**POLITECNICO DI TORINO**

ENGINEERING FACULTY

Master’s degree course in Mechatronic Engineering

# FIDGET CHAIR:
# therapeutic treatment sitting for bariatric patients

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# ABSTRACT

The aim of the project has been the realisation of a concept for a rehabilitative chair for bariatric patient, which purpose is to motivate and introduce movement in the first stage of their rehabilitation path. The main guidelines came from the Medical Science Department of "Università di Torino" and they have been considered as a starting point for the developing of the product. The final purpose of this innovative system is to recover mobility and muscle tone and as a consequence the patient should be more aware, motivated and self-confident especially with work out.

The product concept came out from a multidisciplinary research such that different areas of engineering and design were involved.

Starting from an analysis of obese people in the world, the focus moved to this health issue in Italy. This first step helped to understand causes that lead to obesity and all the physical and psychological aspects of the target users. In this way, the user-machine interface can be better defined and helped to realise a seat that can be pleasing not only to the eye but also while is used.

The next step was to pay attention on movement that can be involved in a seated position. Gym equipment state of art is analysed to better understand which are the most important elements that can be integrated in the chair. Biomechanical elements are also considered to take care about joints and muscular health, such that injury risk can be avoided.

At this point, ergonomics and anthropometry were integrated to make the seat more comfortable and adaptable to multiple individuals with different stature and body proportions as well as their particular condition. Then, indispensable regulations are chosen to make the seat the more adaptable possible.

A kinematic analysis followed to define the elements needed for the seat and to realize the exercises.

A mathematical model is defined to estimate forces exchanged between patient and the machine. Afterward, a pneumatic actuation solution is provided.

In the final step, thanks to all the research carried out, a final mechanical 3D model is realized providing a complete but not yet definitive concept of the chair. Moreover, an aesthetic design study has been performed to meet the need of distinguish the machine from the classical training equipment. According to psychologist, indeed, bariatric patients show a relevant reluctance to the classical way of training.

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# Chapter 1

# Introduction

In this first part of the thesis, obesity issues are provided to understand how this health problem is important to be addressed.

## 1.1 Obesity in the World and in Italy

In 1948 obesity was established to be a disease by the World Health Organization (WHO). Nevertheless, in the last decades of 19th century it is considered to be a relevant potential public health problem by all the governments and mass-media, since researches highlighted how the increase of obesity is related with the increasing rates of cardiovascular disease [(1)]. Obesity emergence was firstly related to an high socioeconomic status, but recent data showed the prevalence of obese people shifts from the higher to the lower socioeconomic level. This effect is due to multiple factors. Urbanization and globalization of food production and marketing

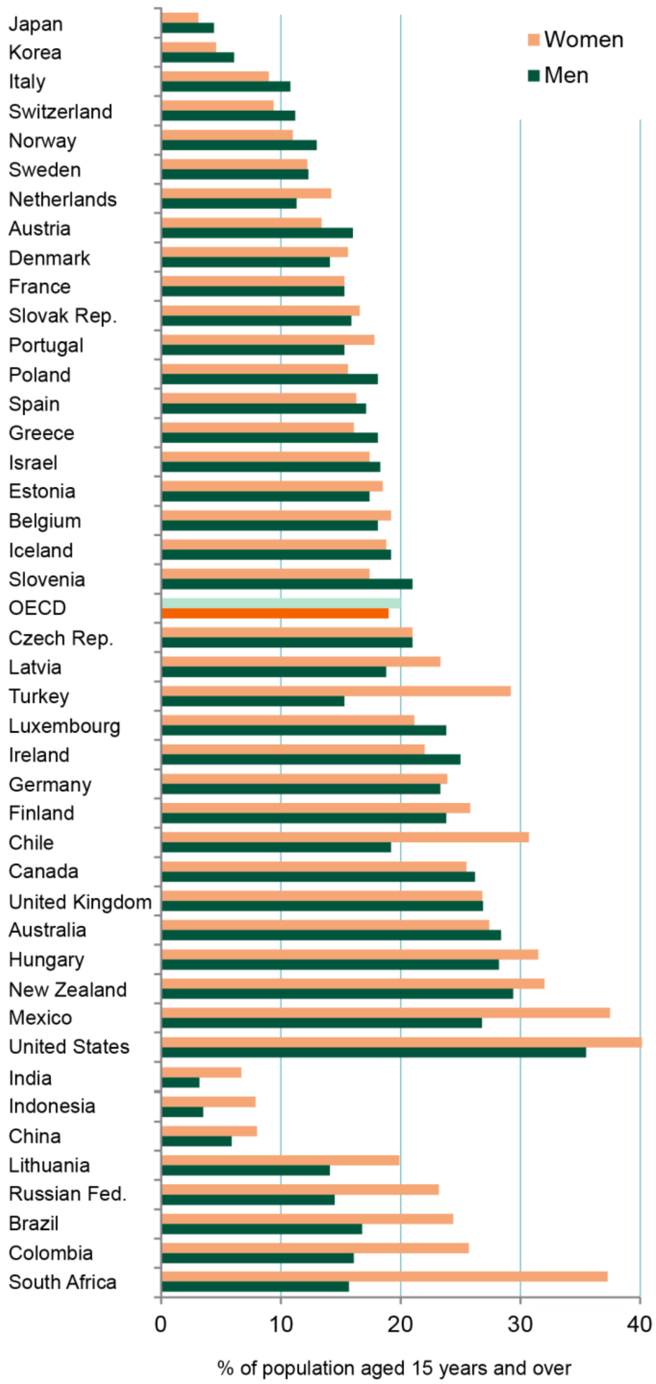



*Figure 1.1: worldwide overview of adult obesity in 2015, OECD data elaboration, source: OECD Health Statistics 2017*

are two of the most important one. The growth of "junk-food" at low price, low quality but with a high calorie content as well as the increment of sedentariness contributed to propagate this disease. The so called "dual burden" phenomena appeared. Indeed, in many low and middle income countries undernutrition and overweight adults and children are co-existing in the same country, community or even in household(2).

It is recognized that obesity is increasing worldwide. The WHO sustains that obesity is tripled since 1975.

In 2016, 38% of adults over 18 years old were overweight and 13% were obese. The problem is also extended to children and teenagers, indeed, 41 million of them were estimated to be obese in 2016(3).

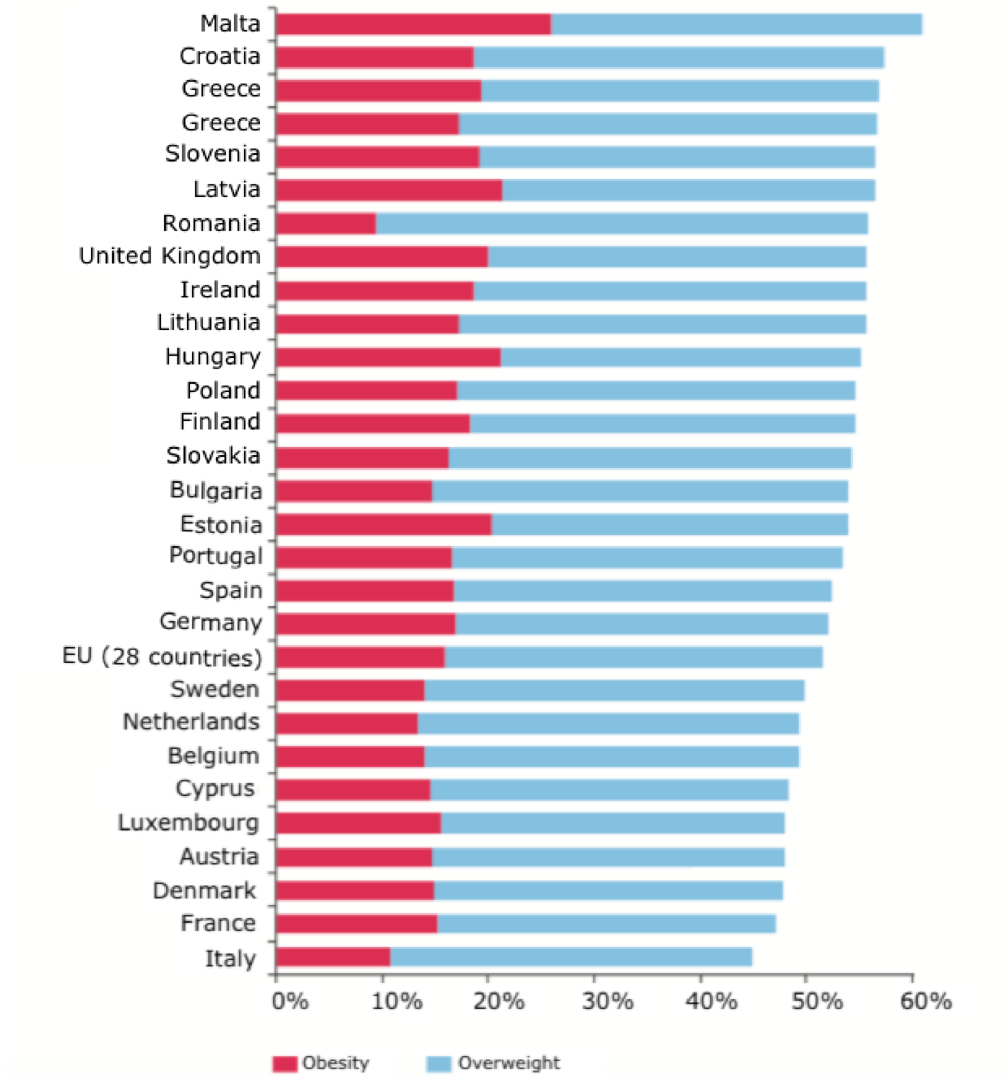



*Figure 1.2: overweight and obese statistic data in over 18 adults, source: Data Base Eurostat, EHIS-European Health Interview Survey, 2014*

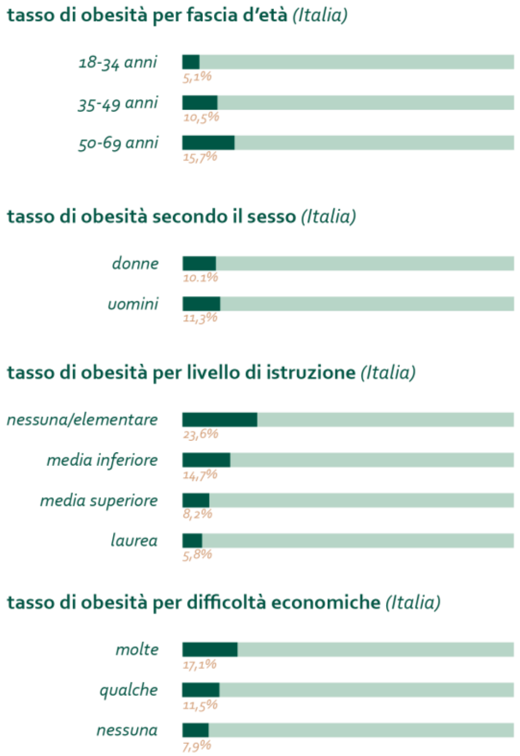



*Figure 1.3: Italian overview about the weight excess, source: sorveglianza PASSI (2014-2017)*

A worldwide overview is shown in figure 1.1, where the obese women and men percentage is represented in different countries.

In Italy the epidemic growth has been slightly slower with respect to other Europe countries. In fact, while in Europe a mean value of 51,6% of people are estimated to be overweight, in Italy this value is about 44,9%. Obesity percentage is inferior too. In Italy is about 10,8% against a 15% in Europe[(4)]. The Mediterranean diet and the low alcohol consumption are the reasons why the number of overweight and obese people is the lowest in Europe[(5)]. Data about overweight and obesity in different in European countries is shown in figure 1.2.

It is interesting to highlight how the excess weight in Italian people is increasing in the last 20 years. Nowadays, there are about +10% of overweight people and +34% of obese with respect to 1994[(6)]. Moreover, data shows that in Italy, there are more male than female in overweight and obese condition in adulthood (1/2 for men and one 1/3 for women). This difference is evident until 65 years old, then it decreased in elderly.

It has been observed that the older is the person the more luckily is the presence of an overweight condition.

## 1.2 Definition and evaluation

Obesity is a chronic disease caused by an abnormal and excessive accumulation of adipose tissue due to an imbalance between energy intake and consumption[(7)].

BMI (Body Mass Index) is a parameter to indicate if health problems may appear or not due to the excess of body fat. The unit measure is expressed in $kg/m^2$ and it is defined as:

$$BMI = \frac{mass}{height^2}$$

In such a way, the amount of tissue mass (fat, bone and muscles) can be approximately quantified.

Health status is used to be classified in function of BMI to diagnose an underweight, overweight or obese disease as indicated in table 1.1.

| **Classification** | **BMI ($kg/m^2$)** |
|---|---|
| Very severely underweight | BMI≤15 |
| Severely underweight | 15≤BMI<16 |
| Underweight | 16≤BMI<18.5 |
| Normal (healthy weight) | 16≤BMI<25 |
| Overweight | 25≤BMI<30 |
| Obese Class I (Moderately obese) | 30≤BMI<35 |
| Obese Class II (Severely obese) | 35≤BMI<40 |
| Obese Class III (Very severely obese) | 40≤BMI<45 |
| Obese Class IV (Morbidly Obese) | 45≤BMI<50 |
| Obese Class V (Super Obese) | 50≤BMI<60 |
| Obese Class VI (Hyper Obese) | BMI≥60 |

*Table 1.1: health status classification due to BMI.*

As can be seen, overweight individuals have a BMI≥25, while obese have a BMI≥30. The last one can be also distinguished in classes according to the severity.

Of course, BMI calculation in children is different from an adult one. So, for a more accurate classification, age, international variations and sex (figure 1.4) should be considered. It is possible to classify the obesity condition in 2 sub-groups according to body fat distribution: gynoid and android (figure 1.5).

In android fat distribution, the adipose tissue tend to rack up mainly in the upper body part (abdomen, shoulder, chest, neck nape), while lower limbs remain spindly. The body assumes an “apple shape” and it is more frequent in male than females.

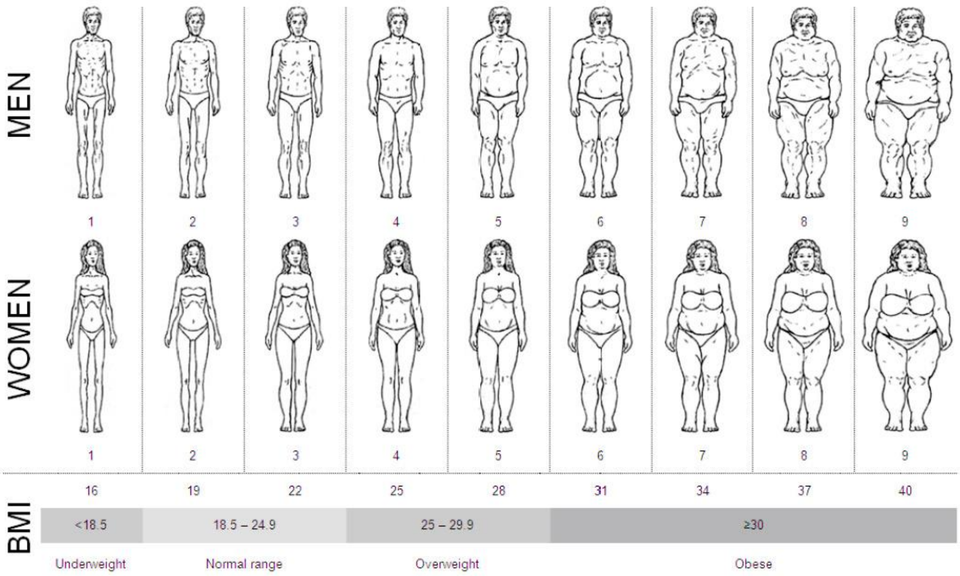



*Figure 1.4: BMI scale, source: C.Patterson,S. Hilton, 2013*

The gynoid body shapes, instead, is characterized by an adipose accumulation around hips, thighs and bottom, shoulders and trunk are spindlier. As a consequence, the body appears as "pear-shape" and it is more common in female than male.

There are different health issues associated to these two kinds of fat distribution. Android biotype is more exposed to diabetes, hypertension and cardiovascular diseases, while blood circulation problem are more common in gynoid biotype, especially in lower limbs(8).

