Infrared Monitoring of Oxygenation Process Generated by Robotic Verticalization in Bedridden People

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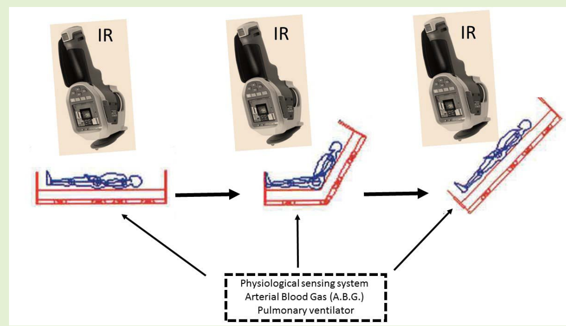
***Abstract*—Bedridden people, especially at home, suffer from diverse pathologies beyond the main one that brings them to a specific position. Long-term cares are suitable at home to avoid congestions within hospital facilities. There are different technologies available to improve such people's conditions in their daily life. The standing posture is the key solution to enhance people's wellness amid the psychological burden due to the almost impossibility to be completely healed. The paper proposes the use of a polyfunctional and robotic bed capable of displaying many positions namely vertical, tilting, anti-trendelenburg with necessary graduation. A three-year monitoring of a patient, using a polyfunctional and robotic bed, suffering from amyotrophic lateral sclerosis (ALS), has been investigated. Different physiological parameters have been measured and, particularly, the variation of temperature has been measured in presence of body position connected to the robotic bed rotation that provokes biomechanical effort. It is demonstrated that certain body positions correspond to major and minor physical effort, hence major and minor oxygenation. An infrared camera has been used. As a positive result, the variation of posture has been delaying the increase of the pathological signs, because of better conditions.**



***Index Terms*—Homecare sensors, bedridden people, elderly patients, infrared sensors, biomedical measurements, neuro-physical respiratory rehabilitation, robotic beds, amyotrophic lateral sclerosis, alzheimer, COVID-19 treatment.**

I. Introduction

BEDRIDDEN people, as well as physically handicapped people, suffering from a panoply of diverse diseases, are requested to practice standing postures several times daily. Moreover, even though the standing posture [1] is the best position, other positions such as anti-trendelenburg with lateral tilting are also welcome for pulmonary drainage as an instance. A lack of standing posture and other physical motions bring [2] to an immobilization whose effects are displayed in Table I. This table illustrates the connection between the effect/action and its impact on human tracts. Taking as an example of the respiratory tract, in case of long immobilization, as it is meant in this paper, a pathology yielding to: low breathing, major endo-abdominal pressure, and respiratory infections. These are generally the effects of prolonged immobilization but also due to pathologies such as coronavirus disease 2019 (COVID-19) [3]. This is an example but in fact, immobilization, as well as COVID-19, brings to all the effects included in Table I. To fight these physiological deteriorations, it is imperative to deploy technologies capable of reducing the impact on human physiology. These technologies are the following: lifters for disabled people, beds for the disabled, and robotic mechatronic beds. Lifters are simple to use and they are generally manual without any automatism and electric drives [4]. They are used to lift a person from a bed and a seat, and vice versa. There are dedicated beds for disabled and elderly people. They are equipped with electric drives [5] for allowing standing up, sitting down, and few positions

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TABLE I
PHYSICAL IMMOBILIZATION AND ITS EFFECTS ON HUMAN PHYSIOLOGY

Action or effect	**Impacted system**
Bedsores formation	Integumentary (skin)
Reduction of muscular mass and force, osteoporosis, fracture, vertebral collapse, and ligamentous laxity	Locomotor (muscles, bones, articulations)
Difficult swallowing in supine position, anorexia, constipation	Gastroenteric
Deep venous thrombosis, Pulmonary embolism, increasing cardiac frequency,	Cardiovascular
Low breathing, major endo-abdominal pressure, respiratory infections	Respiratory
Urinary incontinence, difficult control of urination	Genito-urinary
Reduction of sensory stimuli, mental process slowdown, low capacity of direction	Nervous and psyche

controlled by the drive. Both types of the bed display their limitations. The use of a medical bed for rehabilitation, or in general, any other apparatus, needs a preliminary assessment of the patient under treatment. This assessment requires, in the case, for instance, of COVID-19 or post-acute COVID-19 [6], a series of monitoring and tests such as measurement of the degree of dyspnea, biomechanical issues such as joint range motion, blood oxygen saturation, heart rate variability, respiratory frequency, and blood pressure. The postural configuration is the key issue of this kind of rehabilitation. Changing the positions, thanks to bed movement, brings to the reduction of the degree of dyspnea. Postural changing is a preliminary step for allowing the patient to walk. Given the fact, walking is a strong activity that allows the major generation of oxygen [7] which is beneficial as neuro-rehabilitation [8]. According to the above considerations, the use of biomechanical apparatus such as dedicated beds or robotic gyms is necessary, especially to make the work of home carers easier. The use of robots for training in neuro-rehabilitation takes a strong utilization in the early 1990s; they were used to fight post-stroke disease especially for the rehabilitation of the shoulder and elbow. The robot [9] was equipped with an anti-gravity module pilot. That is an example of a home wellness robot. Rehabilitation has been taken a step further by the introduction of embedded manipulators with robotic beds to increase the amount of training and quality of results. Such a robot has been used with a person suffering from quadriplegia [10]. Globally speaking, the results suggest that a robotic bed and a mobile manipulator can work collaboratively to provide effective personal assistance and that a combination of the two robots is beneficial. However, the use of only manipulators started in the 1960s for functional activities of daily life. For some tasks involving caregivers without precise attention to beds, only manipulators without robotic beds [11] were used. It is mandatory to keep physiological parameters under control before, during, and after neuro-rehabilitation trials. In this sense, monitoring devices are necessary, in particular, sensing systems. The

