) and the axis of longitudinal twisting motion (eversion-inversion).

The ability to quantify during imposed movement therapy the extent to which a patient contributes effort to generation of the imposed movement compared to the extent generated by the forces and motions of the motorized appendage would provide several forms of clinically useful information. First, the information would be useful to assure the safety of imposed movement therapy using a powered appendage. One example would be a subject whose knee joint motion is severely restricted about a specific axis of motion. In the absence of any information related to the elastic and viscous components, the powered appendage might continue to force the knee into positions causing further damaging the joint. With the information provided by the proposed devices, maximum levels of elastic, viscous, and active muscular forces may be established and motions of the appendage halted or otherwise modified whenever one more of these force levels are exceeded.

Further, the information may be used as a measure of treatment progress. Specifically, as a patient's improves over time, the percentage of the movement generated by the efforts of the patient will increase, while that imposed by the motorized appendage will decrease.

In addition, the information may be used as a measure of the effectiveness of the patterned movement therapy. Imposed movement therapy may be problematic in patients with excess spasticity or excessive co-activation of antagonistic muscles, for examples. Spasticity is a condition that causes a paralyzed limb to react reflexively so as to actively resist externally imposed movements such as those provided by the motorized appendage. In the case of imposed movement therapy, the spastic reflex reactions may contribute inappropriately in that they would generate forces actively resisting rather than supporting the motions imposed by the appendage. In patients with excessive co-activation of antagonistic pairs of muscles, the joints of the limb become excessively stiff and thereby also tend to actively resist rather than support the motions imposed by the motorized appendage. Thus, information related to the quality of the patient's contribution to the imposed movement may allow the clinician to modify the pattern of the movement to reduce the confounding effects of spasticity and co-activation or otherwise to take other medical actions to reduce these adverse effects.

Finally, the information may be used as a biofeedback signal provided to the patient and the supervising clinician during the patterned movement therapy. As the patient struggles to regain active control over the paralyzed limbs during the imposed movement therapy and as the treating clinician works to assist in this effort, the biofeedback signal can provide immediate information related to the effectiveness of the subject's efforts as well as help focus effort on those actions having the greatest positive impact on performance. Such biofeedback information is particularly valuable, because a paralyzed patient may be unable to accurately sense how his or her actions contribute to the imposed movement, which in the absence of biofeedback may lead to discouragement and loss of motivation. Embodiments of this invention therefore address such problems.

FIG. 1 is graphical illustration of a mechanical device for moving knee and hip joints in a prescribed pattern in accordance with an embodiment of the invention. A com-

bination trunk brace and hip actuator 101 is coupled to the subject's body at the hip. The trunk brace and hip actuator 101 is used to move the upper leg segment 110 relative to the trunk 112 about the hip joint. In accordance with this embodiment, the trunk brace and hip actuator includes at least one input or signal receiver 103 for accepting signals used to control the position of the hip actuator 101 and thus cause motion of the hip in a prescribed manner. At least one output or signal transmitter 104 provides signals related to the position of the hip joint and the forces generated by the hip actuator 101.

The device also includes a combination upper leg brace and knee actuator 102 which is coupled to the subject's knee. The upper leg brace and knee actuator 102 is used to move the lower leg segment 114 relative to the upper leg segment 110 about the knee joint. Again, the upper leg brace and knee actuator includes at least one input or signal receiver 105 for accepting signals used to control the position of the knee actuator and consequently cause motion of the knee in a prescribed manner. At least one output or signal transmitter provides signals related to the position of the knee joint and the forces generated by the knee actuator. The device further includes a lower leg segment brace 107 which is coupled to the knee joint actuator 102. By employing this embodiment, the upper leg brace and knee actuator is continually coupled to the knee joint even when the knee joint is in a flexed position relative to the upper leg, as shown at 121. Similarly, the trunk brace and hip actuator stays coupled to the hip joint even with the hip joint in a flexed position relative to the trunk as shown at 120.

FIG. 2 is a block diagram illustrating an apparatus for characterizing contributions of forces associated with a body part of a subject in accordance with an embodiment of the invention. The apparatus includes an appendage 201 which is coupled to the body part of the subject. The appendage 201, which may be designed as brace as shown with respect to FIG. 1, or a mechanical device, such as a robotic arm, causes movement of the body part in a prescribed manner. For example, the appendage 201 may cause the body part to move (i) through large displacement amplitudes at very slow displacement rates in order to maximize the effect of the elastic component of force while minimizing the viscous component of force and (ii) through, small, rapid displacements to maximize the viscous component of force as described above. Similarly, the appendage 201 may cause the body part to move in a manner that the body part would move during normal physical activity. For example, the appendage may attach to the leg of the subject and cause knee and hip joints of the leg to move in patterns similar to those generated when walking. To this end, the appendage may include an actuator 203.

A measurement device 204 measures quantities related to at least one of displacement of the body part, external forces on the body part, or forces generated by the motorized appendage as it imposes a displacement on the body part. For example, the measurement device 203 may measure angular displacement of the knee and hip joints and/or forces generated by the appendage in rotating the knee and hip joints. The measurement device may include an input for receiving and an output for transmitting signals related to displacement of the appendage and of the body part and/or signals related to forces generated by the appendage and the body part as shown in FIG. 1. The measurement device 204 may be included in the appendage 201, as shown here, or it may simply be coupled to the appendage as shown in FIG.

3. Similarly, the measurement device may be integrated with the actuator 203.

A computational device 205 is in communication with the measurement device 204. The computation device 205 determines at least one quantity related to a force contribution associated with the body part. The computational device may calculate forces necessary to move the body part when no muscle activity is detected. The computational device 205 may also be in communication with the actuator 203 in order to provide control signals for controlling the actuator. 10 The computation device 205 may also be in communication with a surface electromyographic recorder (not shown) which monitors the activity of a muscle associated with the body part.

FIG. 3 is a block diagram illustrating is an apparatus for characterizing contributions of forces associated with a body part of a subject in accordance with a further embodiment of the invention. In accordance with this embodiment, the measuring device 302 and actuator 303 are not integrated with the appendage 301. The appendage 301 is coupled to 15 the actuator 302 and measuring device 303 which may also be coupled to one another. A computation device 304 is coupled to the actuator 302 and the measuring device 303. A display 305 may be coupled to the computational device 20 304 for displaying at least one quantity related to a force contribution associated with the body part to a clinician, such as a health care provider or therapist, or to the subject. The display 305 may also display data provided to the computational device as an input. 25

FIG. 4 is a flow chart illustrating a method for characterizing contributions of forces associated with a body part of a subject in accordance with a further embodiment of the invention. In process 401, an appendage or mechanical device or a clinician, therapist or other health care provider causes the body part to be moved in a prescribed manner. For example, causing movement of the body part may include causing cyclic movement of a leg typical of walking. Quantities related to at least one of displacement of the body part and external force on the body part are monitored in process 402. Monitoring quantities related to displacement may 30 include monitoring quantities related to the displacement of a joint associated with the body such as monitoring quantities related to the displacement along a knee-flexion-extension axis, a knee pronation-supination axis and/or an eversion-inversion axis. Activity of a muscle associated with the body part may also be monitored when the body part is active and/or when the body part is relaxed. At least one quantity related to a force contribution associated with the body part is then determined 403 from the quantities measured. 40

While the invention has been described in connection with specific embodiments thereof, it will be understood that it is capable of further modification. This application is intended to cover any variation, uses, or adaptations of the invention and including such departures from the present disclosure as come within known or customary practice in the art to which invention pertains.

What is claimed is:

1. A method for characterizing contributions of forces associated with a body part of a subject when the body part is involved in movement, the method comprising:
5 applying external forces to the body so as to cause movement of the body part in a first manner and a second manner, wherein the first manner includes causing a large displacement of the body part at a slow displacement rate and the second manner includes causing a small displacement of the body part at a rapid displacement rate, wherein the body part exerts an internal force to contribute to the movement of the body part;
monitoring quantities related to the displacements of the body part and the external forces applied to the body part; and
determining at least one quantity related to the contribution of the internal force generated by the body part from the quantities measured.
2. A method according to claim 1, further comprising: monitoring activity of a muscle associated with the body part in relation to the displacements of the body part.
3. A method according to claim 1, further comprising; monitoring activity of a muscle associated with the body part when the muscle is relaxed.
4. A method according to claim 1, further comprising: monitoring activity of a muscle associated with the body part when the muscle is active.
5. A method according to claim 1, wherein the body part includes a limb.
6. A method according to claim 1, wherein the body part includes a set of limbs.
7. A method according to claim 1, wherein monitoring quantities related to the displacements of the body part includes monitoring a displacement of a joint associated with the body part.
8. A method according to claim 7, wherein the joint is a knee.
9. A method according to claim 8, wherein monitoring quantities related to the displacement of the knee includes monitoring displacement along a knee-flexion-extension axis.
- 45 10. A method according to claim 8, wherein monitoring quantities related to the displacement of the knee includes monitoring displacement along a knee pronation-supination axis.
11. A method according to claim 8, wherein monitoring quantities related to the displacement of the knee includes monitoring displacement along an eversion-inversion axis.
- 50 12. A method according to claim 7, wherein the joint is a hip.
13. A method according to claim 1, wherein causing movement of the body part further includes causing cyclic movement typical of walking.

* * * * *



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(12) **United States Patent**
Cataldi et al.

(10) **Patent No.:** US 9,108,080 B2
(b4) **Date of Patent:** Aug. 18, 2015

(54) **ORTHOSIS MACHINE**(75) Inventors: **Theodore F. Cataldi**, McKees Rocks, PA (US); **Brian F. Hagen**, Wexford, PA (US)(73) Assignee: **For You, Inc.**, McKees Rocks, PA (US)

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CPC **A63B 21/1488** (2013.01); **A61H 1/0259** (2013.01); **A63B 21/0058** (2013.01); **A63B 21/00178** (2013.01); **A63B 21/143** (2013.01); **A63B 23/03508** (2013.01); **A63B 23/0405** (2013.01); **A63B 23/0494** (2013.01); **A61H 2201/0173** (2013.01); **A61H 2201/0188** (2013.01); **A61H 2201/1642** (2013.01); **A61H 2201/1664** (2013.01); **A61H 2201/5007** (2013.01); **A61H 2201/5048** (2013.01); **A61H 2201/5066** (2013.01); **A61H 2201/5097** (2013.01); **A61H 2203/0425** (2013.01); **A61H 2203/0456** (2013.01); **A63B 2071/0072** (2013.01); **A63B 2071/0081** (2013.01); **A63B 2071/0625** (2013.01); **A63B 2071/0655** (2013.01); **A63B 2071/0683** (2013.01); **A63B 2208/0238** (2013.01); **A63B 2208/0252** (2013.01); **A63B 2209/10** (2013.01); **A63B**

(2220/803 (2013.01); **A63B 2220/89** (2013.01); **A63B 2225/54** (2013.01))(58) **Field of Classification Search**
CPC A61H 1/00; A61H 1/02; A61H 1/0237; A61H 1/0255; A61H 1/0259; A61H 1/0266; A61H 2001/00; A61H 2001/02; A61H 2001/0203; A61H 2001/0237; A61H 2001/0266; A61H 2201/5064; A61H 2201/5066; A61H 2203/045 USPC 601/5, 23, 27, 29, 31–35; 482/92–93, 482/131–133
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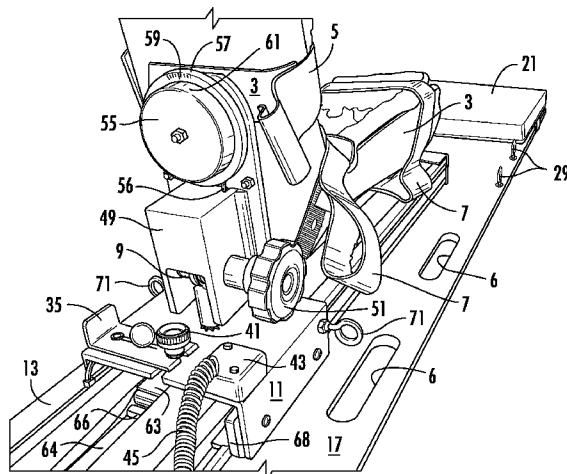
Assistant Examiner — Christopher Miller

(74) Attorney, Agent, or Firm — The Webb Law Firm

(57) **ABSTRACT**

An orthosis machine for providing therapeutic and/or rehabilitative functionalities including at least one of Continuous Passive Motion, Passive Range of Motion, Active Assistive Range of Motion, Active Range of Motion, Resistive Range of Motion, proprioception training and biofeedback from a seated, supine, or recumbent position. Therapeutic and/or rehabilitative functionalities provided by the orthosis machine may be powered by the user or a motor and may be used through one or more phases of post surgical and/or general rehabilitation and physical therapy from multiple angular positions.

20 Claims, 15 Drawing Sheets



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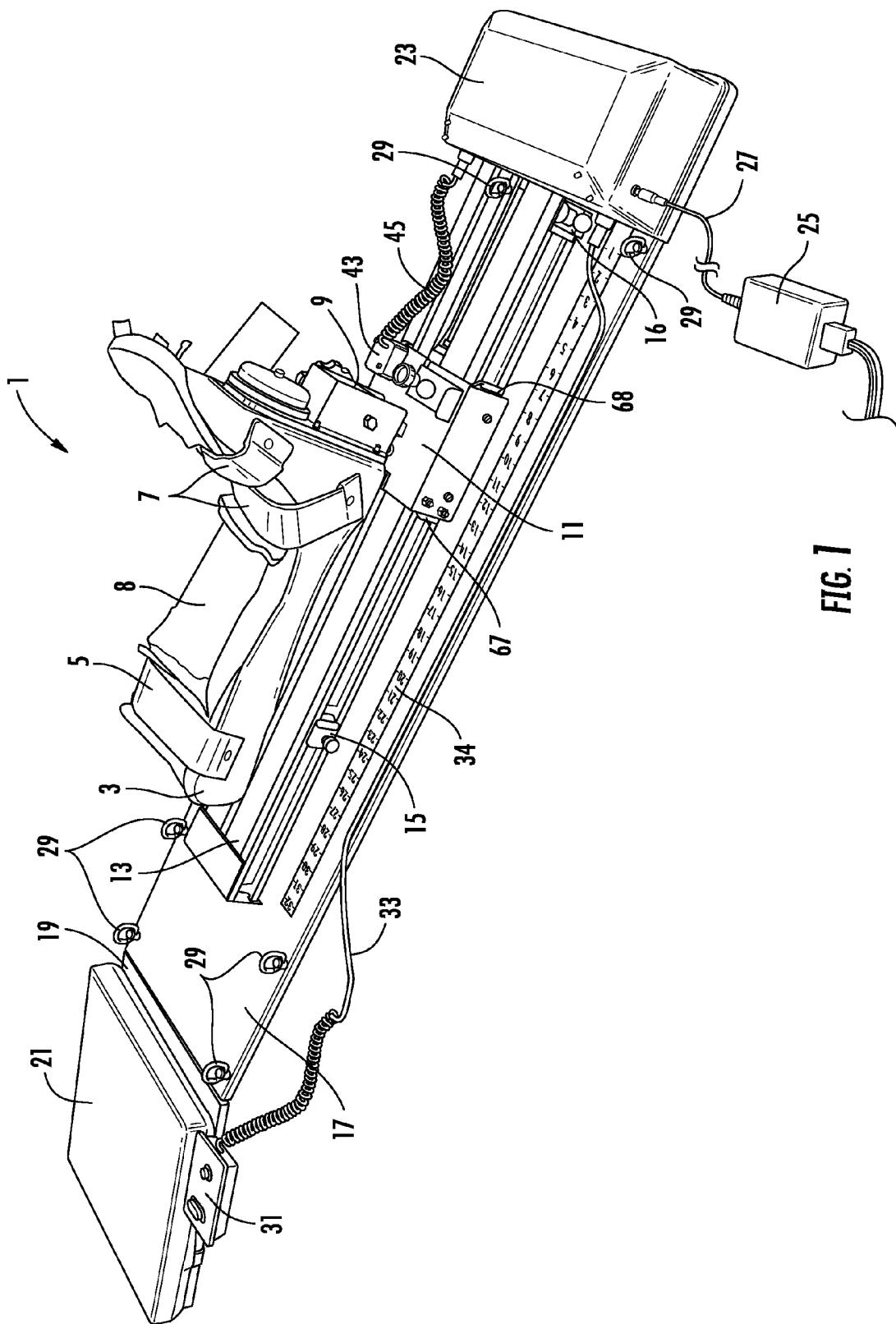


FIG. 1

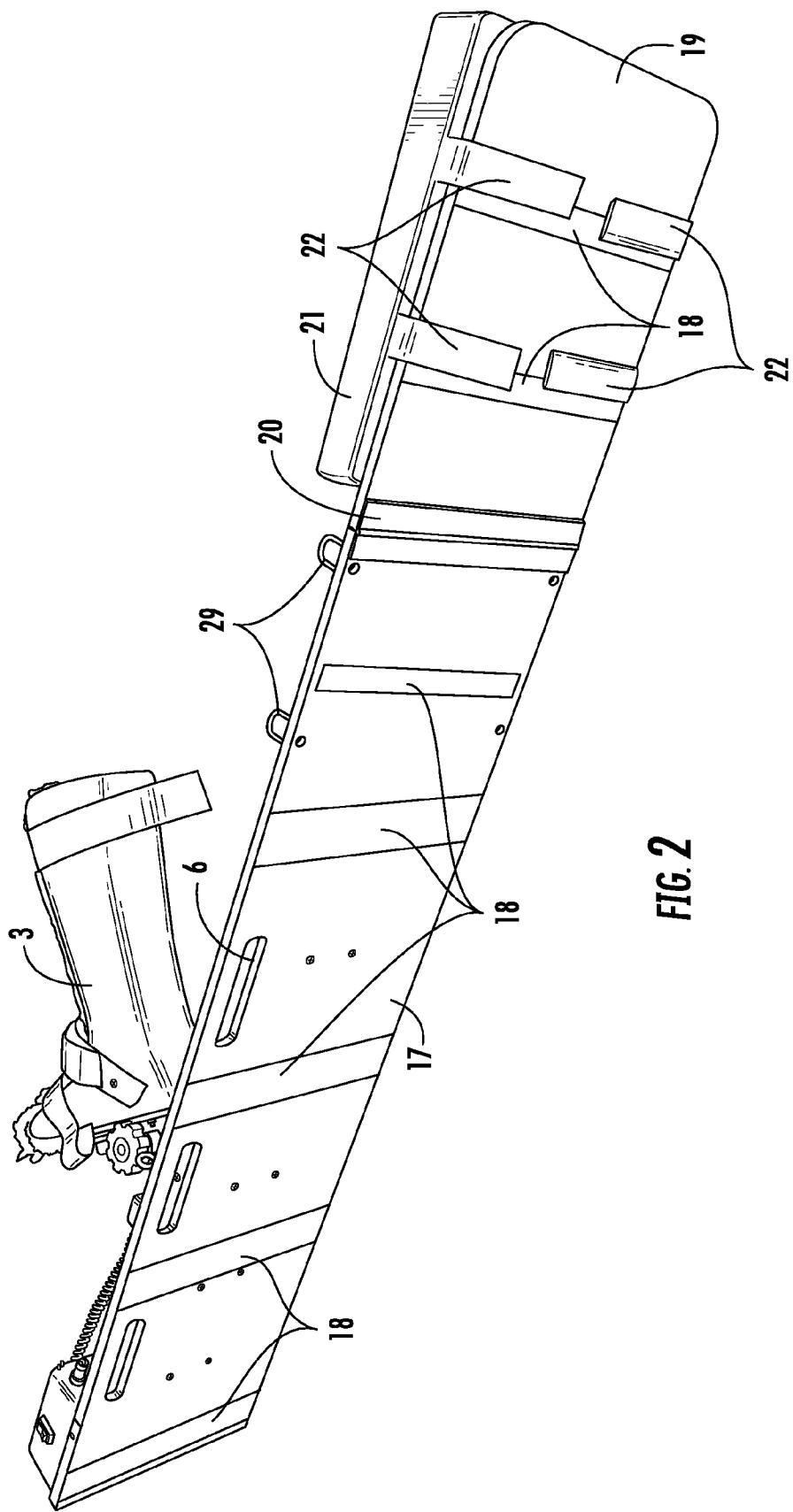
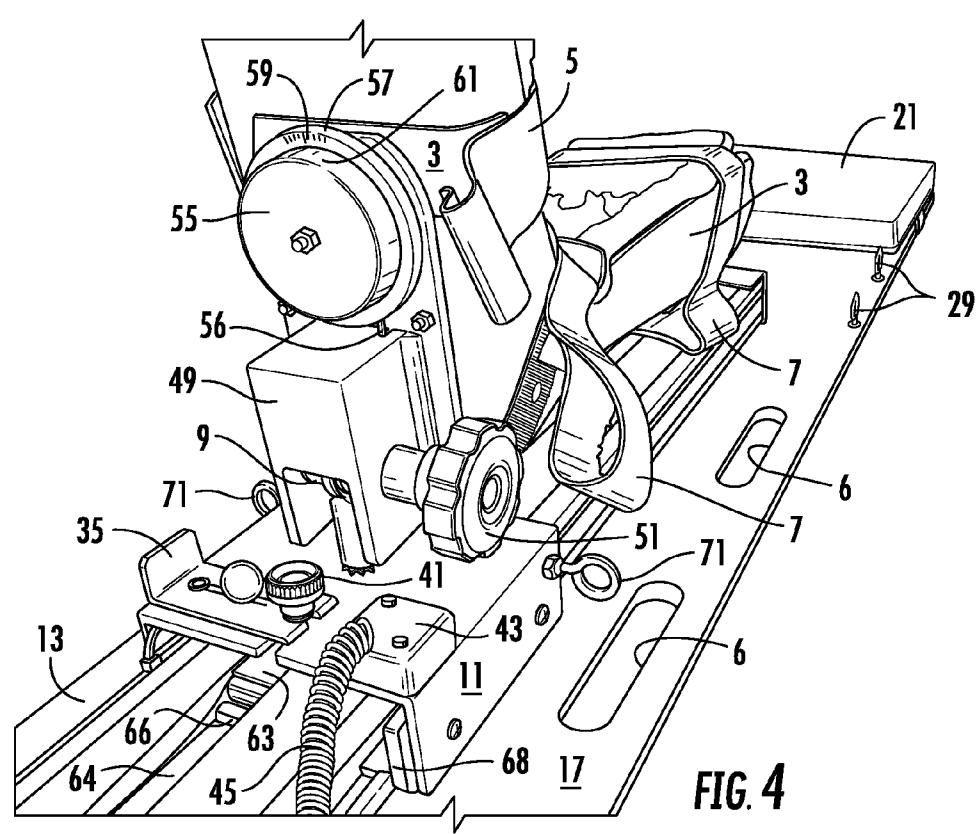
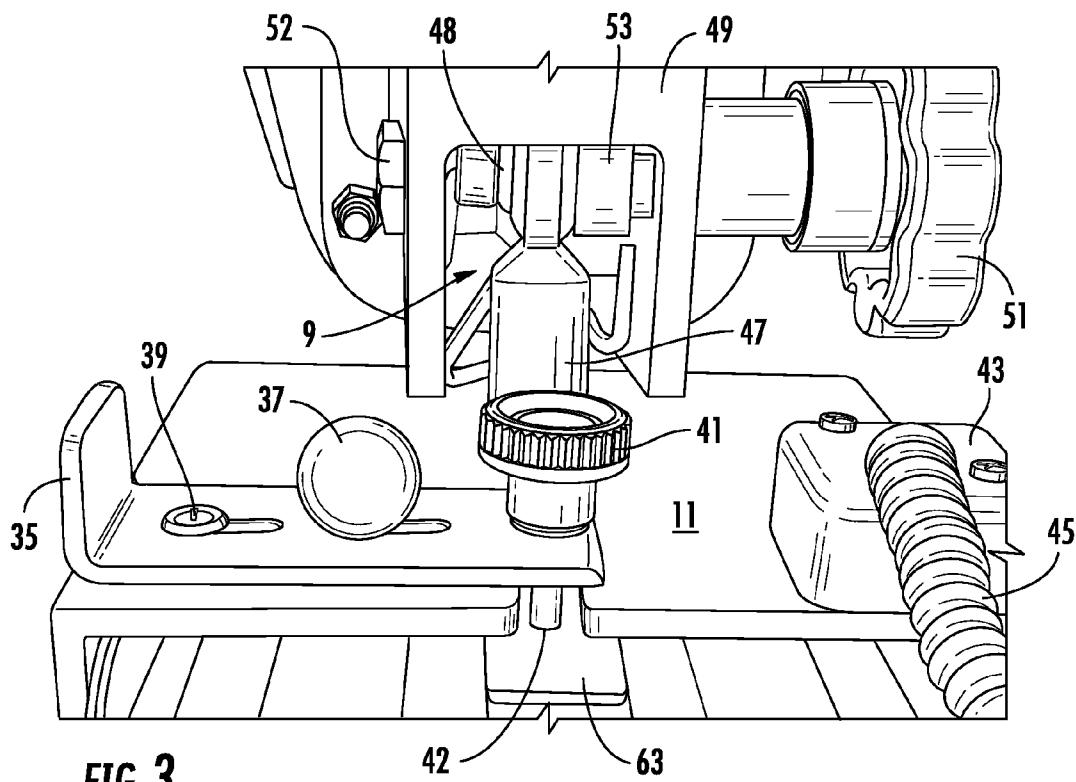


FIG. 2



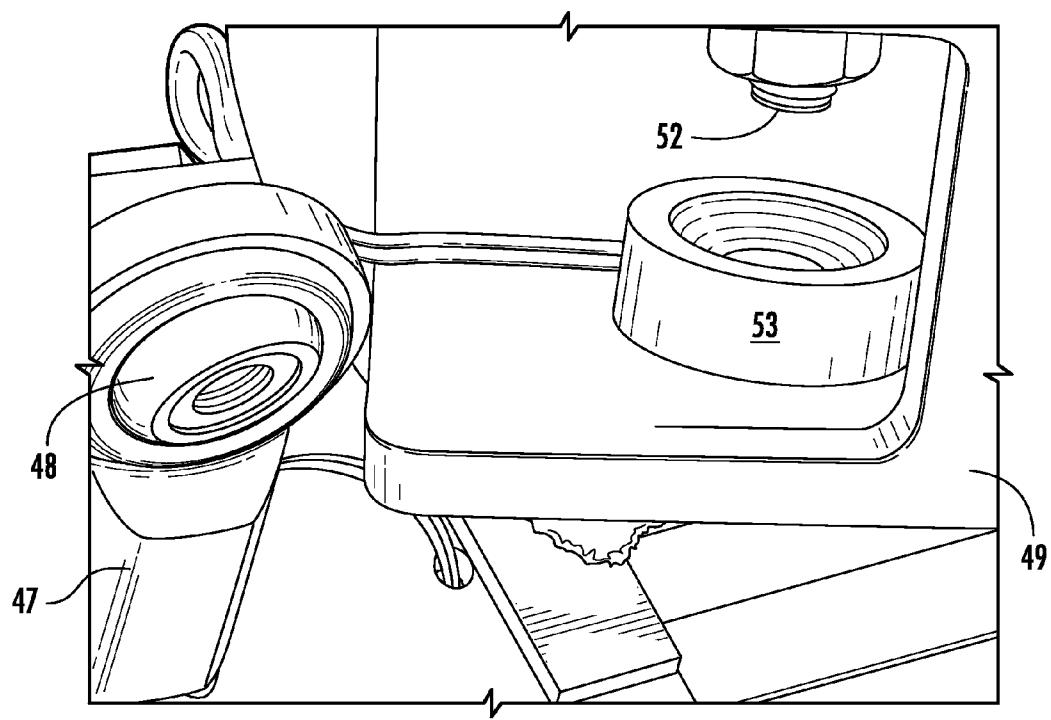
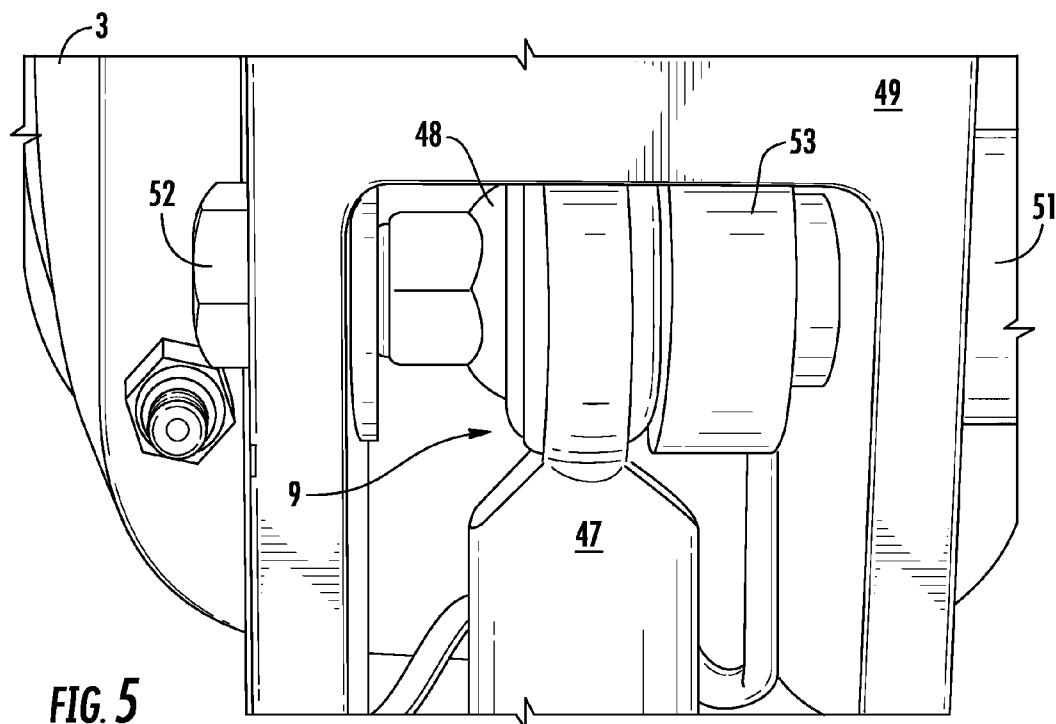