Another classification can be considered looking for the dimension and the number of adipose cells (adipocytes). If the number increase, hyperplasia mechanism is present. Otherwise, if the size increase, it is called hypertrophy.

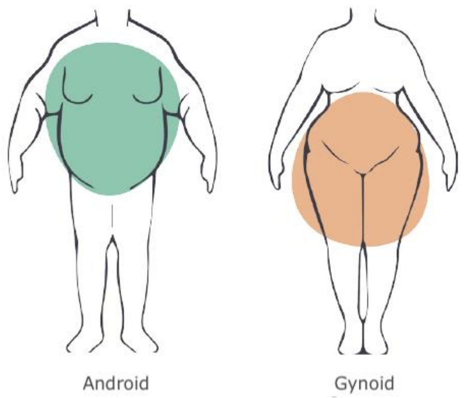



*Figure 1.5: android and gynoid biotype*

Usually, hyperplasia develops in childhood and adolescence, when cells tends to reproduce. After puberty, the cells growth population decreased, and accumulated adipocytes can became smaller but can’t be reduced in terms of number. As a consequence, healing and recovery are harder and more complex. Hypertrophy is developed in adulthood, because adipocytes react becoming bigger to fat accumulation.

For this reasons it is important to intervene in case of obesity in childhood, in such a way adulthood obesity risk can be prevented and it is easier to be addressed[9].

### 1.3 Obesity triggering Factors

There are multiple factors that lead to this status, but the most important ones are: genetical, psychological, social, environmental and metabolic.

Genetics contributes to the regulation mechanisms of energy, metabolism and appetite and there are researches that are relating the tendency to prefer certain foods or predisposition to physical activity. Sometimes genetic factors leads to specific syndromes[10].

Metabolic endocrine diseases like hormonals ones can produce food assimilation imbalances between consumed and provided calories[11].

Eating disorders such as compulsive food consumption are due to psychological factors like stress and anxiety. These emotional disorders, that can lead to depression, can come from obese social discriminations and negative prejudices[12]. So even social aspects are involved in obesity causes. Moreover, in nowadays life style the increment of sedentary creates a greater imbalance between intake and consumed energy[13].

Other involved factors can be pharmacological because of antidepressants and corticosteroids that can increase hunger sensation and can change metabolism reducing daily energy requirements or stimulating the production of fat cells. If hypothalamus area is damaged can influence appetite regulation[14].

### 1.4 Obese psychological analysis

Psychological disorders sometimes are triggering factor that lead to obesity but living in this pathologic condition produces consequences at psychological level.

According to WHO, depression is one of the pathologies linked to obesity. An increased consumption of food and the poor physical activity can be depression warning signals that can lead to overweight and obesity. On the other side, the negative self-image in the society can produce low self-esteem(15). Indeed, from 20 to 60% of obese individuals are more inclined to develop depression and anxiety related to self-esteem lowering(16). They aren't self-confident with their body and, with the pathology growth, obese don't like looking in mirror until they try to avoid them(17).

They are often victims of different shape of discrimination and prejudices that can lead to socializing issues. In fact, obese can be easily considered as lazy in the workplace and not suitable for work. Often, negative comments and unkind treatment can come from health care, work places, casual people met in the streets or even from family members(18).

Although prejudices against obese people increased, attention, care and sensibility towards them are also increased. Nowadays there's greater awareness of the risks and consequences of obesity in both socio-economic and psycho-physical points of view(19).

If the obese individuals are subjected to these negative attitudes coming from the people around them, they try to deny their problem seeking external help and approval. Often, they assumes self-comforting attitudes that leads to the further food consumption. This last option is more frequent among women(20).

Other psychological disease can come from environmental barriers like too narrow chairs or sanitary equipment not suitable for heavier people, aggravated by the verbal comparison that often turns into negative judgment(21).

There isn't for sure a direct link between obesity or overweight and psychological disorders such as depression, anxiety or self-esteem lack. but judgements and the perception of today's society influence negative the obese and the overweight individual more than their health status.

In figure 1.6 there is a summary of psychological factors related to the bariatric condition.

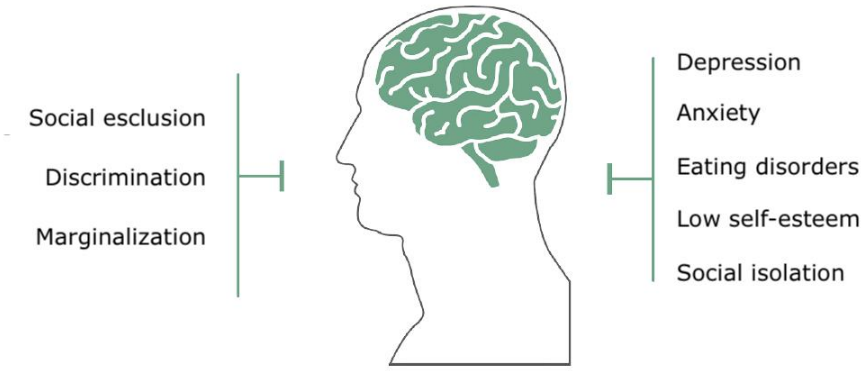



*Figure 1.6: summary of the psychological effects of the bariatric condition*

**1.5 Physical consequences on health and life**

The bariatric condition leads the patient to different psychological and physical negative consequences, among those, the most relevant regarding health physical one are described. The severity of bariatric condition is associated with an increased risk of death and dangerous diseases. The most common ones are: high blood pressure, heart and coronary disease, strokes, type-2 diabetes, metabolic syndrome and certain types of cancer (pancreas, kidney, colorectal, oesophagus, breast and uterus)(22). Indeed, more pathologies are associated to obesity, "comorbidity" is the term to describe this condition.

Studies found out that obese or people who have had the pathology are more exposed to disabilities with advancing age since musculoskeletal system is overloaded(23).

Sleep can be considered a problem as well: researches linked insomnia or difficulty to sleep with obesity, for example obstructive sleep apnea cases. Moderate-intensity aerobic exercise can help obese patient reaching a more comfortable rest(24).

Walking is generally slower, steps are shorter and tends to be distant from each other. Centre of gravity, due to the heavy weight, becomes precarious so that even walking become tiresome and falling risk is higher(25).

Because of accumulated adipose tissue in abdominal area, breathing is harder since diaphragm is blocked in exhalation and trunk bending is limited. In general, movements are restricted by body fat and pain. Even the simplest action of everyday life are harder or in the most serious cases they are compromised.

### 1.5.1 Musculoskeletal system focus

The body changes in response to the accumulation of body fat to achieve a new balance, but the correct functioning of the musculoskeletal system is compromised. In fact, this last one is the most damaged in a bariatric patient.

Obese individuals reject physical training, not just for psychological reasons, but also because muscles become weaker. Muscle strength is 6-10% lower than normal weight individuals(26), because of reduced muscle function, abnormal metabolism and therefore lower oxidative capacity of muscle fibres producing early fatigue(27).

The aerobic workout can easily change in an anaerobic one because of breathing fatigue (previously mentioned) and the low oxygen consumption in relation with the big mass. Because of fat accumulation in diaphragm area lungs don't work well, breathing is hard and hearth with the circulatory system is in fatigue work condition(28).

Musculoskeletal system must withstand decidedly higher weight forces, as a consequence obese frequently suffer from joint pain and osteoarthritis, especially on knee, hip and vertebral column. Training for them is much harder also because they should have the strength to overcome the resistance due to their weight.

Mobility is reduced, movement amplitude is restricted and to maintain a correct posture is harder. As mentioned before, even walking is difficult and this can lead to disability.

Vertebral column is subjected to high loads such that obese patient with disk hernias and sciatica are common. In fact the risk of this disease is greater of 79% in overweight and obese people(29).

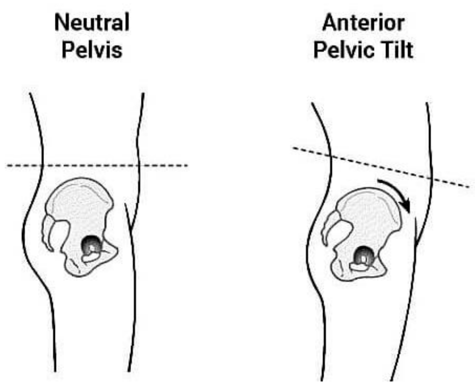



*Figure 1.7: anterior rotation of pelvis causing hyper lordosis and vertebral column deformation.*

Incorrect postures are linked with fat accumulation in determined areas, so that the vertebral column curves has been deformed, because of the heavier weight that must support with respect a normal condition. As can be seen in figure 1.6, hyper lordosis comes and causes chronic pain in the lumbar area, because of the lack of a minimum physical activity lead to the lack of flexibility and the lack of muscle strength. Consequently thoracic and cervical curves are deformed too[30].

Usually, as can be seen in figure 1.7, shoulders joints change and are moved upwards in response to the column curves deformations.

Fat excess is considered one of the causes of lumbar discs degeneration especially in younger patients. There's a theory correlating inflammatory disorders with obesity. This can explain the higher the increasing risk of disc degeneration, diabetes and other chronic diseases in bariatric individuals[31].

Lower limbs are altered to reduce the overload, indeed, obese usually have valgus knee and an altered rotation of the hip towards the inside. Torsion of feet is modified towards the outside and often

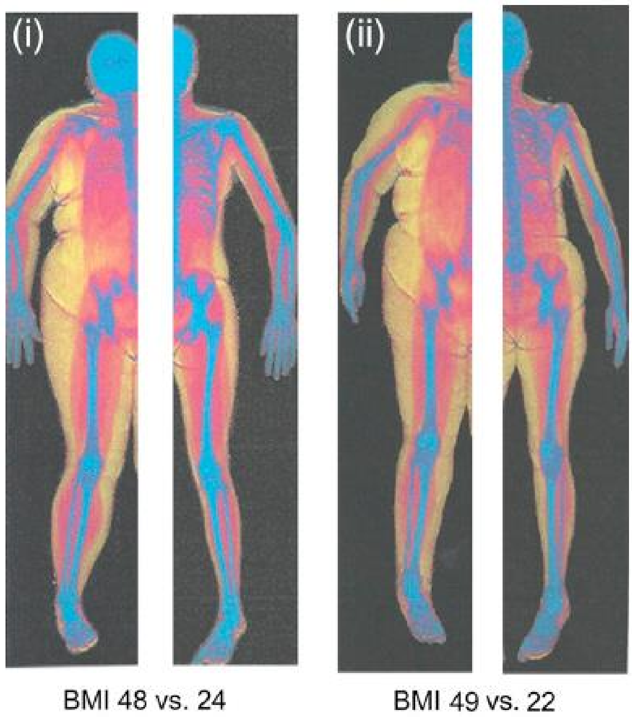



*Figure 1.8: DEXA scan (Tomlinson et al,2016).*
*(i) Comparison between a 48 BMI vs 24 BMI of a young woman.*
*(ii) Comparison between a 48 BMI vs 24 BMI of an old woman.*

the “flat foot” is present to look for a better stability in an upright position and for a less metabolic expenditure[32].

In a seated position the obese patient spread the legs to allow flexion of the trunk and relieve the load on the pelvis[33].

Fat accumulation lead to reach a new equilibrium and the less metabolic expenditure possible modifying all these muscle-skeletal features.

A summary of all health issues in bariatric individuals are shown in figures 1.8 and 1.9.

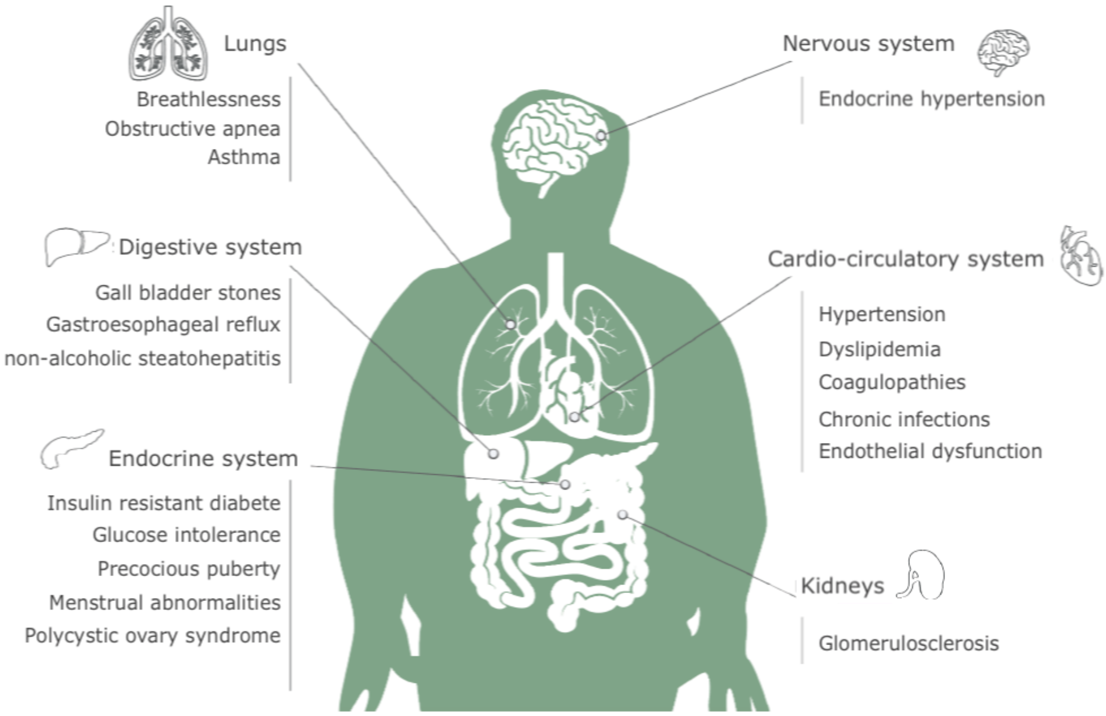



*Figure 1.9: principal obesity health complications on main body systems. Data rework of By C.B. Ebbeling, D.B. Pawlak, D.S. Ludwig, Childhood obesity: public health crisis, common sense cure. Lancet, 2002, 360: 473-482.*

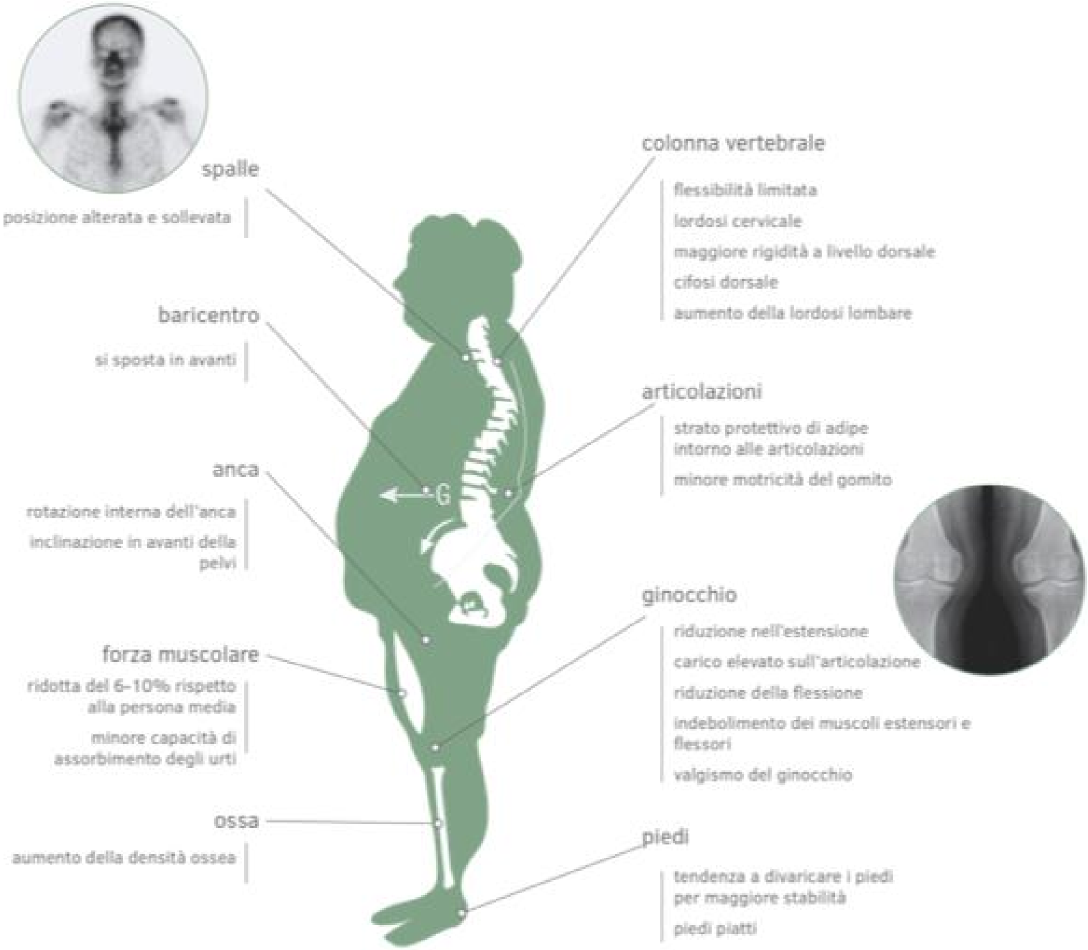



*Figure 1.10: summary of the main changes in muscle-skeletal system in obese individual. Self-elaboration.*

## 1.6 Physical activity rehabilitation

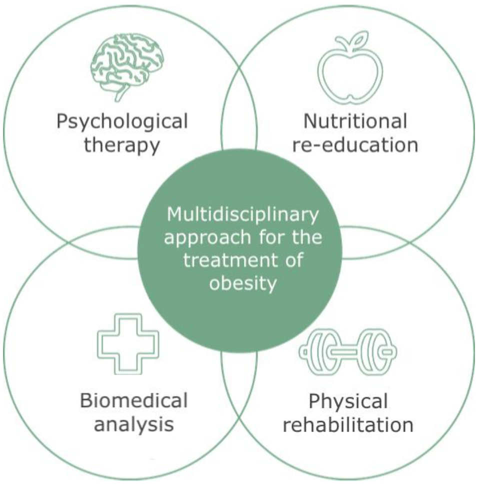



*Figure 1.11: factors needed in obese rehabilitation. Self-elaboration.*

The rehabilitation process takes a long time. It is a life path which goal is to change life in all his little factors. It should restore self-confidence, determination and restore disabilities even in the physical point of view(34). The rehabilitation should improve the whole life of the patient who should be encouraged to adopt a healthy life style with good habits.