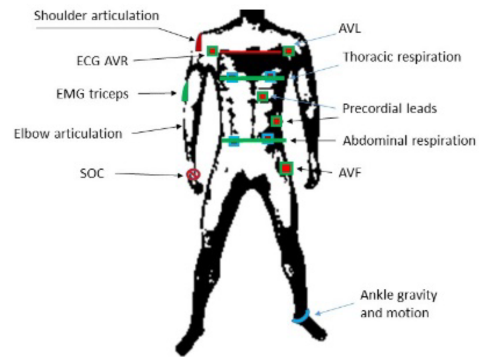

Fig. 1. Main points which biomedical signals are acquired from.

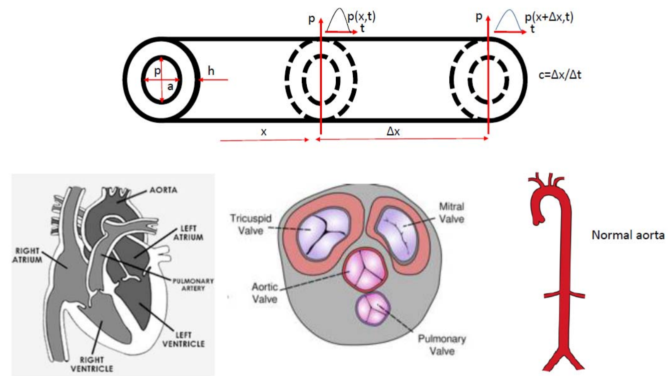

Fig. 2. Measurement schematic of pulse-wave schematic (top), full heart representation (bottom left), cross-section (bottom center), and normal aorta (bottom right).

sensors dedicated to rehabilitation are mostly dedicated to different parameters notably motion assessment [12], and others as reported in Fig.1; control of shoulder articulation by accelerometer and gravity sensor, an ECG AVR (electrocardiogram augmented vector right), an EMG triceps (electromyography) [13], elbow articulation accelerometer, AVL (augmented vector left), thoracic respiration, precordial leads for ECG, augmented vector foot (AVF), ankle gravity and motion, and SoC (system on chip). SoC [14] is an advanced complex of concentrated and small devices, incorporated in one system for sampling and processing physiological data.

II. POLYFUNCTIONAL AND ROBOTIC BEDS

As it is mentioned in the introduction, robotic beds, along with manipulators, are necessary for the neuro-rehabilitation of people suffering from pathologies seeking long-term care such as ALS, quadriplegia, Alzheimer's, acute hemiplegia, and in general acute pathologies that determine the impacts displayed in Table I. To meet the challenge of neuro-rehabilitation for home wellness, and in the sequel to the above table effects, two broad areas of physiological parameters are taken into account, cardiovascular mechanics and pulmonary circulation. Both are beneath oxygenation.

A. Impact on Aortic Stiffness

Human body immobilization must certainly bring effects on the aorta organ since the blood flow is pulsatile [15]. The pulse-wave velocity Vp, given the artery of Fig. 2 (top) is expressed in terms of its dimensions, as

$$V_p = \sqrt{\frac{Eh}{2ap}} \tag{1}$$

which is derived from the governing pulse-wave propagation differential equation

$$\frac{\partial^2 p}{\partial x^2} = \left(\frac{1}{V_p^2}\right)\frac{\partial^2 p}{\partial t^2} \tag{2}$$

to be considered along with the stress of the arterial wall

$$\sigma = \frac{pa}{h} \tag{3}$$

in which σ is the wall stress. The below nomenclature is used for the aforementioned equations, that is E stands for the elastic modulus of the arterial wall, a is the aortic inner radius, and h means the arterial wall thickness.

The hardened artery disease, otherwise called arteriosclerosis, can be characterized using the aortic constitutive property of its wall elastic modulus (E) with respect to wall stress (σ), by determining the elastic modulus per cycle and the wall stress, by using the following relationships,

$$E = \frac{2aV_p^2\rho}{h} \quad and \quad \sigma = \frac{P_d a}{h} \tag{4}$$

in which ρ is the blood density, and the wall elasticity can be expressed as

$$E = E_0 + E_1 e^{b\sigma} \tag{5}$$

in which b is denoted as a constitutive parameter of the artery, E_0 is the elastic modulus of the arterial wall at the initial instant, and E_1 is the incremental elastic wall elasticity [16], [17]. The last two equations, namely, Eq.(4) and Eq.(5) are the basis for the use of ultrasound [18] to measure the dimensions of the artery [19], notably a, and h, and the auscultatory diastolic pressure P_d, as well as the V_p, with reference to the time necessary by a pulse to traverse two aortic cross-sections as reported in Fig.2. This latter also shows the position of the aorta within the cardiac complex (bottom). Eq. (5) implicitly includes the oxygen present in the density and blood mass. A lack of oxygen reduces the tension of the aorta tract.