FIG. 6

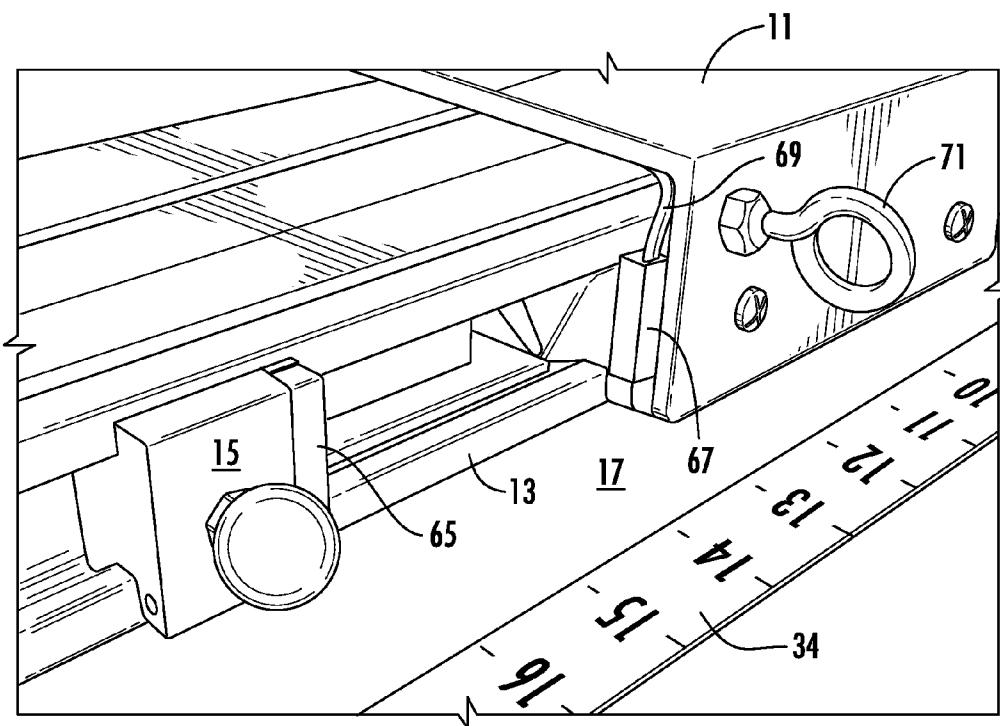


FIG. 7

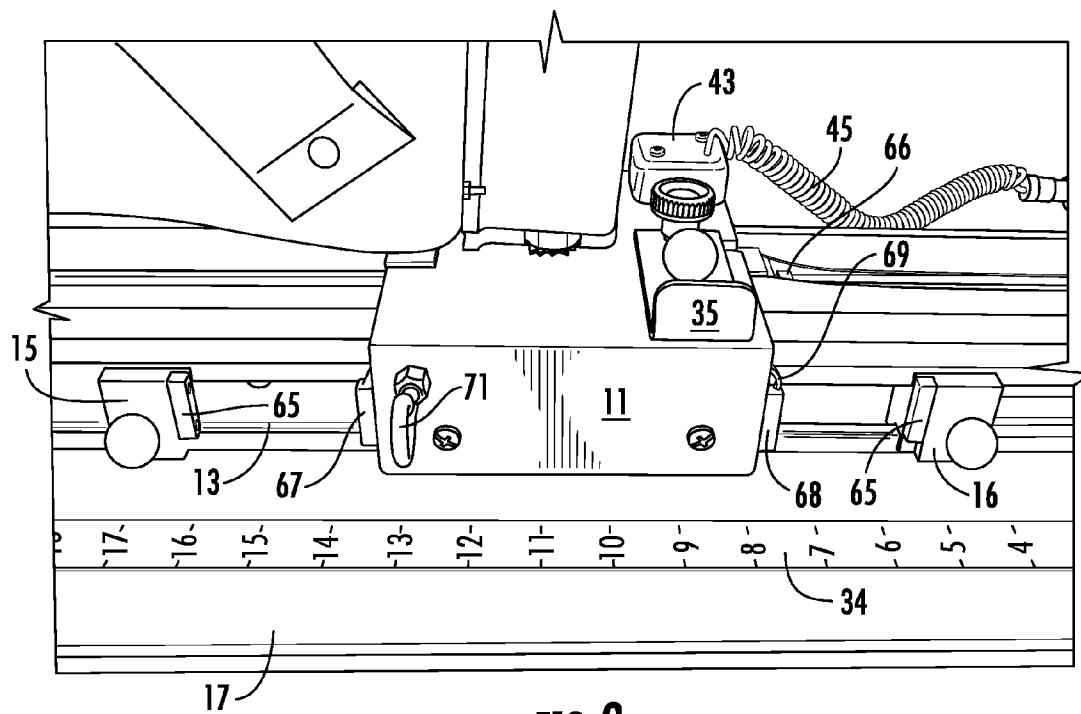


FIG. 9

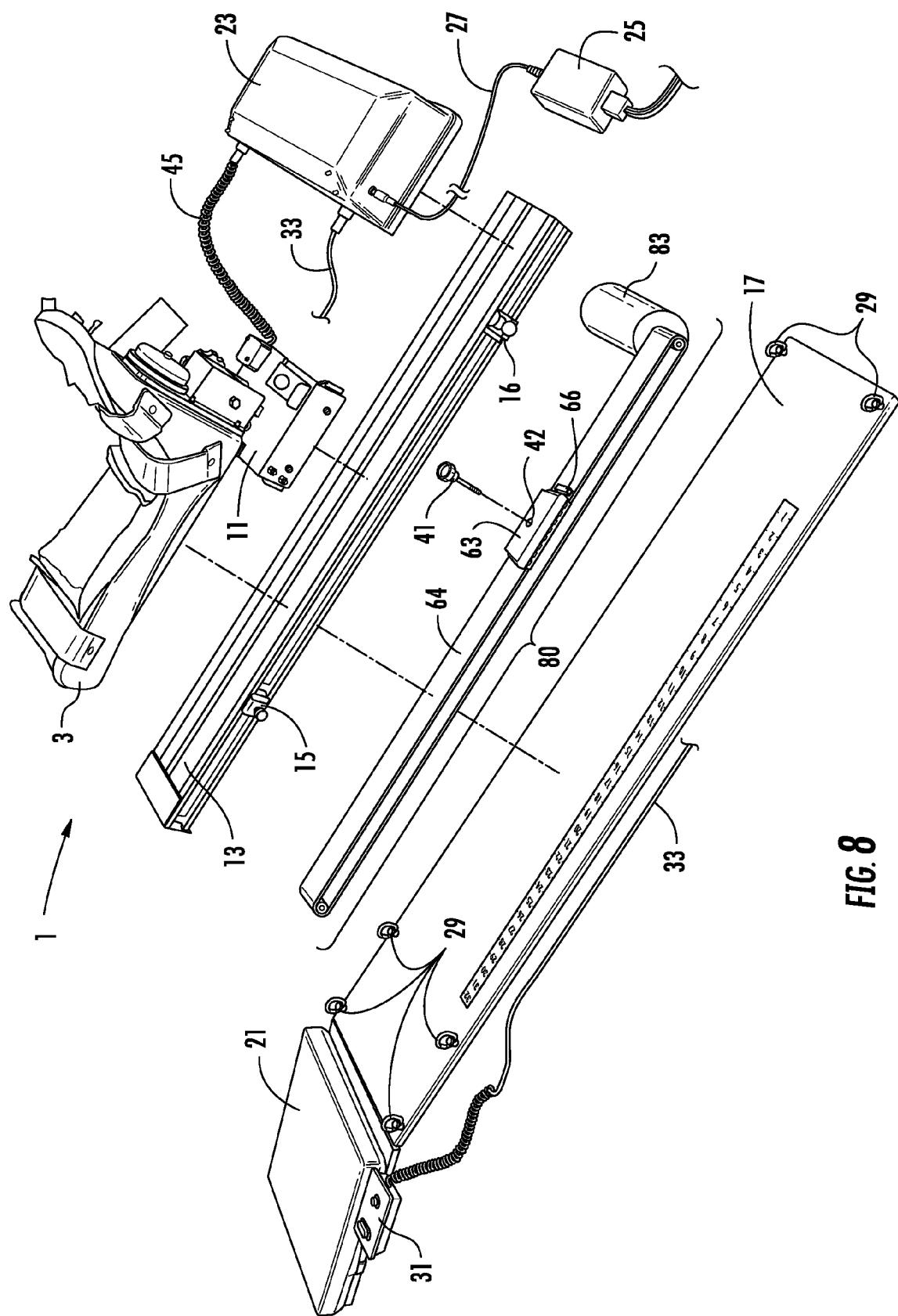


FIG. 8

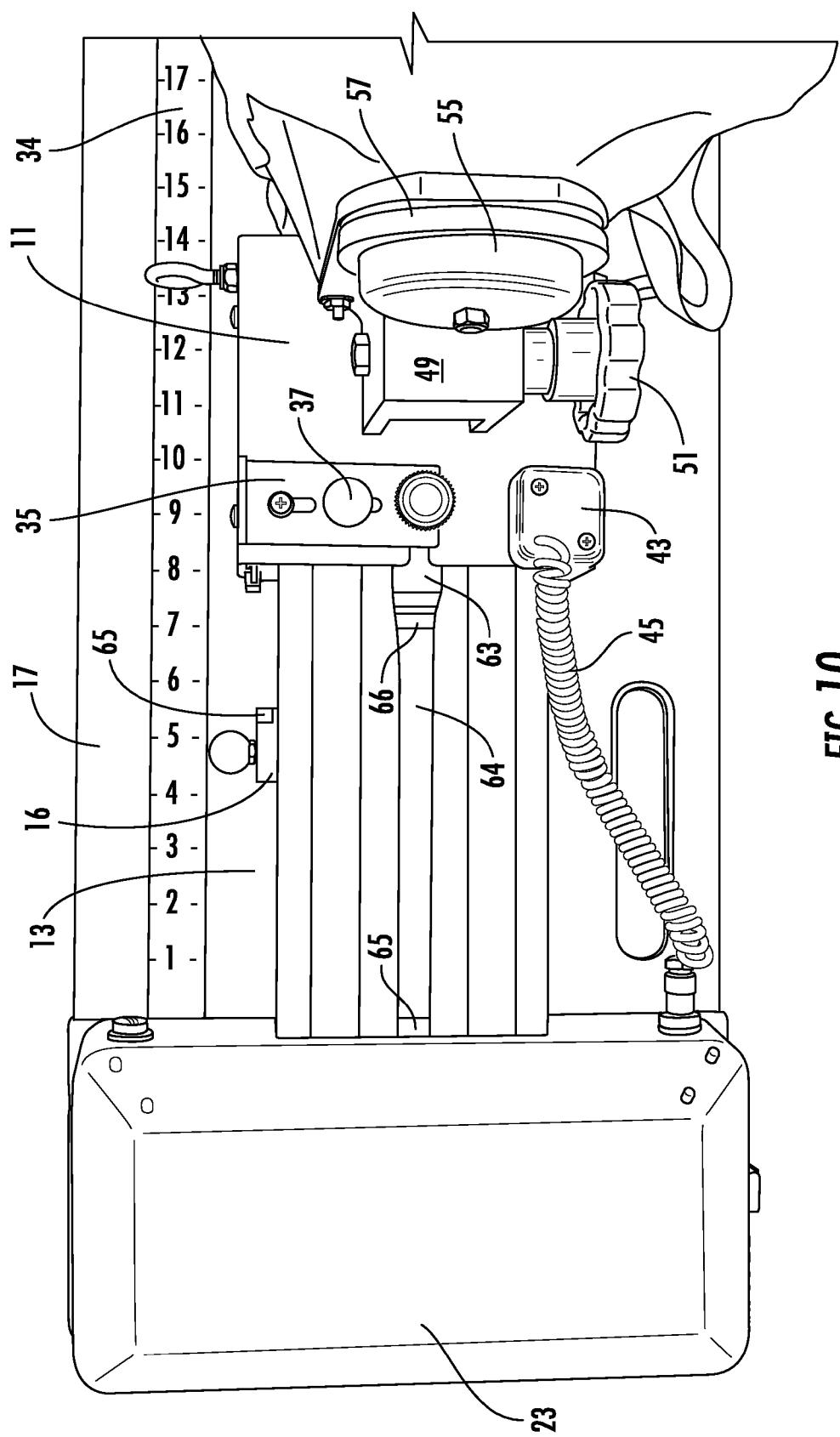


FIG. 10

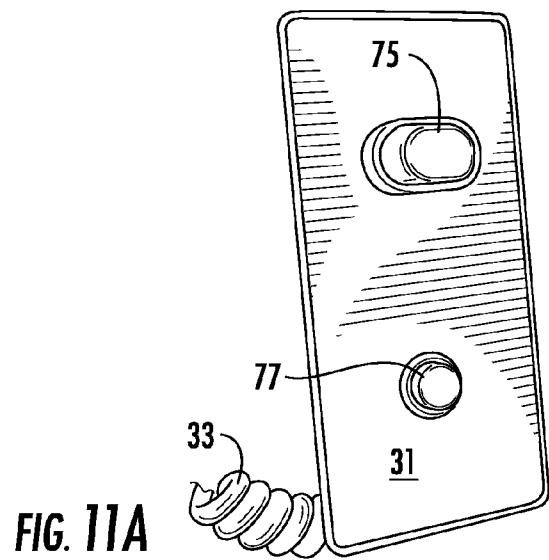


FIG. 11A

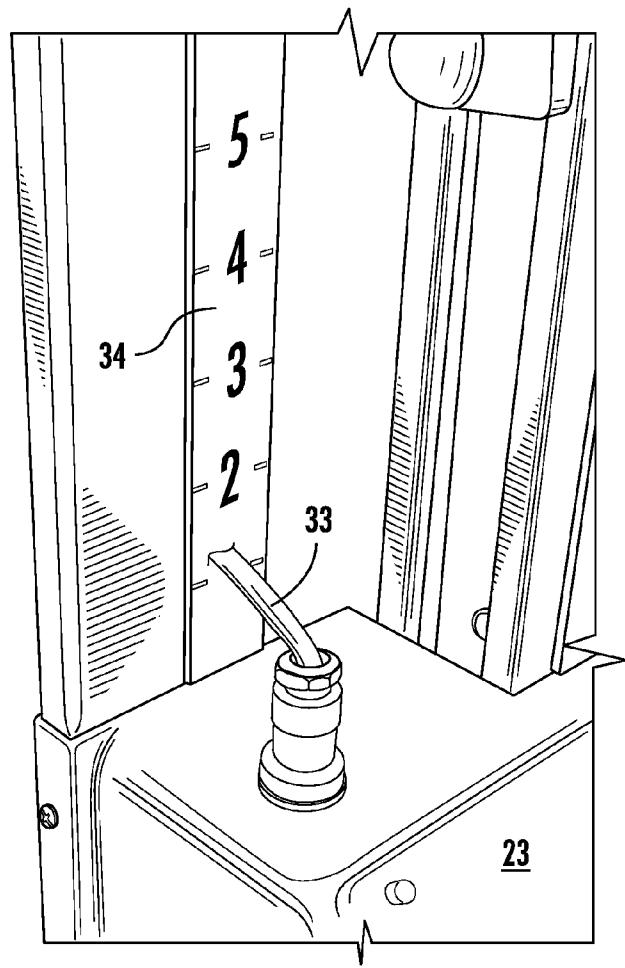


FIG. 11B

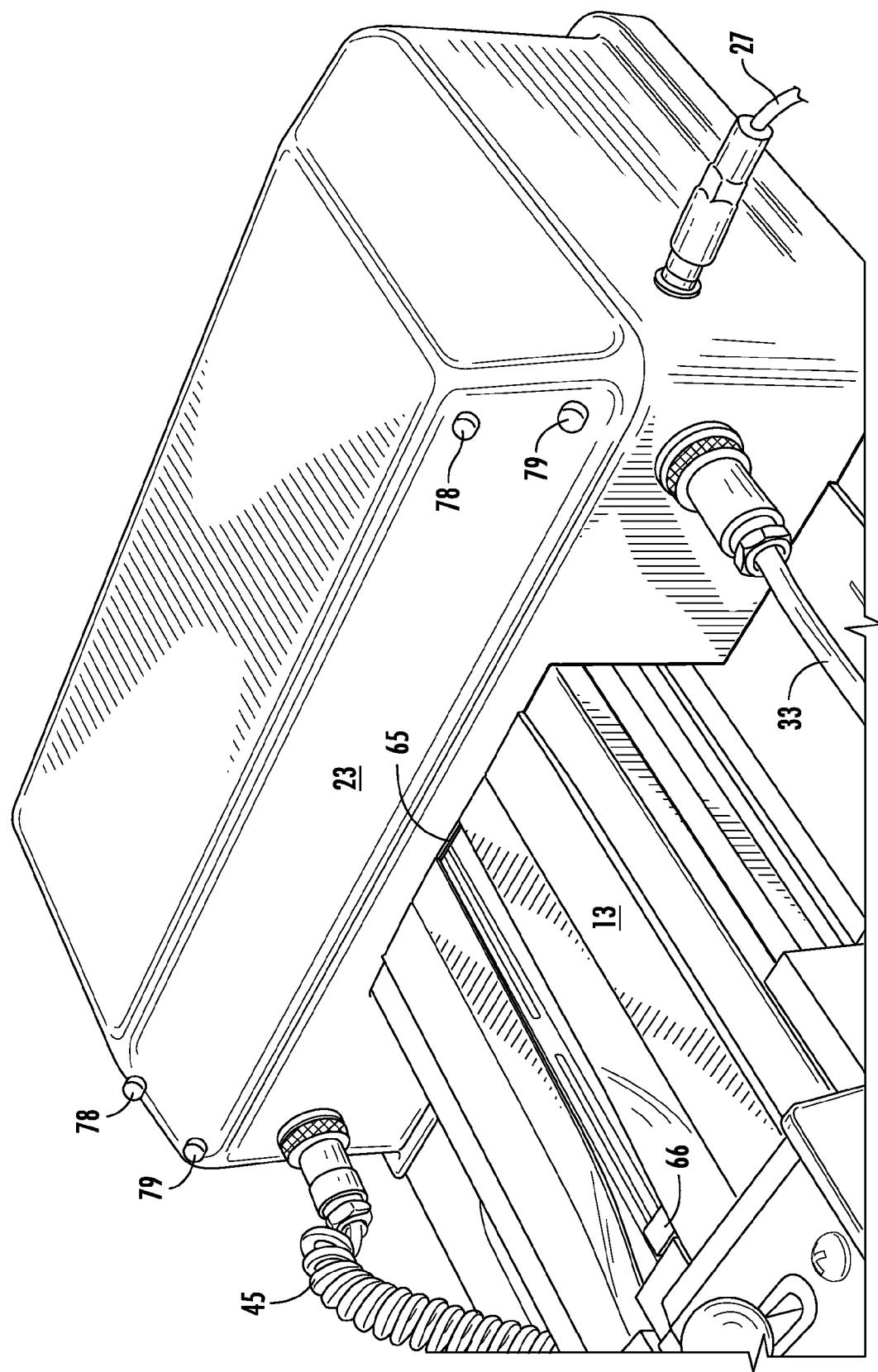


FIG. 12

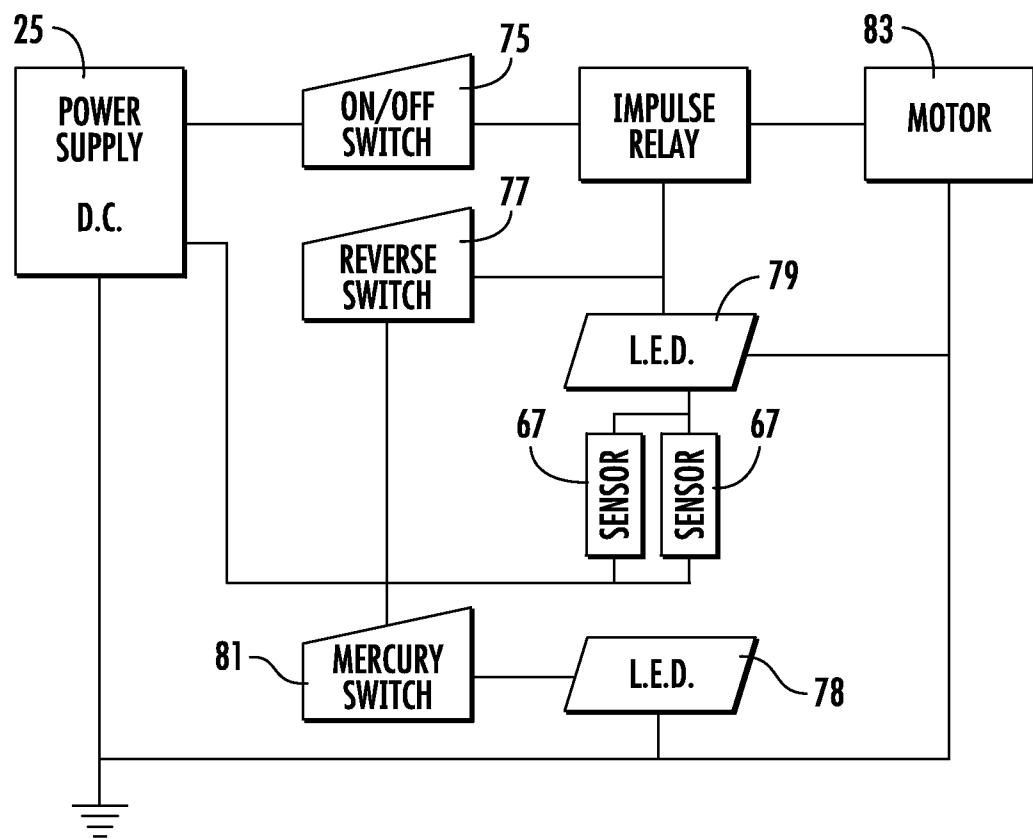
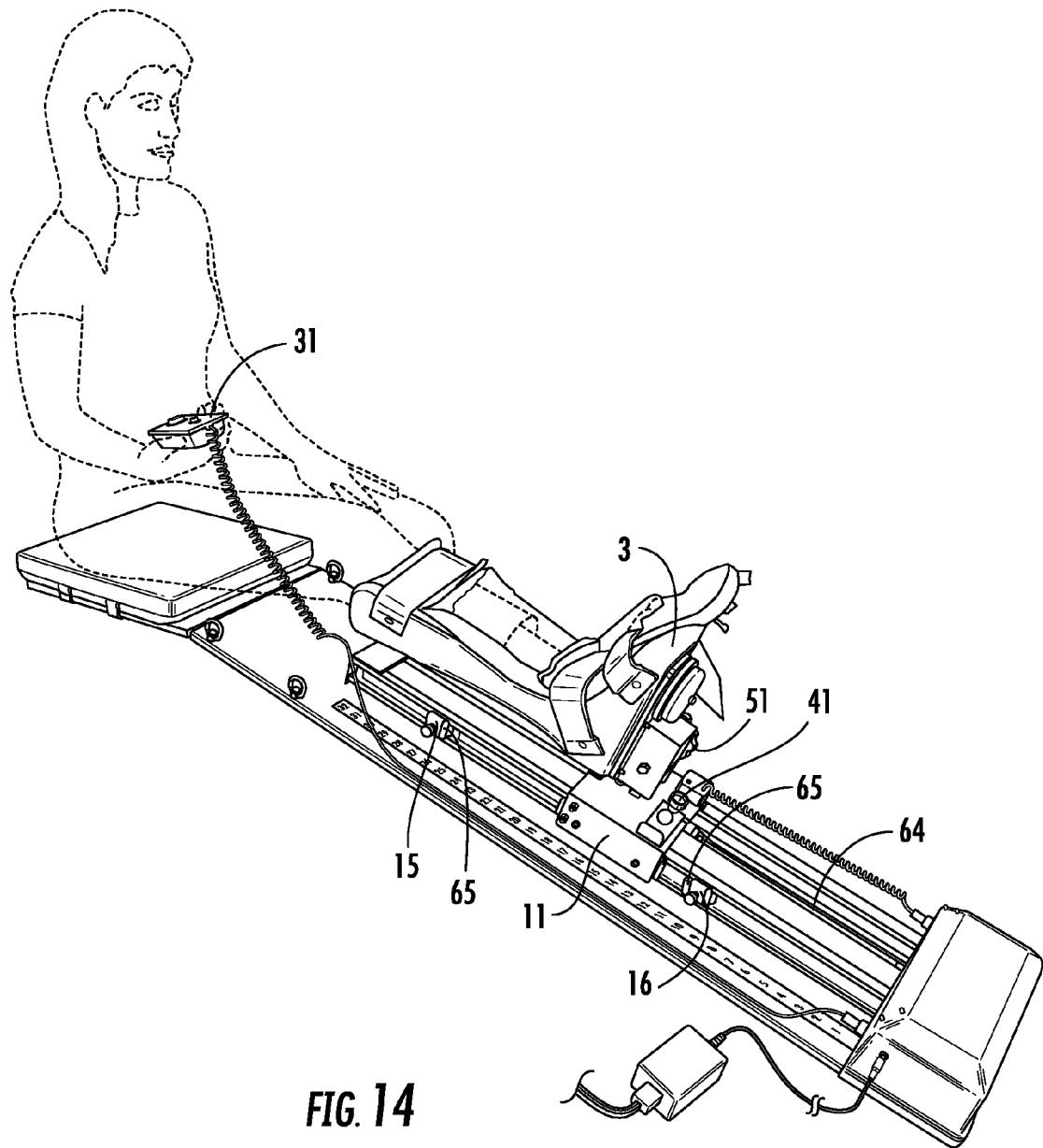