Of course, the obese individual must change the diet and introduce physical activity. The workload should be proportional to the patient skills and capabilities, taking into account the body gradual evolution. The medical team should be able of understand what the patient needs are in all the rehabilitation path, physically and psychologically, to build the therapy. It's important that the patient is encouraged to continue the rehabilitation for a long time, because results are not immediately visible, and the medical equip should provide him all that is necessary for this purpose.

Since obesity is a multifactorial pathology, several factors should be considered to provide a multidisciplinary therapy that must be followed not only by the medical equip, but also by the bariatric patient.

The obese self-perception must be modelled taking into account the environment and the negative prejudice coming from society around him(35).

A summary of what is needed during the rehabilitation path is shown in figure 1.10 where different factors are present are:

biomedical analysis to take into account the health and the skills of the specific patient;

nutritional re-education to erase bad food habits and introduce a healthy diet;

physical education to strengthen muscles and to encourage to work out;

psychological therapy to help the patient to be more self-confident.

The introduction of workout in the obese life is not just about losing weight, there are many benefits: a good physical activity routine improve self-esteem, well-being feeling and emotionality.

Analysis about the physical status can diagnose issues from muscular or joint point of view, but the adipose tissue makes difficult to detect quality data from biomedical equipment such as electromyography and nuclear medicine imaging(36).

The volume growth of muscles is not taken into account, because the main goal physical activity in the first stage of rehabilitation is to stimulate the metabolism to better work when the body rests.

The strength training produces better results for this goal with respect the pure aerobic exercises, because it increases energy expenditure when the individual is in a resting state. While the pure aerobic exercise increase the energy expenditure just for a short time since the workout stops[37].
Workouts should not overload joints and it is preferable to involve large muscle groups for more caloric expenditure instead of more body stressing activity as running[38].
In the long run, aerobic activity also produces beneficial effects such as increased lipid oxidation[39].
The combination of aerobic and resistance training should be promoted because it improves physical function and it reduces frailty better than weight loss with aerobic exercise or weight loss with resistance exercise[40].

### 1.6.1 Perception of physical activity in the obese patient

The effort perception during a workout is subjective but it can be estimated trough "Borg Rating scale of Perceived Exertion" (RPE) in figure 1.11.
Work out shouldn't be so much stressing and hard especially for obese individuals not inclined to do it, because they are still physically frailty and they have to build an active routine which must continue for a long time.
A suitable exercise routine can be composed of:

- walking for 45 minutes with an hearth rate of 60% of the maximum rate every day to build the base for a more intense workout;


*Figure 1.12: Borg scale for estimate the perceived effort following an physical effort exercise.*

- exercises for large muscle groups in a time period between 45 or 60 minutes well distributed during the week (minimum 2 or 3 times a week).

The purpose is to train the cardiovascular system to better respond to the effort and to the workout, so it get used to it gradually(41).

It has been taken into account that bariatric patients are not used to training and psychological barriers are often a great obstacle to overcome, because they may feel inadequate and they may surrender to first difficulties. Moreover, they may not endure physical exertion. So, training and equipment must guarantee comfort and must avoid situations in which the bariatric patient may feel inadequate.

Within the classical way of training, inside the gym, some issue must be considered when dealing with severe obese people.

First at all, the maximum available carrying load of the equipment in order to avoid safety issues and there should be enough space to accommodate the size of an obese individual. The selected exercise must be done in proper hidden place for possible embarrassing situations, then the lifting weight must be proper chosen to make them able to execute the exercise in the correct way. Exercises involving movements and extra "jiggle" of adipose and soft body parts should be avoided to not create uneasiness and embarrassment. Overload of skeleton joints must be considered as well as exercises in which they have to get off from the floor, which is very difficult for them(42).

Finally, the psychological factor must be properly analysed remembering to provide them the right encouragement.

### 1.7 Design guidelines for obesity

With the obesity population increasing, the design of objects of everyday life is developed to meet the obese needs, especially those ones in domestic and health environment. Design goal is to improve life quality. For example, new seats for seating can be found in public places to accommodate people with a greater size.

Bariatric design precautions look for giving dignity to the obese trying to well integrate these objects in the environment. The purpose is to avoid to attract the attention and, at the same time, visibility or embarrassing and frustrating situations[43].

The major studies come from the United States where the problem is widespread. Healthcare and hospital environments are providing larger seating and rigid enough to support heavier people in waiting rooms. Even hospital beds need a bariatric design to accommodate a major size and weight. Even transport equip should be adjusted for the heavier ones to take care not only of patients but also of healthcare professional workers[44].

Also, buildings and standard measures should be reworked to adapt them to the obese sizes.

### 1.7.1 Bariatric chairs

*Figure 1.13: Cache Serie, Terrace Hunt for Zenith. Designing bariatric chairs with the same aesthetics of a standard one, the obese has a place to seat without feeling inadequate or observed for his size preserving his dignity.*

The standard measure for bariatric chairs is bigger with respect to a normal chair. The bariatric chair width is about 70-80 cm compared to a normal chair one which is about 40-50 cm.

It must be able to support a higher weight, especially health facilities should be provided with chairs capable to sustain even 340 kg.
Other small tricks may be the inclusion of a shallow seat. This shrewdness doesn’t allow the patient to give away, in this way the obese is facilitated when getting up.
The armrest may be rigidi enough to bear a possible overload when the obese individual tries to seat down or to get up. Moreover, the distance between the armrests should be appropriate to the bariatric size.
The general guideline is to provide a good aesthetics and to look comfortable to both physically and psychologically points of view. The design should be able to guarantee a to improve the life quality supplying a seat that makes movements easier. The chair should be able to attract the target user to make use of it.

# Chapter 2
# Project introduction

## 2.1 The request from Dipartimento di Scienze Mediche

The project request comes from the "Dipartimento di Scienze Mediche" of "Università di Torino". It concerns the realization of a seat able to tempt obese patient to physical training. The final goal should be the mobility recovery, as a consequence the patient should be more aware, motivated and self-confident especially with work out.

The rehabilitation path is structured with a first physical and health analysis to establish the severity condition of the obese. Guidelines for nutrition and proper diet are provided and a first objective is fixed that the patient should reach in 6 months approximately. 150 minutes of light workout are recommended.

This innovative system may be introduced in this first stage of recovery as a complementary support to motivate the obese to move and to adopt a more active and health life. A muscular tone recovery may be guaranteed, then the patient should be prepared for a more intense work out.

The use of this innovative system is limited in the hospital environment with doctor observation during meetings.

### 2.1.1 Team recruitment

Since the project requires multidisciplinary knowledge, it is included in PIC4SeR (PoliTO Interdepartmental Centre for Service Robotics) activities. At first, mechanical and mechatronic in engineering areas are involved, but soon the designer role was considered essential. So, the teamwork may be multidisciplinary, grouping designers, engineers and doctors. In figure 2.1, engineering skills concerning mechanical and mechatronic aspects about actuation, kinematics and dynamics to develop chair movements, the role of the designer contributed are summarized all the areas involved in the project. In addition to the for what concern the holistic analysis of the obese individuals. Finally, the doctors contributed to design guideline and to provide knowledge about patient’s needs.

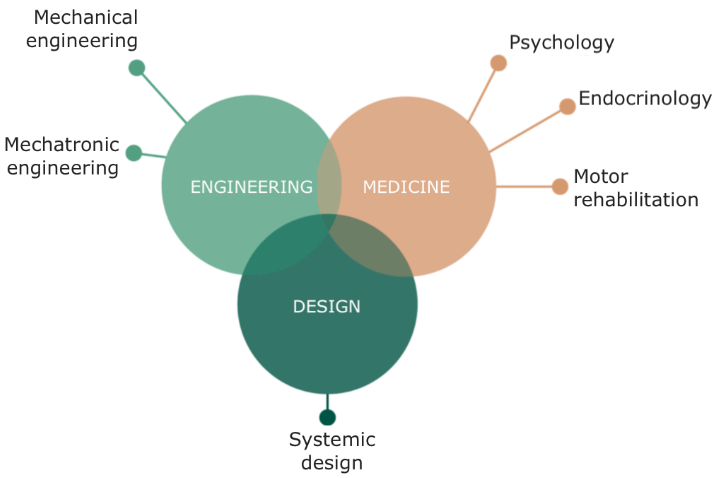



*Figure 2.1: Team work origin areas. Self-elaboration*

## 2.2 Project steps

In all the project path the patient care is always considered at first place. In fact, an accurate analysis about obesity is widely addressed in the first chapter. The knowledge of the disease is particularly helpful to make choice during all the thesis project. It was very important to deepen all the aspects concerning the final user with the disease criticalities.

So at the first step, doctors and a psychologist coming from “Dipartimento di Scienze Mediche” involved in the team have been questioned to found bases, guidelines and prerequisites from which to start to satisfy their requests.

The guidelines coming from doctors who follows this kind of patients are analysed to find proper solutions in relation to the therapy they dispense.

So, needs of patient and analysis about the scenario in which the product will be used were taken into account.

Than the attention is focused to define exercises which can be done from a seated position. So biomechanical elements are studied to understand which movements can be adequate for an obese individual and which one of them are too hard or even dangerous for his musculoskeletal apparatus. In this way, chairs movements can be studied to respond to the biomechanical needs of the human body.

A gym equipment state of art was presented to analyse essential elements providing a correct use of the system and it was particularly useful for the system actuation choice.

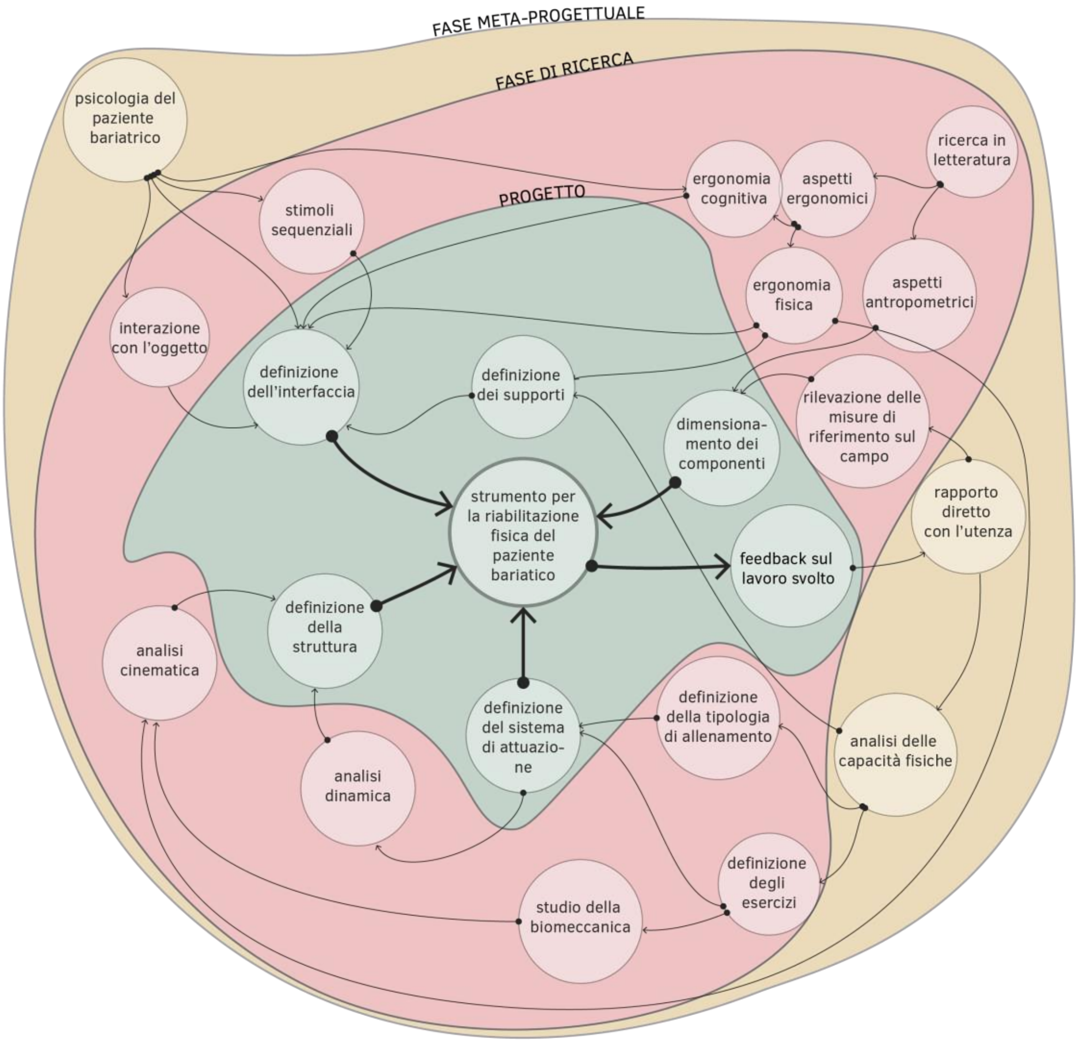



*Figure 2.2: Overview about factors involved in the project.*

Cognitive ergonomics has been considered to understand which are the elements that must be incorporated in the seat to allow a correct and intuitive use.

Anthropometry has been analysed to define chair elements dimensions. Standard measurements are taken into account, in particular, the seated ones are considered to choose which regulation are essential to adapt the chair at each individual. Then, measurements and data of a sample of users have been provided by the involved doctors for a more accurate dimensioning regarding bariatric patients.

In the following step, guidelines for a kinematic and dynamic study have been defined to highlights the system movements. Finally, regulation and chair components are defined to guarantee a correct physical exercise.

Mathematical models have been provided for what concern the motion of the chair parts which move with the patient during the physical exercises. Given appropriate hypothesis, forces exchanged between the patient and the system have been estimated.

A functional scheme of a pneumatic system has been provided with an logic that should be implemented in an electronic board.

In this phase, all elements regarding bariatric physical and health condition has been taken into account, while the psychological analysis has been particularly helpful in to build the executive project. The realization of a 3d model represent the thesis project final step.

A brief visual summary is shown in figures below, where all factors involved in the projects are present in relation to each other, divided by project phases (figure 2.2) and by expertise areas (figure 2.3).