B. Pulmonary Circulation

Lungs are the primary organs connected to breathing hence oxygen. Characterization of the mechanical function of breathing (WOB) has been in use in clinical research for many years and has provided valuable ideas in pathophysiological derangements that exist in patients with chronic obstructive pulmonary disease (COPD). WOB is increased at rest in flow-limited COPD patients, mainly due to increased flow resistance and elastic loads on the inspiratory muscles.

By definition, the WOB [20] can be calculated using the linear first-order differential equation model as follows:

$$WOB = \int_0^{t=T} P_N \frac{dV}{dt} dt \tag{6}$$

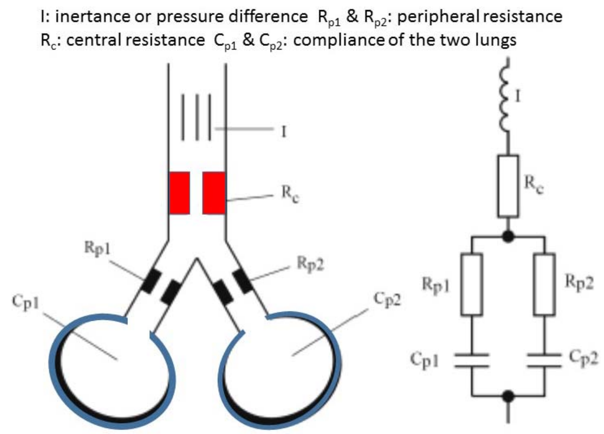

Fig. 3. Two-compartment lung linear model for determining the input impedance: physical model (left), and electrical analogue (right).

Here, $P_N(t)$ is the clinical driving pressure and is given by

$$P_N(t) = R\frac{dV}{dt} + \frac{V}{C} = \sum_{i=1}^{3} P_i \sin(\omega_i t + c_i) \tag{7}$$

the right-hand side symbolizes the net driving pressure normalized to its value at the end of expiration and the associated lung volume response $V(t)$ is derived from [21]. R and C are the resistance and the capacitance of the pulmonary circuit respectively [22].

Recalling [20], P_i is generally determined with at least three blocks of values, that is with $i = 3$, then knowing P_i (P_1, P_2, P_3) in cm H_2O, ω_i (ω_1, ω_2, ω_3) in rad/s, and c_i (c_2, c_2, c_3) in rad. In this way Eq.(7) can be solved in function of the time as

$$\frac{dV}{dt} + \frac{V}{RC} = \frac{1}{R}P_N(t) \tag{8}$$

so that the corresponding lung volume $V(t)$, in liter (L), can be retrieved. Hence a process of verticalization, then a stand-up position, should make easy the respiration process by reducing the resistances included in the pulmonary circuit. The verticalization lowers the WOB. Further confirmation of stand-up position is displayed by the linear lung model for impedance determination reported in Fig.3. For a person with breathing derangement, there is an increase of peripheral resistance due to the elbow appearing in the lung circuit, especially in the supine position. This increase cannot facilitate oxygen circulation.

Undoubtedly, oxygen assumes positive and pervasive importance within the physiology of a bedridden person. Hence the stand-up position is certainly the best one. Moreover, the two-compartment lung linear model also suggests that the two compartments that are lungs should be “shaken” with a low pendulation motion to avoid deposition within the lungs, and along the tract where the central resistance R_c is located. This is to avoid obstruction and difficulty in breathing because of possible mucus accumulation. The pendulation motion suggests the adoption of lateral tilting and rotation for the robotic bed.

We must be aware that the above considerations are close to those associated with some pathology such as COVID-19.

TABLE II
MAIN TREATMENTS PERFORMED BY THE POLYFUNCTIONAL AND ROBOTIC BED

Ref	Treatment
1	Unilateral and bilateral kinetic therapy, from 0° to 60°
2	Trendelenburg and anti-trendelenburg positions even over 30° forseen by Med. Dr. Trendelenburg (1844-1924)
3	Rotational therapy on a variable tilting angle up to 60°
4	Pulmonary drainage therapy
5	Vertical therapy up to 80°
6	Feet corrective therapy
7	Head corrective therapy
8	Rotational therapy for neglect syndrome
9	Moving psychological therapy