FIG. 13



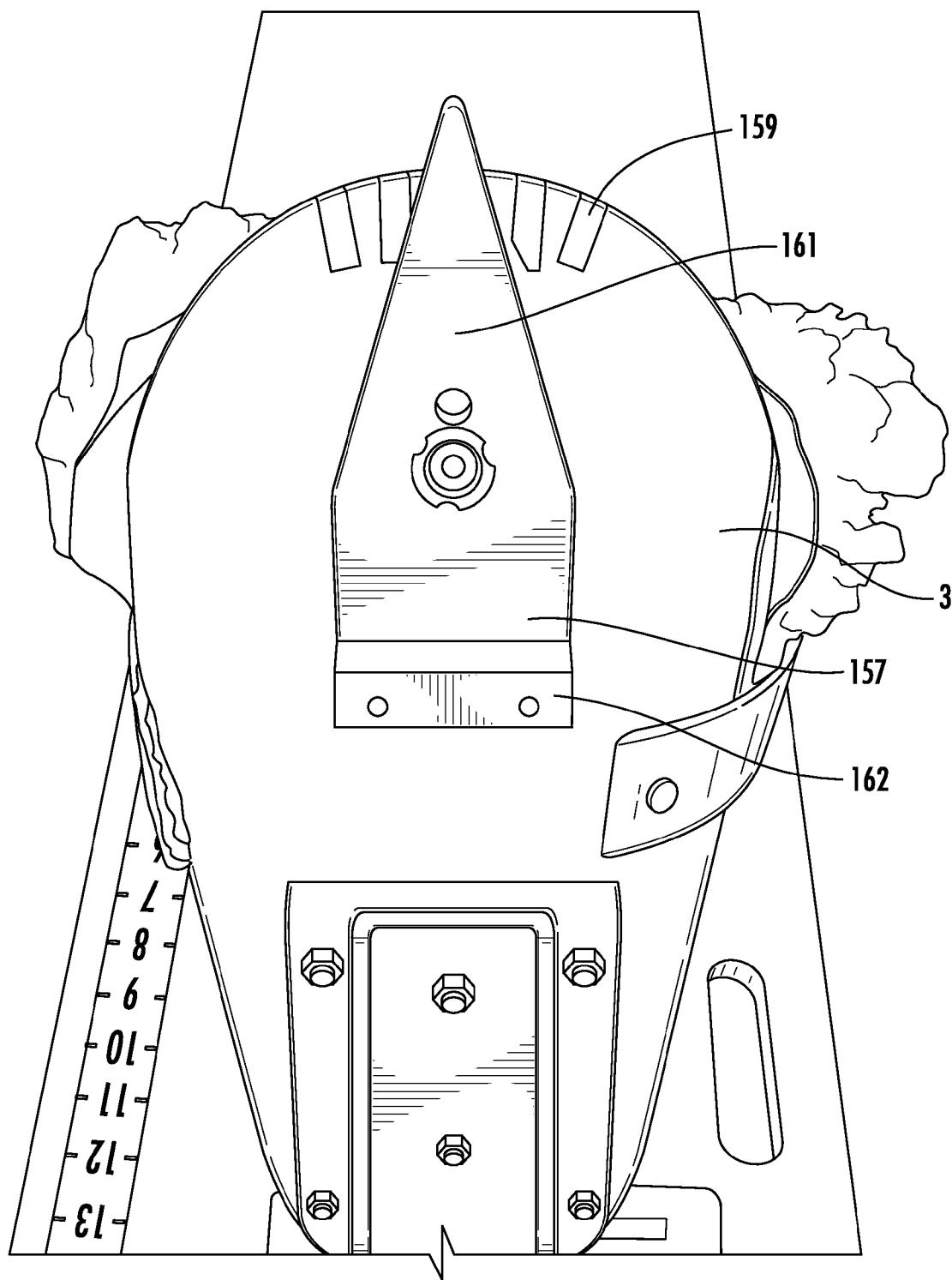


FIG. 15

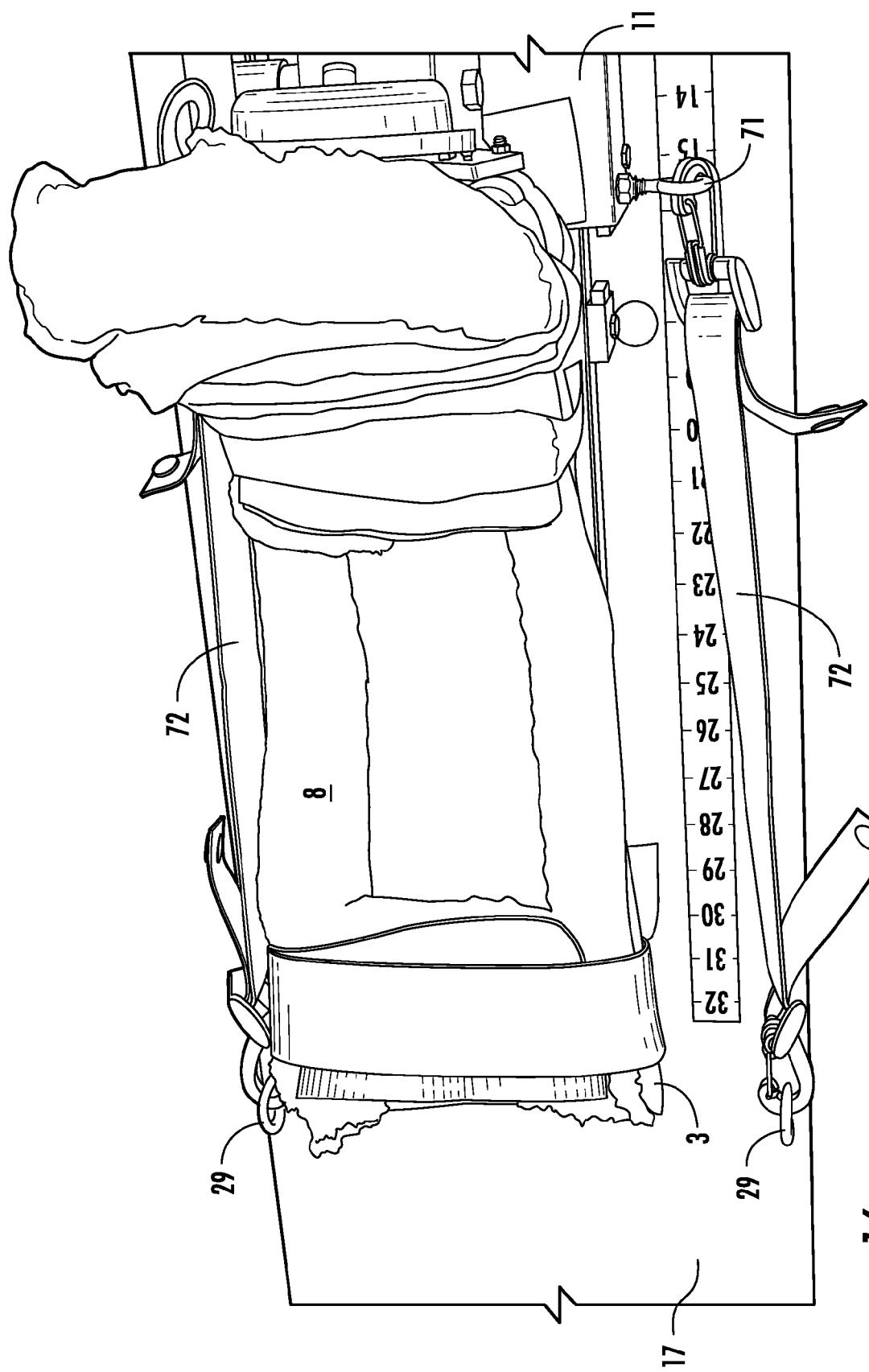


FIG. 16

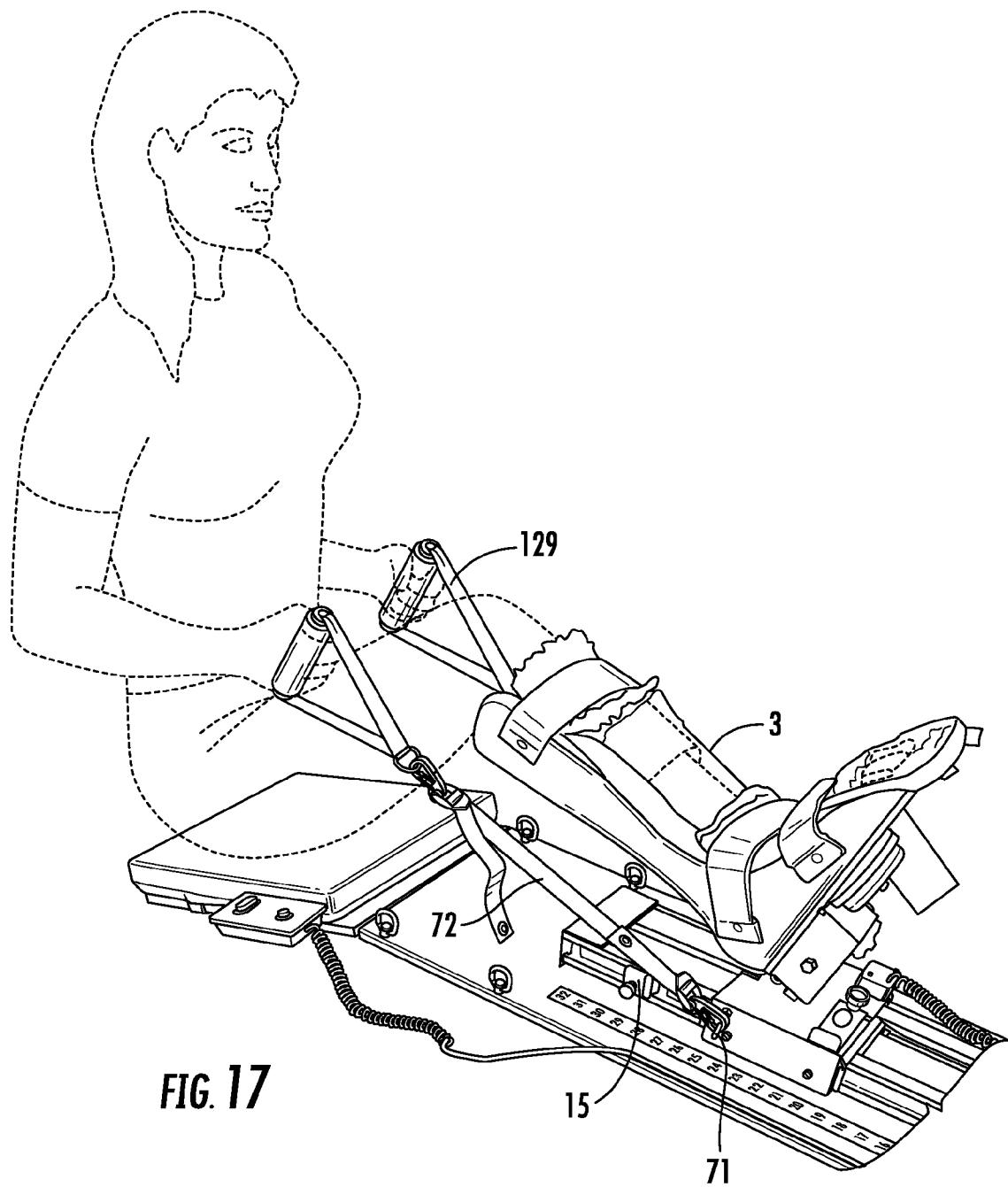


FIG. 17

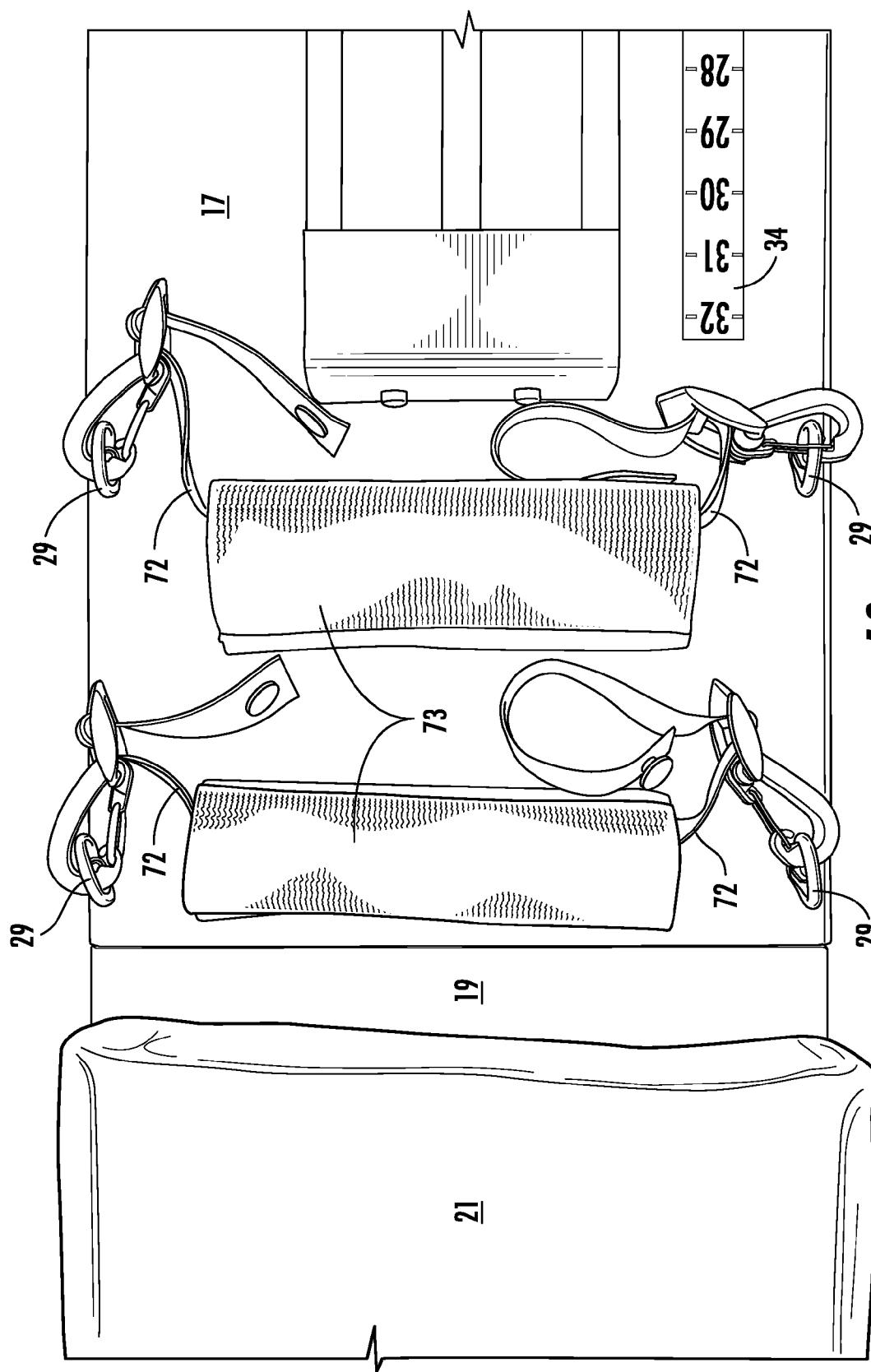


FIG. 18

1
ORTHOSIS MACHINE

BACKGROUND AND SUMMARY

The present invention relates to apparatus and methods for an orthosis machine, and more particularly, to an orthosis machine which may be used to provide continuous passive motion (CPM) and/or other therapeutic and/or rehabilitative functionalities to a user.

It is often beneficial, following operations that involve treatment of a patient's joints, to use a continuous passive motion machine (CPM) to apply passive movement to the affected joint or joints and associated muscles, to avoid various postoperative problems that may occur if the joint is immobilized. Continuous passive motion devices (CPM's) are generally motor-driven and exercise an affected joint by repeatedly flexing and extending the limb portions on either side of the joint. Often, the CPM will support one or more limb portions as it flexes and extends the affected joint. Conventional CPM's for use on a patient's knee can be found in the literature, for example U.S. Pat. No. 6,221,033 to Blanchard et al., which discloses a continuous passive motion device for providing physical therapy for a knee of a patient.

Conventional CPM's are largely designed for one purpose; to provide passive motion via a drive motor to move the joint through its range of motion and in order to restore or maintain range of motion when the patient is unable to adequately do so independently of their own volition, and are generally limited to passive motion in one plane only, as one phase of the rehabilitation process. However, these conventional CPM's generally lack options for progressive rehabilitation during the full range of the healing process.

In general, a rehabilitation process following hip or knee surgery includes four phases: passive range of motion, active assistive range of motion (AAROM), active range of motion (AROM), and resisted range of motion (RROM). Passive range of motion is performed with essentially little to no effort by the user; the primary forces involved are provided by the machine. Active assistive range of motion (AAROM) is generally performed when the user actively tries to move a joint through muscle contraction but is assisted by some outside force such as a machine, another person, or another part of the patient's body such as, for example, an arm. Active Range of Motion (AROM) may be performed when the user actively moves a joint through the range of motion by their own efforts through muscle contraction. Resisted range of motion/strengthening phase of motion (RROM) may be performed when the user actively moves a joint against a resistance placed against the joint during motion via some resistance device such as an elastic band or weight.

It is also useful for the patient to make use of proprioception, the body's ability to detect motion and spatial awareness, during the healing and/or therapy process. This is especially important due to proprioception often being used by the body for protection of a joint or to guide fine motor movements. Accordingly, proprioception training is important because the human body's motion detection system is employed during proprioception (i.e. the body's ability to determine motion in space and sense movement and joint position). Patients that have undergone injury or surgical intervention often have damaged proprioceptive abilities and/or have lost acuity in a joint because soft tissue and/or joint structures have been damaged.

Conventional CPMs that provide passive joint motion are generally useful only for the passive range of motion phase, and generally do not provide any option for additional rehabilitation phases including AAROM, AROM, or RROM/

strengthening on multiple levels. Likewise, conventional CPM's generally do not provide proprioception training or biofeedback, or provide passive knee extension to restore full motion to a stiff knee.

Additionally, conventional CPM devices generally need to be used on a flat surface and generally require the user to be in a supine or recumbent position as is common in the art. These positions often become very uncomfortable and/or create other physical problems for patients. Accordingly, it would be useful and beneficial to provide a CPM that could operate during multiple phases of recuperation, healing, and/or therapy processes, and allow the patient to use the device while in different positions including being comfortably seated on a chair or bed.

Accordingly, one aspect of the present invention is directed to an orthosis machine for facilitating motion of a user which may comprise a base with a track mounted thereto and a carriage slidably mounted to the track. A cradle may be adapted to hold a portion of a bodily appendage of the user and a rotational joint may be configured to connect the cradle to the carriage, wherein the rotational joint may be adjustable into a first configuration in which the cradle is firstly secured to the carriage preventing rotation of the cradle in at least one plane, and a second configuration in which the cradle may be secondly secured to the carriage allowing rotation of the cradle in more than one plane.

Another aspect of the present invention is directed to an orthosis machine for facilitating motion of a user which may comprise a base with a track mounted thereto and a carriage slidably mounted to the track. A cradle may be adapted to hold a portion of a bodily appendage of the user and may be detachably connectable to a drive train. The drive train may be operable by a motor such that the drive train moves the carriage along the track when the drive train is connected to the carriage and the motor is operating. At least one stop may be slidably connected to the track, at least one stop detector may be mounted to the carriage, and electronic circuitry may be configured to reverse the direction when at least one stop detector comes into proximity of at least one stop. An indicator may also be operable to alert the user when the carriage is near at least one stop.

Additionally, one aspect of the present invention is directed to an orthosis machine for facilitating motion of a user which may comprise a base and a track mounted to the base with a carriage slidably mounted to the track. A cradle may be adapted to hold a portion of a bodily appendage of the user. At least one stop may be slidably connected to the track, at least one stop detector may be mounted to the carriage and an indicator may be operable to alert the user when the carriage is near at least one stop.

Another aspect of the present invention is directed to an orthosis machine for facilitating motion of a user which may include a base having an upper baseplate rotatably connected to the base and a track mounted to the base. A carriage may be slidably mounted to the track and a cradle may be adapted to hold a portion of a bodily appendage of the user. A drive train may also be detachably connectable to the carriage and operable by a motor such that the drive train moves the carriage along the track when the drive train is connected to the carriage and the motor is operating.

Additionally, one aspect of the invention is directed to an orthosis machine for facilitating motion of a user comprising a base having at least one attachment portion mounted thereto and a track mounted to the base. A carriage may be slidably mounted to the track and the carriage may have at least one attachment portion mounted thereto. A cradle may be adapted

to hold a portion of a bodily appendage of the user and at least one strap may be secured to at least one attachment portion.

Another aspect of the present invention includes a method of facilitating motion in a seated position on an orthosis machine. The method includes resting on an upper baseplate in a seated position, placing a lower extremity into a cradle positioned below the upper baseplate, and moving the cradle such that the lower extremity changes orientation.

These and other features and characteristics of the present invention, as well as the methods of operation and functions of the related elements of structures and the combination of parts and economies of manufacture, will become more apparent upon consideration of the following description and the appended claims with reference to the accompanying drawings, all of which form a part of this specification, wherein like reference numerals designate corresponding parts in the various figures. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only and are not intended to unduly limit the present invention. As used in the specification and the claims, the singular form of "a", "an", and "the" include plural referents unless the context clearly dictates otherwise.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of an orthosis machine according to an exemplary embodiment of the invention;

FIG. 2 is a perspective view of an orthosis machine according to an exemplary embodiment of the invention, viewed from below;

FIG. 3 is a partial perspective view of an orthosis machine according to an exemplary embodiment of the invention, including the area of the proprioception joint;

FIG. 4 is a partial perspective view of an orthosis machine according to an exemplary embodiment of the invention, including the area of the carriage, the proprioception joint, and the lower appendage cradle;

FIG. 5 is a partial perspective view of an orthosis machine according to an exemplary embodiment of the invention, showing a close-up of the proprioception joint;

FIG. 6 is a partial perspective view illustrating a disassembled portion of the proprioception joint according to an exemplary embodiment of the invention;

FIG. 7 is a partial perspective view of an orthosis machine according to an exemplary embodiment of the invention, showing the area of one of the stops and opposing stop detector on the carriage;

FIG. 8 is an exploded perspective view of portions of an orthosis machine according to an exemplary embodiment of the invention;

FIG. 9 is a partial perspective view of an orthosis machine according to an exemplary embodiment of the invention, showing portions of the invention including the area of the carriage, track, and stops;

FIG. 10 is a partial perspective view of an orthosis machine according to an exemplary embodiment of the invention, viewed from above;

FIG. 11A shows a remote control unit in an orthosis machine according to an exemplary embodiment of the invention;

FIG. 11B is a partial perspective view of an orthosis machine according to an exemplary embodiment of the invention, illustrating a possible configuration for connecting the control cord with the motor compartment;

FIG. 12 is a partial perspective view of an orthosis machine according to an exemplary embodiment of the invention, showing the area of the motor compartment;

FIG. 13 illustrates an electronic circuit schematic showing the power supply and motor section of an orthosis machine according to an exemplary embodiment of the invention;

FIG. 14 is a perspective view illustrating user-controlled selectively motorized use of an orthosis machine from a seated position according to an exemplary embodiment of the invention;

FIG. 15 illustrates a possible embodiment for a rotational position indicator;

FIG. 16 is a partial perspective view, including the lower appendage cradle and straps, of an orthosis machine according to an exemplary embodiment of the invention;

FIG. 17 is a partial perspective view illustrating the lower appendage cradle and straps with grips of an orthosis machine being employed in a seated position according to an exemplary embodiment of the invention; and

FIG. 18 is a partial perspective view of an orthosis machine according to an exemplary embodiment of the invention, showing restraining/resistance straps and pads.

DETAILED DESCRIPTION

The following detailed description is of the best currently contemplated modes of carrying out exemplary embodiments of the invention. The description is not to be taken in an unduly limiting sense, but is made merely for the purpose of illustrating the general principles of the invention, since the scope of the invention is defined by the appended claims.

Various inventive features are described below that may each be used independently of one another or in combination with other features. It should be understood that the invention may assume various alternative variations and/or sequences, except where expressly specified to the contrary. It should be understood that the term "orthosis machine" when referring to embodiments of the claimed invention refers to a device that can be used generally as a CPM machine but that also may have enhanced functions including other modes of rehabilitation/exercise as described further herein.

For purposes of the description hereinafter, the terms "upper", "lower", "right", "left", "vertical", "horizontal", "top", "bottom", "lateral", "longitudinal" and derivatives thereof shall relate to the invention as it is oriented in the drawing figures. It is also to be understood that the specific devices and processes illustrated in the attached drawings, and described in the following specification, are simply exemplary embodiments of the invention. Hence, specific dimensions and other physical characteristics related to the embodiments disclosed herein are not to be considered as unduly limiting.

With reference to FIGS. 1-8, an exemplary embodiment of a knee and hip orthosis machine 1 includes a lower appendage cradle 3 that may be furnished with a shin strap 5, foot straps 7, and/or a supportive cushion 8. The lower appendage cradle 3 may be connected via a rotational joint 9 to a carriage 11.

The carriage 11 may be slidably mounted to a track 13. Upper stops 15 and lower stops 16 may be slidably mounted to either side of the track 13. The track 13 may further be mounted to a base 17. The base 17 may be rotatably or hingedly connected to an upper baseplate 19, for example by a hinge 20

which may be located beneath the base 17 the upper baseplate 19. Friction portions 18 may also be positioned beneath base 17 and/or upper baseplate 19 to prevent slippage of the orthosis machine 1 and/or provide an attachment area for materials requiring frictional engagement such as Velcro®, for example. A seat pad 21 may be releasably mounted to the upper baseplate 19 via attachment extensions 22. A motor compartment 23 may be mounted to the base 17 and con-

nected to a power supply 25 via a power cord 27. Multiple attachments 29 may be mounted to the base 17. A remote control unit 31 may be connected to circuitry in the motor compartment 23 via a control cord 33. A positioning gauge 34 may be mounted on the base 17 running alongside the track 13.

With reference to FIG. 3, an engaging plate 35 may be slidably attached to the carriage 11, held in place by a slide screw 37 and a securing screw 39 and configured to slidably engage an engaging knob 41. The engaging plate 35 is shown as a linearly slidable mechanism, although other engagement mechanisms may be used such as, for example, a gate latch or other device such that carriage 11 may engage and disengage the belt 64. Engaging knob 41 may further be adjustably engaged to a drive anchor 63 via attachment aperture 42. A communication port 43 may be secured to the carriage 11 providing a connection for a communication cord 45, preferably, but not necessarily, a coiled cord that may communicatively connect the communication port 43 with the circuitry in the motor compartment 23, as may be seen in FIG. 10. A joint 47 may be mounted to the carriage 11 which may include a socket portion that surrounds at least a portion of ball 48 near the center of the rotational joint 9 within a joint housing 49. A tightening knob 51 may be mounted to one end of a shaft or bolt 52 that may extend through the joint housing 49 to assist in tightening and/or loosening a bushing 53 operable to secure and/or loosen the rotational joint 9.

FIGS. 4 and 10 show the lower appendage cradle 3 with the joint housing 49 mounted to the underside of the lower appendage cradle 3. A housing 55 may include a proprioception-related gauging such as, for example, a gravity-operable mercury switch (not shown) that may be rotatably mounted to the underside of the lower appendage cradle 3 within the housing 55. The mercury switch may communicate via a switch indication wire 56 to the communication port 43. A circular scale ring 57 may further be positioned between the housing 55 and the lower appendage cradle 3, and may have angle indicator markings 59 inscribed upon it. The housing 55 may have a rotational position marker 61 inscribed upon it. In other possible embodiments other types of rotational position markers may be used, a pointer for instance, as shown in FIG. 15 and discussed further hereinbelow.

FIG. 4 further shows a drive anchor 63 that may be connected to a drive belt 64. The drive anchor 63 may be fitted to screwably receive and secure the engaging knob 41 via attachment aperture 42 to allow the drive belt 64 to operate the lower appendage cradle 3. See FIGS. 10, 12. Further, drive anchor 63 and/or drive belt 64 may have a drive stop detector 66 mounted thereon and in communication with motor 83 via communication cord 45. One or more handles 6 may also be formed in the base 17.

FIG. 5 provide a close-up view of the rotational joint 9, including the joint shaft 47, ball 48, joint housing 49, bolt 52 and bushing 53. FIG. 6 shows a disassembled view to better see the configuration of the ball 48 within the joint shaft 47, and of the bushing 53 that may be secured in place on bolt 52 via tightening knob 51. Accordingly, bolt 52 may be in communication with one or more of tightening knob 52, bushing 53 and ball 48. In addition, one or more nut 46 may be positioned on a threaded bolt 42 to appropriately configure the desired spacial relationship between, for example, the bushing 53, ball 48, and tightening knob 52.

With reference to FIGS. 7, 9, AND 10, the upper and lower stops 15, 16 may be slidably mounted to the track 13 and may be equipped on a side facing the carriage 11 with stop detectors 65. Stop detectors 65 may be electromagnetic, magnetic, RFID, or other sensing technology. Upper and lower stop

detectors 67, 68 may be mounted to either end of one or both sides of the carriage 11 opposite a respective stop detector 65. Alternatively, upper and lower stop detectors 67, 68 may be able to sense stop 15 via infrared or other sensing technology without stop detector 65 as shown in the illustrated embodiment. Further, stop detectors 65 may be able to sense the carriage 11 approaching and affect the position of carriage 11. A stop indication wire 69 may extend under the carriage 11 to connect the stop detectors 67, 68 with the communication port 43.

As shown in FIGS. 7 and 9, the positioning gauge 34 may be placed substantially parallel and close to the portion of the track 13 upon which the stops 15, 16 slide, to better gauge the positions of the stops 15, 16 and/or the stop detectors 65 or stop detectors 67. Attachment portions 71 may be mounted to one or more sides of the carriage 11 for securing straps 72, that may be resistance straps, and/or non-yielding straps with grips 129, as described hereinafter (see FIGS. 14, 16, and 17).

FIG. 8 illustrates the exploded view of the orthosis machine 1, wherein the lower appendage cradle 3 may be rotationally secured to the carriage 11. The carriage 11, and/or components thereof/thereon, may be in communication with the motor 83 within motor housing 23 via communication cord 45. Further, power supply 25 may also be in communication with the motor 83 within the motor housing 23 via power cord 27. The carriage 11 may also be slidably mounted to the track 13. The carriage 11 may also be detachably connectable to a drive train 80 for movement along track 13. As can be seen in FIG. 8, the drive train may include belt 64, drive anchor 63, engaging knob 4 and/or motor 83. Further, drive train 80 may be controlled by a user via remote control unit 31 in communication with motor 83 by way of, for example, control cord 33. Engaging knob 41 may be adjustably or fixedly attached to drive anchor 63 via attachment aperture 42. The track 13 may be mounted to the base 17.

Alternatively, as can be seen in the figures, wireless communication between motor 83 and remote control unit 31 and/or between motor 83 and/or stops/sensors 65, 66, 67, 68 can be employed according to the present invention. Further, in embodiments where the motor 83 is disengaged or otherwise not included in the embodiment at all, communication between one or more stops/sensors 65, 66, 67, 68 and the biofeedback functions may be accomplished via communication cord 45 and/or wirelessly.

FIGS. 11A and 11B illustrate the remote control unit 31 that may include an on-off switch 75 and a motion reversing button 77. The control cord 33 may communicatively connect the remote control unit 31 with the circuitry inside the motor compartment 23.

With reference to FIG. 12, LEDs or other lights of different colors such as, for example, green LEDs 78 and red LEDs 79 may be positioned on either side or both sides of the motor compartment 23. Other colored LEDs 78, 79 and/or indicators may be used within the spirit and scope of the present invention.