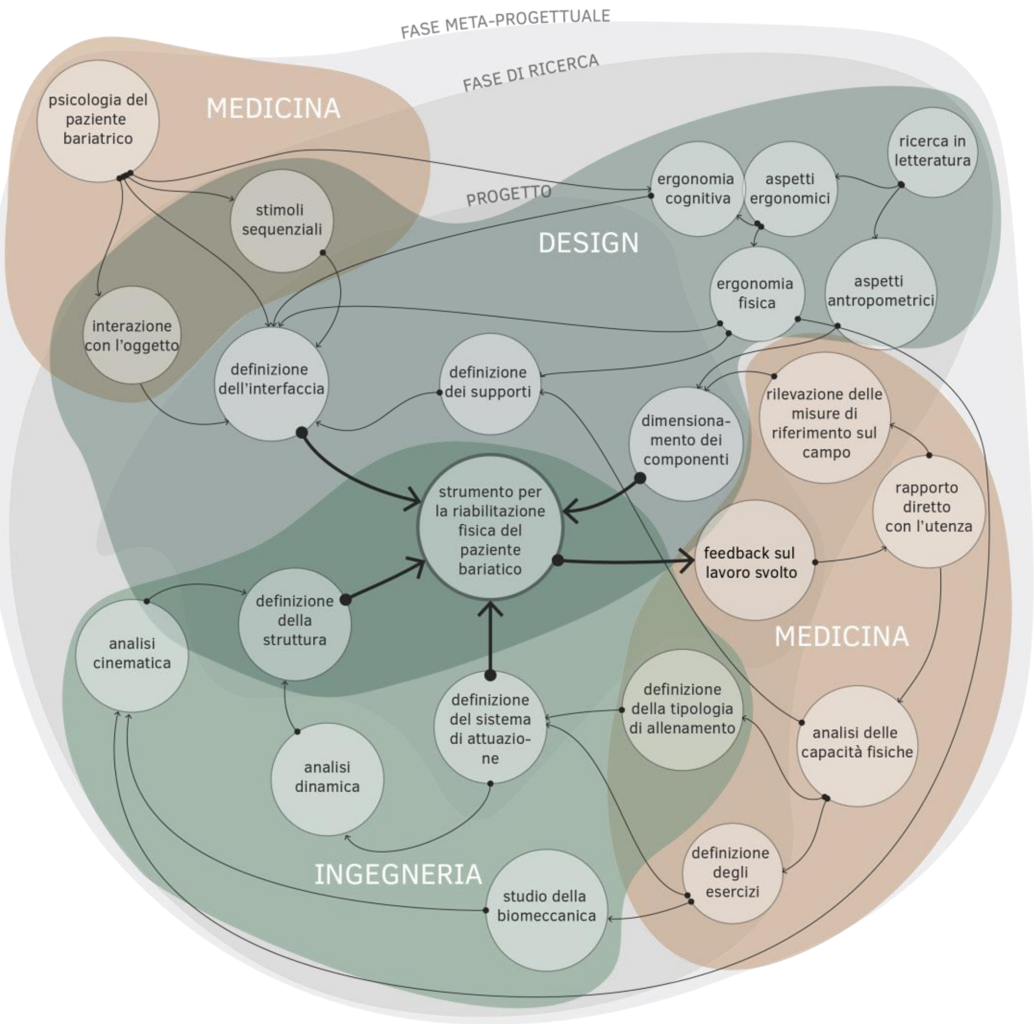



*Figure 2.3: Overview about factors involved in the project highlining areas*

### 2.3 Project specifications

As introduced in the previous paragraph, guidelines (figure 2.4) for the thesis project have been given by doctors who have the need to stimulate their obese patients to move and to in order to recover the muscular tone. The object chosen is a seat or a chair where obese patient may perform physical exercises. This choice is determined by observing the obese attitudes.

The movements suggested by them should involve the large muscle masses, such as quadriceps, hamstrings, biceps and triceps and if possible, the abdominal part too. Movements with a low effort, but with a high frequency are preferred. Moreover, the system should perform simple and quick short movements such as the hand rapid beat on the armrest, or the leg trembling. Since the cardiovascular system is overloaded as well as joins which hold up the high weight, the exercise resistance load should be light considering the general health status of users.

A motivational feedback should be provided to the patient to stimulate him to continue the workout and to help him building a good mindset inclined to improve himself and, as a consequence, self-esteem. The user should not be tired or bored while training on the seat, so visual stimuli may be useful for this purpose.

A feedback results should be shown both to patient and doctors to monitor progressively the health status or the consumed energy or similar data while training. The feedback shown to doctors may be different with respect to those ones shown to patients, because they can be sensitive to some of them.

Guidelines about the aesthetics concern the general shape that should not be associated to a gym machine. Indeed, as the team psychologist said, obese people generally has a negative impact for everything that concern the classical gym in addition to develop a certain kind of denial for workout. So, the system should be hidden and disguised as a normal chair or seat, covering the mechanical parts, such that it invites the obese individual to use it.

It’s preferable to minimize noises to make the training more comfortable.

# Chapter 3
# Exercises and gym machine

## 3.1 Choice of physical exercises

According to specification projects, training has to be executed from a seated position by obese patients. Movements have to be light to not overload joints already stressed by the body fat.
Since great muscle bundles require more energy to be moved, according to doctors, exercises involving quadriceps and hamstrings for legs and biceps and triceps for arms are preferred. So, possible movements involving these muscles are searched (figure 3.1).
Most of the analysed exercises were "bodyweight", that means free or without an extra weight, but they are also completely released from the chair. At this step the main problem is to guarantee a correct exercise performance. Furthermore, an obese, that has never done a training, should be guided through it. Otherwise, the movement could be wrong and in the worst case may damage joints and cause pain, creating the opposite effect with respect to the desired one.
It has decided to choose exercises that can be done moving physical elements connected to the chair. In this way the patient can "play" with the system and enjoy more. This is another reason that leads to this decision.
A soft load resistance may be considered if the patient acquires confidence to exercises and accepts an harder challenge with doctors approval.
Finally, the exercises are chosen and can be divided in two subgroups. In the first one there are those ones that an eventual soft load can be added, and chair elements must follow the patient motion. These ones are listed below:

- biceps curl;
- triceps pushdowns;
- leg curl;
- leg extension.

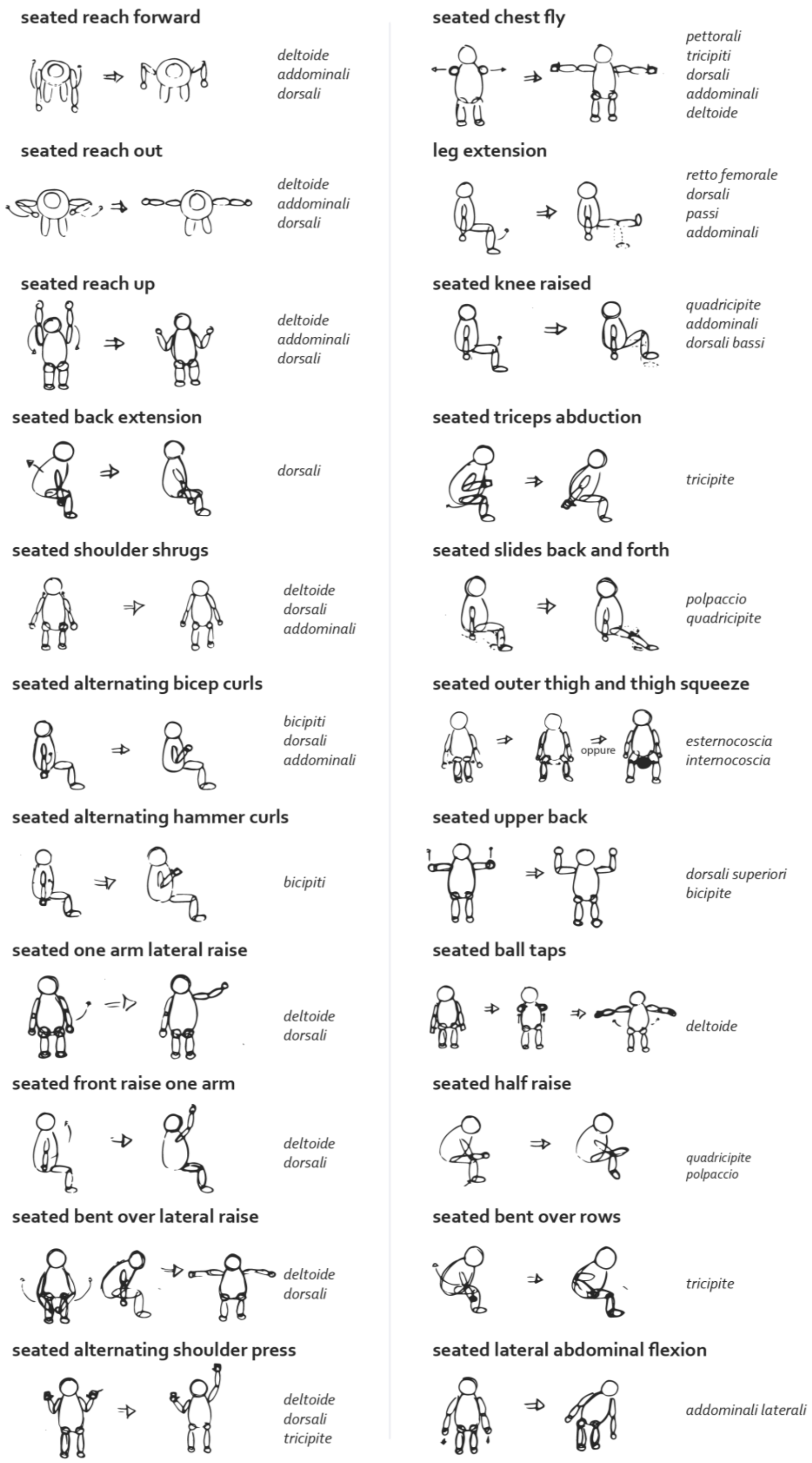



*Figure 3.1: movements and exercises that can be performed from a seated position. Self-elaboration*

In the second subgroup there are those ones that don't require an extra load, because they may be executed at high frequency, the range of movement is restricted and don't require too much muscle stress.
They are:

- foot or feet beat;
- heel or tiptoe beat;
- hand beat on the armrest;
- hand grasp on anti-stress elements.

## 3.2 Exercises description and involved muscles

In this paragraph the exercises are briefly analysed. In particular, those ones that requires the chair motion. Even if these kinds of exercises may be executed in different positions with different kind of gym equipment, only description of the seated version of these exercises is helpful for the project purpose. Then, the term "seated" is omitted, but all the exercises refer to the seated version one.
Different variations are intended to activate and develop more some parts of the muscle considered. Remembering that users of this tool are obese people and its aim is to restore mobility and not to define muscles shape, so all these little details are neglected. Furthermore, the back of the user that perform the exercise is considered completely in touch with the backrest in all the exercises avoiding vertebral column stress and overload.

### 3.2.1 Biceps Curl

Biceps curl (figure 3.2) exercise activates mainly the biceps muscles bat also brachialis and brachioradialis are activated. In the initial position the arm is extended in normal weight individuals the movement ends when the forearm is vertical to the elbow and the hand is as

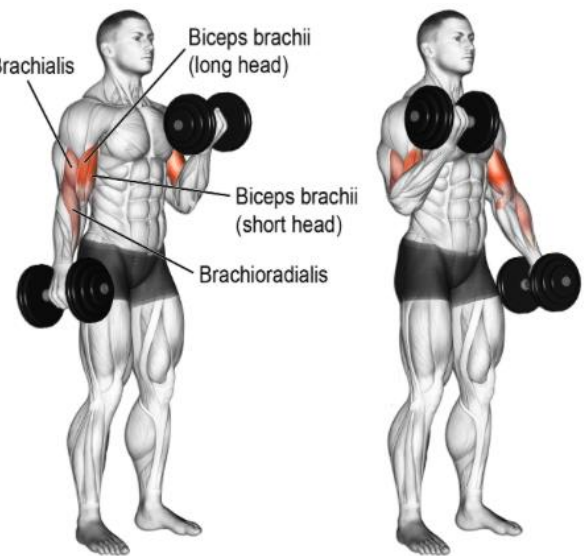



*Figure 3.2: example of biceps curl with dumbbell*

close as possible to the shoulder. The greatest effort occurs when starting from a position of complete extension of the elbow (initial position). Usually a weight is held by hands. The exercises can be performed with different downwards. Performing the exercise, the flexion of the elbow is involved. handle position, but the chosen one is the classical one: the hand palm is facing upwards. Then the arm return in the initial position following the same movement in the opposite direction.

### 3.2.2 Triceps Pushdown

The aim of triceps pushdown exercise is to activate the biceps antagonist: arm triceps muscle. Its contraction takes place by extending the elbow. In the initial position the elbow is flexed, and the hand is near the shoulder. After the movement, the hand is brought down. Then the initial position is restored reversing the movement. The chosen handle position is that one with palm facing down.

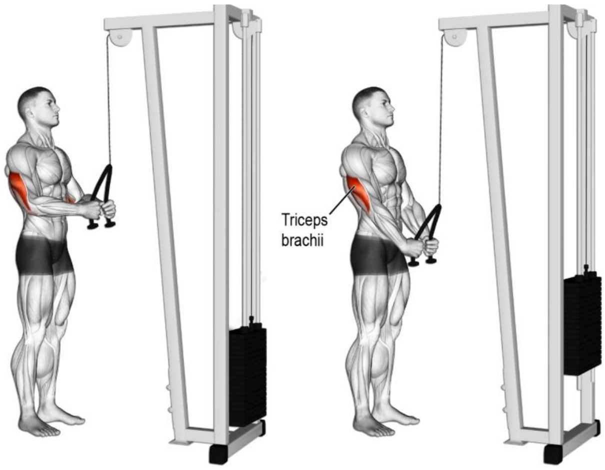


*Figure 3.3: example of triceps pushdown with cables.*

### 3.2.3 Leg extension

Leg extension (figure 3.4) exercise activates the femoral quadriceps. Starting from an initial position, that is the seated normal one, the knee from 90° is extended until the leg is completely extended. A load is posed on the front of the ankle. After the quadriceps effort the movement is reverted turning back in the initial position.

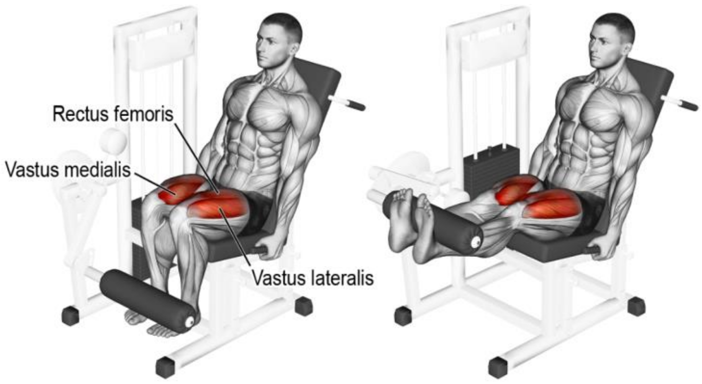


*Figure 3.4: seated leg extension exercise.*

### 3.2.4 Leg curl

Leg curl is exactly the opposite movement exercise of leg extension and mainly hamstrings (leg extension antagonists) are involved with sartorius, gracilis and gastrocnemius. From a seated position with the knee at his maximum extension, the leg is supported by a cushion. This one is used to apply the resistance load and is collocated behind the ankle. The final position is reached contracting hamstring and so flexing the knee until the knee forms an angle of 90°.

