Innovative Devices for Bedridden Older Adults Upper and Lower Limb Rehabilitation: Key Characteristics and Features

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Abstract. Older adults are often bedridden as a consequence of acute disease that leads to hospitalization. Immobilization in a bed for a long period can affect negatively the function of many body systems, especially when talking about skeletal muscle. Lower limbs are strongly affected which will difficult the achievement of independence and will slow down the discharge moment. This study aims to identify the current patents of medical devices that allow for physical rehabilitation of bedridden patients, particularly of upper and lower limbs. Also, the scope of this patent review is to describe the key characteristics and features of the identified devices. A patent review was conducted between May 2019 and July 2019, identifying 39 devices for physical rehabilitation of bedridden patients. The majority of the devices are designed for lower or lower/upper limbs rehabilitation, which allows for early prevention or even reversion of main immobilization complications like physical disability. Modularity, flexibility, and automation are important features of the developed mechatronic solutions and seem to be able to enrich and promote a more efficient rehabilitation program in hospitals and nursing homes.

Keywords: Self-help devices · Exercise · Bed rest · Rehabilitation · Aged · Aged, 80 and over · Mechatronic system · Bedridden elderly people

1 Introduction

Institutionalized older adults are often confined to a bed for many days, weeks or even months. Only after the 1950s, bed rest effects on the human body started to be studied in depth [1] since previously, bed rest was a common recommendation for the majority of traumatic events that lead a person to a hospital.

Either the case, in acute, subacute or chronic disease, bed rest is highly probable as a therapeutic method. Although being a way to promote a systematic recovery, immobilization is not devoid of major complications, like loss of muscle mass, lower limb weakness, respiratory and cardiovascular system atrophy, pressure ulcers, deep vein thrombosis (DVT), urinary tract infections (UTI) and pneumonia [1, 2].

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Therefore, hospitalized older adults due to acute or subacute diseases can experience long-term disability symptoms, having a high probability to develop new disabilities, compared to the pre-hospitalization phase [3–5]. This is true, since the lack of muscle and bone stimulation damage their function, particularly in the lower limbs [6].

Early mobilization, particularly in this kind of patients, is very important to prevent or reverse complications [7, 8], which, when present, might delay the discharge moment, increase family and patient's anxiety, increase institutional costs and other long-term negative outcomes.

Some authors [9], after studying a group of stroke patients, report that physical sequels are the most prevalent after institutionalization periods, namely 'hemiparesis' and 'inability to walk without assistance'. Another study [10] also reports this, stating that physical complications, like 'upper extremity weakness', are primary contributors to prolonged disability.

Also, there is an important geriatric syndrome distinct from disability [11], which is frailty. The decline in functionality during and after an acute hospitalization is a severe output and there are some studies [12] that indicate that multicomponent exercise interventions might reverse this decline.

In fact, early mobilization is good for the health of skeletal muscle [13–15] and is particularly important to reverse frailty [11].

Considering that nurses have an important responsibility in preventing complications related to immobility, by delivering proper physical care to promote and maintain muscle tone and skeletal density in upper and lower limbs in bedridden patients, it would be an advantage to develop more efficient ways to perform this.

In this sense, it is an advantage, if efficient and secure to both the professional and to the patient, to use a device that allows for active and/or passive mobilization, without the necessity to rise from bed.

Thus, this study aims to identify the current patents of medical devices that allow for physical rehabilitation of bedridden patients, particularly of upper and lower limbs. Also, the scope of this patent review is to describe the key characteristics and features of the identified devices.

2 Method

A patent review was conducted between May and July 2019 with recourse to the following databases: European Patent Office (EPO) for patents registered in the European Region and Google Patents for patents registered outside of Europe, namely in the United States.

The following descriptors were used: *"self-help devices"; exercise; "bed rest"; rehabilitation; aged; "aged, 80 and over"; "mechatronic system"; "bedridden elderly people"*.

The inclusion criteria for the medical devices were being registered in the above-mentioned databases, having a summary of the invention and the respective objects available in the patent description, allow upper, lower or both limbs exercises.

The exclusion criteria for the medical devices were: devices that allow exercise in patients, except bedridden.

3 Results and Discussion

This review allowed for the identification of 45 novel medical devices (Fig. 1), which were specifically designed for physical exercise of patients and were registered between 1949 and 2018.

After the review of the devices' descriptive documents, the research team excluded 2 documents because they were duplicated and 4 documents because they described devices that did not allow for exercise in bedridden patients (exclusion criteria).