FIG. 13 depicts the circuitry of an embodiment of the invention that may be powered by a remote 24 V DC power supply 25, and driven by a 24 VDC reversible motor 83. Other components may include the on-off switch 75 and the motion reversing button 77, LEDs 78, 79, sensors (e.g., the stop detectors) 67, 68, and a mercury switch 81 housed within the housing 55. While in the illustrated exemplary embodiment the power supply 25 may be a direct current (DC) power supply that receives power from an alternating current (AC) power supply such as an electric outlet (not shown) and the power cord 27 may removably plug into circuitry within the motor compartment 23. In other possible embodiments dif-

ferent power source types may be used such as, for example, battery power, and the connection could be made non-removable. Further, other circuitry may be employed in accomplishing the beneficial functionality as outlined in more detail below including circuitry implementing biofeedback functionality only.

Functional Utilization

In an exemplary embodiment of the invention, as shown in the figures in basic operation, the upper baseplate 19 may be hinged 20 to enhance the portability of the device and may further make it easier to move or ship. The hinge of upper baseplate 19 also may permit the exemplary embodiment to be used in a variety of positions, so that the patient may be able to perform most or all of the therapy from a seated, supine, or recumbent position. For example, the upper baseplate 19 could be placed on a chair and the patient could sit on the seat pad 21. As shown in FIG. 2, for example, a full-length hinge may be employed to allow the hinged upper baseplate 19 to move as much as 180° in a downward direction so that it folds back against the base 17. The upper baseplate 19 could be also parallel with the base 17 forming a flat surface for use when the patient is recumbent.

In an exemplary embodiment, a user may position stops 15 by sliding one or more of them along the track 13 and secure them in place. Accordingly stops 15 may then define the motion range of the carriage 11 and lower appendage cradle 3, as may be recommended by a physician or physical therapist. The user may then position themselves on the seat cushion 21 and place their lower leg within the lower appendage cradle 3. The user's lower leg may then be secured by one or more foot straps 7 and/or one or more shin straps 5, wherein the user's foot may rest upon the optional supportive cushion 8 positioned within the lower appendage cradle 3.

The user may then operate the orthosis machine 1 by picking up the remote control unit 31. When the on-off switch 75 is turned on, power is supplied from the power supply 25 to the motor 83 within the motor compartment 23 via the power cord 27. When the power is supplied to the motor 83, the carriage 11 may move along the track 13 via drive belt 64 carrying the attached lower appendage cradle 3 with it and thereby moving the patient's foot and providing therapy for the patient's joint being treated. When the carriage 11 moves far enough so that at least one of the stop detectors 67, 68 on either side of the carriage 11 comes into contact and/or close proximity with the stop detector 65 of the stop 15 on that side of the carriage 11, a signal may pass through the stop indication wire 69 to the communication port 43. From communication port 43, the signal may then pass through the communication cord 45 to the circuitry in the motor compartment 23 to cause the drive belt 64 to reverse direction. Accordingly, while the carriage 11 is engaged by way of drive anchor 63 to the drive belt 64, the lower appendage cradle 3, and thus the patient's foot, will reverse direction as the drive belt 64 reverses direction.

FIG. 14 shows a patient (shown in shadow) using the device with manual control. In this figure the user is shown in a sitting position and holding the remote control unit 31. In this configuration the carriage 11 (and accordingly the lower appendage cradle 3 due to engagement with belt 64 via engaging knob 41) will be moved by operation of the motor 83 between the desired positions dictated by the selected positions of the upper stop 15 and the lower stop 16. With reference to FIG. 11A, with the remote control unit 31 the user may manually control the motor 83 on and off with the on-off switch 75 and reverse direction of the carriage with the motion reversing button 77. With the range of motion shown in FIG. 1, for example, with the tightening knob 51 secured,

the lower appendage cradle 3 may rotate about at least one vertical axis running the length of the track 13. The tightening knob 51 may also be loosened so that the lower appendage cradle 3 will be able to rotate more freely, allowing the user to bend the knee while being able to rotate the ankle with greater range of motion about the rotational joint 9. The upper stop 15 and the lower stop 16 could be positioned closer together for a smaller range of motion in order to provide limited flexion-bending of the joint area for controlled bending of the knee. In addition, the upper and lower stops 15, 16 may be configured to be selectively positioned along track 13 so as to not be able to be overcome by the driving force of the motor 83 in the event stops 65, 67, 68 might fail.

Additionally, a biofeedback indicator function may be provided by this feature by alerting the user when the carriage is in a certain position or positions. Biofeedback allows a user to set goals for range of motion with feedback (e.g. light, audible, tactile, etc.) when the goal is met such as with bending or straightening. Accordingly, as the carriage 11 may approach one or more of the stops 15, 16, an electronic signal may be sent and one or more of the LEDs 78, 79 may be lit, for example the red LEDs 79, thereby alerting the user that a motion goal has been met, or that a change of direction should be made. In other possible embodiments an audible or even tactile signal could be used in place of, or in addition to, the LEDs or other light as shown in FIG. 13. The stopping point of the carriage 11 may be stationary in some embodiments, or in other embodiments may be made adjustable by manipulating the position of the stops 15. Or, as explained above, the stops 15 may also be used to change the direction of the carriage 11 automatically. Other modes of biofeedback using varied modes for providing light, audible or vibration indications to a user may be implemented in accordance with the spirit and scope of the invention.

Unlike conventional CPM machines, which generally do not provide proprioception or biofeedback training mechanisms, passive knee extension and/or operate from a seated position, embodiments of the orthosis machine 1 disclosed herein, like the exemplary embodiment(s) illustrated in the drawing figures, allow such training to take place.

With reference to FIGS. 3-5, when proprioception training is desired, the tightening knob 51 may be manipulated to allow the ball 48 to rotate within the joint 47 by permitting the bushing 53 to loosen from engagement with the joint 47. When the proprioception training is not desired, the tightening knob 51 is generally manipulated to push the bushing 53 against the joint 47, which straightens joint housing 49 and thus the lower appendage cradle 3 with respect to the carriage 11, keeping the user's foot aligned with the track 13 and preventing side-to-side motion. But when the tightening knob 51 is manipulated to loosen the ball 48, the lower appendage cradle is permitted to swivel within the joint 47 socket, allowing side-to-side motion during use by the user.

FIGS. 5 and 6 help to illustrate how this is accomplished. In particular, FIG. 6 gives a disassembled view showing the internal structure of the assembly comprising the joint shaft 47, the ball 48, and the bushing 53. From these figures it can be seen how when the tightening knob 51 is tightened the flat side of the bushing 53 is pushed securely against the opposing flat side of the joint shaft 47, thus keeping the joint shaft 47 rigid in its position. But when the tightening knob 51 is loosened the flat side of the bushing 53 is pulled away somewhat from the opposing flat side of the joint shaft 47, which allows the joint shaft 47, via the ball 48 within it, to rotate and move within a sculpted recess within the bushing 53. Accordingly, in the illustrated exemplary embodiment, such loosening of the bushing 53 from the joint 47 may allow the patient's

lower leg and foot to pivot left or right (i.e., about the axial plane of the patient's lower leg).

Further, by operation of the tightening knob 51 to release the lower appendage cradle 3 from a secured position, the patient's foot may be permitted to rotate up and down toward the motor housing 23. As used herein, the term "rotatively attached" refers to allowing this side-to-side motion, up/down pivoting, and/or left/right rotation of the lower appendage cradle 3 to be performed by the patient.

Thus it can be seen that the exemplary embodiment illustrated herein that the orthosis machine 1 of the present invention allows side-to-side as well as front-to-back motion of the lower leg and foot of the patient, thereby providing the possibility of movement in multiple planes simultaneously. This allows proprioception training to occur during use of the orthosis machine 1 when the tightening knob 51 is loosened. Accordingly, the purposely created instability created by the joint 47 and ball 48, allows simultaneous multiple-plane movement allowing patients to engage their neurological proprioception receptors in an effort to stabilize one or more joints. Further, the rotational joint 9 can be adjusted, via the tightening knob 51 for example, to allow more or less movement to occur giving the patient control of range of rotation the joint and limb may undergo during therapy and/or training.

This proprioception training may occur during all phases of the therapy: passive range of motion, active assistive range of motion, active range of motion, and resistive range of motion thus better allowing the patient to learn to control the muscular functions of the joint for which therapy is being provided. Accordingly, the orthosis machine 1 may allow the patient to train and enhance proprioception in the joint, and/or work on strengthening the knee and surrounding muscles, should that be necessary, as the tightening knob 51 can be either loosened or tightened as described herein so that the therapy can be performed either with or without proprioception during any of the phases.

With regards to providing a patient with more specific goals to achieve desired outcomes, the proprioception function may be used to allow the patient to practice keeping his foot at a certain desired angle. Such functionality may be accomplished by employing one or more mercury switches 81, which may be positioned within the housing 55. As may be prescribed or suggested for therapy, the patient may be instructed as to the length of time and rotational goals of the lower appendage cradle that may be further established by the rotation of the rotational position marker 61. Accordingly, when the rotational position marker 61 is set by the patient to a setting indicated on the circular scale ring 57 and the lower appendage cradle 3 is rotated to the left or the right by the patient to match that setting, the one or more mercury switches 81 may send a signal to the LEDs 78, 79 via the switch indication wire 56 to alert the patient that they have reached the indication angle set on the circular scale ring 57. Thus, when the patient's leg and foot is held in place at the correct angle, the one or more mercury switches 81 may send an indication via the switch indication wire 56, communication port 43, and communication cord 45, to light one or more of the LEDs on the motor compartment 23, for example the green LEDs 78, thereby providing biofeedback indication to the patient that the foot/leg is being held in the correct position. Having LEDs 78, 79 on either sides of the motor compartment 23 can be beneficial in case the position of the foot, at whatever angle it is being held, obscures one or more of the LEDs 78, 79 on one side.

In the illustrated exemplary embodiment, the proprioception functionality may be attached to the lower appendage

cradle 3 as a rotational gauge type mechanism with incremental markings on the circular scale ring 57 that are utilized to set targets or markers for the patient to attempt to control motion, as described above. However, various other types of motion control means can be used as well as described herein.

Other embodiments may include, as illustrated in FIG. 15 for instance, an angular gauge assembly 157 rotatably attached to the lower appendage cradle 3, for example (as shown in FIG. 6) on the underside of the lower appendage 10 cradle 3. The angular gauge assembly 157 may include a pointer 161 and a plumb weight 162, with the pointer 161 projecting toward an angular scale 159 on the lower appendage 15 cradle 3 that indicates the rotational angle achieved by the rotation of the foot by the user. Pointer 161 may be configured to be various shapes and/or opaque, translucent or otherwise illuminated such that the patient may adequately observe where the pointer is directed based upon the articulation of the patient leg. Such scale 159 provides a target for alignment of the user during proprioception related use of the orthosis 20 machine 1. The plumb weight 162 will normally be positioned toward the bottom of the positioning gauge assembly 157 so that gravity will cause the pointer 161 to rotate relative to the angular scale 159 as the lower appendage cradle 3 is rotated. Both the pointer 161 and the angular scale 159 may 25 preferably be visible from both sides of the bottom of the lower appendage cradle 3, so that both the patient and an assistant on the other side of the device may visualize where on the angular scale 159 the pointer 161 is pointing.

Unlike conventional CPM machines, various phases of 30 therapy may be accomplished with embodiments of the orthosis machine 1 of the present invention described herein. For example, for the passive motion phase the apparatus may be used in the basic mode described above, with the carriage 11 moved automatically up and down along the track 13 over a prescribed range as set by the stops 15, 16 and operational 35 by the remote control unit 31. The leg may further be held down into a straightened or extended position by the restraining pads 73 secured either with elastic resistance straps 72, or non-yielding straps 72, to attachment portions 29. Thus, passive knee extension can be facilitated between flexion training sessions to permit the leg to be pushed into extension or straightened.

Active Range of Motion (AROM) may be performed with 40 this device, such that the patient may be enable to use his/her volitional muscle contractions to move the carriage with the desired range of travel on the track 13. The carriage 3 may 45 thus assist in stabilizing the patient's hip, leg, knee and/or ankle as the surrounding muscles are strengthened and/or treated via the orthosis machine 1. AROM may thus be performed, for example, with the power turned off, the engaging knob 41 and/or slide screw 37 loosened, and the engaging plate 35 slid back from the engaging knob 41. Thus, the carriage 11 may be operated by the patient along the track 13 without being restricted by the drive belt 64 engaged with the 50 powered off motor 83. Further, in accordance with the present invention, in the event the patient does turn on the motor 83 while the carriage 11 is disconnected, one or more stop detectors 65 may be positioned to engage at least one drive stop detector 66 to prevent damage to the orthosis machine 1. Accordingly, at least one stop detector 65 may prevent over 55 rotation of the belt 64 clockwise while another stop detector 65 may prevent over rotation of the belt 64 counterclockwise.

As can be seen in FIG. 16, various straps 72 may be implemented to provide for Resistive Range of Motion (RROM). 60 Accordingly, straps 72 made permanently mounted or detachable from attachments 29, 71 for convenience while using the orthosis machine 1 in various modes. Straps 72 may

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be elastic, adjustable, interchangeable, vary in thickness and/or length to provide desired resistance. Accordingly, the force required to translate the carriage 11 up and/or down the track may be adjusted. In a preferred embodiment, the carriage 11 may be released from the drive belt 64 by disengaging knob 41, while the remote control unit 31 and the control cord 33 are optionally detached and removed from the motor compartment 23, to enable the patient to move the carriage 11 up and down the track 13 against the force of the straps 72. For further ease of use, the power cord 27 may also be detached and removed from the motor compartment 23 as well to avoid possible entanglements with the straps 72.

Various other ways of providing resistance during resisted range of motion (RROM)/strengthening phases of therapy using exemplary embodiments of the orthosis machine 1 of the present invention are also possible. For instance, resistance straps 72 may secure the restraining pads 73 to the attachments 29 to provide resistance against the leg while bending the knee, and to provide resistance while pulling the foot toward the body. Conversely, additional and/or other resistance straps 72 can be connected between one or more attachments 29 mounted to the base 17 and one or more attachments 71 mounted to the carriage 3, to provide varied desired resistance while the patient pushes the foot away from the body as described above. In addition, proprioception training may be accomplished in this phase, as well as others, by disengaging knob 51 to a desired range of motion.

FIG. 17 illustrates another possible configuration, wherein straps 72 may be connected between grips 129 and the attachments 71 of the carriage 11, giving the patient physical control over the travel of the foot in the cradle 3 along the track 13 for accomplishing the Active Assisted Range of Motion (AAROM) phase. AAROM may thus be performed with the orthosis machine 1, through the patient manually self guiding the effort along and thus assisting the joint in a predictable path with the motor 83 preferably disengaged. Accordingly, AAROM phase treatment may allow the patient to manually assist and thus guide the limits of the range of motion to both directions. In some cases, extending beyond the end range may be encouraged to gain more motion as part of the rehabilitative process that may be guided by the patient supporting the cradle 3 via grips 129 and straps 72. Stops 15, 16 may also be positioned as a fail-safe in the event the patient loses grip or strength to actively assist in controlling the range of motion.

FIG. 18 illustrates another possible configuration, wherein, restraining pads 73 may be secured by resistance straps 72 to the attachments 29 at a position near seat pad 21. In this configuration, resistance could be provided by providing resistance against the patient's thigh rising during bending of the joint. Accordingly, at least a three point pressure system may be provided with the present invention to encourage the patient's leg to straighten. These points of pressure may include the heel area, below the kneecap and the thigh. Such treatment is often necessary following knee surgery to regain full range of motion. This configuration may allow the patient to apply pressure into extension while having the leg being biased to straighten by restraining pads 73 and resistance straps 72. Accordingly, straps 72 of varying pressure grades based on the amount of resistance needed can be used to push the knee straight.

With reference to FIG. 13, the circuitry of an illustrated exemplary embodiment allows for several different functions. With reference to FIG. 11A, the handheld component circuitry allows for a safety-reverse system in which the patient may reverse the motion of the carriage by pushing the motion reversing button 77 and may stop the motion by oper-

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ating the on-off switch 75. The on/off-switch 75 controls power to the motor 83 which drives the drive belt 64 to move the carriage 11. The circuitry may also control the function of the stops 15, stop detectors 65, and stop detectors 67, 68 that affect the proprioception and/or biofeedback indicator function, as described above.

For example, with further reference to FIG. 13, an embodiment of the invention may be powered by a remote 24 V DC power supply 25, and driven by a 24 V DC reversible motor 83. Other components may include the on-off switch 75 and the motion reversing button 77, LEDs 78, 79, sensors (e.g., the stop detectors) 67, and a mercury switch 81 housed within the housing 55. While in the illustrated exemplary embodiment the power supply 25 may be a direct current (DC) power supply that receives power from an alternating current (AC) power supply such as an electric outlet (not shown) and the power cord 27 may removably plug into circuitry within the motor compartment 23, in other possible embodiments different power source types may be used, and the connection could be made non-removable. Further, other circuitry may be employed in accomplishing the beneficial functionality.

Feedback may be provided to the user when the carriage 11 reaches its set range of motion limit via one or more LEDs 78, 79. When the electromagnetic switch/sensor receives a signal, it may be sent to one or more LEDs 78, 79 giving the user biofeedback that the goal has been reached for flexion or extension. The proprioceptive mechanism may use a mercury switch to light one or more LEDs 78, 79 when the user centers the foot piece to a desired positional attitude. One or more LEDs 78, 79 stay illuminated as long as the foot is being held on target as the carriage 11 moves through the range of motion.

As can be seen from the above description, any CPM device utilizing the invention may allow a patient to progress through various phases of the rehabilitation process following an injury or surgical intervention, to a knee or hip joint, for example. Combining one or more of these functions in the same machine will reduce medical cost to the insurer and patient as well as providing consolidation of the various phases of rehabilitation to speed recovery. For example, a patient who has had knee surgery can perform passive range of motion (PROM) early during the recovery process, then progress to active assistive range of motion (AAROM) exercise, thereafter to active range of motion (AROM) exercise, and finally to resistive range of motion (RROM) exercises wherein all of these may be performed from a seated position with proprioception and biofeedback features. Such enabled positioning of the patient may further increase compliance and improve outcomes. In addition, the present invention may exclude features such as the PROM treatment capabilities by removing the power train 80 and features and functions associated therewith such that AAROM, AROM and RROM are the primary features of the orthosis machine 1. Accordingly, the patient would provide all the necessary travel force to translate up and down the track 13 in the cradle 3 therein requiring less power than the PROM/drive train functionalities of the invention.

Although the invention has been described in detail for the purpose of illustration based on what is currently considered to be the most practical and preferred exemplary embodiment(s), it is to be understood that such detail is solely for that purpose and that the invention is not limited to the particular means and structure of the disclosed embodiments, but, on the contrary, is intended to cover modifications and equivalent arrangements that are within the spirit and scope of the appended claims. It is to be understood that the present invention contemplates that, to the extent possible, one or more

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features of any embodiment can be combined with one or more features of any other embodiment. For example, other types of drive trains may be employed beside or in addition to a belt drive such as, for example, a screw drive, rack and pinion, etc. Further, instead of the particular lower appendage cradle of the illustrated exemplary embodiment, a differently shaped cradle that can hold or secure any part of the foot and/or leg and/or hip, or arm, or other bodily appendage, may be used. Since other modifications and changes varied to fit particular operating requirements and environments will be apparent to those skilled in the art, the invention is not considered limited to the example chosen for purposes of disclosure, and covers all changes and modifications which do not constitute departures from the spirit and scope of this invention as set forth by the claims.

We claim:

1. An orthosis machine for facilitating motion of a user, comprising:

- a base;
- a track mounted to the base;
- a carriage slidably mounted to the track;
- a cradle adapted to hold a portion of a bodily appendage of the user; and
- a rotational joint configured to connect the cradle to the carriage, wherein the rotational joint is adjustable into a first configuration in which the rotational joint secures the cradle to the carriage such that the cradle is permitted to rotate with respect to the carriage in at least a first plane of rotation and is prevented from rotating with respect to the carriage in at least a second plane of rotation, and a second configuration in which the rotational joint secures the cradle to the carriage such that the cradle is permitted to rotate with respect to the carriage in at least the first plane of rotation and the second plane of rotation.

2. The orthosis machine of claim 1, further comprising: a drive train detachably connectable to the carriage and operable by a motor such that the drive train moves the carriage along the track when the drive train is connected to the carriage and the motor is operating.

3. The orthosis machine of claim 2, further comprising: a controller in communication with the drive train and operable by a user to select the motion in which the drive train moves the carriage along the track.

4. The orthosis machine of claim 1, wherein the base includes an upper baseplate rotatably connected to the base.

5. The orthosis machine of claim 1, further comprising:

- at least one stop slidably connected to the track; and
- at least one stop detector mounted to the carriage.

6. The orthosis machine of claim 5, including an indicator operable to alert the user when the carriage is near at least one stop.

7. The orthosis machine of claim 2, further comprising:

- at least one stop mounted to one portion of the drive train;
- at least one stop detector mounted to another portion of the drive train; and
- electronic circuitry configured to reverse direction of the drive train when at least one stop detector comes into proximity of at least one stop.

8. The orthosis machine of claim 1, including an indicator operable to alert the user when the cradle is in a desired positional attitude.

9. The orthosis machine of claim 8, wherein the alert of the indicator provided is at least one of visual indicator, an audible sound, and a tactile disturbance.

10. The orthosis machine of claim 8, wherein sensors are positioned on the cradle to communicate with the indicator when the bodily appendage is in a desired positional attitude.

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11. An orthosis machine for facilitating motion of a user, comprising:

- a base;
- a track mounted to the base;
- a carriage slidably mounted to the track;
- a cradle adapted to hold a portion of a bodily appendage of the user;
- a drive train detachably connectable to the carriage and operable by a motor such that the drive train moves the carriage along the track when the drive train is connected to the carriage and the motor is operating;
- at least one stop slidably connected to the track;
- at least one stop detector mounted to the carriage, the at least one stop detector being configured to transmit a signal when the at least one stop detector comes into proximity with the at least one stop;
- electronic circuitry in communication with the at least one stop detector and configured to reverse the direction of the drive train when the at least one stop detector comes into proximity with the at least one stop and transmits the signal; and
- an indicator in communication with the at least one stop detector and operable to alert the user when the at least one stop detector comes into proximity with the at least one stop and transmits the signal, wherein the carriage remains slidably mounted to the track and is movable along the track when the drive train is detached from the carriage.

12. The orthosis machine of claim 11, wherein the base includes an upper baseplate rotatably connected to the base.

13. The orthosis machine of claim 11, wherein the alert of the indicator provided is at least one of visual indicator, an audible sound, and a tactile disturbance.

14. The orthosis machine of claim 11, further comprising a rotational joint configured to connect the cradle to the carriage.

15. The orthosis machine of claim 14, including an indicator operable to alert the user when the cradle is in a desired positional attitude.

16. An orthosis machine for facilitating motion of a user, comprising:

- a base;
- a track mounted to the base;
- a carriage slidably mounted to the track;
- a cradle adapted to hold a portion of a bodily appendage of the user;
- at least one stop slidably connected to the track;
- at least one stop detector mounted to the carriage, the at least one stop detector being configured to transmit a signal when the at least one stop detector comes into proximity with the at least one stop;
- an indicator in communication with the at least one stop detector and operable to alert the user when the at least one stop detector comes into proximity with the at least one stop and transmits the signal; and a drive train detachably connectable to the carriage and operable by a motor such that the drive train moves the carriage along the track when the drive train is connected to the carriage and the motor is operating, wherein the carriage remains slidably mounted to the track and is movable along the track when the drive train is detached from the carriage.

17. The orthosis machine of claim 16, wherein the base includes an upper baseplate rotatably connected to the base.

18. An orthosis machine for facilitating motion of a user, comprising:

- a base having an upper baseplate rotatably connected to the base;

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a track mounted to the base;
a carriage slidably mounted to the track;
a cradle adapted to hold a portion of a bodily appendage of
the user; and
a drive train detachably connectable to the carriage and
operable by a motor such that the drive train moves the
carriage along the track when the drive train is connected
to the carriage and the motor is operating,
wherein the carriage remains slidably mounted to the track
and is movable along the track when the drive train is
detached from the carriage.

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- 19.** An orthosis machine for facilitating motion of a user,
comprising:
a base having at least one attachment portion mounted
thereto;
a track mounted to the base;
a carriage slidably mounted to the track, the carriage hav-
ing at least one attachment portion mounted thereto;

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a cradle adapted to hold a portion of a bodily appendage of
the user;
at least one strap secured to the at least one attachment
portion mounted to the base; and a drive train detachably
connectable to the carriage and operable by a motor such
that the drive train moves the carriage along the track
when the drive train is connected to the carriage and the
motor is operating, wherein the carriage remains slid-
ably mounted to the track and is movable along the track
when the drive train is detached from the carriage.

- 20.** The orthosis machine of claim **19**, wherein the at least
one attachment portion mounted to the base comprises at least
two attachment portions mounted to the base and the at least
one strap is secured to the at least two attachment portions
mounted to the base.

* * * * *



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(54) **REHABILITATION MECHANISM FOR PATIENTS CONFINED TO BED AND BED COMPRISING THE REHABILITATION MECHANISM**

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A63B 22/06 (2006.01)
A63B 24/00 (2006.01)
A63B 21/00 (2006.01)
A63B 21/16 (2006.01)

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(57)

ABSTRACT

The invention relates to a rehabilitation mechanism (30) implemented for planned, automated rehabilitation of at least the joints, muscles, and tendons of the legs (92) of a bedridden patient (90) and comprising at least:

a foot module (40) for operatively connecting to the feet (94) of the bedridden patient (90),
a knee module (50) for operatively connecting to the knee joints (93) of the bedridden patient (90), and
a control module (60) for controlling planned rehabilitation motions of at least the joints, muscles, and tendons of the legs (92) of the bedridden patient (90) by means of the foot (40) and/or knee module (50).

The invention is further characterized in that at least the knee module (50) is implemented as a module for disposing between the patient (90) and the mattress (20) and supported directly or indirectly on a bed (11) or mattress frame (21). The modular design of the rehabilitation mechanism (30) has the advantage that bedridden and particularly intensive-care patients (90) can receive planned, automated rehabilitation directly in the bed (10), wherein said bed can be implemented as a hospital bed, clinical bed, gurney, and/or intensive-care bed, without requiring high-risk transfer between beds and/or the ability to cooperatively contribute.