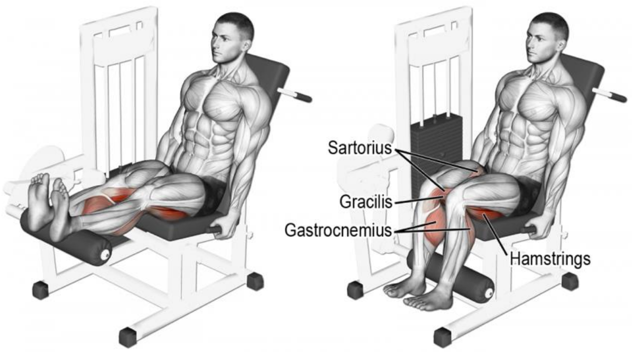



*Figure 3.5: seated leg curl.*

### 3.2.5 Exercises variations

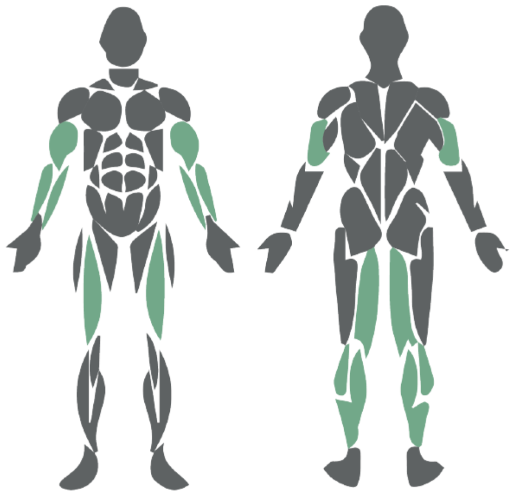


*Figure 3.6: Schematic representation of muscles in selected exercises. Self-elaboration.*

Once the exercise is chosen, it may be performed alternating the limbs movement. In this way, the exercise is easier, and it can be ideal for the project goal. So, it is decided to allow the alternating movement as well as the movement with both the arms or both the legs. This last option requires more coordination, but it wants to be allowed if the patient feels confident to try a harder challenge to variegate the exercises.

Summing up, trained muscles involved in these exercises can be seen in figure 3.6.

### 3.3 Biomechanics of human body

It's important to understand how the levers of the body moves and how joints involved in chosen movements work. In this way gym machine analysis may be better understood in the next paragraph, highlining the most important elements that allows a correct body motion.

The human body may be represented through the use of levers, that can be of the first second or third class (figure 3.7):

first class lever: fulcrum is positioned between effort and resistance.

second class lever: resistance is positioned between fulcrum and effort.

third class: effort is positioned between fulcrum and resistance(1).

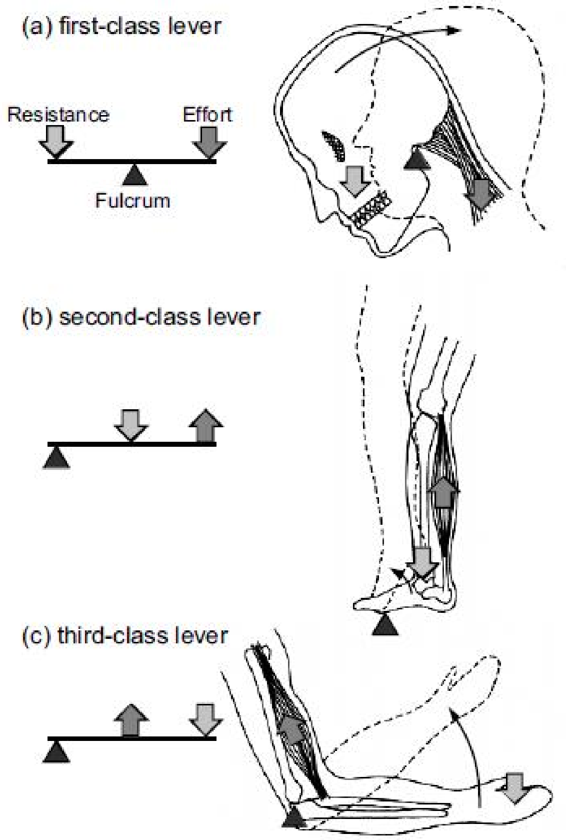



*Figure 3.7: The tree types of lever in the human body. Source: A. Tozeren, Human Body Dynamics – Classical mechanics and human movement, Springer, New York, 2000.*

The flexion and extension of elbow as well as of the knee are levers of third class. The rotation of the elbow can be represented and schematized as a mechanical rotational join as in figure 3.8. Obviously, it's not a pure rotating motion, because there's also a translational component, but it's too insignificant that can be neglected. The knee flexion-extension is more complex with respect to the elbow one, because,

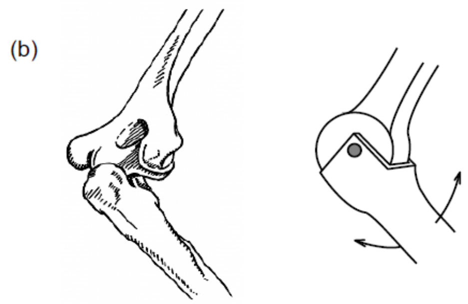



*Figure 3.8: Human body joint represented as rotational mechanical joint. Source: A. Tozeren, Human Body Dynamics – Classical mechanics and human movement, Springer, New York, 2000.*

the rototranslation movement is more evident (figure 3.9). In particular, it the femur perform a posterior “roll-back”.

So, the chair system must be provided of a centre of instantaneous rotation positioned in correspondence of the elbow and of the knee. Taking into account the roll back a little rubbing can be present between leg and the cushion of the machine moving with it.

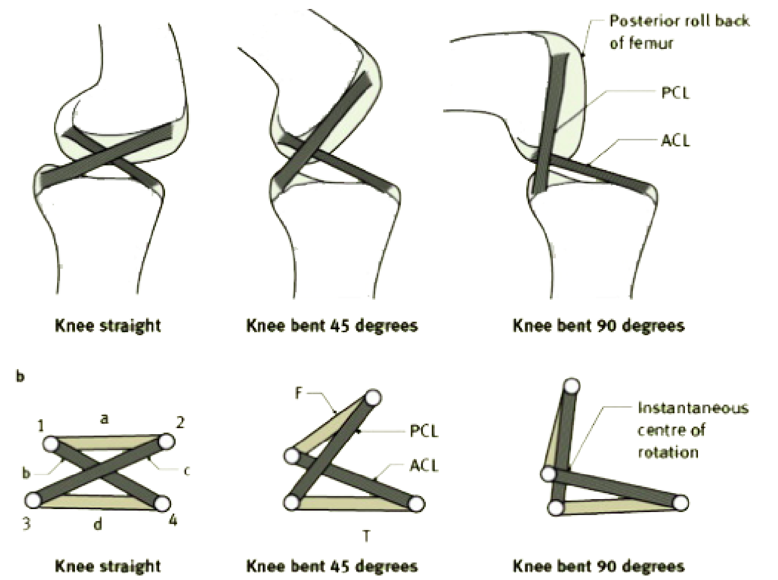



*Figure 3.9: the knee joint rotation. Source: R. Shenoy, P.S.Pastides, D,Nathwani, Biomechanics of the knee and TKR, Orthopaedics and trauma, Vol. 27, Issue 6:364-371.*

It is fundamental at this point quantify the range of motion (ROM) of elbow and knee joint, such that amplitude of the angular excursion can be defined. The Range of Motions taken as a reference for the project do not refer to bariatric users, but the standard ones are considered in order to allow the analysis of maximum motility levels to be carried out.

The arm goes from a position of maximum extension of 0° to 140° of flexion as can be seen in figure 3.10.

While knee goes from an extension position of 0° to 150° when is in flexed position (figure 3.11).

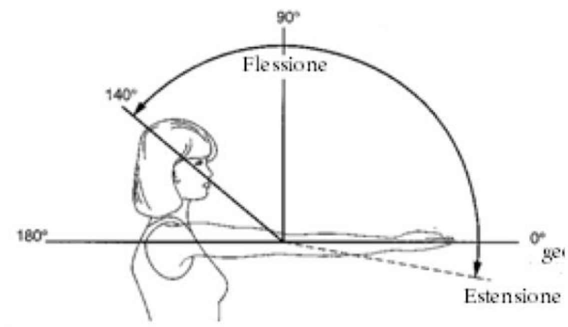



*Figure 3.10: Elbow range of motion. Source: Luttgens e Hamilton (1997)*

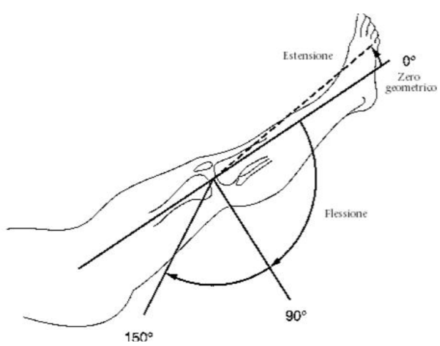



*Figure 3.11: Knee range of motion. Source: Luttgens e Hamilton (1997)*

### 3.3.1 Muscular contraction classifications and efforts

In muscular physiology there are essentially 3 types of contraction: concentric, eccentric and isometric contraction.

The concentric contraction is characterized by the muscle shortening and swelling, so basically the analysed muscle is in contraction phase. The force is greater than the resistant load. On the contrary, the eccentric contraction represents the braking mechanism to a concentric action. The muscle length in eccentric phase grows up while the muscle force is less than the resistance opposed to the movement.

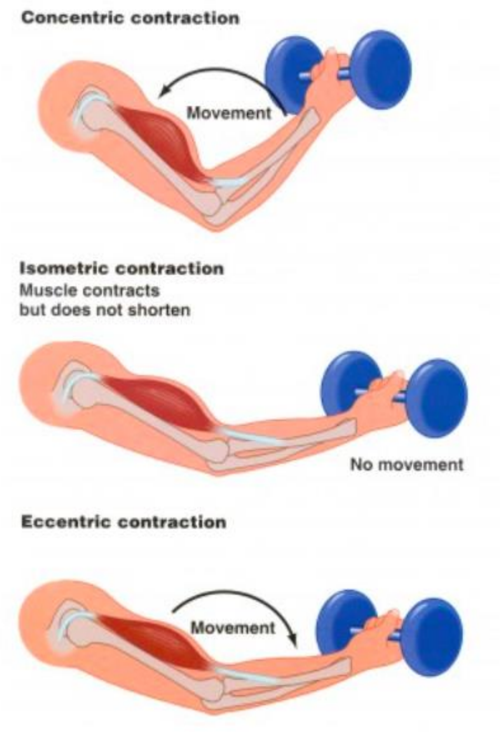


*Figure 3.12: 3 phases contraction involved in movements.*

Instead, isometric contraction is used in stability exercises and the movement is not expected. The muscle length stays unchanged and the load is equal to the resistance.

Different type of machine and exercises are studied to produce different muscle contractions like the isokinetic contraction in which the movement is performed with a constant angular velocity and torque increases or decreases in function of the resistance during all the execution, such that the resistance load is constant and maximum during all the ROM.

## 3.4 Gym machine analysis

Different tools are used to perform a workout like cable or barbells. They produce an isotonic contraction, in other words all the three phases (concentric, eccentric and isometric) are crossed by the target muscle and the resistant load doesn’t change.

However, these methods may be easily associated with gym, so this choice could produce bad result from the phycological point of view.
At this point, different gym machines are analysed to choose an actuation system that can be easily integrated in a chair and what kind of muscle effort produces. The resistance load can be applied with:

- weight stack;
- hydraulic cylinder;
- air cylinder;
- electric motor.

### 3.4.1 Weight stack machines

The most common gym machines are those one with a weight stack. They use gravity, that act on the weight stack, to generate the resistant force. This kind of machines produce an isotonic effort, such that the user, feel a constant load during all the exercise. To allow this behaviour, usually, cams are inserted in the machine system, usually in correspondence of joints. Cam's shape can be projected based on the effort curve through biomechanical studies.
In figures below, "Technogym" machines are analysed for what concern the 4 exercises chosen that needs an actuation. This research is helpful to understand what kind of devices are integrate in a gym machine looking at the products of an expert company in the sector such as Technogym.
Some of this characteristic described in figures can be neglected for what concerning the thesis project, because these kinds of machines are built to perform strength training with high weight. Some of these are:
the superior cushion of the leg curl, because the chair needs to be without constraint for psychological reasons and because of low weight considered in specifications; backrest inclination, because of the main goal isn't defining the shape of the muscle.
All the other features are really interesting, such that regulations and the system to allow a constant effort with cam systems.


*Figure 3.13: 3 leg extension machine, Thechnogym. 1) lever to modify range of motion from -20° to 110°; 2) roller cushion with height regulation; 3) backrest regulation to activate different part of the quadriceps muscle; 4) Cam; 5) anatomic shape of the seat cushions; 6) depth regulation of all the seat for thigh length. Self-elaboration.*


*Figure 3.14: 3 leg curl machine, Thechnogym. 1) Upper roller cushion lever to minimize the risk of hypertension and to stay in stable and correct position with the tibial cushion to apply the effort; 2) possibilities to shift superior cushion while sitting; 3) height regulation of the roller cushions; 4) ROM regulation form 0° to 110°; 5) Fulcrum axially aligned with the knees; 6) entire backrest regulation to align knees with the rotating joint of the machine Cam; 7) backrest tilt of 95 °, 102.5 ° or 110 ° to involve specific muscles; 6) depth regulation of all the seat. Self-elaboration; 8) Counterweight to increase or reduce the inertia value associated with each movement of the exercise. Self-elaboration*

*Figure 3.15: arm curl machine, Thechnogym. 1) Arm support, which must be motionless during the exercise; 2) Cam for both the arms; 3) Seat regulation to adapt to all heights; 4) fulcrum positioned at height of elbow. Self-elaboation*

*Figure 3.16: arm extension machine, Technogym. 1) Cam for both the arms; 2) height seat regulation; 3) Design to adapt the tool to forearms of different lengths and to make it less constrained to the alignment of specific elbow rotation axis; 4) Flexible handles. Self-elaboration.*

However, this kind of machine are really bulky and can realize just one exercise at a time. Moreover, the alternating type exercise is not intuitive for leg extension and leg curl.

But the most important reasons to avoid weight stack are the big dimensions and because they look like the classical gym equipment, which from the point of view of a bariatric patient can lead to psychological issue.

### 3.4.2 Hydraulic gym machines

Hydraulic machines (figure 3.17), on the other hand, have a resistance which is given by the presence of a hydraulic cylinder that performs the function of a brake. The physical effort depends on the speed of execution of the movement: the higher the speed, the greater the load(3).

Some types of exercises such as leg curl and leg extension or triceps and biceps are performed on the same machine. Indeed, the muscular effort is concentric-concentric, because 2 muscles are activated in the same machine whit the same exercise. It is important to see how the size of entire system is reduced and noise is very low. However, since quick movement are preferable the effect "the higher the speed, the greater the load" it is not adequate. Moreover, remembering psychological factors about limits and constrains in movements, limbs are wrapped between cushions and this is a disadvantage.

*Figure 3.17: hydraulic gym machines of "Curves"; triceps/biceps on the left and leg curl/leg extension on the right.*

### 3.4.3 Pneumatic gym machines

The pneumatic machines are distinguished from the hydraulic ones by the type of cylinder, is pneumatic with compressed air. The actuator not only acts as a brake, as in the previous case, but allows for a concentric-eccentric type of effort. They can be categorized as isotonic machines. Also in this case some types of exercise can be realized with a single mechanism(6). There are a lot of advantages regarding this type of exercises:

- system actuation size is small;
- constant effort;
- limbs are free and not constrained.

The noise is not so low, but it can be managed. "Hur" machines (figure 3.18) allow to have more than one exercise with one system as in the case of hydraulic cylinders and are particularly efficient for elder people and recovery of mobility. Moreover, there can be machine like those ones of Keiser, which don't allow more than one exercise in one machine.


*Figure 3.18: pneumatic gym machines. "Hur" machine on the left allows multiple exercises. Keiser on right allows one exercise.*

### 3.4.4 Robotic gym machines

Robotic gym machines are the most innovative. They are very versatile, because with just one system they can reproduce different kind of effort. Training can be isometric, isotonic, isokinetic, viscous (which reproduces the perceived resistance in water), elastic and with variable resistance. These machines use electric motors, actuators, sensors and microprocessors for the calculation of physical parameters and effort diagrams and for the realization of immediate feedback.

One of the most complete is "Kineo intelligent load".


*Figure 3.19: Kineo intelligent load.*

One of the problems related to this machine could be a not negligible noise, moreover the complexity is high with respect to the other ones.

### 3.5 Effort and system actuation choice

Taking into account all the effort analysis, according to doctors, the most appropriate for bariatric patient is the isotonic contraction with all the 3 phases of concentric, eccentric and isometric phases.

Exercises may be performed with or without a resistance load and repetitions may be high to perform an aerobic training, but also may be a little bit harder, shifting in strength training, adding load or not alternating limbs exercises.

In this way the training can be more complete and can allow to spend energy and to tone muscles.

According to advantages and disadvantages for all the machine types, merging all the need and matching the project specifications, a pneumatic actuation may be adequate for the purpose.