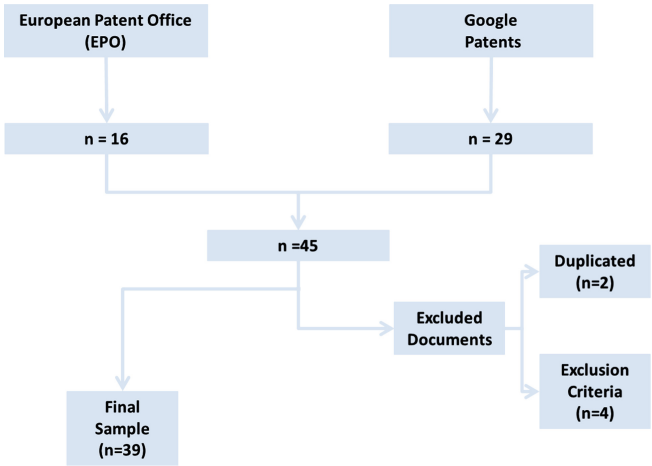

Fig. 1. Patent review process flowchart. The initial sample was constituted by 45 articles, from which 6 were excluded, either by being duplicated or met exclusion criteria. The final sample gathered 39 documents of registered patents.

The final sample ($n = 39$) is representative of the devices for physical exercise and rehabilitation of bedridden patients in the last 70 years. The main key characteristics and features can be found in Table 1.

Of the 39 devices identified, 36% ($n = 14$) were patented in the European Region and 64% ($n = 25$) in the United States. All of the devices are indicated for the physical rehabilitation of bedridden patients, by means of different physical exercises, positions, and interactions between components (Table 1).

From the 39 devices, 38% ($n = 15$) only describe the possibility to exercise lower limbs (D1, D4, D5, D6, D7, D9, D10, D16, D18, D29, D30, D31, D34, D36, D38), 3% ($n = 1$) only exercises upper limbs (D23), and 26% ($n = 10$) are able to exercise both upper and lower limbs (D15, D17, D19, D21, D24, D26, D28, D32, D33, D39). This means that 64% ($n = 25$) are able to rehabilitate lower limbs, which is consistent with the literature, that states that lower limbs are more damaged with bedrest [6]. Along the last 70 years, the effort was in developing lower limb rehabilitation devices, rather than upper limbs. In fact, upper limbs are not strictly ignored by the programs to be developed. For example, D1 describes the possibility to operate the pedals using the arms, which also promotes the person's independence in its self-care.

Table 1. Key characteristics and features of medical devices (n = 39) for physical exercise in bedridden patients.

Year	No.	Name	Patent	Key characteristics
1949	D1	Exercising device	US2484153	Lower limbs; Pedals (can be operated by the upper extremities); Massages for the sides of the legs; Modular; Attachable to a bed
1956	D2	Exercising Apparatus	US2772881	Hand and foot control; Exercises joints and muscles; Able to attach to a bed or wheelchair; Simple to operate
1972	D3	Exercise apparatus and method for paralytic patients	US3693614	Circular or rotary motion in vertical planes; Indicated for the arms and legs of paralytic patients' subject to muscle spasms; Physiotherapy; Motor and pedals; Modular
1973	D4	Spring Type Leg Exercise Device	US3749400	Lower limbs; Longitudinal movements with resistance; Attachable to bed and wheelchair
1975	D5	Patient Lift and Exercise Apparatus	US3877421	Able to lift the patient and exercise his lower limbs; Motor; Adjustable; Minimal nursing effort
	D6	Exercise Apparatus for Bedridden Patients	US3887180	For bed only; Adjustable for patient's position; Prevention of blood clots by stimulating blood stimulation in lower limbs; Patient operated
	D7	Therapeutic Foot Rest	US3901228	Lower limb exercise; Restriction to upright position
	D8	Foot Exercising Device	US3917261	Both foot exercises with a pedal; Motor; Active and passive exercise; Self-controlled or motor controlled; Prevention of thromboembolism of bedridden patients; Can be used in prone or sitting positions

(*continued*)

Table 1. (*continued*)

Year	No.	Name	Patent	Key characteristics
1979	D9	Led Exercising Apparatus	US4159111	Lower limbs; Normal walking mimic; Prone or sitting positions; Able to prevent varicose veins or thrombosis; Light in weight
1983	D10	Portable multiple use exerciser	US4422635	Promotes blood circulation; Light exercise of weakened muscles; Able to be used while in a chair or lying in bed; Lower limbs
1986	D11	Horizontal force exercise apparatus	US4614338	Weight lifting
	D12	Motorized Exercise Apparatus for Mounting on Hospital Bedrail	US4615335	Motor; Portable; Indicated for stroke patients who can't stand or sit; Rotational movements of the arm or leg while in bed
1990	D13	Bed-Mountable Leg Exercise Device	US4925184	Cycle-like device for post-operative exercise while in bed; Pedal; Minimal nursing staff effort
1991	D14	Exercise Machine for Patients Confined to Bed	US5005829	Easy active exercise for patients; Elements in good reach; Resistance exercises
	D15	Orthopaedic Exercise Frame	US5035233	Lower and upper extremity; Motor-driven; Modular
1996	D16	Exercise machine	US5518474	Pedals; Air pump/resistance; Modular; Sitting position; Multi-tasking; Lower limbs
2000	D17	Adjustable resistance exercise device	US6036626	Adjustable; Strings; Different exercises; Resistance; Portable; Upper and lower limbs
	D18	In-Bed Exercise Machine and Method of Use	US6152855A	Portable; Lower limbs strength training; Closed kinetic chain in concentric and eccentric modes and for isometric, isotonic and isokinetic exercise