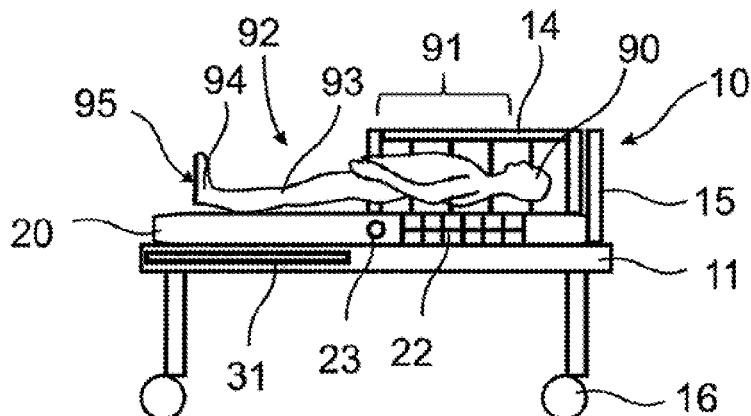


Fig. 1

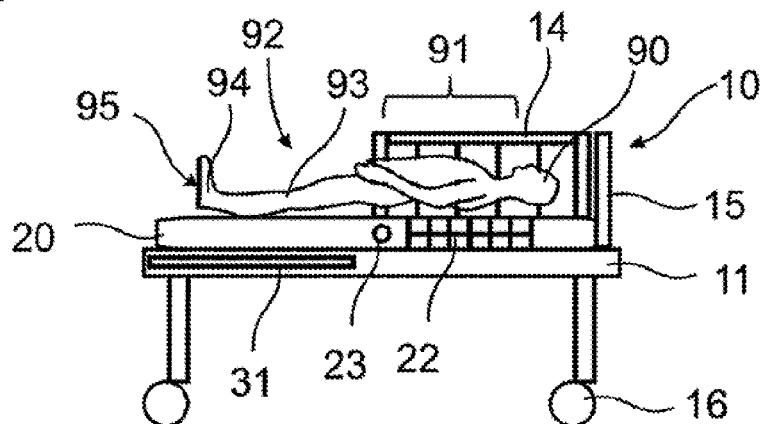


Fig. 2

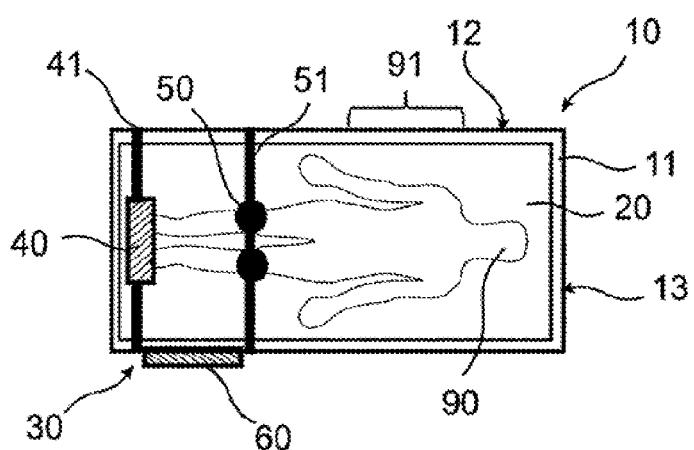


Fig. 3

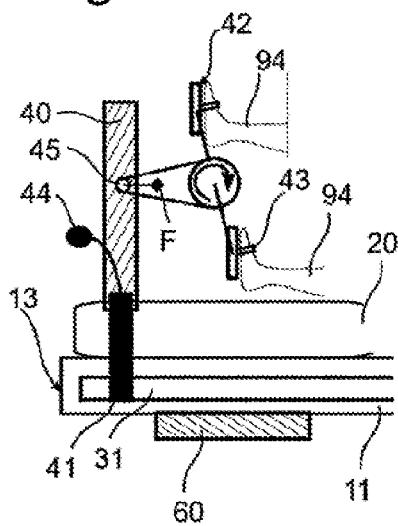


Fig. 4

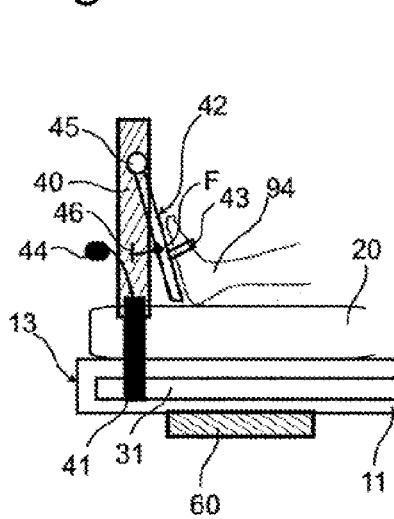


Fig. 5a

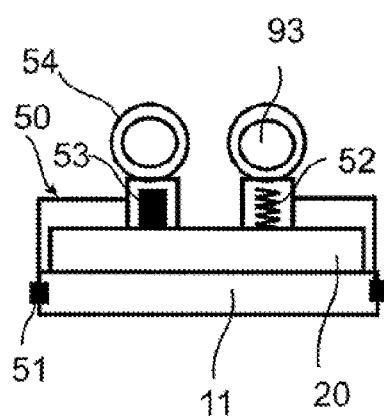


Fig. 5b

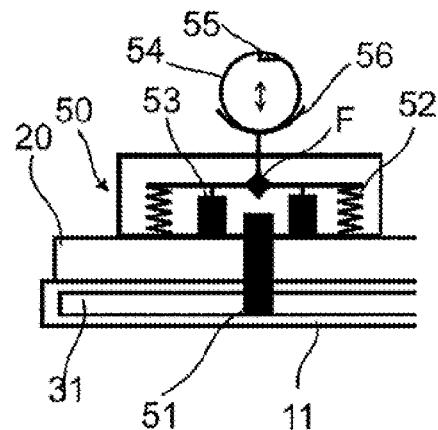


Fig. 6

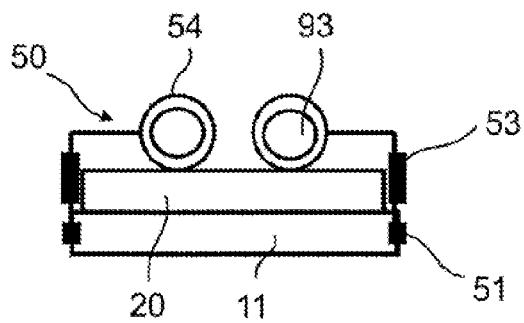


Fig. 7

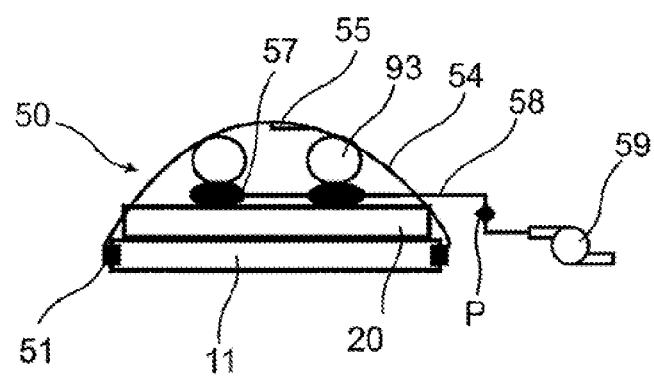


Fig. 8

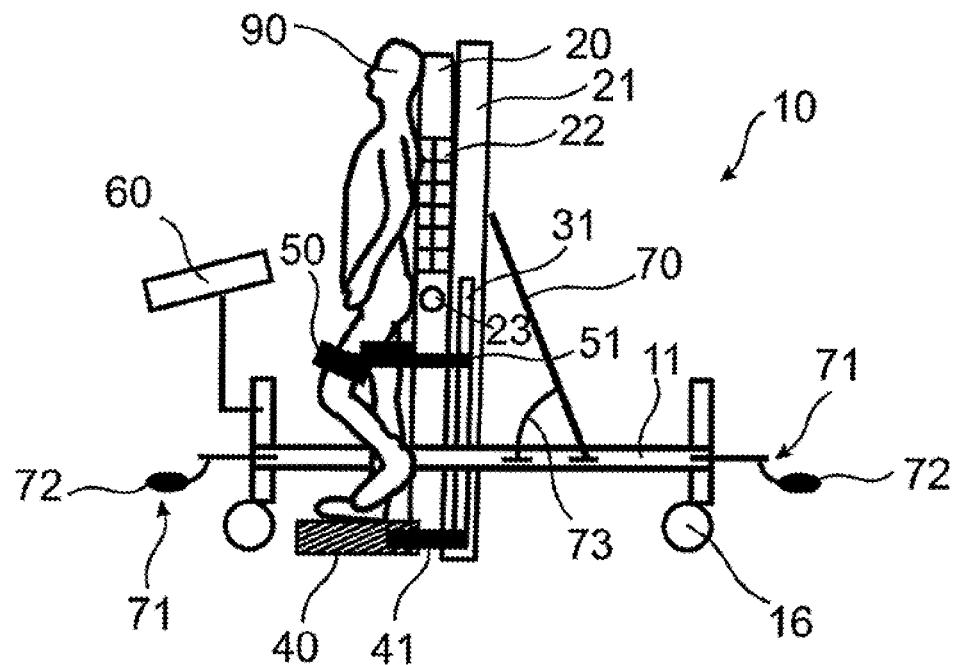


Fig. 9

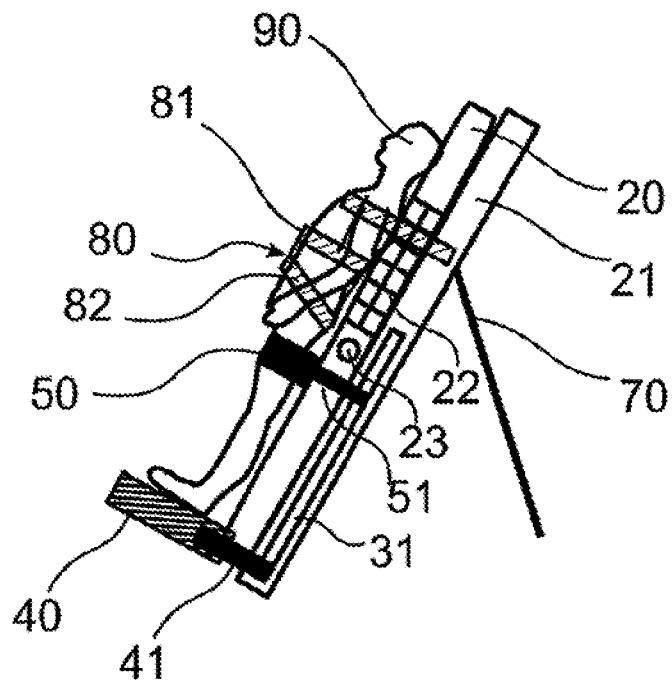


Fig. 10

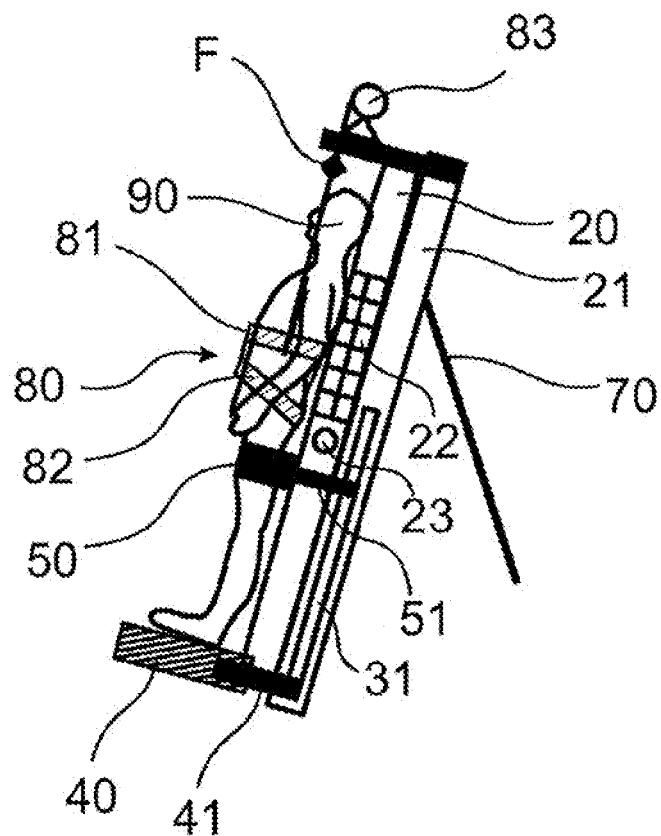
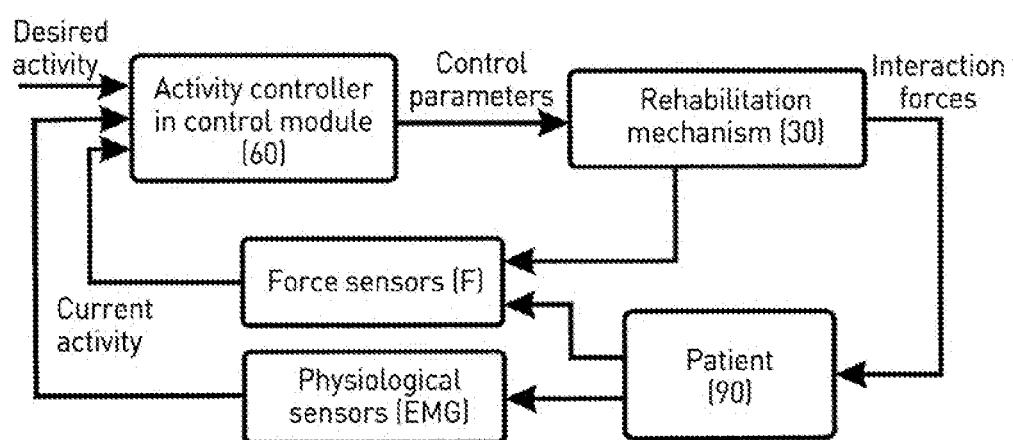


Fig. 11



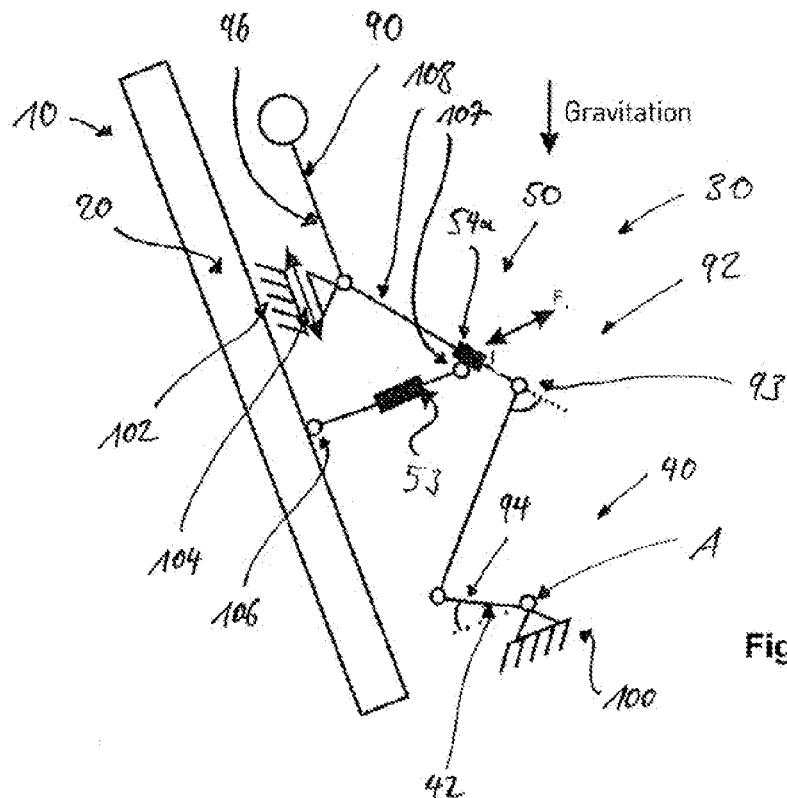


Fig. 12

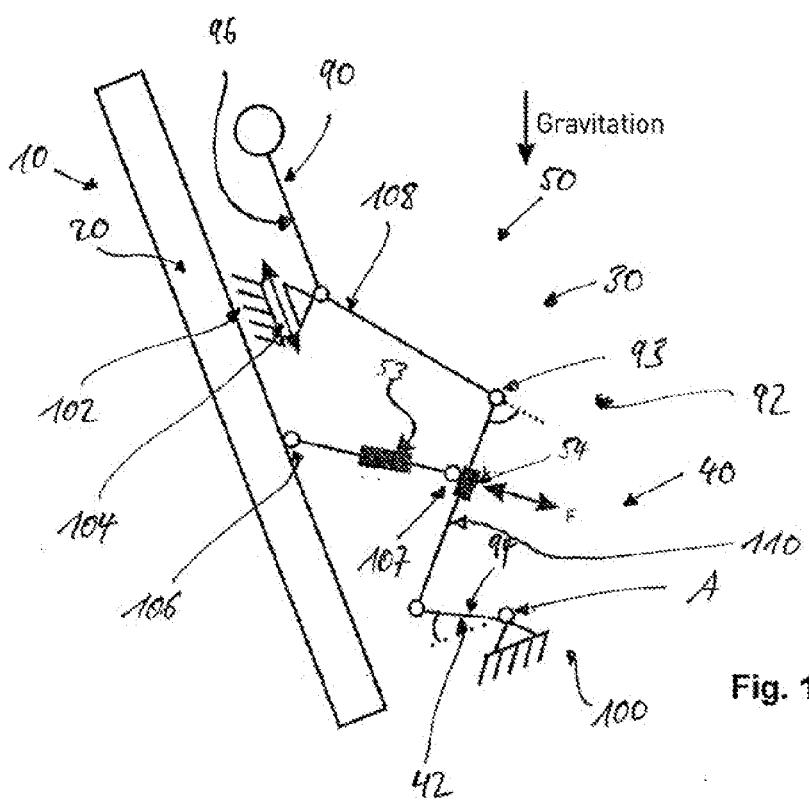


Fig. 13

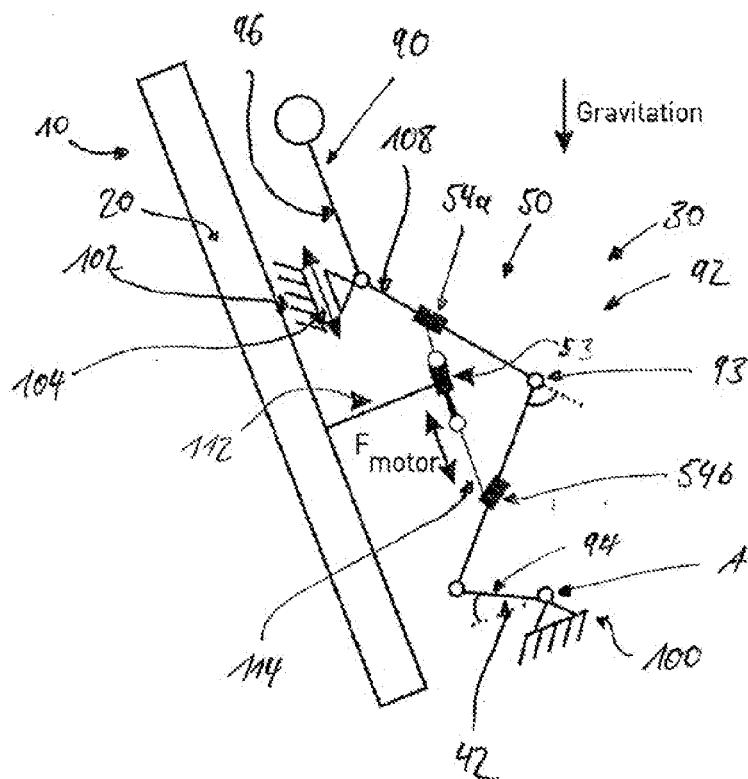


Fig. 14

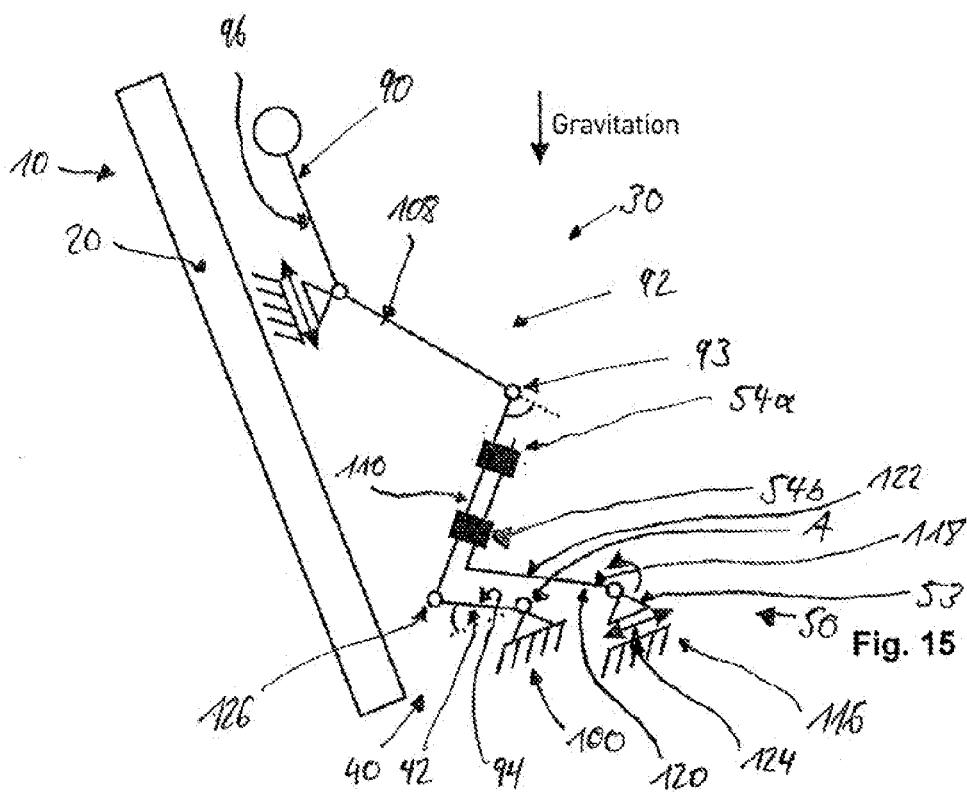
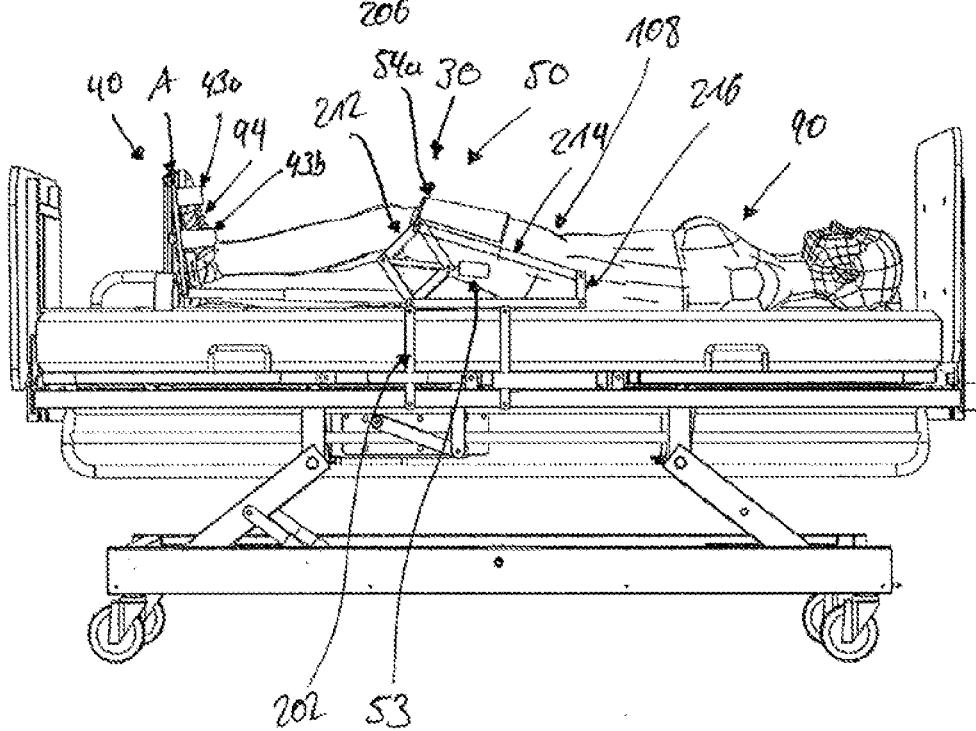
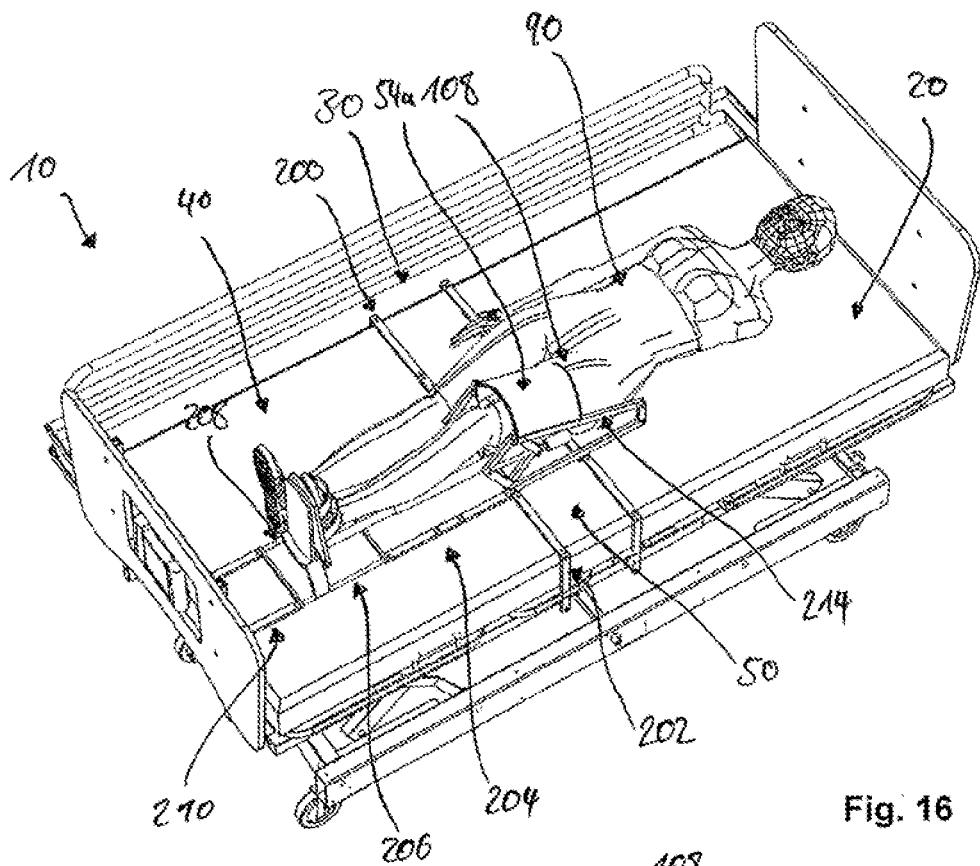