# Chapter 4
# Anthropometry and ergonomics

## 4.1 Ergonomics in sitting position

During the design process of a training-chair for bariatric patients some issues must be considered carefully to avoid the introduction of additional musculoskeletal diseases. The seated position, indeed, could appear as a "rest" situation while in reality, a wrong posture can lead to several and also permanent damages.

Analysing the motion from stand-up position to the seated position the angle between the trunk and the thighs goes from 180° (erected) to 90° (seated). The hip bone and lumbar vertebras tends to have a motion towards back in such a way the proper spinal column curve is not respected(1), as showed in figure 4.1. As a consequence, the system increases the pressure on the spline to preserve the equilibrium position(2).

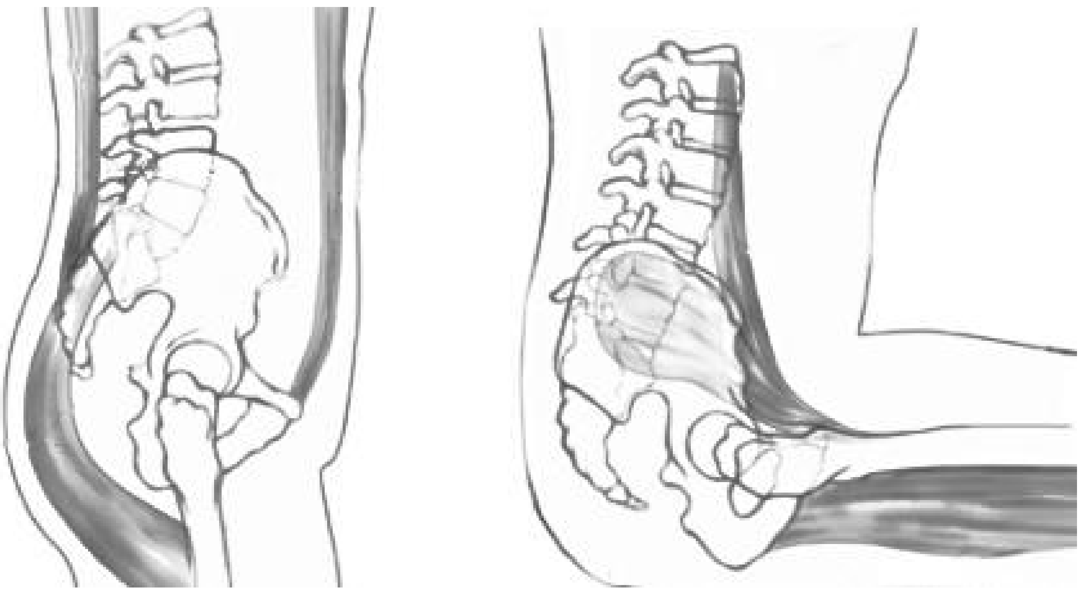


*Figure 4.1: hip bone rotation while sitting, source: http://fkt.it/rachide-lombare.*

To reduce the spline axial pressure, it is necessary to “force” the correct curve shape on the back by means of a proper support as showed in figure 4.2.

*Figure 4.2: B. Akerblom and G. Ekloef for Akerblom Stolen chair, Sweden, 1950.*

Another non-negligible issue for the design phase of this kind of product is the contact interface between body and chair surface. In particular, according to Akerblom(3), varying the chair configuration, the hip bone angle changes, as a consequences, the spinal goes back to a proper curvature.

However, the sizes and proportions in human body are strongly affected by the belonging population, and, within the same group, significant variations are present. Of course, to achieve a benefit for the user, the chair dimensions should be adjustable(4).

Generally, the back and thighs are the zones most exposed to pressure, on a stress level instead, ischial tuberosity are the most critics(5).

The seat should guarantee the lowest level of asymmetry possible and the greater uniformity for the pressure distribution.

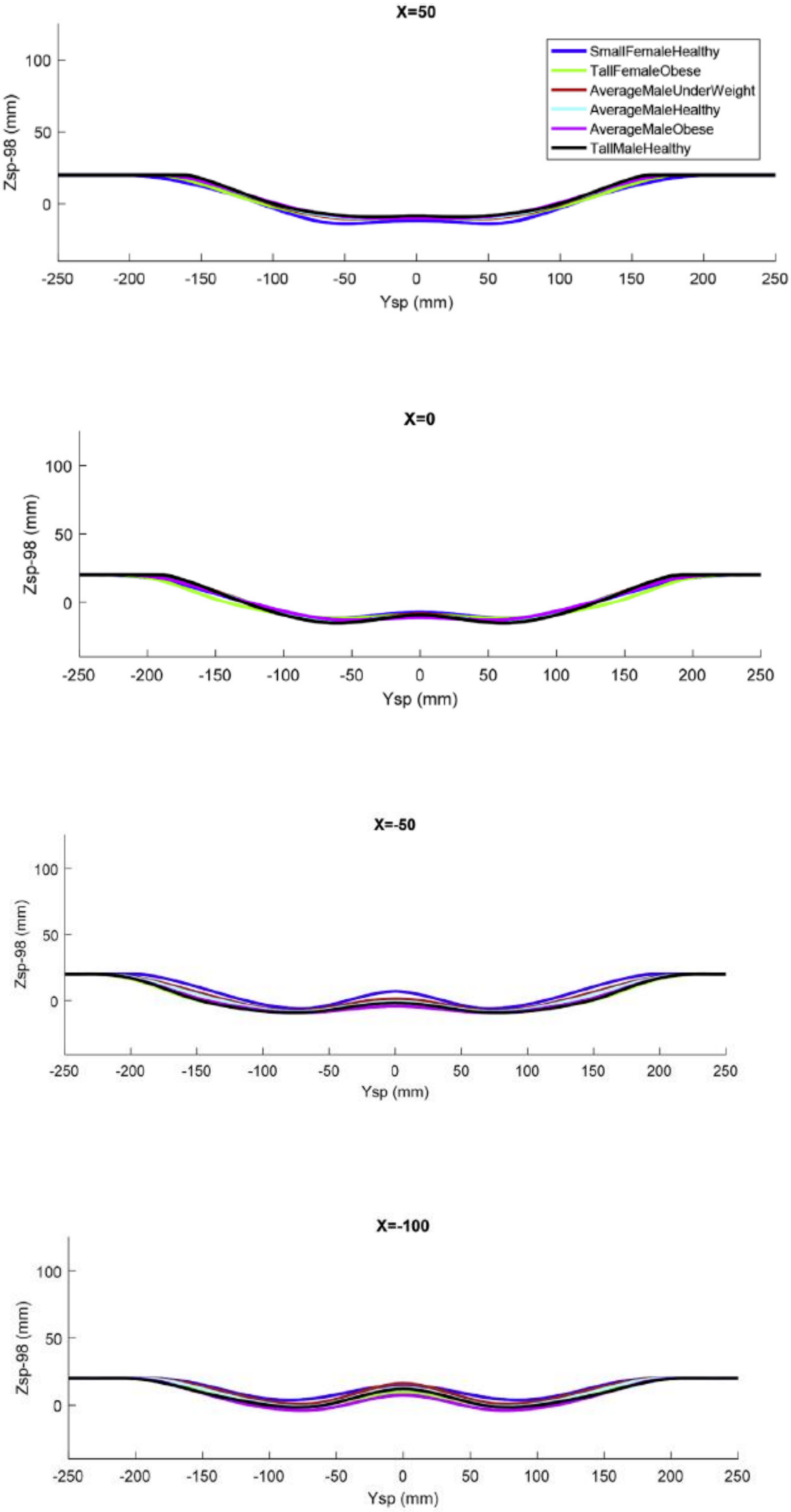



*Figure 4.3:* frontal section according to different users. Source: X. Wanga, M. Cardoso, G. Beurier, Effects of seat parameters and sitters' anthropometric dimensions on seat profile and optimal compressed seat pan surface, Applied Ergonomics 73 (2018) 13–21.

The exerted pressure in the contact zone between body and object, is an important feature to be considered during the design process. The factors that are influencing the pressure perception of the body are the external shape and the material softness.
Recorded data regarding the pressure sensitiveness are the key to select the kind of material in the interface between chair and user.
Regarding the seat, the most sensitive zones are the frontal one. According to Wanga et al. (2018)(6) scans (fig. 33 – fig. 34), extrapolated from the resultant pressure contour on a seat according to different typology of users, it is possible to notice how the portion with the greatest grade of variability is the frontal one. This means that this zone must be characterised by a greater flexibility. In particular a “waterfall” shape in the front section may prevent the user from experiencing a wrong blood circulation(7).

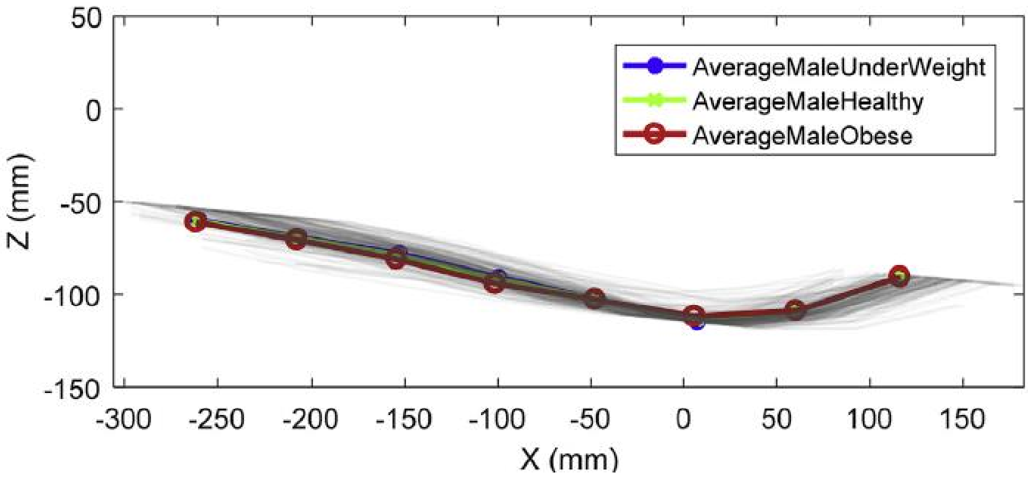



*Figure 4.4: Lateral section according to different users. Source*: X. Wanga, M. Cardoso, G. Beurier, Effects of seat parameters and sitters’ anthropometric dimensions on seat profile and optimal compressed seat pan surface, Applied Ergonomics 73 (2018) 13–21.

As already stated, the lumbar support is a key portion of the chair which needs a focus. Adding a lumbar support is the most effective way to preserve the proper curvature of the back-bone(8). With a 4 cm support positioned in correspondence to the lumbar curve, a 30° lordosis is achieved, which is close to the natural one(9). It is necessary to underline how important is the correct position of the support to get the proper working condition (between L2 and L3 vertebras). This means that, to have a chair suitable for a wider population, even the lumbar support height should be adjustable.

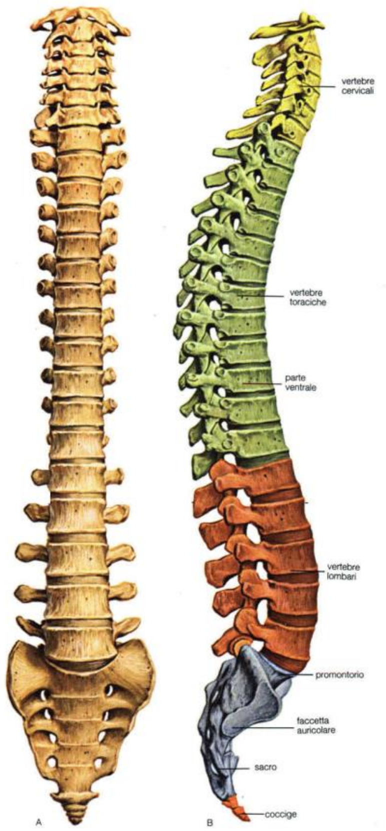



*Figure 4.5: human backbone.*

**4.2 The case study of a bariatric chair**

Dealing with the very peculiar case of bariatric patients, some additional factor must be prioritized, especially, the weight of the patient, the range of motion, the mobility of the patient itself. Moreover, the mass of the patients prevents the lumbar support to be placed in the most correct zone. The excessive fat, force the bariatric people to seat in a wrong way (fig-4.6) that can lead to long term musculoskeletal disease, the risk is increased during the motion from seated to stand and vice versa.

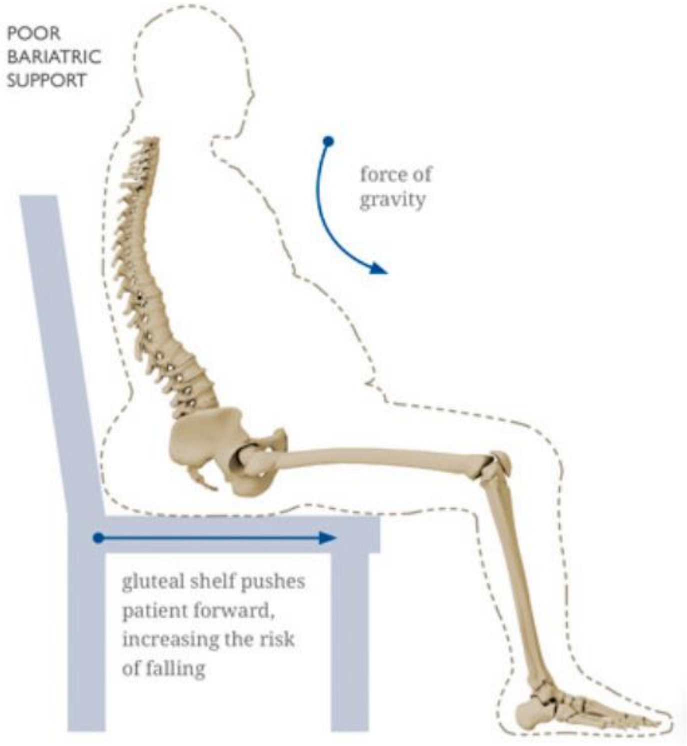



*Figure 4.6: bariatric patient risk on a standard seat.*

As consequences, it is very important to guarantee a proper space to allow the positioning of excessive fat tissue, maintaining the lumbar support function. It is now possible to summarize some guidelines that can be used for the chair design:

the chair width must be properly chosen to receive the legs but also the abdomen;

the contact surface must be sufficient enough to reduce the risk on overloaded zones;

an additional support for calves is added to make possible the weight transmission to the ground.

the patients should be independent while sitting and vice versa.

#### 4.3 Patient Anthropometry

At this point an anthropometric data analysis is fundamental going throw the design phase. In this phase, the collection of data is not easy due to the lack of databases. To address this problem, as a starting point the P99 (percentile 99) man (tallest individual) and P1 female (smallest individual) have been considered (fig 4.7)

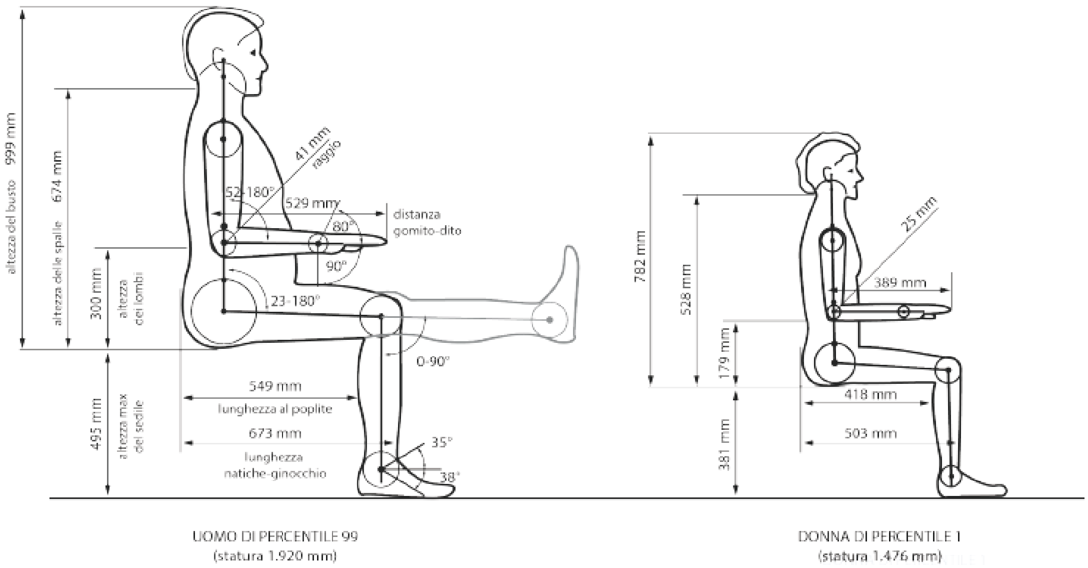



*Figure 4.7: Reference anthropometric models.*
*Source:* Henry Dreyfuss Associates, Milano, 1994.