(*continued*)

Table 1. (*continued*)

Year	No.	Name	Patent	Key characteristics
2001	D19	Bed Exercise Machine	US6241642	Ropes; Upper and lower limbs; Adjustable; For patients with missing limbs; Easy installation; Light in weight; Portable; Blind people (force adjustments without visual confirmation); Small increments in range of motion
2005	D20	Means and Method of Exercising Feet and Legs of Bedridden Patient	US6935991	Shoe-attachable unit; Passive exercise; Exercise with shoes
	D21	Self-exercise device for limited mobility patients and method of exercise	US20050119095A1	Auto-mobilizations; Modular; Strands; Decrease pain; Lower and upper limbs
2011	D22	Multipurpose stretching/exercise cane	US7967021	Multipurpose: walking, muscle stretching, exercising; Light weight
	D23	Variable-resistance exercise device	US20110237407A1	Portable; Variable-resistance exercise; Lightweight; Adjustable; Data storage (e.g., number of repetitions) to an external computer; Upper limb
2013	D24	Exercise Apparatus and a Brake Mechanism	US8602943	Upper and lower limbs; Resistance; Braking system; Motor.
2014	D25	Rehabilitation training frame for bedridden patients	CN203090356	Elastic bands; Modular; Simple structure; Neurosurgical patient.
	D26	Limb exercise recovery device for bedridden patients	CN203777600	Adjustable; Indicated for amputations or partial limb paralysis; Upper and lower limbs; Simple structure; Low cost; Modular
	D27	Simple self-help exercise bed for bedridden patients	CN203989708	Simple; Modular; Low cost; Muscle of the arms, legs and waist can be exercised at the same time

(*continued*)

Table 1. (*continued*)

Year	No.	Name	Patent	Key characteristics
2015	D28	Limb exercise device for bedridden patients	CN204447140	Adjustable; Sliding; Indicated for early stroke recovery; Upper and lower limbs; Simple structure; Low cost
	D29	Lower limb function exercise device	CN104586607	Solves the problems of chicken tissue atrophy, tissue adhesion, joint stiffness and poor blood circulation; Improves quality of life
	D30	Ring type leg exerciser	CN105147502	Lower limbs; Only allows passive movements by the professional
	D31	Bed lower limb vertical exerciser	CN204106959	Vertical motion; Lower limbs; Simple structure
	D32	Limb exercise device for bedridden patients	CN204447140	Adjustable; Sliding; Indicated for early stroke recovery; Upper and lower limbs; Simple structure; Low cost
	D33	Patient support apparatuses with exercise functionalities	US9125785	Closed chain exercise functionalities; Upper and lower limbs
2016	D34	Leg exercise bed	CN105310857	Lower extremities; Promotes blood circulation; Standing function; Low cost Simple structure
	D35	Bedridden patient exercise device	CN105943304	Massage manipulator; Motor; Automatic exercise; Prevents lung infection, muscle atrophy, thrombosis
2017	D36	Lower limb rehabilitation treatment device	CN106963610	Lower limbs; Air pump for resistance; Vertical movement; Improves venous blood flow stagnation; Avoids deep vein thrombosis and atrophy of muscle; Reduces feeling of joint stiffness; Shortens rehabilitation period

(*continued*)

Table 1. (*continued*)

Year	No.	Name	Patent	Key characteristics
2018	D37	Medical bed rest patient rehabilitation device	CN108607198	Sliding; Treadmill
	D38	Lower limb rehabilitation device for bedridden patient and using method thereof	CN108743278	Lower limbs; Motor; Cam; Patient's foot can be at rest and massaged by fixing the patient's sole and performing all-round compression; Promotes blood circulation in the patient's foot and accelerates the recovery of the patient's foot
	D39	*Medical body rehabilitation exercise device*	*CN108888902*	Slider; Upper and lower limbs

Some devices describe a specific way to promote limb health, either by allowing a massage (D1, D35, D38), exercising muscles and joints differently (D2), allowing different types of motion (circular or rotative) in vertical planes (D3, D31, D36), horizontal planes (D28, D32, D37) or complex planes (D12). Flexibility in these kinds of devices seems to be an important factor to allow for different types and forms of rehabilitation programs, which will also allow the healthcare professional to design a specific program.