Fig. 15



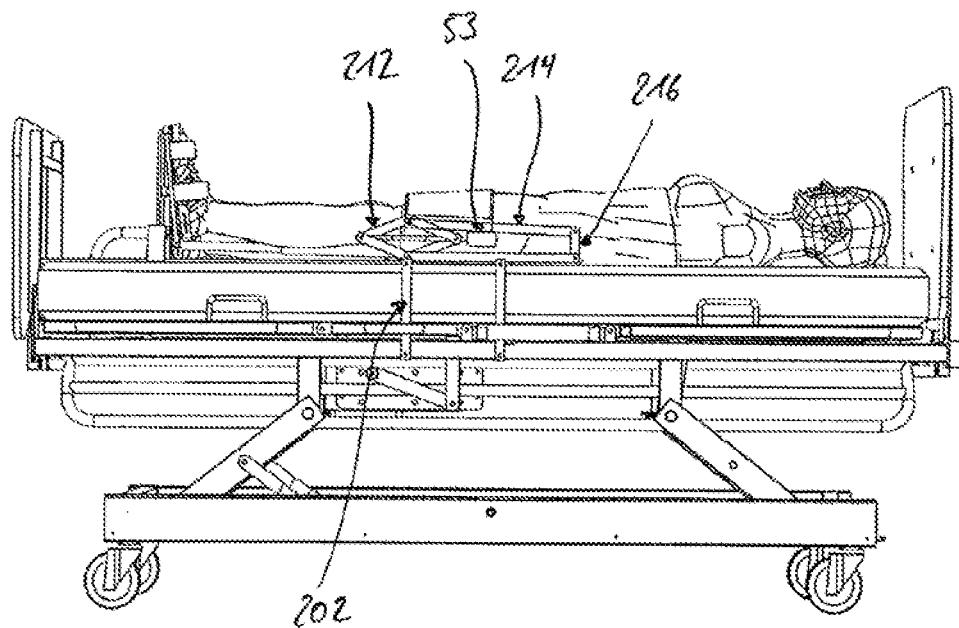


Fig. 18

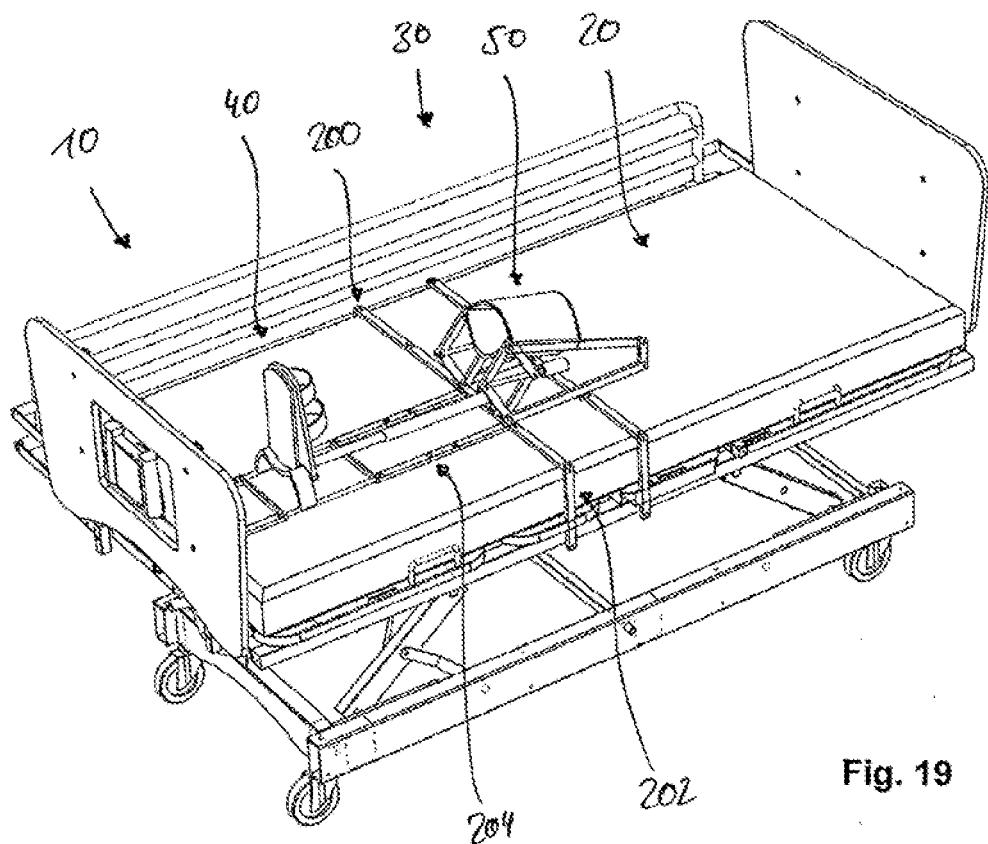


Fig. 19

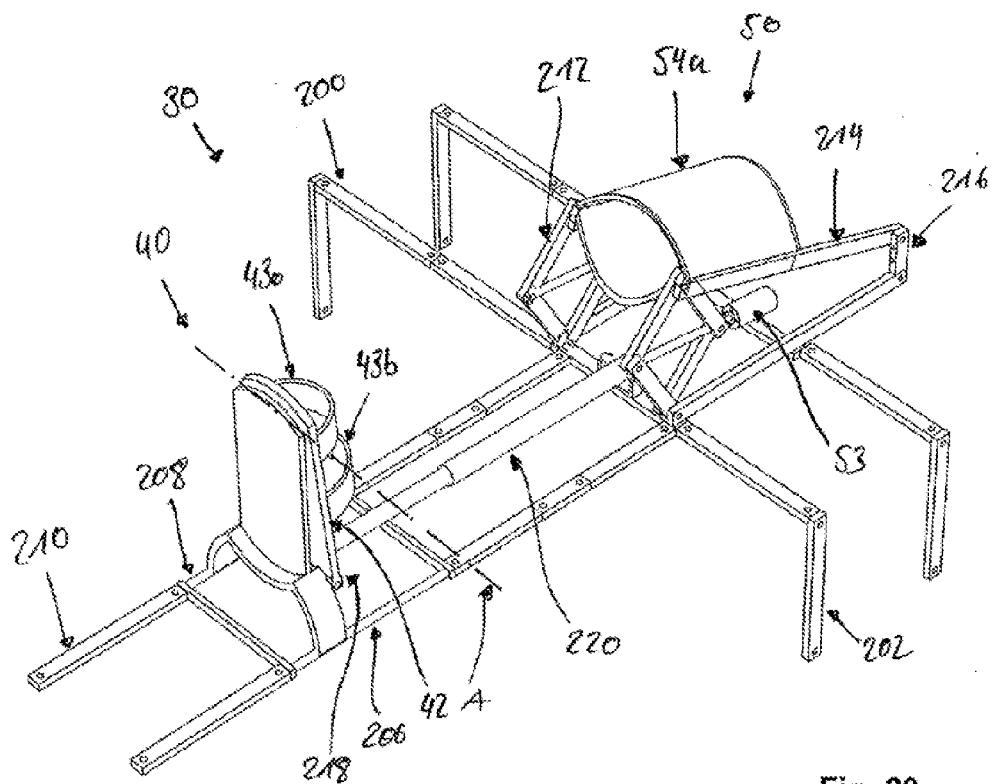


Fig. 20

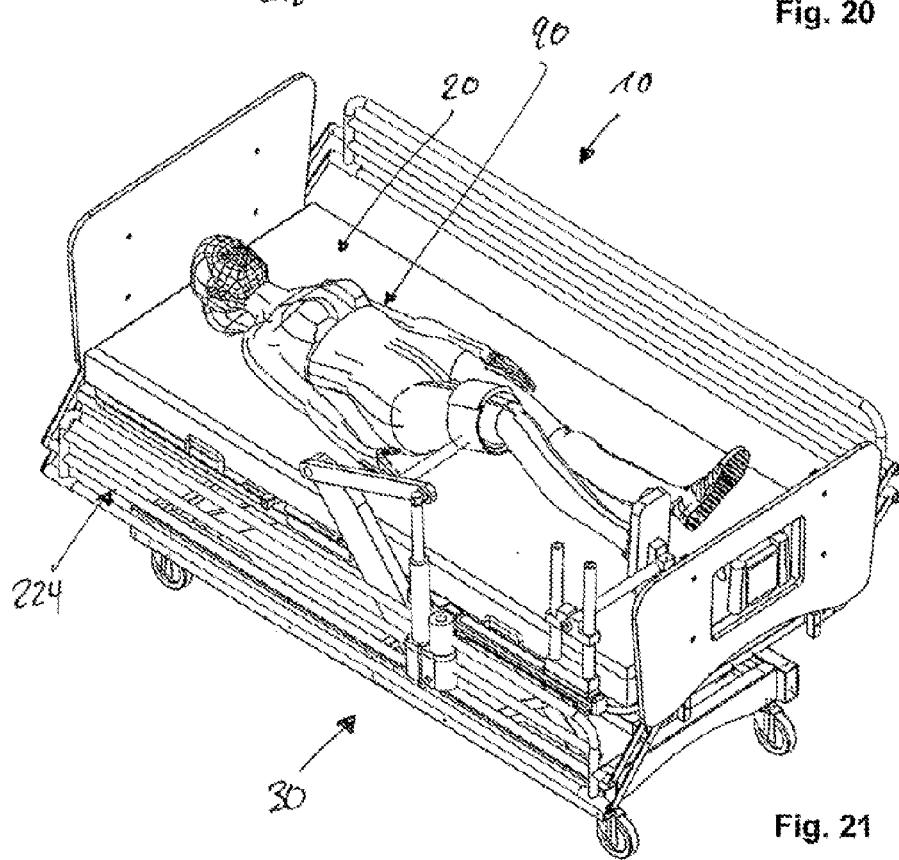


Fig. 21

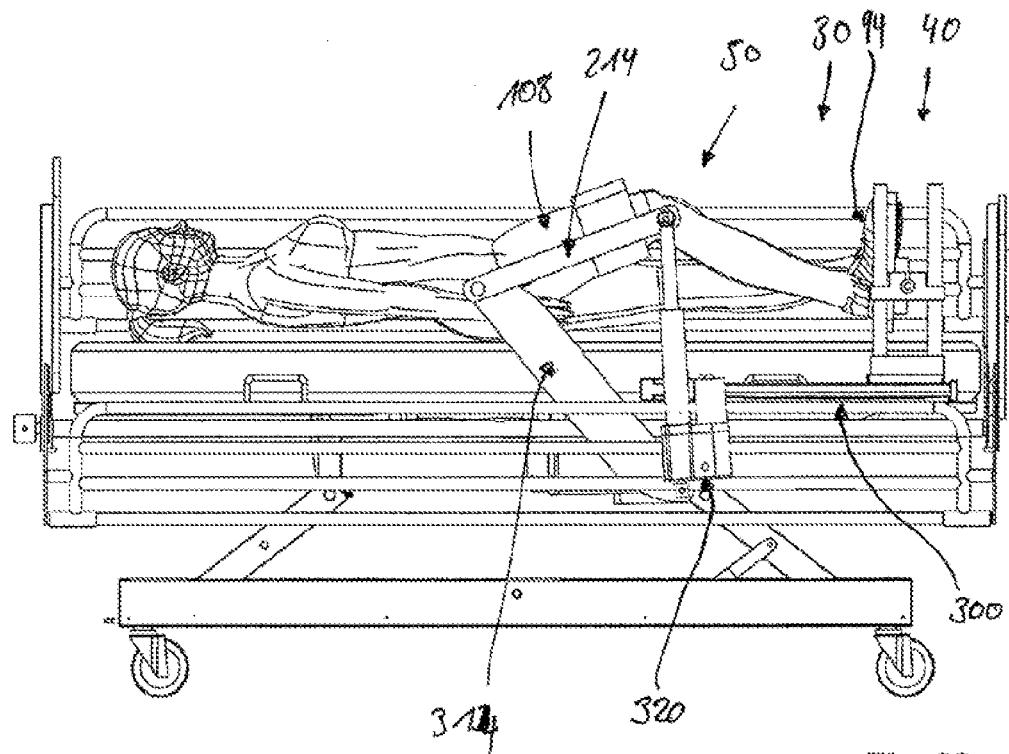


Fig. 22

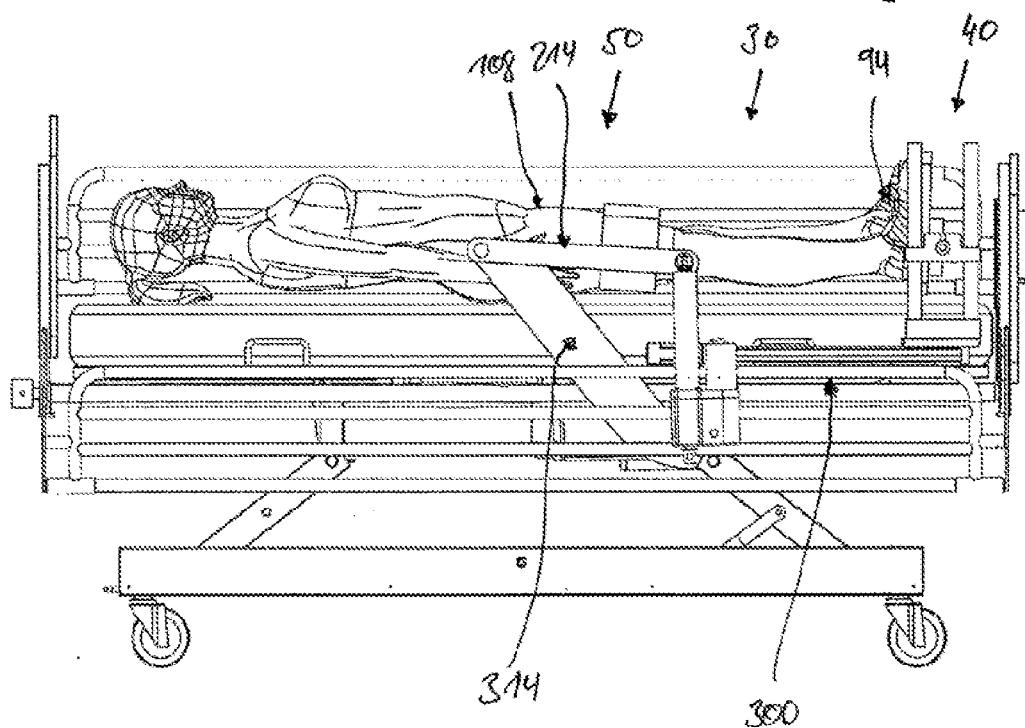
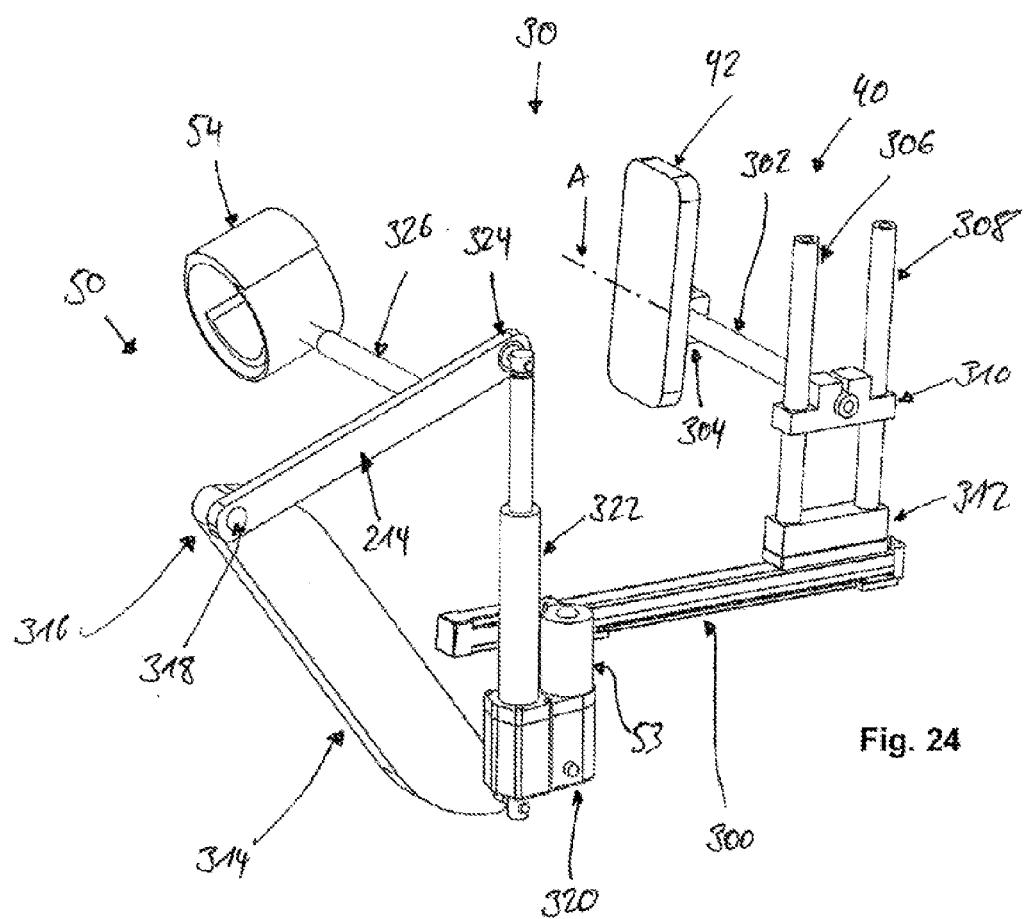


Fig. 23



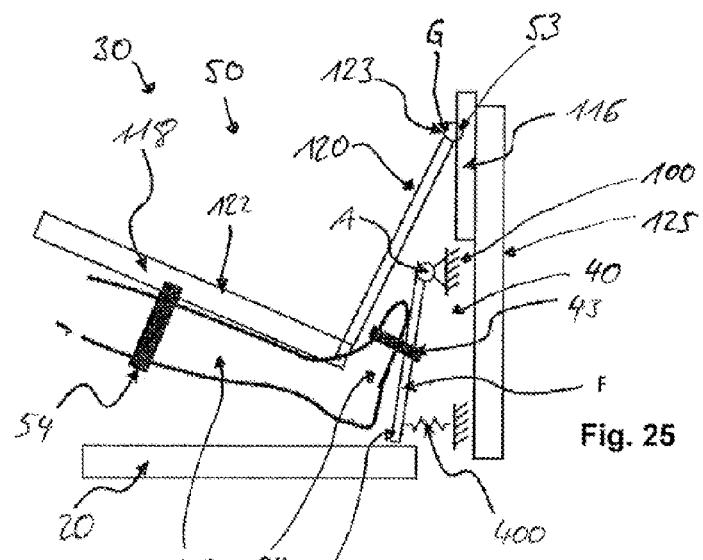


Fig. 25

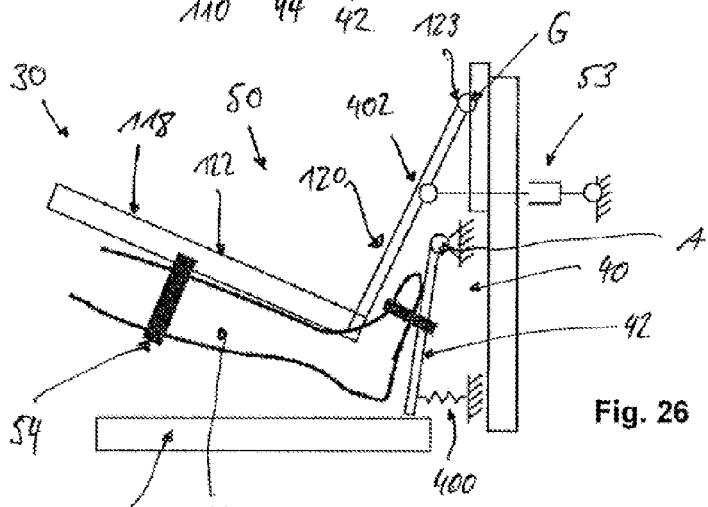


Fig. 26

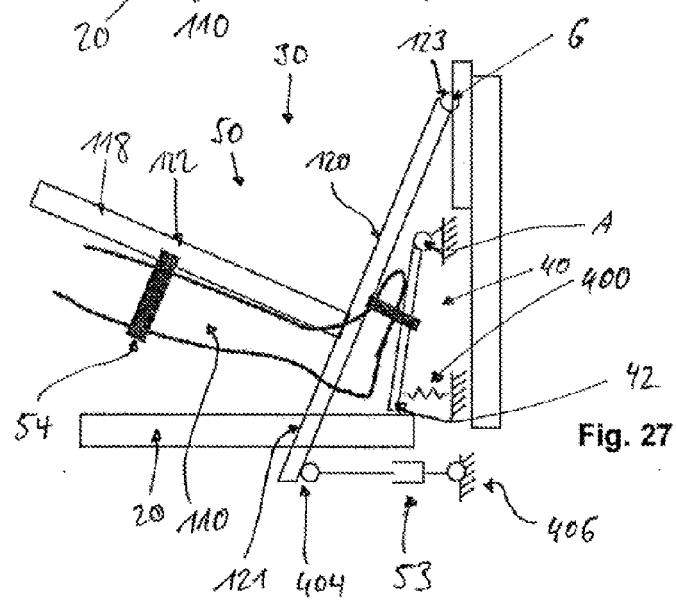
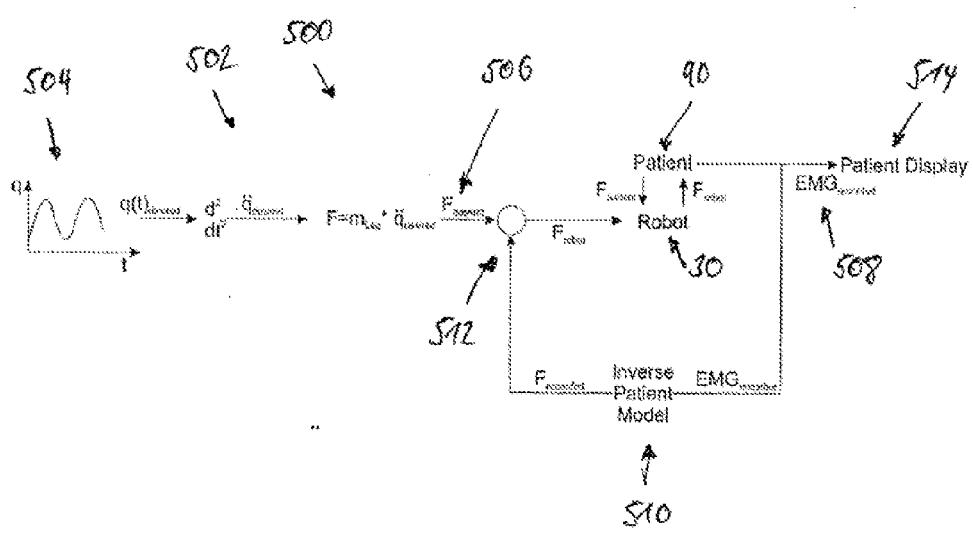
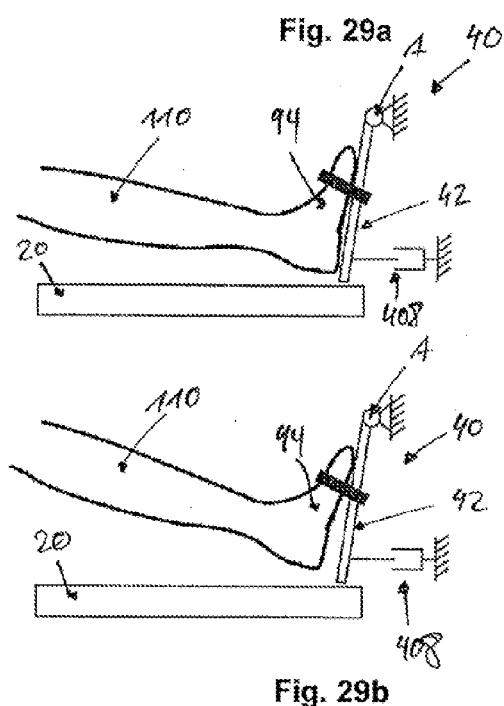
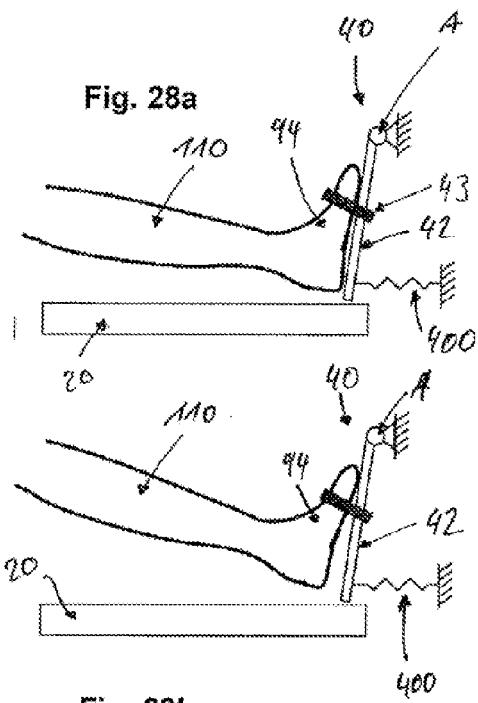


Fig. 27



REHABILITATION MECHANISM FOR PATIENTS CONFINED TO BED AND BED COMPRISING THE REHABILITATION MECHANISM

[0001] The present invention relates to a rehabilitation mechanism for bedridden patients and a bed comprising the rehabilitation mechanism, particularly a hospital bed, clinical bed, gurney, or intensive-care bed.

[0002] Persons suffering from an illness or as a result of an accident, for example, or who are "bound" to a bed as a patient for other reasons for longer than the normal night-time rest period (referred to below as bedridden patients) often have restrictions on activity that lead to such persons being poorly able or even unable to participate in social life after leaving the bed, that is, unable or only partially able to work and requiring assistance in daily life.

[0003] Through rehabilitation, the patient can regain part of his activity. In the medical field, rehabilitation means the application and effects of measures intended for reducing to a minimum the physical, psychological, and social consequences of a handicap or limitation on activity (formerly: disability, now: activity) and interruption of participation (formerly, handicap; now, participation) in social life.

[0004] Medical rehabilitation has been proven to be particularly significant for the human locomotor system. If the bones, joints, muscles, and tendons, particularly of the human legs (comprising the buttocks, hip joint, thigh, knee joint, calf, and foot) are not moved regularly, they will stiffen—the related locomotion centers located in the human spinal tissue can atrophy.

[0005] Unlike persons who are physically able and have a stable circulatory situation allowing participation in treadmill training, for example, said training is typically denied to bedridden patients. The particular reasons can be orthopedic, intensive-care, and/or neurological limitations on activities encountered individually or cumulatively.

Rehabilitation of Orthopedic Restrictions on Activity

[0006] Orthopedics is the field of activity of a specialist for orthopedics and trauma surgery and addresses the occurrence, prevention, detection, and treatment of congenital or acquired defects in the form or function of the musculoskeletal system, that is, the bones, joints, muscles, and tendons, and the rehabilitation of such patients.

[0007] Orthopedic treatments include surgical methods such as particularly prosthetic surgery (e.g., but not limited to, hip or knee joint replacement). After an accident or surgical intervention, bedridden patients are typically not able to apply full body weight to the bones, joints, muscles, and tendons of one or both legs due to orthopedic limitations on activity.

[0008] In order to nevertheless prevent stiffening of the legs, an in-bed exercise machine is known from WO 00/45897 A1, for example, allowing performing of cyclical leg motions in a reclined position when pushed up to the end of a hospital or clinical bed. The known in-bed exercise machine, however, particularly does not allow exercise in a vertical position. In order for the feet to be fully or partially loaded by the body's own weight, however, which can accelerate the healing process after a joint replacement or bone fracture, for example, it is necessary to be able to bring the bedridden patient completely or partially into a vertical position.

[0009] Said consideration is addressed, for example, by the standing table disclosed by WO 00/61059 A1. It is thereby problematic that said standing table or comparable known devices are typically located in a separate training room, but in any case require relocating the patient from the bed to the corresponding rehabilitation device. At least for intensive-care patients, but also for patients requiring intensive-care treatment, this is generally not possible, but in any case is associated with particular risks.

Rehabilitation of Intensive-Care Limitations on Activity

[0010] Intensive care is a medical specialty addressing the diagnosis and therapy of life-threatening conditions and illnesses. Intensive-care services are typically provided in specially equipped units of a hospital or clinic, known as intensive-care units, led by specially trained specialists such as anesthesiologists, internists, surgeons, or neurologists.

[0011] The results of intensive-care services cover a wide range, depending on the underlying illness. In principle, there must be a certain positive prognosis of the illness condition. The goal of intensive-care services is namely to restore full health or at least to achieve a largely autonomous condition for the patient. So-called life-extending measures, therefore, are not pursued for their own sake.

[0012] Patients are admitted to intensive-care units whose condition is life-threatening or could become life-threatening, particularly due to a weak cardio-circulatory system, risk of cardiac arrest, infection risk, and the like. Said fact is addressed in standardized monitoring measures in intensive-care units.

[0013] Intensive-care units have extensive technical building structures and equipment. A focal point is the design of the intensive-care bed, which serves for safely supporting the most ill patients in intensive-care units. In addition to apparatus supporting the monitoring measures, an intensive-care bed is particularly characterized by a mattress suitably designed for preventing bedsores and for immediately manually resuscitating at least the heart and/or lungs of an intensive-care patient. The mattress must also be non-conductive for performing defibrillation and resistant to liquids, blood, and wipe-down disinfection using commercially available disinfecting agents.

[0014] In order to secure intensive-care patients against falling out of bed, the mattress is usually enclosed by barriers on the long and transverse sides that can be attached to the long and transverse sides of a bed or mattress frame and often support at least part of the monitoring apparatus.

[0015] Due to said typical design of intensive-care beds, the known rehabilitation devices described above cannot be easily brought adjacent to a modern intensive-care bed and/or require repositioning of the patient. The latter, however—as has already been mentioned—is typically not possible for intensive-care patients, who are normally weak or require intensive-care services for other reasons, but in any case is associated with special risks.

[0016] Meanwhile, patients in intensive-care units already have a five to ten times higher risk of infection in comparison with patients in normal units. Various infection-promoting factors add up for intensive-care patients, originating both from the patients themselves and from the treatment measures using in intensive care (many catheters, tubes, etc.) Therefore, in order to reduce the risk of infection, special hygienic measures are specified for intensive-care unit, and

rehabilitation devices such as the known in-bed exercise machine or known standing table meet such specifications only with difficulty.

[0017] Rehabilitation strategies supported by rehabilitation devices therefore have typically been first used up to now after the patient has left the intensive-care unit.

Rehabilitation of Neurological Limitations on Activity

[0018] Neurology is the study of diseases of the nervous system. The organ system that are addressed in neurology are the central nervous system, that is, the brain and spinal cord, surrounding structures and blood-supply vessels thereof, and the peripheral nervous system including structures thereof connecting to the muscles, and the musculature.

[0019] For neurological rehabilitation, recent studies have shown that rehabilitation should begin as early as possible. In order to maximum the success of rehabilitation, for example, rehabilitation measures should be started 24 hours after a stroke exhibiting unilateral or other paralysis, or a traumatic brain injury with or without quantitative loss of consciousness, presenting as a coma in the most severe form.

[0020] Because patients affected by paralysis and/or loss of consciousness are typically still in an intensive-care unit at this point in time, the neurological rehabilitation strategies to be begun at an early point are doubly difficult: in addition to the intensive environment describe above, which is problematic in itself, the entire leg motion must be performed cyclically solely by the rehabilitation device, at least for paralyzed and/or comatose patients, at least at first.

[0021] For these reasons, exercises for maintaining activity of patients in intensive-care facilities are mostly performed by special physical therapists who manually move the limbs of intensive-care patients—daily if possible, but at least several times a week. Said manual physical therapy is disadvantageous in that the therapists can fatigue quickly due to the physical exertion, leading to difficulty in planning, let alone evaluating, session progress. Furthermore, it is not guaranteed that the physical therapist will work at the same (maximum) effort and efficiency for every physical therapy session. The physical therapist also cannot perform an objective quantification of the activity of the patient, only subjective, making objective quantification of the success of the therapy over several therapy sessions difficult. Finally, a therapy session, particularly in the intensive-care environment, can require not only the presence of one or more physical therapists, but also the presence of a nurse who must monitor the vital parameters of the patient [90] during the session, for example in order to be able to react to cardiac circulatory problems. The additional presence of highly qualified clinical personnel causes such therapy sessions to be unaffordable.

[0022] On this basis, the object of the present invention is to provide an improved rehabilitation mechanism in comparison with the prior art, particularly for patients having become bedridden due to orthopedic, intensive-care, and/or neurological limitations on activity, allowing planned, automated rehabilitation of at least the joints, muscles, and tendons of the legs of bedridden patients without requiring bed-to-bed transfer of the patient. In addition to commercially available or self-built hospital or clinical beds, the rehabilitation mechanism should also be usable in commercially available or self-built gurneys or intensive-care beds,

regardless of whether the bedridden patient can be brought into a partially or completely vertical position in the corresponding bed, wherein the rehabilitation mechanism can support a rhythmic loading and unloading of the soles of the feet of bedridden patients in any position of the bedridden patient between a horizontal and a vertical position.

[0023] Said object is achieved first by a rehabilitation mechanism having the features of the independent claim 1.

[0024] A rehabilitation mechanism according to the invention implemented for planned, automated rehabilitation of at least the joints, muscles, and tendons of the legs of a bedridden patient, comprises at least:

[0025] a foot module for operatively connecting to the feet (94) of the bedridden patient,

[0026] a knee module for operatively connecting to the knee joints of the bedridden patient, and

[0027] a control module for controlling planned rehabilitation motions of at least the joints, muscles, and tendons of the legs of the bedridden patient by means of the foot and/or knee module.

[0028] The invention is further characterized in that at least the knee module is implemented as a module for disposing between the patient and the mattress and supported directly or indirectly on a bed or mattress frame.

[0029] The modular design of the rehabilitation mechanism has the advantage that bedridden and particularly intensive-care patients can receive planned, automated rehabilitation directly in the bed, without requiring high-risk transfer between beds and/or the ability to cooperatively contribute.

[0030] The term “module” or “modular design” should be understood hereafter particularly such that components so designated form individual, self-contained assemblies, indeed operatively connected to further elements but reversibly separable for the purpose of storing and/or transporting. The modules, particularly the foot module and the knee module, are fully mechanical and electrically separable from a bed on which said modules are used and can thus be stored separately. Alternatively or additionally, said modules can be folded away, for example in a space beneath a mattress of a bed.