In a second moment, the available data have been merged and weighted in relation to the measurement taken from the reference population of bariatric patients. As a guideline, the maximum value of a given dimension is considered for the design phase, while the minimum is used to set the regulation range. In fig 4.8 the data measured from a sample of 20 patients in seated position are presented.

| | Sex | Age | Height [cm] | Weight [kg] | BMI [kg/m^2] | Internal knee distance [cm] | External Knee Distance [cm] | Internal foot distance [cm] | External foot distance [cm] | Chest width [cm] | Shoulders width [cm] | Knee width [cm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | M | 54 | 174 | 125,9 | 41,6 | 18 | 55 | 28 | 47 | 50 | 51 | 21 |
| 2 | M | 62 | 167,5 | 103 | 36,7 | 34 | 53 | 40 | 61 | 43 | 48 | 19 |
| 3 | M | 57 | 158 | 103 | 41,2 | 20 | 51 | 27 | 48 | 52 | 46,6 | 22 |
| 4 | M | 26 | 171 | 113 | 38,6 | 35 | 58 | 32 | 56 | 44 | 51 | 18 |
| 5 | M | 53 | 178 | 140 | 44,2 | 36 | 60 | 30 | 52 | 48 | 55 | 21 |
| 6 | M | 57 | 170 | 88 | 30 | 21 | 41 | 19 | 39 | 42 | 44 | 16 |
| 7 | M | 66 | 176 | 133 | 43 | 31 | 51 | 25 | 48 | 40 | 50 | 19 |
| 8 | F | 31 | 163 | 83 | 31,2 | 51 | 40 | 18 | 35 | 44 | 37 | 17 |
| 9 | F | 51 | 157 | 78,5 | 33,1 | 15 | 43 | 25 | 41 | 39 | 44 | 16 |
| # | F | 42 | 166,5 | 79,5 | 28,2 | 17 | 40 | 31 | 40 | 40 | 42 | 16 |
| # | F | 32 | 162 | 109 | 41,2 | 16 | 43 | 18 | 38 | 59 | 51 | 29 |
| # | F | 47 | 155 | 73,5 | 30,6 | 15 | 33 | 21 | 38 | 31 | 34 | 15 |
| # | F | 47 | 165 | 111,5 | 41 | 18 | 40 | 25 | 41 | 38 | 42 | 20 |
| # | F | 37 | 166 | 118 | 42,8 | 20 | 45 | 20 | 35 | 43,2 | 41 | 24 |
| # | F | 45 | 165 | 115,7 | 42,5 | 20 | 45 | 19 | 38 | 40 | 50 | 19 |
| # | F | 44 | 158 | 82,4 | 33 | 18 | 40 | 23 | 42 | 42 | 36 | 18 |
| # | F | 53 | 150 | 91,6 | 40,7 | 13 | 45 | 25 | 42 | 38 | 41 | 23 |
| # | F | 57 | 153,5 | 79,1 | 33,8 | 16 | 38 | 19 | 36 | 36 | 43 | 17 |
| # | F | 48 | 165 | 85 | 31,2 | 9 | 32 | 20 | 40 | 40 | 40 | 24 |
| # | F | 44 | 174 | 94 | 31 | 7 | 25 | 8 | 25 | 37 | 42 | 15 |

| | Age | Height [cm] | Weight [kg] | BMI [kg/m^2] | Internal knee distance [cm] | External Knee Distance [cm] | Internal foot distance [cm] | External foot distance [cm] | Chest width [cm] | Shoulders width [cm] | Knee width [cm] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mear** | 47,65 | 164,725 | 100,335 | 36,15 | 21,5 | 43,9 | 23,65 | 42,1 | 42,31 | 44,43 | 19,45 |
| **Max** | 26 | 150 | 73,5 | 28,2 | 7 | 25 | 8 | 25 | 31 | 34 | 15 |
| **Min** | 66 | 178 | 140 | 43 | 51 | 60 | 40 | 61 | 59 | 55 | 29 |
| **Std.** | 10,47 | 7,79 | 19,77 | 5,28 | 10,65 | 8,86 | 6,79 | 8,09 | 6,23 | 5,71 | 3,62 |

*Figure 4.8: Anthropometric data from Molinette Hospital- Medical science department.*

## 4.4 Project Guidelines

It is now possible to summarize the guidelines extrapolated from all this set of information.

Back designed to have a proper shape, replicating the correct backbone shape, additional supports are added in the zones considered most critical for the bariatric patient such as lumbar and cervical. Regulation for height and inclinations are mandatory especially during exercise execution; shoulders are kept as free as possible (fig 4.9).

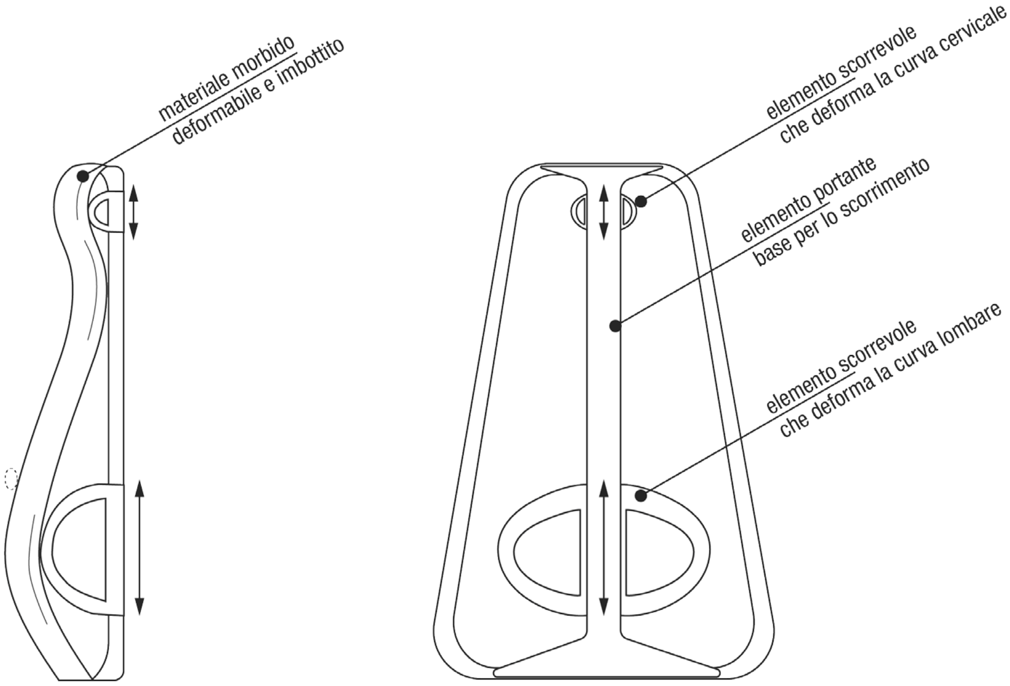



*Figure 4.9: backrest concept.*

Seat has been designed trying to keep the pressure as uniform as possible, following the curve shapes as presented before (fig 4.10).

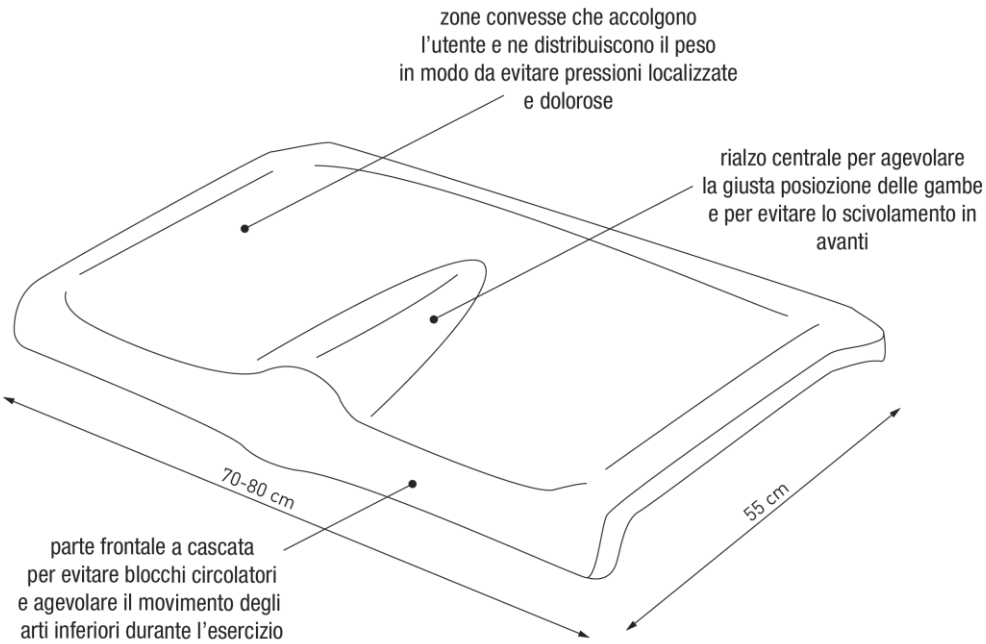



*Figure 4.10: seat concept.*

Armrests have been thought both for receiving the arm in an ergonomic, comfortable way and to allow a power grip allowing exercises. The handler is meant for 2-direction motions as showed in fig 4.11.

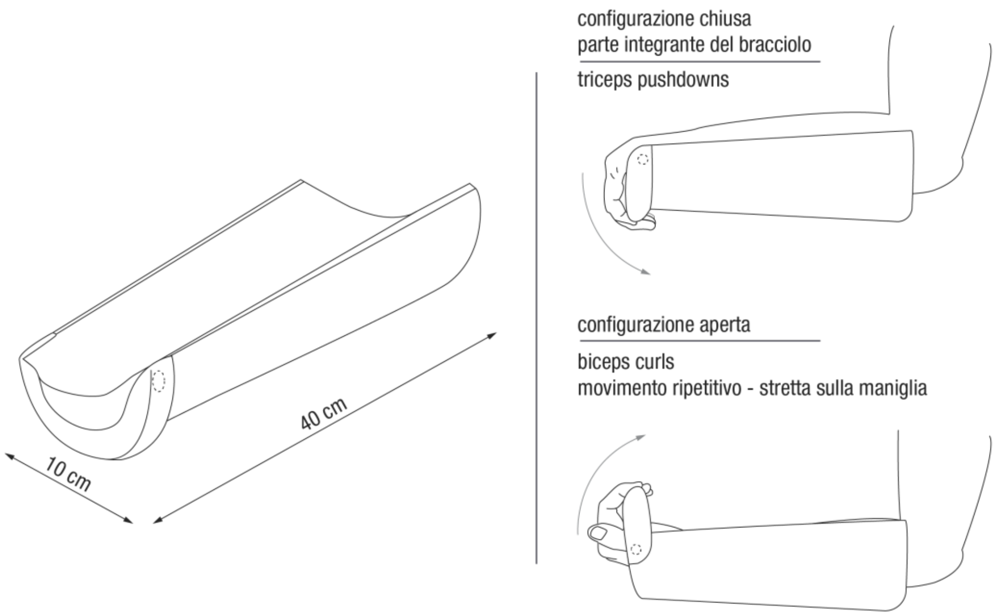



*Figure 4.11: Armrest concept.*

# Chapter 5
# Kinematics

## 5.1 Reference systems

The very first step for the development of the project is the definition of the reference system of the chair in the space. The fundamental elements constituting the product are:

- the seat,
- the back,
- the armrest,
- legs support.

Moreover, the components are schematized in the following way:

- S-seat,
- B-backrest,
- A-armrest,
- L-support for legs,
- E-elbow reference,
- K-knee reference,
- W-wrist,
- C-chair,
- Ch-chassis,
- G-global.

The seat is represented in such a way, the mobile elements are underlined.

The global reference frame is fixed and positioned under the seat to have positive coordinates for the mobile reference systems (figure 5.1).

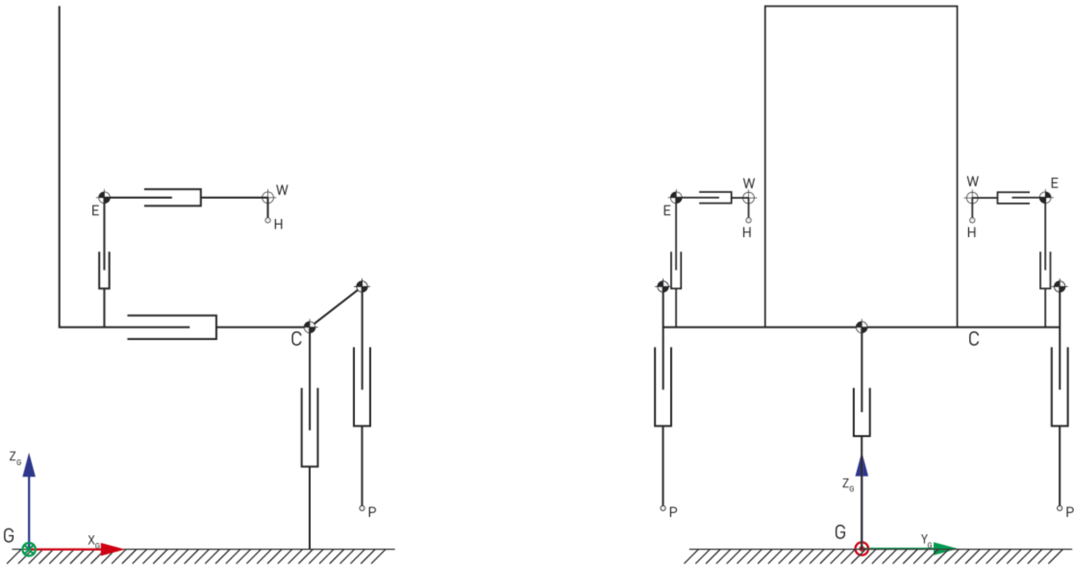
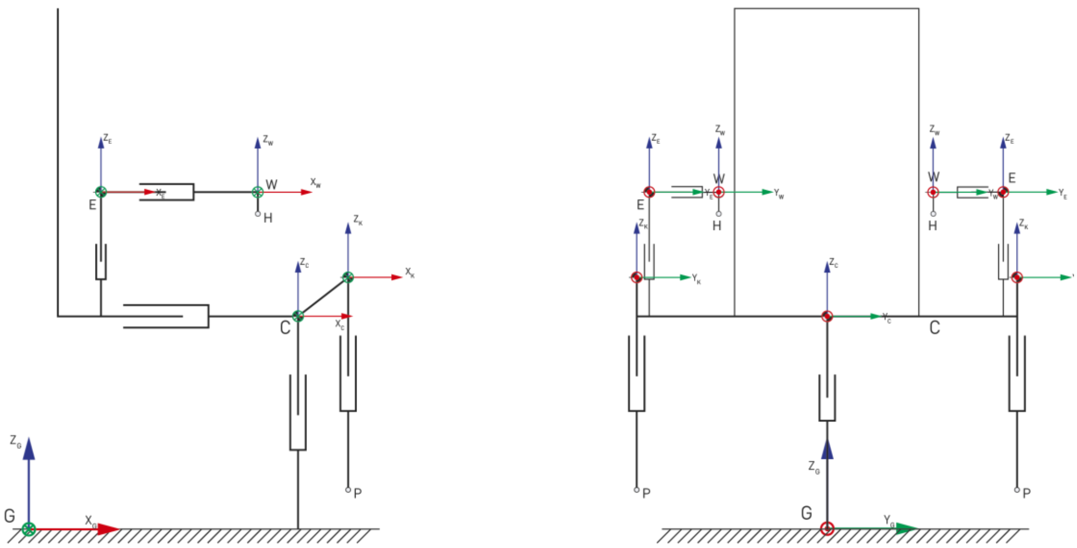



*Figure 5.1: Global reference system.*

The mobile reference frame are then presented in the following figure 5.2.