Recent studies on the effects of COVID-19, especially the clinical features of patients with COVID-19, indicate that infection with SARS-Cov-2 causes severe, and sometimes fatal, acute lung injury like SARS-CoV infection, often requiring intensive care and oxygen therapy [23]. In case of Non-invasive ventilation failure, resulting in respiratory acidosis and/or refractory hypoxia despite raising levels of inspired oxygen (FiO_2), the fatigue of the respiratory muscles, or reduction of consciousness, patients were admitted to intensive care for intubation and mechanical ventilation. In [24] all intensive care COVID-19 patients received lung-protective respiratory support, consisting in low tidal volume (4-5 ml/kg on ideal body weight), at the lowest fraction of inspired oxygen (FiO_2) able to maintain oxygen saturation (SpO_2) higher than 90%, with positive end-expiratory pressure (PEEP) titrated to keep a driving pressure lower than 14 cm H_20. The respiratory rate was regulated to maintain either carbon dioxide pressure (pCO_2) lower than 55 mmHg or pH higher than 7.2. Thus, post COVID-19 or critical patients, maybe in intensive care, can be positioned on a bed having certain and peculiar characteristics for implementing stand up, lateral tilting, and rotating positions. It is used in addition to pharmacological treatments, polyfunctional and robotic beds.

III. TREATMENT CASE STUDY AND INFRARED MONITORING

Considering the pathologies and derangements illustrated in Table I of Section 1, we have found that a polyfunctional bed that must work to alleviate the consequences of the considered pathologies, by helping the production and circulation of oxygen, should implement the treatments displayed in Table II. The list of treatments includes notably verticalization, rotation, lateral tilting, and pulmonary drainage through bi-lateral tilting on the inclined plane.

Three types of polyfunctional and robotic beds, for neurorehabilitation, have been designed, constructed, and are available in the market. They are the result of technical and scientific cooperation between the Measurement and Instrumentation Laboratory I of the University of Salento, shepherd by the corresponding author of this paper and the Roam 2000 Srl company [25]. One of the beds has been using since May 2017 for treating a 77-year-old patient, affected by ALS, a former football player; more than 3 years of using

Fig. 4. Instrumentation and sensing systems beneath the patient bed, and infrared camera.

Fig. 5. Partial and opposite view of pulmonary ventilator and bed cross-section with the patient.

the bed are sufficient to try to understand the evolution of his conditions. The scope is not to stop the pathology, which is neurodegenerative but to delay and postpone the irreversible effect of ALS. The "mother bed", one of the three, is very complete since it can exhibit 40-52 positions in the plan and space. It is also useful to trigger nano-drug utilization [26]. The polyfunctional and robotic bed is also a chair. This version of the bed, provided by Roam 2000 Srl company, partner of the project, does not perform the rotation of item 3 of Table II. It is designed for small rooms, especially for home care and/or hospital with limited space for individual rooms. As shown in Fig.4, the patient has been monitored since May 2017 up today with specific instrumentation to measure the following physiological parameters: O_2 saturation with an oximeter, arterial pressure with a pressure instrument, cardiac frequency, peak pressure of pulmonary ventilator (see Fig.5), temperature with a small instrument, and blood gas instrument. Besides, an infrared camera "Fluke" for measuring body temperature with different features.

The patient, the footballer, has been verticalizing for at least 3 years, almost every day or many days per week, improving the quality of his life, that is, delaying the irreversible effect of ALS. Fig. 6 depicts the 45° standing up positions. It is possible to notice two different tones of the color of his skin: normal white and significantly red-white due to major flow of blood involving biomechanical exertions connected to biomechanical joints, namely elbow, knee, leg, foot, and ankle. This is an extraordinary result justified by the action of gravity forces acting on the body and the biomechanical joints. We limited the verticalization to 45° because of the age of the person, having today 77 years and suffering from ALS. For another case, not included in this paper, the verticalization reached 70° thanks to the young age, 12 years old. Since the person

Fig. 6. Verticalization (standing up) position at 45°, displaying changes in the color around arms and legs due to major vascularization connected to biomechanical charges.

Fig. 7. Knee captured by the infrared sensor during verticalization (standing up) position before reaching the 45° angular position. Temperatures are reported in the pictures.

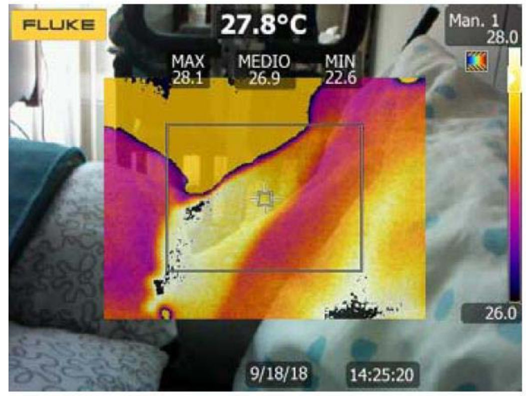

Fig. 8. Ankle captured by the infrared sensor during verticalization (standing up) position before reaching the 45° angular position. Temperatures are reported in the pictures.