[0031] The modularity, removability, or separability of the foot and knee module from the bed, whether by separating or by storing the therapy module beneath the bed, is particularly advantageous because the bed can be used as a normal bed outside of the therapy periods. The term “normal use” is understood thereby to mean that no element of the rehabilitation mechanism prevents access to the patient from all sides in any form, prevents the transfer from or into the bed, or prevents or hinders any necessary emergency measures or care measures.

[0032] The rehabilitation mechanism can preferably be reversibly releasably fixed to a hospital bed, in particular a conventional hospital bed. Said mechanism is provided and set up for reversibly disposing on conventional hospital beds in order to thus provide therapy for a patient lying in the bed. The rehabilitation mechanism preferably comprises support and/or clamping means in order to achieve reversible fixability. The rehabilitation mechanism can preferably be removed from a hospital bed as a module, particularly from a conventional hospital bed, and/or can be stowed beneath the hospital bed. The use of the rehabilitation mechanism is

thereby substantially simplified. Said module is a self-contained system usable selectively on existing hospital beds.

[0033] Disposing a knee module between the patient and mattress and supporting the same directly or indirectly on a bed or mattress frame particularly makes it possible to apply supporting force to the knee joints of bedridden patients, advantageously rhythmically loading and unloading the soles of the feet of said patients, in any position assumed by the patient between a horizontal and a vertical position.

[0034] For orthopedic patients, the rhythmic loading and unloading of the soles of the feet is important, for example to accustom an injured joint to walking again and/or to a load in a partially or fully vertical assumed position. For intensive-care patients, the rhythmic loading and unloading of the soles of the feet is significant in order to prevent stiffening of the legs and atrophy of the locomotion centers located in the spinal cord.

[0035] For neurological patients, the alternating motion generates additional sensory input in the soles of the feet, said input being transmitted to the central nervous system. Said "efferent sensory input" ensures that the brain regions involved in generating walking motions are also excited.

[0036] The planned automated rehabilitation of at least the joints, muscles, and tendons of the legs of bedridden and particularly intensive-care patients by means of a rehabilitation mechanism according to the invention has the objective of limiting to a minimum the limitations on activity and/or interruption in participation in social life. The underlying central therapeutic idea is to quantify and/or control to a desired level the activity of bedridden or particularly intensive-care patients as early as possible, that is, while still in bed. The determining of individual parameters of a planned automated rehabilitation in this respect in the course of the present invention is nevertheless the responsibility of physical therapists or at least comparably trained technicians in practice.

[0037] The rehabilitation is particularly preferably a walking motion, a stepping motion, and/or a motion simulating stair-climbing. A walking motion, stepping motion, or motion simulating stair-climbing is substantially more advantageous for rehabilitation than a bicycle-riding motion, for example. A pure foot module allowing a bicycle-riding motion is known from DE 41 13 135 A1, for example. It is much more important, however, for rehabilitation patients to acquire a walking motion, stepping motion, or motion simulating stair-climbing and to simulate the loads occurring during such a walking motion, stepping motion, or motion simulating stair-climbing, and to measure progress thereby. A bicycle-riding motion is suitable only under certain conditions, as here in particular no rolling of the foot occurs and a torque applied to the ankle joint of the foot tends to be low.

[0038] According to the invention, the foot module and the knee module together form an exoskeleton for the patient. The modules forming the exoskeleton act together by means of the control module and support the patient in performing the motion. The rehabilitation mechanism further preferably comprises a biofeedback module for providing a visual and/or audible feedback to the patient. Such a biofeedback module preferably comprises a display or the like disposed in the field of vision of the patient in order to give said feedback. Such a biofeedback module can fundamentally be implemented as disclosed in US 2010/0042022 A1. Said module is preferably implemented for indicating to

the patient whether said patient is performing a motion properly and/or is making progress. The biofeedback module is further preferably implemented for indicating to the patient that said patient is not performing a motion correctly, should change exercises, should stop an exercise, and the like.

[0039] The object of the present invention is therefore also a bed comprising the rehabilitation mechanism according to the invention, wherein said bed can be implemented as a commercially available or self-built hospital bed, a clinical bed, a gurney, or particularly an intensive-care bed.

[0040] Advantageous embodiments and refinements, usable individually or in combination with each other, are the objects of the dependent claims.

[0041] Said details and additional details and further advantages of the invention are described below using preferred embodiment examples, to which, however, the present invention is not limited, and in conjunction with the attached drawing. They show schematically:

[0042] FIG. 1 A bedridden or intensive-care patient in a commercially available bed, particularly an in intensive-care bed, in a side view;

[0043] FIG. 2 A rehabilitation mechanism disposed on a bed according to FIG. 1 and comprising a foot module, a knee module, and control module in a plan view;

[0044] FIG. 3 A first embodiment example of a foot module having an electrical and/or mechanical design in a side view;

[0045] FIG. 4 A second embodiment example of a foot module having an electrical and/or mechanical design in a side view;

[0046] FIG. 5 A first embodiment example of a knee module having an electrical and/or mechanical design in a section view (FIG. 5a) and a side view (FIG. 5b);

[0047] FIG. 6 A second embodiment example of a knee module having an electrical and/or mechanical design in a section view;

[0048] FIG. 7 An embodiment example of a knee module having a fluid-dynamic design in a section view;

[0049] FIG. 8 An embodiment example of an adjusting mechanism for raising the mattress frame by e.g. 90° to a vertical position, in a side view;

[0050] FIG. 9 A first embodiment example of a stabilizing mechanism at a vertical level of e.g. 60°, in a side view.

[0051] FIG. 10 A second embodiment example of a stabilizing mechanism at a vertical level of e.g. 75°, in a side view.

[0052] FIG. 11 A control schematic of the control module for controlling and executing planned rehabilitation motions;

[0053] FIG. 12 A schematic view of a bed having a rehabilitation mechanism according to a first embodiment example;

[0054] FIG. 13 A schematic view of a bed having a rehabilitation mechanism according to a second embodiment example;

[0055] FIG. 14 A schematic view of a bed having a rehabilitation mechanism according to a third embodiment example;

[0056] FIG. 15 A schematic view of a bed having a rehabilitation mechanism according to a fourth embodiment example;

[0057] FIG. 16 A perspective view of a bed having a rehabilitation mechanism according to a fifth embodiment example;

[0058] FIG. 17 A side view of the bed from FIG. 16 having the rehabilitation mechanism in a first condition;

[0059] FIG. 18 A side view of the bed from FIGS. 16 and 17 having the rehabilitation mechanism in a second condition;

[0060] FIG. 19 A further perspective view of the bed from FIG. 16 through 18, without the patient;

[0061] FIG. 20 A perspective detail view of the rehabilitation mechanism according to FIG. 16 through 19;

[0062] FIG. 21 A perspective view of a bed having a rehabilitation mechanism according to a sixth embodiment example;

[0063] FIG. 22 A side view of the bed from FIG. 21 having the rehabilitation mechanism in a first condition;

[0064] FIG. 23 A side view of the bed from FIGS. 21 and 22 having the rehabilitation mechanism in a second condition;

[0065] FIG. 24 A perspective detail view of the rehabilitation mechanism according to FIG. 21 through 23;

[0066] FIG. 25 A schematic side view of a rehabilitation mechanism according to a seventh embodiment example;

[0067] FIG. 26 A schematic side view of a rehabilitation mechanism according to an eighth embodiment example;

[0068] FIG. 27 A schematic side view of a rehabilitation mechanism according to a ninth embodiment example;

[0069] FIG. 28a A schematic side view of a foot module in a first position;

[0070] FIG. 28b A schematic side view of the foot module from FIG. 28a in a second position;

[0071] FIG. 29a A schematic side view of a foot module in a first position;

[0072] FIG. 29b A schematic side view of the foot module from FIG. 29a in a second position; and

[0073] FIG. 30 A closed-loop control circuit for EMG control.

[0074] In the description below of preferred embodiments of the present invention, identical reference numerals indicate identical or comparable components

[0075] FIG. 1 shows a bedridden or intensive-care patient 90 in a commercially available bed 10, particularly an in intensive-care bed, in a side view. The bed 10 shown can particularly be implemented for medical requirements typical of intensive-care beds, but can also be used in a non-intensive-care environment, particularly as a hospital bed, clinical bed, or gurney. In addition to apparatus for supporting monitoring measures (not shown), the bed 10 shown is characterized by a mattress 20 suitably designed at least for preventing bedsores. For an intensive-care bed, the bed 10 shown is further characterized by a mattress 20 additionally implemented for immediately manually resuscitating at least the heart and/or lungs 91 of an intensive-care patient 90, and non-conductive for performing defibrillations, and resistant to liquids, blood, and wiping disinfectant using commercially available disinfection means, wherein mattresses 20 having a non-divided or continuous design are preferred for cleaning and disinfecting purposes. In order to secure bedridden and particularly intensive-care patients 90 against falling out, the mattress 20 is entirely or partially surrounded by long 14 and transverse side barriers 15 for attaching to the long 12 and transverse sides 13 of a bed 11 or mattress frame 21 of the bed 10, typically supporting at least part of the

monitoring apparatus (not shown). In order to be able to displace the bed 10, said bed has roller legs 16, for example. The roller legs 16 can be motor-driven in design for improving maneuverability. Embodiments wherein the bed 11 and/or mattress frame 21 are implemented for adjusting in height and/or in slope (whether lengthwise or transverse), wherein the head and foot ends can be preferably separately adjustable, that is, having different and/or opposite slopes from each other (not shown).

[0076] FIG. 2 shows a rehabilitation mechanism 30 according to the invention disposed on a bed 10 according to FIG. 1 and comprising a foot module 40, a knee module 50, and a control module 60 in a plan view.

[0077] It is evident how in a first preferred embodiment of the rehabilitation mechanism 30 said module comprises a foot 40 and a knee module 50 implemented as modules for disposing above the mattress 20 and for directly or indirectly supporting on a bed 11 or mattress frame 21. An advantage thereof is that commercially available, particularly non-divided and easily cleaned and disinfected mattresses 20 can be used, because (unlike particularly the standing table mentioned above), as said mattresses need not make space for mechanics. In addition, when rehabilitation is not taking place, the foot 40 and knee module 50 can be advantageously removed from the bed 11 or mattress frame 21, whereupon the bed 10 functions as a standard bed 10, such as a hospital bed, clinical bed, gurney, or intensive-care bed. The removed modules can be stowed on or under the bed 10, for example, until the rehabilitation is continued—optionally after prior cleaning or disinfection—or preferably used in the meantime for performing further planned automatic rehabilitations on other bedridden patients 90, whereby the investment costs incurred for the rehabilitation mechanism 30 are advantageously amortized more quickly.

[0078] In order to be able to operatively connect the foot module to the feet 94 and to operatively connect the knee module 50 to the knee joints 93 of the bedridden patient 90, in a further preferred embodiment of the rehabilitation mechanism 30 according to the invention the foot 40 and the knee module 50 are implemented as modules for fixing on both of the long sides 12 of the bed 10. The ability of the foot 40 and/or knee module 50 to be fixed can be provided in a low-cost embodiment by means of two guide rails 31, each of which can be mounted on one long side 12 of the bed 11 or mattress frame 21 and thus advantageously allow retrofitting for a plurality of existing beds 10. For fixing variably along the long sides 12, the foot 40 and the knee module 50 can comprise suitable fixing means 41 and 51 by means of which the modules 40 and 50 can advantageously be operatively connected to the feet 94 and knee joints 93 of the bedridden patient 90 corresponding to the anatomical conditions. In order to handle different widths of beds 10 and/or special anatomical considerations of the bedridden patient 90, fixing means 41 and 51 variably adjustable in not only the longitudinal direction but also the transverse direction of the bed 10 are finally preferred.

[0079] In a further preferred embodiment of the rehabilitation mechanism 30, the foot 40 and/or the knee module 50 can be electromechanical in design. A complete or partial electromechanical design of the foot 40 and/or knee module 50 has the advantage that electric motors can be actuated very simply and very precisely. Electric motors 45 or other actuators 53 (in contrast to pneumatic compressors, for example) are also relatively low-noise. Electromechanical

drives can also be displaced very quickly, which can be advantageous in an emergency situation.

[0080] Alternatively or cumulatively thereto, in a further embodiment of the rehabilitation mechanism 30 the foot 40 and/or the knee module 50 can have a fluid-dynamic design. A complete or partial fluid-dynamic design of the foot 40 and/or knee module 50 has the advantage that the force transmission to the patient 90 can be generated by means of cushions 57, for example, being expanded and/or contracted via a hose system 58 by means of a vacuum pump 59. Said design would distribute the compressive and tensile forces F required for the motion of the legs 92 over a larger area on the patient 90, thus preventing risks of injury as the force F cannot be transferred at points potentially having greater intensity, but rather over a larger area having a lower point force.

[0081] The above is shown more clearly using the embodiment examples shown in the following FIGS. 3 through 7.

[0082] FIG. 3 shows a first embodiment example of a foot module 40 having an electrical and/or mechanical design in a side view.

[0083] It is evident how the foot module 40 can be constructed similarly to a fitness stepper, for example. To this end, the bedridden patient 90 typically puts on shoes. The step surfaces 42 of the foot module 40 can also be designed, however, so that training can be performed barefoot or in socks. The feet 94 can be fixed to the foot module 40 by means of elastic fixing bands 43, similar to a snowboard binding or the like. It is thus ensured that the soles of the feet 95 of the bedridden patient 90 make contact with the step surfaces 42 of the foot module 40 independently of any vertical position. In a further embodiment, the foot module 40 can comprise an adjusting lever 44 by means of which the distance between the step surface 42 and the sole of the foot 95, for example, can be finely adjusted.

[0084] The foot module 40 can have a mechanical and/or electromechanical design. In the mechanical variant, a bedridden patient can—assuming appropriate consciousness and fitness—can push against a mechanism and/or damping elements. For an electromechanical variant, an electric motor 45 provides complete or partial support force, particularly at the level to which the bedridden patient is not able to independently execute motions of the legs 92 and/or load the soles of the feet 95. Finally, combined embodiments of a foot module 40 are also conceivable, wherein for example a mechanism can have supporting force from an electric motor connected or disconnected, or vice versa.

[0085] FIG. 4 shows a second embodiment example of a foot module 40 having an electrical and/or mechanical design in a side view. The step surfaces 42 with which the soles of the feet 95 of the patient 90 make contact or on which said patient stands after a complete or partial vertical repositioning are displaced in opposition to a mechanism and/or by means of an electric motor 45. An angle sensor 46 measures the current angle at which the step surfaces 42 are currently located, wherein at zero degrees the step surfaces 42 are perpendicular to the mattress 20. By means of the control module 60, the actual angle measured by means of the angle sensor 46 is compared with the planned target angle and any necessary support forces are calculated and executed.

[0086] According to said embodiment example (FIG. 4), two step surfaces 42 are provided, one for each of the patient's 90 feet. Said step surfaces are connected to the

electric motor 45, for example the motor shaft, pivotally about the axis of the motor shaft. A stepping motion is thus advantageously achieved. The patient's foot can rotate about an axis near the tip of the foot. The elements applied to the patient's feet, such as fixing straps 43, thereby act as a retaining mechanism holding the feet in place. The only degree of freedom is raising and lowering the foot in the superimposed rotating motion about the motor axis of the electric motor 45. For a passive foot module 40 with no electric motor, a suspension in the form of a rotary bearing can be provided here, for example pretensioned using springs, in order to thus generate a load for the patient 90.

[0087] It is important for implementing a walking motion, stepping motion, and/or motion simulating stair-climbing that the device ensures that the foot can roll during the walking motion, stepping motion, and/or motion simulating stair-climbing, that is, the foot does not set down flat on the heel and tip at the same time, but rolls from the front part of the tip of the foot, across the middle of the foot, to the heel. For one thing, the loading situation on the patient's body is thereby closer to natural loading when a foot module similar to a bicycle (cf. FIG. 3) is used. It can also thereby be better recognized in a vertical repositioning how much the rehabilitation has progressed. For another, said embodiment example allows the body's sensory signals transmitted from the soles of the feet to the brain to be similar to those from a real walking motion. Said motion is advantageous for rehabilitation and can lead to more rapid rehabilitation of the patient.

[0088] The embodiment examples according to FIGS. 3 and 4 both have the corresponding foot module operatively connected to mechanical end stops for preventing overextension or excess stretching of the foot 94, particularly the ankle joint.

[0089] Unlike the foot module 40, which can also be purely mechanical and particularly passive in design, a knee module 50 according to the invention is intended to continuously advantageously apply supporting forces just below, directly at, and/or just above the knee joint 93. The knee module 50 is inserted between the mattress 20 and the patient 90 beneath the knee joints 93 thereof and fixed to the bed 11 or mattress frame 21 for executing planned rehabilitation motions.

[0090] FIG. 5 shows a first embodiment example of a knee module 50 having an electrical and/or mechanical design in a section view (FIG. 5a) and a side view (FIG. 5b). In a low-cost, purely mechanical embodiment of a knee module 50, for example, the knee joint can be extended when extending a leg 92 by means of the foot module 40 against a spring or damping element 52, said element releasing the kinetic energy stored thereby during subsequent retraction of the leg 92, thus supporting the knee joint 93 during the bending motion executed thereby. Alternatively or cumulatively thereto, electrical actuators 53 can be installed in the knee module 50, by means of which a planned support force can be applied to the knee joints 93 of the patient 90.

[0091] FIG. 6 shows a second embodiment example of a knee module 50 having an electrical and/or mechanical design in a section view. Unlike the embodiment example according to FIG. 5, two actuators 53 are not directly integrated in the knee module 50, but rather in the side fixing means.

[0092] Common to the embodiment examples according to FIGS. 5 and 6 is that the corresponding knee module 50

is operatively connected to mechanical end stops preventing overextension or excess stretching of the knee joint 93 by switching off the rehabilitation mechanism 30 if the forces become too great.

[0093] Also common to the embodiment examples according to FIGS. 5 and 6 is that the knee joints 93 of bedridden patients 90 can be fixed in position on the knee module 50 by means of a cuff 54. The support force of the actuators 53 can thereby be applied to the cuff 54 directly or by means of a gearbox 56. If the cuff 54 is preferably implemented in two parts and comprises a hook-and-loop closure 55 at the end thereof, for example, then the cuff 54 can be advantageously adapted to the anatomy of the bedridden patient 90. Two-part cuffs also provide the ability to be opened in case of overload.

[0094] FIG. 7 shows a knee module 50 having a fluid-dynamic design as a further embodiment example in a cross section. Instead of electromechanical actuators, a knee module 50 having a fluid-dynamic design preferably comprises two cushions 57 for positioning beneath the knee joints 93 of the patient in that said cushions are pushed beneath the patient's knee similar to a belt. Both cushions 57 are connected to a vacuum pump 59 by means of a hose system 58 and can be filled with and emptied of liquid, air or another fluid independently of each other. For example, the fill level of the cushions 57 can be controlled by means of a pressure sensor P and in combination with the control module 60, so that a planned support force is exerted on the knee joints 93 of the patient 90. The cushions 57 expand when filled and contract when emptied, much like a balloon. An expanded cushion 57 presses with equal force in the direction of the mattress 20 and in the direction of the knee joint 93 of the patient 90. Because the cushion 57 presses down against the mattress 20, the loaded knee joint 93 of the patient 90 bends in as planned. When the cushion 57 contracts, the leg 92 of the patient can extend again or be extended by the foot module 40. The knee joints 93 can in turn be fixed in position relative to the cushions 57 by means of a type of cuff 55 able to span both knee joints 93 as shown in FIG. 7, so that the cushions 57 remain in contact with the mattress 20.

[0095] In order to prevent overextending the knee joint 93, the cushions 57 can be controlled so that a residual amount of fluid remains in the cushion 57. To prevent excess expansion of the cushion and/or of the hose system 58, an overpressure valve set to a maximum threshold pressure can further be provided.

[0096] It is ultimately critical for the controlling of planned rehabilitation motions that the foot module 40 as well as the knee module 50 can be adapted to the anatomical conditions of the bedridden patient 90 in an individual home position of the patient 90 in which the legs 92 thereof take on an extended position aligned flush to each other. To this end, a final position can be finely matched, even perpendicular to the mattress 20, for example by means of the lever 44 provided on the foot module 40. Alternatively or cumulatively thereto, the actuators 53 of a knee module 50 having an electromechanical design can be displaced to a flush point of said home position, from which the planned rehabilitation motion can be executed and controlled. For a knee module 50 having a fluid-dynamic design, the cushions 57 can be implemented having a base fill level or a base-filled chamber system, wherein the base filling in turn corresponds to the desired flush point of said home position.

[0097] In a further preferred embodiment of the rehabilitation mechanism 30, said mechanism comprises at least one sensor F, EMG, by means of which a quantification of any self-contribution by bedridden patients 90 during planned automated controlling of rehabilitation motions is made possible by measuring compressive forces F at the soles of the feet 95 of the patient 90 and/or by measuring compressive and/or tensile forces F at the knee module 30 and/or by measuring muscle activity EMG in the legs 82 of the patient 90.

[0098] An objective clinical qualification of the change (improvement) can thereby be performed of the ability of the patient 90 to independently generate the forces required for the motion. Considered over the time period for rehabilitation (typically a plurality of days to weeks), said quantification can then provide insight into the rehabilitation process and success thereof. Based on said data provided by the at least one sensor F, EMG, the specialists (physicians, physical therapists, or the like) can adapt, or plan, the automated rehabilitation motions, particularly with respect to the methodology and/or intensity for each patient 90 over the course of the rehabilitation process.

[0099] In a further preferred embodiment of the rehabilitation mechanism 30, the control module 60 accesses compressive and/or tensile force measurement signals and/or EMG measurement signals for executing planned automated rehabilitation motions. The rehabilitation motions can thereby be performed automatically, so that the patient 90 obtains the right amount of support force at the right time. Or, in other words, the bedridden patient 90 obtains a support force only in the part of the motion cycle in which he requires support. The rehabilitation mechanism 30 behaves "transparently", in contrast, in the part of the motion cycle in which the patient 90 can perform motions without help, that is, said mechanism merely follows the motion of the patient 90 without applying any force. Executing, that is, determining the support force required in each case, can be performed by measuring the compressive and/or tensile forces F and processing them in the control module 60 so that the rehabilitation mechanism 30 applies exactly the amount of force to the patient 90 that the patient 90 requires in order to perform the motion, but no more. Said concept can be referred to as "assist as needed."

[0100] The active participation of the patient 90 can be maximized for the first time by means of monitoring and controlling. This is primarily done by measuring the activity of the legs as a function of the load applied to the patient 90 and held to a desired level by closed-loop control. Quantification of the patient's 90 own contribution can take place by measuring compressive forces on the soles of the feet 95 of the patient 90 and/or by measuring muscle activity in the legs 92 of the patient 90. Monitoring and controlling patient activity is advantageous in that the patient 90 can be rehabilitated to the limit of his load-bearing capacity. Planned automated motions at the limit of load-bearing represent substantial therapeutic progress, particularly for intensive-care and/or comatose patients 90. Said measurements also provide insight into the clinical progress of the patient 90.

[0101] For safety reasons, the control module 60 continuously monitors all sensor values to that said module shuts down the rehabilitation mechanism 30 and/or emits suitable warning signals if inconsistencies or deviations from the planned rehabilitation are detected. In addition, particularly

when used with coma patients 90, both the sensor side and the control side can be redundantly designed.

[0102] The rehabilitation mechanism 30 according to the invention is particularly suitable for commercially available or self-built beds 10 of all kinds, particularly for hospital beds, clinical beds, gurneys, and/or intensive-care beds.

[0103] FIGS. 8 through 10 below make this clear:

[0104] FIG. 8 shows an embodiment example of an adjusting mechanism 70 for raising the mattress frame 21 by e.g. 90° to a vertical position, in a side view.

[0105] In order to rehabilitate a bedridden patient 90 as close to the limit of his own ability as possible, the patients feet 94 should always bear as much of the patient's body weight as possible and thus contribute to a walking motion, stepping motion, and/or motion simulating stair-climbing. In order for the feet 94 to be loaded by the patient's body weight, it is necessary to bring the bedridden patient 90 into a vertical position. In order to ensure that the soles of the feet 95 of the bedridden patient 90 are in contact with the step surfaces 24 of the foot module 40 before vertical positioning, it is preferable to operatively connect the feet 94 of the patient 90 to the foot module prior to beginning the vertical positioning. The same applies to operatively connecting the knee joints 93 to the knee module 50. The level of vertical positioning (between 0 degrees=lying down and 90 degrees=standing) should be able to be freely adjusted as a parameter of the planned automated rehabilitation by the responsible physical therapist, that is, not only at 90° but also particularly at 45° or 60° or 75° or other arbitrary intermediate levels. A bed 10 according to the invention therefore comprises a suitably designed adjusting mechanism 70 for adjusting the mattress frame 21 at least between a horizontal and a vertical position, by means of which all other required positions than a horizontal and a vertical position can preferably also be assumed, and from which positions the mattress frame 21 can be returned to a horizontal position at any time. The adjusting mechanism 70 can comprise electric motor and/or hydraulic means for adjusting the mattress frame 21 connected to the bed frame by means of a joint, said means raising the mattress frame 21 including the mattress 20 and the patient 90 affixed thereto to the planned level of vertical positioning, for example by means of a driven angle-control mechanism. The vertical position thus assumed also advantageously allows the patient 90 to train the heart and circulatory system and to load the same optimally by adjusting the vertical positioning level according to the individual progress in healing.

[0106] FIG. 9 shows a first embodiment example of a stabilizing mechanism 80 at a preferred vertical level of e.g. 60°, in a side view. It is evident how the knee joints 93 of the patient 90 are fixed at maximum extension (that is, fully extended) until the planned prescribed vertical positioning. Said extension advantageously prevents the patient 90 from sliding down by bending the knee joints 93 during the process of vertical positioning. The force of the weight of the patient 90 thereby slowly shifts in the direction of the feet 94. A medical monitoring and/or supply apparatus typically provided in particular for intensive-care beds (not shown) can, if needed, be attached to the bed frame 11 of the bed 10 and/or can be vertically positioned together with the mattress frame 21.

[0107] In order to prevent the patient 90 from falling out of the bed 10, particularly as the vertical positioning of a

bedridden patient 90 increases, it is necessary to suitably stabilize the bedridden patient 90 with respect to the mattress 20.

[0108] In a preferred embodiment of the bed 10 according to the invention, the stabilizing mechanism 80 therefore comprises a hip fixing element 81 by means of which the hips of the bedridden patient 90 can be fixed to the mattress 20.

[0109] FIG. 10 shows a second embodiment example of a stabilizing mechanism 80 at a preferred vertical level of e.g. 75°, in a side view.

[0110] In order to also allow at least partial relieving of the body weight in a vertical position, it is necessary to support the body weight of the bedridden patient 90 not only by means of the patients legs 92 but also partially by means of the stabilizing mechanism 80 in order to obtain a planned relief of the body weight. The amount of the body weight to be borne by the legs 92 of the patient 90 should be able to be freely adjusted as a further parameter of the planned automated rehabilitation by the physical therapist, preferably between fully relieved (0 kg) and fully loaded (full body weight). In a preferred embodiment of a bed 10 according to the invention, the stabilizing mechanism 80 therefore comprises a support harness 82 for receiving the bedridden patient 90, a winch 83 connected to the support harness 82 and the mattress frame 21 at the head end, and a sensor F by means of which the force of the patient's body weight on the legs 92 of the bedridden patient 90 can be controlled. The sensor F can be operatively connected to the winch 83 as shown. Alternatively or cumulatively thereto, however, a force sensor F associated with the foot module 50 can provide the signal data required by the control module 60 for controlling the body weight to be applied to the feet 94 of the patient 90.

[0111] Common to the embodiment examples according to FIGS. 9 and 10 is that each stabilizing mechanism 80 can be operatively connected to end stops, particularly for preventing the patient 90 from falling out or otherwise being injured, for example due to sudden opening and/or dropping of the stabilizing mechanism 80.

[0112] In daily use, the mattress 20 of a bed 10 for bedridden 90 should prevent the bedridden patient 90 from developing wounds or even bedsores. The mattress 20 should be suitably soft in design in order to prevent such damage. In addition to suitable foam materials, an arrangement in the mattress 20 of chambers 22 particularly for fully or partially filling with air is preferred (as shown in FIGS. 1 and 8 through 10). The mattress should also be suitably designed for immediately manually resuscitating at least the heart and/or lungs in the thorax 91 of intensive-care patients 90, particularly for a bed 10 implemented as an intensive-care bed. In a preferred embodiment of a bed 10 particularly implemented as an intensive-care bed, the mattress 20 thereof therefore comprises a mechanism 23 for emergency hardening, that is, for changing the hardness of the mattress 20 as a support at least in the region of the thorax 91 of the intensive-care patient 90 in case of need for immediately manually resuscitating the heart and/or lungs. One potential solution for hardening the mattress 20 of a bed 10 suitable as an intensive-care bed in a short time is to use a mattress 20 comprising chambers 22 for fully or partially filling with air at least in the region of the thorax 91 of the intensive-care patient 90. By releasing the air, the mattress 20 quickly becomes sufficiently hard for using as a support for resus-

citation efforts, such as particularly the performing of heart and lung massage. Releasing the air can be done by means of a vacuum pump (not shown) under normal conditions. In case of power loss, the mechanical and manual opening of a larger opening in the cover (e.g., several centimeters in diameter) can be provided, so that the air escapes from the chambers 22 of the mattress under the weight of the intensive-care patient 90.