There are devices that allow for differentiated exercises, which may imply the introduction of progression in the physical exercise programs to be implemented. Actually, the inventor of patent D18 - In-Bed Exercise Machine and Method of Use, Robert C. Dean, which, together with the inventors of D3 (Kenneth A. Schon), D20 (Denise F. Mangino), D21 (Will Kramer) and D38 (unidentified authors), describes a method to be used along with the novel device. The author identifies seven principles of in-bed exercises to be accounted for:

1. Overloading of the muscles must occur through voluntary muscular actions;
2. Intensity during exercises is required to increase the power output of the muscles and not just their ability to overcome maximal resistances;
3. Training volume is a measure of the total work performed over a time period;
4. Periodization refers to incorporating variation in training volume and intensity;
5. Progressive overloading of the muscles is required to produce gains in strength and power;
6. Rest periods between sets of an exercise, between exercises and between training sessions are essential to the success of a program;
7. Specificity means that each muscle group requiring strength must be trained in a fashion similar to that required during use.

Moreover, along with these seven principles, three criteria should be met before starting any program: (i) A means of providing forces up to body weight and a bit

beyond; (ii) A means of joining any bed and the exercise machine into a single exercise unit that is capable of safely supporting said body-weight-level forces and the reaction forces from the patient; (iii) A means of providing said forces in a manner that simulates weight-bearing and functional activity.

In fact, devices like D4, D14, D16, D17, D23, D24 and D36 allow for resistance training, by presenting air pumps/compartments or having components like elastic bands, which contribute to adding difficulty to the exercise performed. This type of training has a positive effect on functioning maintenance, improving physical fitness and functionality of older adults [16].

Many devices are designed specifically for a particular group of patients or pathologies like paralytic patients subject to muscle spasms (D3), blood circulation deficits (D6, D8, D9, D10, D29, D34, D35, D36, D38), stroke patients (D12, D28, D32), post-operative patients (D13), amputation contexts (D19, D26), blind people (D19) and neurosurgical patients (D25).

Only two inventors – Cicero C. Brown (D5) and Howard P. McJunkin (D13) – refer directly the possibility to minimize the effort of the nursing staff, while others, indirectly, refer a way to perform active exercises (D8 and D14), auto-mobilizations (D21) or automatic exercise (D35). It would be important to increment this outcome since it's a significant motivation for the development of these novel devices.

Restriction of movements and/or positions should be avoided, by promoting structural flexibility, like the devices described until now. There is one device (D30) that does not contribute to the reduction of workload, by restricting its function to passive movements performed only by the professional. The independence of the bedridden older adults is an important achievement [17] and activities of daily living (ADLs) should be associated with the device in use.

Some devices promote long-term independence in several ADLs by early exercising lower limbs for walking activities (D9 and D22). Also, some devices foresee an attachable function to a wheelchair (D2 and D4), which is an interesting feature, if the professional starts an early transition to walking training. Other devices are able to exercise while in a sitting position (D8, D9, and D16), which will also contribute to the long-term outcome achievement of a complete orthostatic position and its maintenance.

There also seems to be a general concern about usability and ergonomic features like portability (D10, D12, D17, D18, D19, and D23), low cost (D26, D27, D28, D32, and D34), and lightweight (D9, D19, D22, and D23), together with a description of quality of life (QoL) improvement (D29), either by relaxation (e.g., applying a massage, as seen previously) or reducing pain (D21).

Despite these important features, none of the devices drew attention to safety measures, which could be implied by some descriptions or device drawings. Nevertheless, it's a necessary component of any novel device and medical intervention [18] and should be introduced when developing or upgrading such works.

4 Conclusion

The development of novel solutions to improve physical rehabilitation programs for bedridden patients, by means of efficacy and safety of the devices, has a heterogeneous evolution through the last 70 years.

The majority of the devices are designed for lower or lower/upper limbs rehabilitation, which allows for early prevention or even reversion of main immobilization complications like disability. Modularity, flexibility, and automation are important features of the developed mechatronic solutions and seem to be able to enrich and promote a more efficient rehabilitation program in hospitals and nursing homes.

In this sense, nurses can contribute to the prevention of complications related to immobility in a more effective way, also involving the patient in the rehabilitation process, with positive health outcomes, thus increasing quality of life.

The limitation of this study is related to the restriction of patent review from EPO and Google Patent databases, which might imply that similar devices were missed from this review.

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