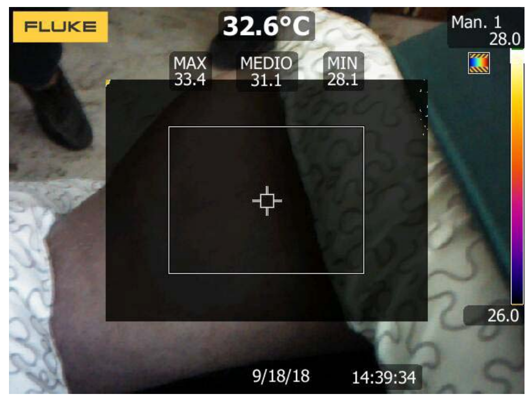

Fig. 9. Leg captured by the infrared sensor during verticalization (standing up) position while reaching the 45° angular position. Temperatures are reported in the pictures.

under test, the patient, has been suffering from ALS for about 12 years, the operating mode of verticalization takes place gradually. The angular position of 45° has been considered a precautionary limit advised by the medical doctor to avoid irreversible consequences.

IV. Results and Discussion

The main scope of the activities is to illustrate the effect of continuous stand-up position through verticalization. The polyfunctional and robotic bed does not provide any rotation around the vertical axis; that means verticalization and anti-verticalization (anti-trendelenburg). All the physiological parameters have been measured during the gradual verticalization, from 0 degrees up to 45 degrees.

Fig.7 and Fig.8 depict the temperature measurement and acquisition as well its distribution on the skin; while the features of Fig.9 are obtained at the maximum of verticalization, in particular, the temperature is 32.6°C. These features coincide with, exactly the position of Fig.6, requiring major biomechanical efforts. A summary of all features in diverse angular positions is reported in Table III and Table IV. These features are:

TABLE III

Different Physiological Parameters Recovered From Measurements: Inclination Angle, Saturation, Arterial Pressure, Cardiac Frequency, Peak Ventilator Pressure, the Temperature of the Leg, the Temperature of the Knee, Starting Time, and Closing Time

Incline angle	Sat O_2 %	Arterial pressure mmHg	Card Freq b/min	Peak ventilat pressure cmH_2O	T °C Leg	T °C knee	T
0°	99	110↔70	65	21	27.4	24.1	14:20
+10°	99	110↔69	68	21.3	27.8	26.4	
+20°	99	110↔67	65	21.2	27.6	26.5	
+30°	99	110↔69	67	21	28.1	29.1	
+40°	98	110↔65	68	21.3	26.9	27.4	
+45°	98	110↔66	68	21.1	32.6	27.7	14:39

- saturation of oxygen (O_2) necessary as a parameter. It is generally between 95% - 100%; values less than 95% denote the lack of oxygen, that is hypoxia.

TABLE IV
A.B.G.: ARTERIAL BLOOD GAS CHARACTERIZATION PH(7.35↔7.45), $PACO_2$(35↔45), PAO_2 (80↔100), BE(−2 ↔ +2), HCO_3 (22↔26)

	T °C	pH	$PaCO_2$ mmHg	PaO_2 mmHg	Be Mmol/L	HCO_3 Meq/L	T
Initial A.B.G	0	7.48	27	101	-3	20.2	14:20
Final A.B.G.	35	7.46	24.6	94	-6	17.6	14:39

- arterial pressure, for adults (115-140) max, and (75-90) min; they are intended as systolic pressures.
- cardiac frequency, for adults, ranging from 60-100 beats/min.
- temperature.
- time, denoting the duration of the activities in terms of verticalization; from 14:20 up to 14:39, that is 19 minutes of gradually verticalization.

Further, A.B.G (Arterial Blood Gas) [27] measurement has been carried out as per Table IV. As for the previous table, the following parameters have been detected:

- pH, a necessary parameter for indicating an acid or basic environmental.
- $PaCO_2$, partial pressure of carbon dioxide in the arterial blood.
- PaO_2, the partial pressure of oxygen in the arterial blood.
- Be, base excess, necessary to quantify the (non-respiratory) metabolic component of acid-base balance.
- HCO_3, bicarbonate salt containing the anion HCO_3^- which is the important buffer in the blood regulated by the kidney.

Certainly, the continuous verticalization, in the effort to improve the life quality, has been positively impacting the oxygen generation and flow within the patient's physiology. The indicators of performance, given the date of the measurement, autumn (October 18th, 2018), are described below:

- the patient is usually brought to the hospital for pathological issues and troubles, at least three or four times a year. Since May 2016, this frequent hospitalization is reduced to one time, and/or none a year.
- it is an extraordinary result, in 19 minutes, to get 5.2°C of temperature increase related to the leg, and 3.2 °C for the knee.
- the saturation of oxygen is 98% after 19 minutes, indicating a good process of oxygenation. This a confirmation of heating.
- the maximum peak of ventilation pressure is less than 40 cmH_2O for an adult. But the values recovered from the measurement indicate that the patient did not need a major flow of ventilation, instead of a small flow thanks to the standing up position. That is due to the low resistance described in Fig.3.

Moreover, the A.B.G. test allows us to extract the following confirmation, as indicators of performance:

- a decrease of pH towards a good value with a little bit of reduction of alkalosis. A pH > 7.45 is alkalosis and a pH < 7.45.

Fig. 10. A 12-years old polytraumatized teenager treated with the robotic bed.