[0113] In order to be able to return the mattress frame 21 of a bed 10 particularly implemented as an intensive-care bed in case of an emergency, a mechanism 71 for emergency horizontal positioning of the mattress frame 21 is provided in a preferred embodiment of such a bed 10. The mechanism 71 for emergency horizontal positioning preferably comprises at least one emergency lever 72, operable for example from the head and/or foot end of the bed 10 particularly implemented as an intensive-care bed, for example symmetrically on the left and right sides thereof, and particularly operable by a foot 94. By actuating the emergency lever 72, rapid lowering of the mattress frame 21 into the horizontal position can be initiated in a short time (for example in only about 5 seconds). If the mattress 20 comprises a mechanism 23 for emergency hardening, said mechanism can also preferably be activated by actuating the emergency lever 72 as described. In addition, it can be provided that in an emergency, the rehabilitation mechanism 30, that is, the foot 40 and knee module 50, immediately stop in positions in which the legs 92 of the patient 90 are extended. The emergency lever 72 is preferably operatively connected to the electric motor and/or hydraulic means and thus allows activation of emergency horizontal positioning even in case of power loss, preferably mechanically by further actuating the emergency lever 72, particularly by pressing the lever even further down, or by pulling. If the adjusting of the mattress frame 21 of a bed 10 particularly implemented as an intensive-care bed is performed by means of electric motors, the emergency horizontal positioning can be performed by means of the electric motors under normal conditions. In order to be able to perform an emergency horizontal positioning even in case of power loss, non-self-braking or backdrivable motors are preferred. If the adjusting of the mattress frame 21 of a bed 10 particularly implemented as an intensive-care bed was performed by means of hydraulic systems, then under normal conditions the hydraulics should also allow rapid lowering of the mattress frame 21. Hydraulic valves for discharging the pressure cylinders of the hydraulic system rapidly, but in a controlled manner, can be used for this purpose. In case of power failure, the valves can be opened manually by actuating the above-mentioned emergency lever 72, for example.

[0114] In order that bedridden or particularly intensive-care patients 90 are not subjected to excessive forces during rapid lowering of the mattress frame 21, the electric motor and/or a gearbox connected thereto for the adjusting mechanism 70 can be designed so that a predefined angular velocity is not exceeded. Alternatively or cumulatively thereto, a spring and damper system can also be provided for decoupling the motors from a mechanism in case of emergency and allowing rapid but controlled horizontal positioning of the mattress frame 21. In a preferred embodiment of a bed 10 particularly implemented as an intensive-care bed, the adjusting mechanism 70 therefore comprises an electronic angle meter 73 controlling the electric motor and/or

hydraulic means of the adjusting mechanism 70 to a definable target angle and/or angular velocity.

[0115] A responsible therapist or comparable specialist ensures, for planned automated rehabilitation:

[0116] that the knee module 50 is correctly positioned beneath the knee joint 93 and is fixed to the bed 22 or mattress frame 21 and is electrically and/or hydraulically connected as needed;

[0117] that the foot module 40 is correctly connected to the feet 94 of the patient, is fixed to the bed 22 or mattress frame 21, and is electrically connected as needed; and

[0118] that the stabilizing mechanism 80 is put on correctly.

[0119] Using the control module 60 (cf. FIG. 11) the therapist controls the desired vertical positioning angle. The therapist then selects the desired stepping speed and starts the rehabilitation motion. The control module 60 thereby controls the interplay of the foot module 40 and the knee module 50 so that the legs 92 of the patient 90 are set in cyclical motion, particularly as follows: while the knee joint 93 of the left leg 92 is bent by the knee module 50, the foot module 40 performs an ankle joint extension on the left foot 94. The knee module 50 simultaneously performs an extension of the knee joint 93 on the right knee joint 93 and the right foot module 40 performs an ankle joint flexion. The fixation to the knee joint 93 and the stabilizing mechanisms 80 ensure that the patient 90 has extended the right leg 92 and thereby bears the entire or partial body weight on the right leg 92. By alternating said procedure between the left and right leg 92, the left and right leg 92 are alternating loaded and unloaded in that one knee joint 93 is extended while the other knee joint 93 is bent.

[0120] FIG. 11 shows a control schematic of the control module 60 for controlling planned rehabilitation motions. Accordingly, a desired activity can be set up, for example by a therapist or a comparable specialist. Said desired activity can then be compared in the control module 60 with the activity currently performed by the bedridden patient 90. The activity currently performed by the patient 90 is calculated as the difference between the rehabilitation motions produced by the patient 90 and the forces that the rehabilitation mechanism 30 exchanges with the patient 90. The control module 60 can calculate the required control parameters for determining how much force the rehabilitation mechanism 30 produces in which direction, at what time, with what amplitude, etc. Said forces then act on the patient 90 by means of the foot 40 and/or knee module 50 of the rehabilitation mechanism 30. Because the control module 60 of the rehabilitation mechanism 30 knows how great the forces generated by itself are, it can calculate how great the forces produced by the patient 90 are. The forces produced by the patient and the directions thereof are measured by the force sensors F, the positions of which are known.

[0121] Cumulatively thereto, further measurements can be performed or monitoring data can be incorporated. So-called physiological sensors for measuring muscle activity (EMG) can be provided on the patient 90, for example, particularly for checking the forces produced by the bedridden patient as calculated in the control module 60. In addition, physiological parameters such as heart rate or other vital parameters of the patient 90 can be measured and particularly controlled to a desired level, in that the level of vertical positioning of the mattress frame 21 is adjusted. This is often not possible,

particularly for intensive-care beds. Thus, in addition to rehabilitation targets, care can be taken for the safety of the patient 90 in that the rehabilitation is interrupted prior to the onset of bodily overexertion, or is simplified to the point that the patient 90 experiences less bodily stress. The level of vertical positioning in particular can be reduced if the heart rate of the patient 90 increases too greatly or drops.

[0122] The control module 60 preferably comprises a control interface and display unit from which the functions described above can be accessed.

[0123] The control interface can preferably be used by the therapist for controlling some or all of the following processes, or adjusted to the therapeutic requirements and capabilities of the patient 90.

[0124] vertical position (particularly between 0 degrees and 90 degrees);

[0125] weight relief (particularly between 0% and 100% of the patient's body weight);

[0126] step frequency (particularly between 0 Hz and about 2.0 Hz or less, such as 1.5 Hz);

[0127] the radius of motion of the knee joints 93 in particular;

[0128] the amount of support force provided by the rehabilitation mechanism 30 to the patient 90 for supporting the execution of the motion (particularly between 0%—patient is moving the leg autonomously; and 100%—the patient is moved entirely by the system);

[0129] the amount of bodily activity (self-contribution) produced by the patient 90;

[0130] monitoring the heart rate of the patient 90;

[0131] additional technical and clinical parameters.

[0132] The display unit particularly displays the current status of the rehabilitation mechanism 30, particularly the current vertical position, current weigh relief, current activity, etc. . . .

[0133] The operator interface and display unit of the control module 60 is preferably also operatively connected to the emergency mechanisms 23 and/or 71.

[0134] Furthermore, the control module 60 can comprise a history memory recording the significant parameters of the planned and performed rehabilitation, in particular such as the vertical angle, the amount of weight relief, the activity, and the associated parameters and/or time duration. For example, by counting the bending and extending cycles for the knee joint 93, the number of steps can be calculated and saved as a clinical parameter.

[0135] FIGS. 12 through 15 show four further schematic embodiment examples of a bed 10 including a rehabilitation mechanism 30. The bed 10 comprises a mattress 20 as in the preceding embodiment examples, said mattress being a single piece, that is, having no recesses, slits, or the like. The rehabilitation mechanism 30 comprises a foot module 40 and a knee module 50. The patient 90 is shown schematically and the feet 94 of the patient 90 are disposed on the foot module 40. All four embodiment examples of the system shown, comprising the bed 10 and the rehabilitation mechanism 30, are designed so that the rehabilitation motion performed by the patient 90 is a walking motion, a stepping motion, or a motion simulating stair-climbing. To this end, the feet 94 of the patient are each fixed to step surfaces 42. The step surfaces 42 are rotationally disposed about an axis A. The axis A is fixed in location, as is illustrated by the fixed bearing 100. The step surfaces 42 are each pivotable independently of each other. It can also be provided that the step

surfaces 42 are connected to a mechanism such that said surfaces are displaceable in opposition in order to support the walking motion, stepping motion, and/or motion simulating stair-climbing.

[0136] The foot 94 of the patient 90 is disposed on the step surface 42 such that the toes are near the axis A. Said implementation is identical for all four embodiment examples (FIG. 12 through FIG. 15). Also common to all four embodiment examples is that the back 96 of the patient 90 lies on a sliding bearing 102 or forms the same with the mattress 20. Said circumstance is indicated by the arrow 104; the back 96 of the patient 90 can slide "up and down" on the mattress 20. Alternatively, it can also be provided that the back 96 of the patient lies stationary on the mattress, and that instead the bearing 100 is implemented as a sliding bearing and is displaceable in the same direction as the arrow 104. As a rule, however, merely lifting the heels in conjunction with rotating about an axis A lying in a plane somewhat in front of the toes is sufficient for bending the knee without making it necessary for the foot module 40 to slide toward the patient 90 or for the patient 90 to slip on the mattress.

[0137] The differences among the four embodiment examples according to FIGS. 12 through 15 are particularly in the actuating of the knee module 50 and are described below.

[0138] According to FIG. 12, the knee module is substantially implemented as shown in FIGS. 5a through 9. Said module is supported on the mattress 20 by means of a support 106 and is connected to the thigh 108 just above the knee 93 by means of a cuff 54. The actuator 53 is implemented such that the distance between the support 106 and the cuff 54 varies. The cuff 54 is thereby rotationally connected to the knee end 107 of the knee module 50. The knee module 50 is thus substantially implemented as shown in FIGS. 5a through 6. By actuating the actuator 53, the distance between the action point of the cuff 54 and the mattress 20 is changed, and thus a stepping motion is performed. Due to the attachment of the foot 94 to the step surface 42, said surface being pivotally supported about the axis A, a rolling motion of the foot 94 is performed.

[0139] FIG. 13 shows a similar embodiment, wherein the cuff 54 is disposed not on the thigh 108 but rather on the calf 110, again just below the knee 93. The method of function is substantially the same. By actuating the actuator 53, the distance between the support 106 and the cuff 54 is changed, whereby the calf 110 is raised from the mattress 20 so that a walking motion, stepping motion, and/or motion simulating stair-climbing is performed.

[0140] FIG. 14 shows an embodiment example wherein two cuffs 54a, 54b are provided for the patient 90, wherein the cuff 54a is attached to the thigh 108 and the cuff 54b is attached to the calf 110. The actuator 53 is supported on the mattress 20 by means of a frame 112. The actuator 53 is coupled to the cuff 54a and to the cuff 54b by means of a transmission 140 and implemented for changing the distance between said two cuffs 54a, 54b substantially parallel to the mattress, in order to thus provide a walking motion, stepping motion, and/or motion simulating stair-climbing as a rehabilitation motion. The transmission 114 can be implemented by means of telescoping rods, for example, or by a type of scissor mechanism. Said arrangement is particularly advantageous if the patient is very weak and is barely able to perform the rehabilitation motion independently. A scissor

mechanism has the further advantage that the forces do not need to be transmitted over long lever arms. The mechanical loading of the system is thereby reduced. Due to the two cuffs **54a**, **54b**, the forces required for extending and bending the leg are distributed to the thigh and the calf. It should be understood that two cuffs can be provided for all other embodiment examples as well, even if only one is shown. The force acting on the thigh and calf can thereby be less than if the same force were to be applied only to the thigh or only to the calf. Said mechanism is further very far from the hands of the patient. The risk of injury due to pinching is therefore reduced.

[0141] FIG. 15 shows a further embodiment example, wherein the knee module **50** acts exclusively on the calf **110** of the patient. According to the present embodiment example, the knee module **50** has an angle **118** comprising a first arm **120** and a second arm **122**. The two arms extend at about right angles to each other, wherein the first arm extends above the foot **94** of the patient **90** and the second arm **122** extends substantially along the calf **110**. The second arm **122** is fixed to the calf by means of both cuffs **54a**, **54b**. The first arm **118** is coupled to the actuator **53**, said actuator applying a rotary motion to the angle **118**. The actuator **53** itself is mounted on a sliding bearing **116** so as to be displaceable in the direction of the arrow **124**, even if not absolutely necessary. In this manner, a walking motion, stepping motion, and/or motion simulating stair-climbing can be performed particularly well as a rehabilitation motion. Rolling and applying torques to the ankle joint **126** can be particularly advantageously performed. As can be seen in FIG. 15, the arm **120** of the angle **122** extends past the foot **94**, so that the bearing **116** is disposed beneath the foot **94**.

[0142] While the FIGS. 12 through 15 illustrate various embodiment examples purely schematically, FIGS. 16 through 27 show more detailed views of said embodiment examples. FIGS. 16 through 20 substantially show an embodiment example corresponding approximately to FIG. 14, but having only one cuff; FIGS. 21 through 24 show an embodiment example corresponding approximately to FIG. 12; and FIGS. 25 through 27 show an embodiment example corresponding approximately to FIG. 15.

[0143] Similar elements are labeled with identical reference numerals, so that full reference is made to the description above. In the following the special features of the individual embodiment examples are substantially explained and the differences from the preceding embodiment examples are shown.

[0144] FIG. 16 shows a bed **10** having a mattress **20** and patient **90**. The rehabilitation mechanism **30** is releasably attached to the bed **10** and supported at the side by two struts **200**, **202** on the mattress. The rehabilitation mechanism **30**, particularly the knee module **50**, can be aligned to the patient **90** by means of said struts **200**, **202**. The foot module **40** is coupled to the knee module **50** by means of a rail system according to the present embodiment example, said system being displaceable relative to the knee module **50** and allowing guiding of the foot module **40** on the two rails **6**, **208**. The foot module **40** is attached to the mattress **20** at the foot end by means of a further strut **210**.

[0145] The rehabilitation mechanism **30** comprises a motor **53** disposed here on the knee module **50**, said motor being most easily seen in FIG. 20. The motor **53** is coupled to a scissor mechanism **212**, in turn pivoting a thigh strut

214, one end thereof being pivotally disposed on a cantilever **216**. The thigh strut **214** extends substantially along the thigh **108** of the patient **90** and ends at about hip height. The thigh strut **214** supports a cuff **54a** disposed about the thigh **108** for fixing the same relative to the mechanism. By actuating the motor **503**, the scissor mechanism **212** is adjusted and the thigh strut **214** is displaced back and forth between a horizontal position (see FIG. 18) and a slightly pivoted position (see FIG. 17). When the thigh strut **214** is raised, the heel of the foot **94** of the patient **90** is simultaneously raised. The foot module **40** is designed to allow pivoting about an axis **A** present slightly forward of the toes of the foot **94**. A walking motion is thus simulated. Because the foot module **40** can simultaneously slide on the rails **206**, **208**, "raising" of the entire foot **94**, or drawing in toward the hips, as occurs in realistic walking motions, is possible when the thigh strut **214** is pivoted far enough.

[0146] The foot **94** of the patient is thereby fixed by means of two straps. As can be seen further in FIG. 20, a telescoping strut **220** is disposed between the step surface **42**, more precisely the heel-side end **218** of the step surface **42**, and the knee module **50**. Said telescoping strut **220** can be implemented as a pneumatic spring or a mechanical spring and additional apply a force to the sole of the foot of the patient in that the step surface **42** is preloaded in a pivoted position, that is, in a position in which the heel of the foot **94** of the patient is raised. Said arrangement also promotes rehabilitation.

[0147] FIGS. 21 through 24 show an alternative. In the present alternative, the rehabilitation mechanism **30** is implemented so as to be operated solely from the side of the bed **10**. Disposing the mechanism **30** beneath the patient **90** is not required, thereby largely avoiding lifting of the patient. The rehabilitation mechanism **30** according to FIGS. 21 through 24 is attached to the frame **224** of the bed **10** in a simple manner, such as by means of clamps or the like. Such a frame **224** is typically provided as a standard for hospital beds, so that mounting of the rehabilitation mechanism **30** according to the present embodiment example is particularly simple. The rehabilitation mechanism **30** (cf. FIGS. 22 through 24) comprises a rail **300** functioning as a support for the knee module **50** and the foot module **40**. The foot model **40** is passive in design according to the present embodiment example and comprises a step surface **42** pivotally supported on a strut **302** by means of a bearing **304**. The step surface **42** is adjustable along a longitudinal direction, that is, between a toe end and a heel end, relative to the strut, in order to thus adjust a pivot axis **A**. The height of the pivot axis **A** relative to the rail **300** is adjustable by means of two struts **306** and **308** on which the strut **302** is mounted by means of a clamping connection **310**. The foot module **30** is mounted on the rail **300** by means of a mounting foot **312** and adjustable relative to the rail in the direction of the longitudinal direction of the rail **300**.

[0148] The knee module **50** comprises a support **314** extending approximately to a hip of the patient **90** in an assembled state. A thigh strut **214** is disposed on the hip end **316** of the support **314** by means of a pivot bearing **318** and extends substantially along the thigh **108** of the patient **90** (cf. FIGS. 22 and 23). The support **314** is in turn displaceably coupled to the rail **300** by means of a body **320**. The body **320** supports a motor **53** driving a piston **322**, said piston in turn being connected to the thigh strut **212** by means of a pivot bearing **324** and pivoting the same in order

to thus raise the knee 93 of the patient. In the present embodiment, the thigh 108 is connected by means of a cuff 54a coupled to the thigh strut 214 by means of a further strut 326. The strut 326 is in turn displaceably fixable to the thigh strut 214. As can be seen by comparing FIGS. 22 and 23, the rehabilitation mechanism brings about a pivoting of the thigh 108, whereby in turn a raising of the heel of the foot 94 is brought about, in order to thus produce a walking motion, stepping motion, and/or motion simulating stair-climbing. Due to the variable adjustability of the foot module 40 according to the present embodiment example, special loading conditions can be produced. As can be further seen from the present embodiment example, the rehabilitation mechanism 30 is particularly easy to stow and use on other beds 10 without having to lift the patient or transfer the patient to another bed. It is further also possible to couple two such mechanisms 30 to the bed 10 in order to apply the therapy to both legs of the patient at the same time.

[0149] FIGS. 25 through 27 largely schematically show an arrangement of a foot module 40 and a knee module as shown in FIG. 15. The knee module 50 engages exclusively at the calf 110 of the patient here as in FIG. 15. The knee module 50 has an angle 118 comprising a first arm 120 and a second arm 122. It is not absolutely necessary that both arms 120, 122 be disposed substantially at right angles to each other, rather, the angle 118 can also be implemented as a curved shaped. It is solely critical that one segment, formed here by the arm 122, extends substantially along the calf 110 of the patient and the other end, implemented here as the arm 120, is pivotally supported about an axis on a support 125, such as a bed frame or the like, by means of a joint 123. According to the present embodiment example, the joint 123 is disposed on a sliding bearing 116, even if not absolutely necessary. The calf 110 of the patient is coupled to the calf 122 by means of a cuff 54. In this manner, rotation of the calf 110 including the foot 94 about the axis G, here perpendicular to the plane of the drawing, is made possible. In the present embodiment example (FIG. 25), a motor 53 is further provided in the joint 123 and drives the angle 118 rotationally about the axis G.

[0150] The foot module 40 is preferably passive. Said module comprises a step surface 42 pivotally supported about an axis A by means of a bearing 100. The bearing 100 couples the foot module 40 to the support 125. The foot 94 is fixed to the step surface 42 by means of a strap 43. The step surface 42 is pretensioned by means of a spring 400 implemented as a compression spring on the heel side, so that a force is exerted on the sole of the foot 94 in order to configure a walking motion as realistically as possible. Because the foot 94 is fixed only by means of a strap 43, motion of the foot relative to the step surface 42 is possible and the heel can raise up away from said surface as shown in FIG. 25.

[0151] FIGS. 26 and 27 show alternative drive concepts. While the drive motor 53 in FIG. 25 is implemented as a rotary motor acting directly on the joint 123, the motor 53 according to FIG. 26 is implemented as a linear drive and can be implemented, for example, as a pneumatic or hydraulic piston. The motor 53 engages at an engagement point 402 at approximately the center of the arm 120 of the knee module 50. A rotation of the angle 118 about the axis G can also be produced by means of said motor 53.

[0152] FIG. 27 shows a further alternative for actuating the knee module 50. The first arm 120 comprises an exten-

sion 121 extending (in the assembled state) beneath the mattress 20. The motor 53 is coupled to the arm 120 at the end of said extension at a pivot point 404, wherein the motor 53 in turn is supported on a support 406 also disposed beneath the mattress 20. The motor 53 substantially corresponds to the motor 53 according to FIG. 26 and can be implemented, for example, as a pneumatic piston. Said arrangement can be advantageous if the rehabilitation mechanism 30 is disposed on the side of a bed, for example. [0153] FIGS. 28a through 29b again clarify the freedom of the foot 94 when said foot is fixed to the step surface 42 of the foot module 40. FIGS. 28a, 28b show this for a passive foot module 40 and FIGS. 29a, 29b for an active foot module 40. According to FIGS. 28a, 28b, the calf 110 including the foot 94 of the patient is shown. The foot 94 is fixed to the step surface 42 by means of a strap 43. The step surface 42 is pivotally fixed about the axis A by means of a joint. The step surface is loaded by means of a spring 400 on the heel side.

[0154] When a knee module (not shown) is activated as shown in FIG. 28b, the calf 110 is pivoted and the foot 94 is simultaneously rotated about the axis A. In order to avoid injury to the patient and allow greater freedom, the heel of the foot 94 can release from the step surface 42. To this end, it can be provided that the spring 400 is implemented so as to allow rotation about the axis A only in a certain range. The raising of the sole of the foot 94 from the step surface 42 also leads to the walking motion, stepping motion, and/or motion simulating stair-climbing being more realistic. During natural walking, the foot is also raised from the ground and the sole of the foot is unloaded. This is also achieved by means of the foot module 40 according to the invention.

[0155] The same applies substantially to the active foot module 40 as shown in FIGS. 29a, 29b. The foot module 40 in turn comprises a step surface 42 pivotally disposed about the axis A. Unlike the embodiment example as in FIG. 28a, 28b, however, the spring 400 is replaced here by an active motor 408, implemented in the present embodiment example as a linear motor and able to be implemented as a pneumatic or hydraulic piston drive, for example. A targeted force than thereby be applied to the foot 94 of the patient by means of the step surface 42 in order to achieve an even better stepping motion.

[0156] FIG. 30 finally clarifies a closed-loop control circuit for EMG control. The closed-loop control circuit 500 comprises a servo control 502 in which a defined motion profile 504 over time is converted into a force setting parameter 506. Said force setting parameter 506 is transferred to the patient 90 via the rehabilitation mechanism 30 (here designated as F Robot). The reaction of the patient is measured by means of an EMG measurement device 508 and fed back into the closed-loop control circuit via an inverse patient model 510 at the point 512. The measured EMG data are displayed to the patient and/or a therapist via a patient display 514. The therapist can adjust the defined motion profile 504 in order to thus achieve particularly good rehabilitation of the patient.

[0157] The present invention provides a rehabilitation mechanism 30 improved relative to the prior art and able to be integrated in all known clinical procedures without a problem, for patients 90 who have become bedridden for orthopedic, intensive-care, and/or neurological limitations on activity. Without having to transfer said patient 90, the present invention enables planned automated rehabilitation

of at least the joints, muscles, and tendons of the legs **92** of bedridden patients **90**. Due to the modular construction, the rehabilitation mechanism **30** can be quickly removed and is not a hindrance in either an emergency or in daily clinical activity. The ability to load the feet **94** with the complete or partial body weight of the patient **90** further trains the musculature and the skeleton and prevents degeneration of the musculoskeletal system. The ability to vertically position also trains the cardiovascular system. For orthopedic and intensive-care and neurological patients **90** this is equally important. In addition to commercially available or self-build hospital or clinical beds **10**, a rehabilitation mechanism **30** according to the invention can easily also be attached to and removed from commercially available or self-built gurneys or intensive-care beds **10**, regardless of whether the bedridden patient **90** can be brought into a partially or fully vertical position in the corresponding bed, wherein at any position of the bedridden patient **90** between a horizontal or an assumed vertical position a rhythmic loading and unloading of the soles of the feet **95** of bedridden patients **90** is supported.

1. A rehabilitation mechanism (**30**) implemented for planned, automated rehabilitation of at least the joints, muscles, and tendons of the legs (**92**) of a bedridden patient (**90**) and comprising at least

- a foot module (**40**) for operatively connecting to the feet (**94**) of the bedridden patient (**90**),
- a knee module (**50**) for operatively connecting to the knee joints (**93**) of the bedridden patient (**90**), and
- a control module (**60**) for controlling planned rehabilitation motions of at least the joints, muscles, and tendons of the legs (**92**) of the bedridden patient (**90**) by means of the foot (**40**) and/or knee module (**50**);

wherein at least the knee module (**50**) is implemented as a module for disposing between the patient (**90**) and the mattress (**20**) and supported directly on a bed (**11**) or mattress frame (**21**), and

wherein said mechanism can be reversibly releasably fixed to a hospital bed as a module and/or can be stowed beneath the hospital bed.

2. The rehabilitation mechanism (**30**) according to claim **1**, characterized in that the rehabilitation motion is a walking motion, step motion, and/or a motion simulating stair-climbing.

3. (canceled)

4. The rehabilitation mechanism (**30**) according to claim **1**, characterized in that in addition to the knee module (**50**) the foot module (**40**) is also implemented as a module for disposing above the mattress (**20**) and supported directly or indirectly on a bed (**11**) or mattress frame (**21**).

5. (canceled)

6. The rehabilitation mechanism (**30**) according to claim **1**, characterized by two guide rails (**31**) for mounting one on each long side (**12**) of a bed (**11**) or mattress frame (**21**).

7. The rehabilitation mechanism (**30**) according to claim **6**, characterized in that the foot (**40**) and the knee module (**50**) comprise suitable fixing means (**41**, **51**) for variably fixing along the long sides (**12**), by means of which the modules (**40**, **50**) can be advantageously operationally connected to the feet (**94**) and knee joints (**93**) of the bedridden patient (**90**), corresponding to the anatomical conditions, wherein the fixing means (**41**, **51**) are variably adjustable in the transverse direction of the bed (**10**).

8-15. (canceled)

16. The rehabilitation mechanism (**30**) according to claim **1**, characterized in that the foot module (**40**) is constructed similarly to a fitness stepper having step surfaces (**42**).

17. (canceled)

18. The rehabilitation mechanism (**30**) according to claim **1**, characterized in that the foot module (**40**) comprises an adjusting lever (**44**) by means of which a distance between a step surface (**42**) and the sole of the foot (**95**) can be finely adjusted, for example.

19. The rehabilitation mechanism (**30**) according to claim **1**, characterized in that said mechanism comprises at least one sensor (F, EMG) by means of which any self-contribution by the bedridden patient (**90**) when executing planned, automated rehabilitation motions can be quantified by measuring compressive forces (F) on the soles of the feet (**95**) of the patient (**90**).

20. The rehabilitation mechanism (**30**) according to claim **1**, characterized in that said mechanism comprises at least one sensor (F, EMG) by means of which any self-contribution by the bedridden patient (**90**) when executing planned, automated rehabilitation motions can be quantified by measuring compressive and/or tensile forces (F) at the knee module (**50**).

21. The rehabilitation mechanism (**30**) according to claim **1**, characterized in that said mechanism comprises at least one sensor (F, EMG) by means of which any self-contribution by the bedridden patient (**90**) when executing planned, automated rehabilitation motions can be quantified by measuring muscle activity (EMG) or muscle forces (F) in the legs (**92**) of the patient (**90**).

22. The rehabilitation mechanism (**30**) according to claim **1**, characterized in that the control module (**60**) accesses compressive and/or tensile force measurement signals for controlling planned, automated rehabilitation motions.

23. (canceled)

24. The rehabilitation mechanism (**30**) according to claim **1**, characterized by a biofeedback module for providing visual and/or audible feedback to the patient (**90**).

25. A bed (**10**) for bedridden patients (**90**), at least comprising a rehabilitation mechanism (**30**) according to claim **1**.

26. The bed according to claim **25**, further comprising an adjusting mechanism (**70**) suitably designed for adjusting the mattress frame (**21**) at least between a horizontal and a vertical position from which the mattress frame (**21**) can be returned to the horizontal position at any time; further comprising a stabilizing mechanism (**80**) suitably designed for stabilizing the bedridden patient (**90**) with respect to the mattress (**20**), wherein the stabilizing mechanism (**80**) comprises a hip fixing element (**81**) by means of which the hips of the bedridden patient (**90**) can be fixed to the mattress (**20**).

27-28. (canceled)

29. The bed (**10**) according to claim **26**, characterized in that the stabilizing mechanism (**80**) comprises a support harness (**82**) for receiving the bedridden patient (**90**), a cable winch (**83**) attached to the support harness (**82**) and the head of the mattress frame (**21**), and a sensor (**84**), by means of which the body weight force on the legs (**92**) can be applied to the legs (**92**) of the bedridden patient (**90**).

30-32. (canceled)