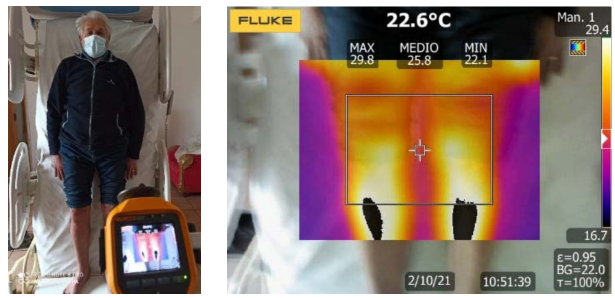

Fig. 11. Normal person monitoring. Experimental acquisition and position (left) and the focus of knees and leg bones (tibia) with related temperatures (right). The right pictures also exhibit the position of rotula and the thickness of meniscus.

TABLE V
METRICS OF THE TREATMENT OF THE POLYTRAUMATIZED TEENAGER AFTER 3 MONTHS OF ACTIVITIES. ALL THE FOUR INDICATORS DEMONSTRATE THE EXCELLENCY OF THE APPROACH

Designation	Barthel index	Motricity index	Trunk control test	Modified rankin scale
Checkin	0	14	0	5
Checkout	60	75	62	3

- the above alkalosis brings to a Base excess (Be) and a decrease of $PaCO_2$.

As an overall assessment of performance indicators, we have demonstrated the basic importance of stand-up positions, especially a recurrent and gradually verticalization using poly-functional and robotic bed such as Lole.k2 as that used in this paper. In many indicators of performance, the oxygen is a precursor, and a catalyzer of any neuro-rehabilitation process; this research testifies its basic importance. Two further categories have been investigated: a polytraumatized teenager, 12 years old as reported in the conclusions (see Fig. 10), after an accident with a heavy lorry pressing his head, and a group of 4 "normal" persons without any specific pathologies, and an example is depicted in Fig.11. In the first case, the proposed care, thanks to the vascularization and oxygenation, has allowed to save at least 60% of the envisaged time for treating the teenager: 3 months instead of 6-9 months. Table V reports the typical indices used for the care of polytrumatized

TABLE VI
DIFFERENT PHYSIOLOGICAL PARAMETERS RECOVERED FROM MEASUREMENTS: INCLINATION ANGLE, OXYGEN SATURATION, TEMPERATURE, HEARTBEAT FOR NORMAL PERSONS

Gender	Age	Weight (kg)	Distance Femoral head/knee (cm)	Distance knee/ankle (cm)	Rotation (degree)	Time	Body area	T°max (°C)	T°min (°C)	Oxy sat (%) SpO_2	Heart Beat (beat/ min)
Male	74	95	50	46	0	10:28	knee	19.4	15.3	97	74
					30	10:30	knee	19.6	15.4	96	78
					60	10:47	knee	27.1	16.5	91	60
					60	10:48	left hand	25.1	17.9	98	75
					80	10:49	knee	27.4	22.5	99	78
					80	10:50	ankle	29.8	18.7	96	76
					80	10:53	head	32.4	20.2		
Male	53	75	43	40	0	11:00	knee	18.2	15.5	98	68
					30	11:02	knee	18.8	15.8	99	62
					60	11:03	knee	28.7	15.6	97	69
					60	11:05	left hand	27.5	19.2	99	62
					80	11:06	knee	28.7	15.8	97	66
					80	11:07	ankle	25.5	18.8	99	71
					80	11:08	head	34.2	21.1		
Male	25	80	46	43	0	11:11	knee	20.7	15.7	99	70
					30	11:13	knee	26.6	16.6	97	67
					60	11:14	knee	29.8	15.7	92	79
					60	11.16	left hand	33.6	19.9	97	76
					80	11:18	knee	29.9	21.0	96	87
					80	11:19	ankle	27.4	19.4	97	80
					80	11:20	head	34.8	21.4		
Female	31	75	45	23	0	11:22	knee	19.9	16.6	99	83
					30	11.24	knee	25.3	16.3	98	81
					60	11:25	knee	28.2	16.0	97	85
					60	11.27	left hand	29.4	20.0	97	86
					80	11:28	knee	28.5	17.7	97	85
					80	11.29	ankle	28.8	20.7	96	91
					80	11:30	head	24.8	22.1		

persons [28]. In particular, the decreasing of MRS (modified rankin scale), is demonstrating that the patient was almost close to death and after the treatment, there is a spectacular improvement, also confirmed by the Barthel index [29]. The results are depicted in Table V. And a last trial is for four normal persons as indicated in Fig. 11 and Table VI.

One can notice the variation of oxygen saturation due to the position of the bed, hence the variation of the heartbeat due to major vascularization. That is a further confirmation.

V. CONCLUSION

The role of oxygenation is a basic issue in the neurorehabilitation of all patients, in particular, for bedridden persons. The oxygen can be measured utilizing different techniques and amongst them, we find that related to tissue oxygen saturation [30]. Certainly, the verticalization, as we have seen, is a way of deploying biomechanics forces that must produce temperature fluctuations, then major oxygen, and hence as much vascularization. Different physiological parameters can be measured using sensors and on-site blood characterization. The wellness of the patient depends upon both kinds of measurements. The sensors based on SoC and wearable technologies are very challenging for homecare activities, especially for long-term treatments. The use of polyfunctional, physio-therapeutic, and robotic beds, as Lole.k2, is a major achievement for improving the wellness of bedridden people.

The paper has illustrated three categories of trials and cares performed on persons: the first trial of around 3 years on the same person affected by amyotrophic lateral sclerosis; the second trial on a 12-years old polytraumatized teenager displaying cerebral lesions (left subdural hematoma), multiple rib fractures of right clavicle, right scapula, pelvis fracture, jaw fracture, fracture of transverse processes D5-D10; the last trial was performed on four "normal" persons without a specific pathology. An interesting element to be considered, in the case of pathologies seriously involving muscles (e.g. neurodegenerative diseases), the infrared sensor has difficulty to clearly separate bones from muscles even though it reveals fluctuations of temperature and possible vascuralization. This aspect can be exploited as a reverse result. But if neurodegenerative process does not yet take place, the infrared sensor is able to also capture the surface condition of bones. We have also seen the importance of the infrared sensing system for monitoring the left hand which is directly connected to the descending aorta as first contact in case of major exertion. The combination between poyfunctional robotic bed and infrared sensing is a successful mix.

The COVID-19 is still an unknown disease since we are not aware of the long-term consequences such as interstitial pneumonia, hemiplegia, kidney impairments, etc. The proposal included in this paper, along with its approach, is confirmed by recent studies regarding COVID-19. The first, [31] of them, suggests the use of standing up positions for rebuilding muscle mass that requires a training stimulus and the right nutrients; the second [32] reinforces the challenge by arguing that electric beds are necessary for verticalization. Such a bed is also useful to trigger [26], by means of motion, the use of nano drugs.

References

[1] L. H. Thomas *et al.*, "Repetitive task training for improving functional ability after stroke," *Stroke*, vol. 48, no. 4, pp. e102–e103, Apr. 2017.

[2] K. Bezerra *et al.*, "A new methodology for use by a single caregiver to bathe bedridden elderly persons using advanced mechatronic systems," *Healthcare*, vol. 7, no. 124, pp. 1–15, 2019.

[3] *WHO Coronavirus (Covid-19) Dashboard*. Accessed: Nov. 10, 2020. [Online]. Available: https://covid19.who.int/

[4] I. Ghersi, M. Mariño, and M. T. Miralles, "Smart medical beds in patient-care environments of the twenty-first century: A state-of-art survey," *BMC Med. Informat. Decis. Making*, vol. 18, no. 1, pp. 1–12, Dec. 2018.

[5] E. M. Capodaglio, "Electric versus hydraulic hospital beds: Differences in use during basic nursing tasks," *Int. J. Occupational Saf. Ergonom.*, vol. 19, no. 4, pp. 597–606, Jan. 2013.

[6] Y. Zhu *et al.*, "Summary of respiratory rehabilitation and physical therapy guidelines for patients with COVID-19 based on recommendations of World Confederation for Physical Therapy and National Association of Physical Therapy," *J. Phys. Ther. Sci.*, vol. 32, pp. 545–549, Mar. 2020.

[7] A. Lay Ekuakille *Et al.*, "Low-frequency detection in ECG signals and joint EEG-ergospirometric measurements for precautionary diagnosis," *Measurement*, vol. 46, no. 1, pp. 97–107, 2013.

[8] F. S. Koopman *et al.*, "Exercise therapy and cognitive behavioural therapy to improve fatigue, daily activity performance and quality of life in postpoliomyelitis syndrome: The protocol of the FACTS-2-PPS trial," *BMC Neurol.*, vol. 10, no. 1, pp. 1–10, Dec. 2010.

[9] H. I. Krebs, B. T. Volpe, D. Lynch, and N. Hogan, "Stroke rehabilitation: An argument in favor of a robotic GYM," in *Proc. 9th Int. Conf. Rehabil. Robot.*, Chicago, IL, USA, Jun./Jul. 2005, pp. 219–222.

[10] S. Ariel Kapusta, P. M. Grice, H. M. Clever, Y. Chitalia, D. Park, and C. C. Kemp, "A system for bedside assistance that integrates a robotic bed and a mobile manipulator," *PLoS ONE*, vol. 14, no. 10, Oct. 2019, Art. no. e0221854.

[11] C.-S. Chung, H. Wang, and R. A. Cooper, "Functional assessment and performance evaluation for assistive robotic manipulators: Literature review," *J. Spinal Cord Med.*, vol. 36, no. 4, pp. 274–289, 2013.

[12] A. RajKumar, F. Vulpi, S. R. Bethi, H. K. Wazir, P. Raghavan, and V. Kapila, "Wearable inertial sensors for range of motion assessment," *IEEE Sensors J.*, vol. 20, n.7, pp. 3777–3877, Apr. 2020.

[13] E. P. Doheny, C. Goulding, M. W. Flood, L. Mcmanus, and M. M. Lowery, "Feature-based evaluation of a wearable surface EMG sensor against laboratory standard EMG during force-varying and fatiguing contractions," *IEEE Sensors J.*, vol. 20, no. 5, pp. 2757–2765, Mar. 2020.

[14] K. Basterretxea, J. Echanobe, and I. del Campo, "A wearable human activity recognition system on a chip," in *Proc. Conf. Design Archit. Signal Image Process.*, Madrid, Spain, Oct. 2014, pp. 1–8.

[15] D. Ghista, "Determination of the *in-vivo* elasticity of the blood vessel & detection of arterial disease," *Automedica*, vol. 1, no. 3, pp. 151–164, 1974.

[16] K. Khanafer, M. S. Schlicht, and R. Berguer, "How should we measure and report elasticity of aortic tissue?" *Eur J. Vasc Endovasc Surg.*, vol. 45, pp. 332–339, 2013.

[17] C. G. Caro, T. J. Pedley, R. C. Schroter, W. A. Seed, *The Mechanics of the Circulation*. London, U.K.: Oxford Univ. Press, 1978.

[18] S. Casciaro, F. Conversano, L. Massoptier, R. Franchini, E. Casciaro, and A. Lay-Ekuakille, "A quantitative and automatic echographic method for real-time localization of endovascular devices," *IEEE Trans. Ultrason., Ferroelectr., Freq. Control*, vol. 58, n.10, pp. 2107–2117, Oct. 2011.

[19] F. Conversano, R. Franchini, A. Lay-Ekuakille, and S. Casciaro, "*In vitro* evaluation and theoretical modeling of the dissolution behavior of a microbubble contrast agent for ultrasound imaging," *IEEE Sensors J.*, vol. 12, no. 3, pp. 496–503, Mar. 2012.

[20] A. Lay Ekuakille, G. Vendramin, and A. Trotta, "Spirometric measurement post-processing: Expiration data recovery," *IEEE Sensors J.*, vol. 10, no. 1, pp. 25–33, Jan. 2010.

[21] D. N. Ghista, K. M. Loh, and M. Damodharan, *Lung ventilation modeling and assessment, in Human Respiration: Anatomy and Physiology, Mathematical Modeling, Numerical Simulation and Application*, V. Kulish, Ed, Southampton, U.K.: WIT Press, 2000, ch. 4, pp. 95–115.

[22] I. Jablonski and J. Mroczka, "A forward model of the respiratory system during airflow interruption," *Metrol. Meas. Syst.*, vol. 16, no. 2, pp. 1–14, 2009.

[23] N. Tang, H. Bai, X. Chen, J. Gong, D. Li, and Z. Sun, "Anticoagulant treatment is associated with decreased mortality in severe coronavirus disease 2019 patients with coagulopathy," *J. Thrombosis Haemostasis*, vol. 18, no. 5, pp. 1094–1099, May 2020.

[24] R. Bussani *et al.*, "Persistence of viral RNA, pneumocyte syncytia and thrombosis are hallmarks of advanced COVID-19 pathology," *EBioMedicine*, vol. 61, Nov. 2020, Art. no. 103104, doi: 10.1016/j.ebiom.2020.103104.

[25] *Lole.k2*. Accessed: Nov. 10, 2020. [Online]. Available: http://www.roam2000.it/

[26] C. Chiffi and A. Lay-Ekuakille, "Physiotherapeutic movements by advanced robotic beds: Perspectives in triggering nanodrugs," in *Proc. IEEE Nanofim*, Chemnitz, Germany, Sep. 2016, pp. 5–16.

[27] J. E. Tannoury, M. Sauthier, P. Jouvet, and R. Noumeir, "Arterial partial pressures of carbon dioxide estimation using non-invasive parameters in mechanically ventilated children," *IEEE Trans. Biomed. Eng.*, vol. 68, no. 1, pp. 161–169, Jan. 2021, doi: 10.1109/TBME.2020.3001441.

[28] J.-M. Yamal and J. C. Grotta, "National institutes of health stroke scale as an outcome measure for acute stroke trials," *Stroke*, vol. 52, no. 1, pp. 142–143, Jan. 2021.

[29] J. Wojtusiak, N. Asadzadehzanjani, C. Levy, F. Alemi, and A. E. Williams, "Computational barthel index: An automated tool for assessing and predicting activities of daily living among nursing home patients," *BMC Med. Informat. Decis. Making*, vol. 21, no. 1, pp. 1–15, Dec. 2021.

[30] C.-M. Chen, R. M. Kwasnicki, V. F. Curto, G.-Z. Yang, and B. P. L. Lo, "Tissue oxygenation sensor and an active *in vitro* phantom for sensor validation," *IEEE Sensors J.*, vol. 19, no. 18, pp. 8233–8240, May 2019.

[31] M. A. Spruit, A. E. Holland, S. J. Singh, T. Tonia, K. C. Wilson, and T. Troosters, "COVID-19: Interim guidance on rehabilitation in the hospital and post-hospital phase from a European respiratory society and American thoracic society-coordinated international task force," *Eur. Respiratory J.*, vol. 56, no. 6, Dec. 2020, Art. no. 2002197, doi: 10.1183/13993003.02197-2020.

[32] B. Zeng *et al.*, "Expert consensus on protocol of rehabilitation for COVID-19 patients using framework and approaches of WHO International Family Classifications," *AGING Med.*, vol. 3, no. 2, pp. 82–94, Jun. 2020, doi: 10.1002/agm2.12120.