| | | | |
|---|---|---|---|
| G = Global | S = seat<br>B = backrest<br>A = armrest | L = support for legs<br>E = elbow reference<br>K = knee reference | W = wrist<br>C = chair<br>Ch = chassis |

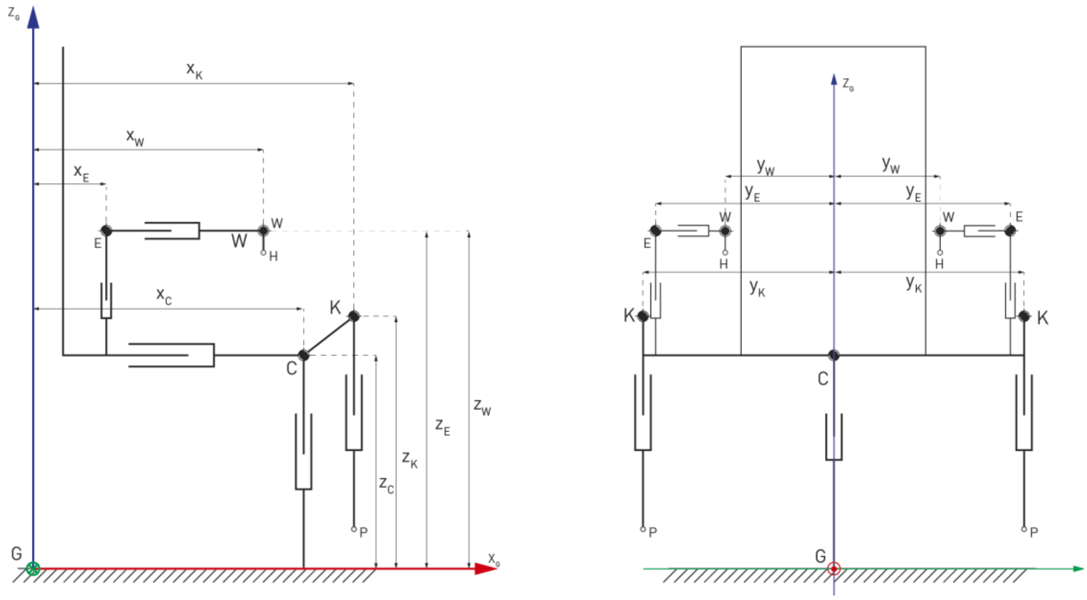



*Figure 5.2: Mobile reference systems with respect to the global one reference system.*

## 5.2 Nominal position definition

The nominal position is defined on the basis of the rest posture of the user in seated position.

The most important features are:

- soles of feet must be placed on the ground to ensure a correct weight transmission,
- a 90° angle is granted between feet and leg,
- the leg must be kept in vertical position,
- leg, thigh and trunk describe a 95° angle,
- trunk is vertical,
- arm and forearm describe a 90° angle.

The seat configuration in nominal position (figure 5.3 and figure 5.4) is thus considered as a reference for the definition of variables and mobile frames.

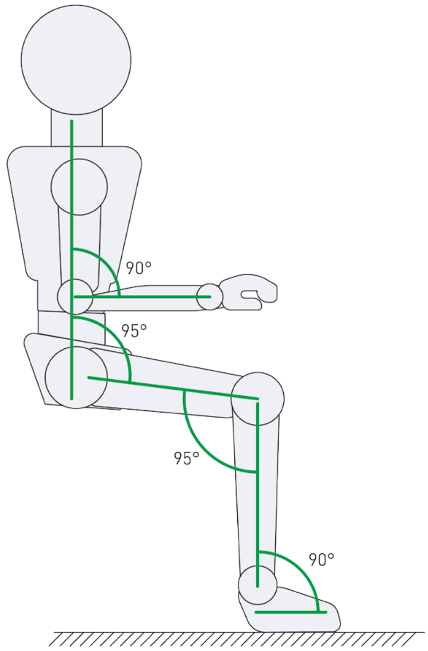



*Figure 5.3: reference posture.*

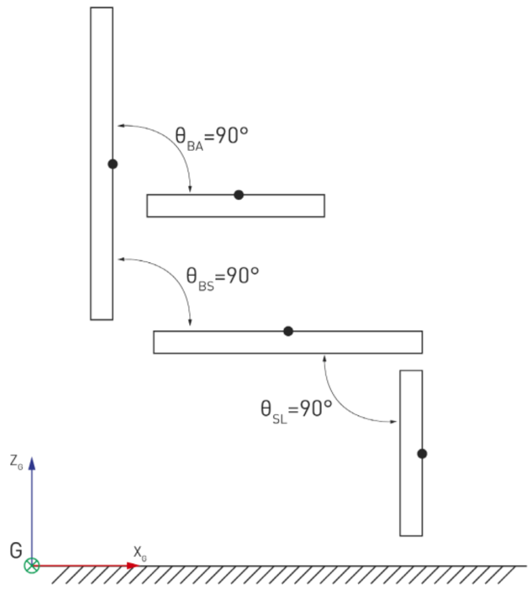



*Figure 5.4: mobile elements in nominal position*

## 5.3 Kinematics of the armrest

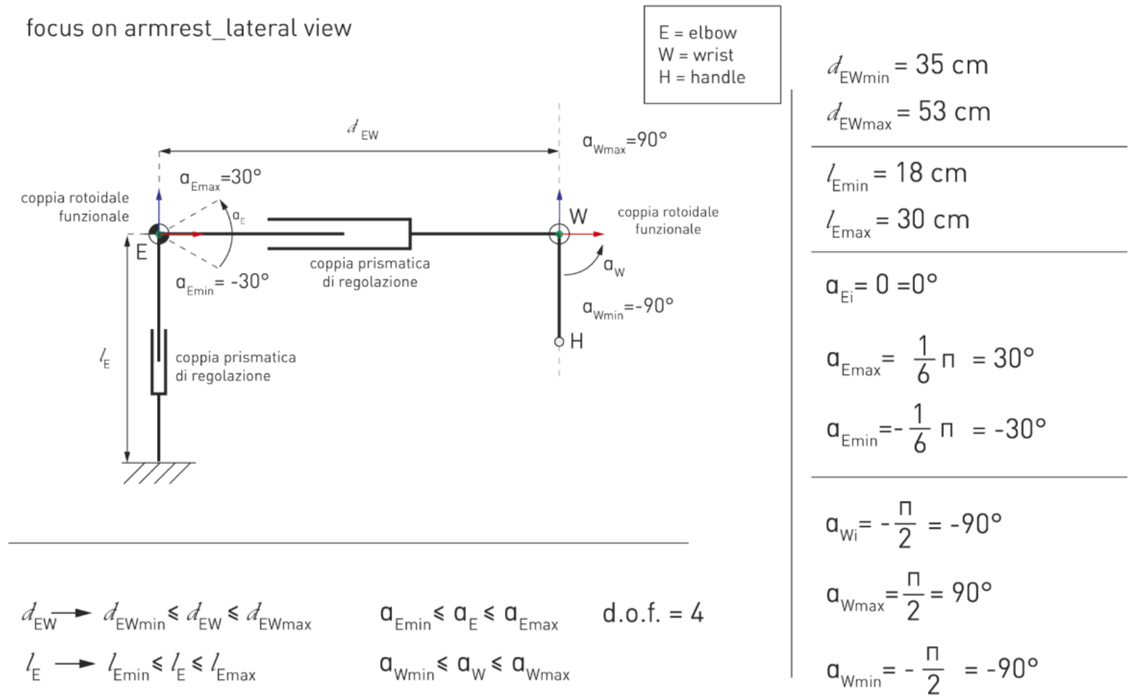
The upper limb exercises are in charge of the armrest, in figures 5.5 and 5.6, the functional scheme is presented.

In which "l" and "d" are adjustable prismatic coupling, "l" is describing the vertical regulation while "d" is representing the width regulation. The regulation "w" is instead considering the trunk lateral width of the user.

The distance d_EW is representing the width of the armrest going from a minimum value of 35 cm to a maximum value of 53 cm according to the anthropometric design already discussed. As a consequence, a range of 12 cm is proposed. The distance l_EW is representing the height regulation of the armrest from the frame of the seat. The minimum value is 18 cm while the maximum is set as 30 cm.

The WH segment represents the handle.

Given the structure dimensions and geometry the range of motion centred in point E is -30° to +30°. The regulation w_EW is going from 3 to 10 cm.



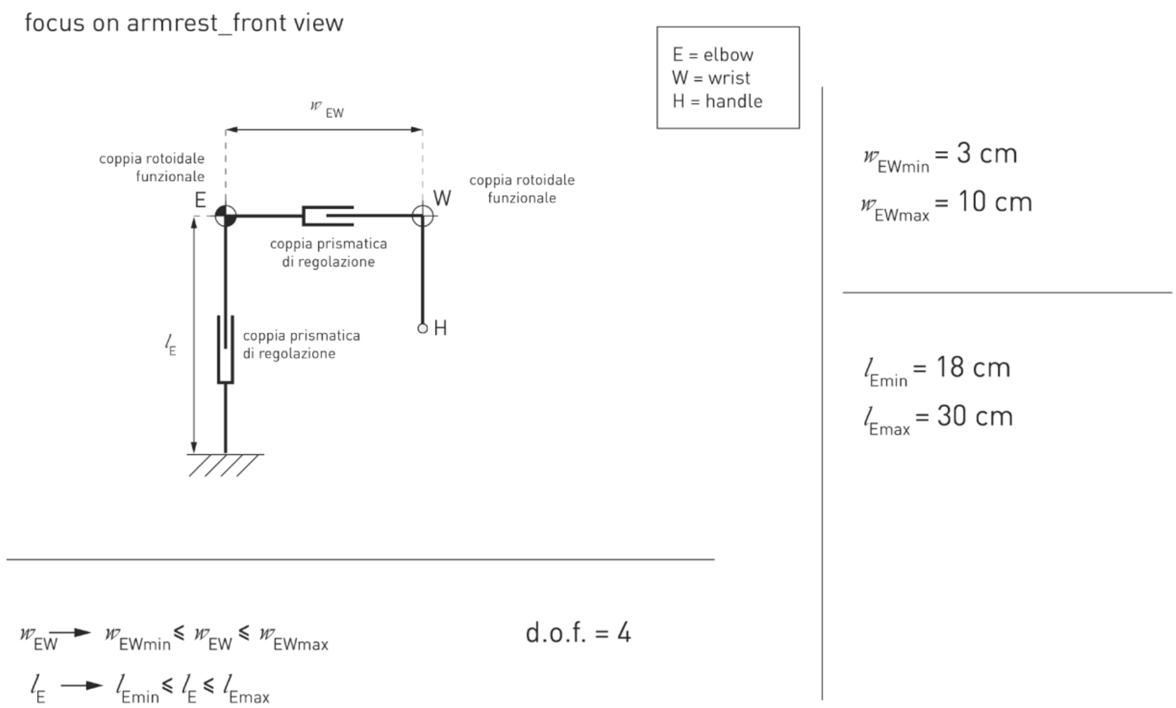




*Figure 5.5 – 5.6: armrest functional scheme.*

## 5.4 Kinematics of the seat and backrest

In figure 5.7 the seat and backrest functional scheme is presented. The parameters l_CH and d_S are prismatic coupling in charge of regulation of height and width of the seat. The first one ranges from 42 to 60 cm. The range of d_S goes from a minimum value of 41 cm to a maximum of 54 cm. The rotoidal coupling positioned in point C is giving the possibility of tilting the seat-back system of 10°. This solution is used to guarantee a particular position needed in some exercises. The dimensions L_BC and L_BL are representing lumbar and cervical support that can slide on the frame of the seat. The regulation range of supports is of 12 cm.

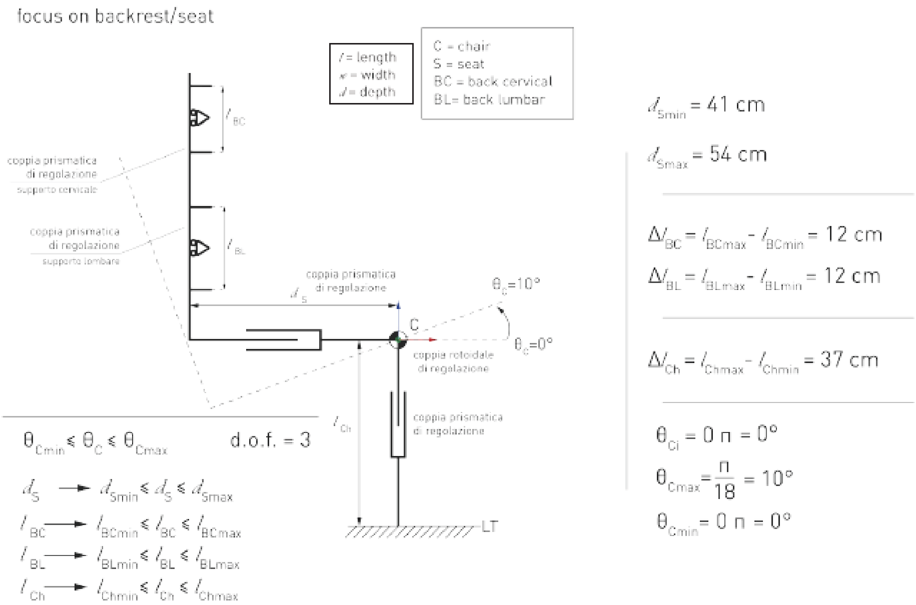



*Figure 5.7: backrest-seat functional scheme.*

## 5.5 Kinematics of the leg support

The leg support is composed by a rod and a soft cushion, the possibility of adjusting the height of the rod is given by the prismatic coupling represented in figure 5.8. The distance L_KP can vary from a minimum value of 28 cm to a maximum of 39 cm from ground. The exercise is given by a motion around the point K, which is placed in correspondence of the centre of instantaneous rotation of the knee. The maximum range of motion possible is from 0° to 110°. Nevertheless, this value is considered overestimated.

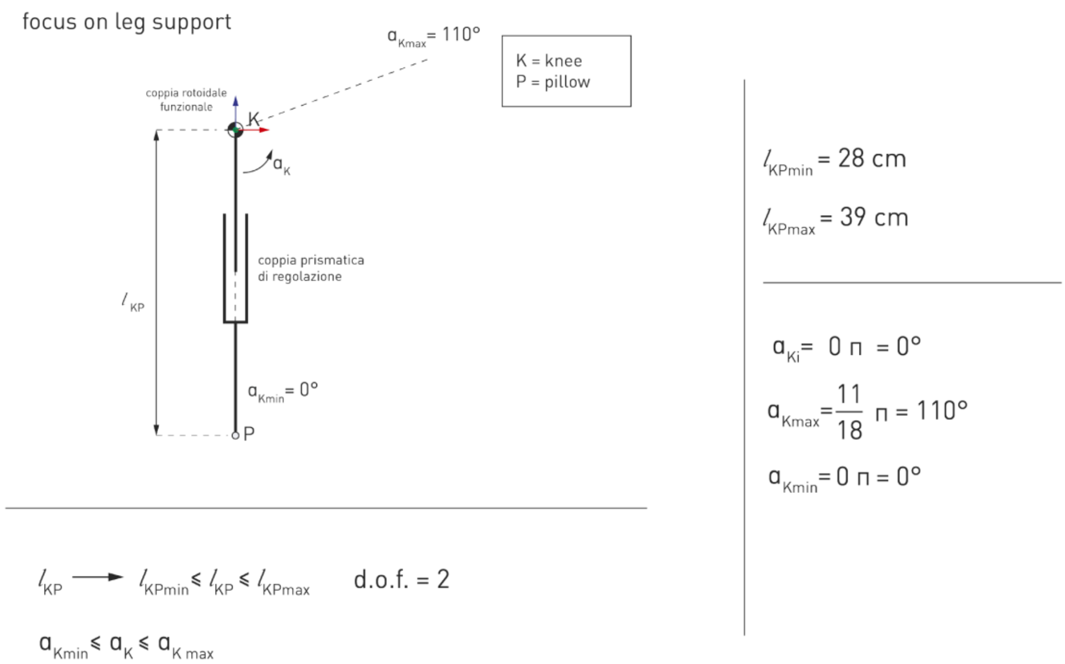



*Figure 5.8: leg support functional scheme.*

## 5.6 Regulation overview

In the following figures an overview of the possible measures is provided considering both range of motion and regulation together with anthropometric issue.

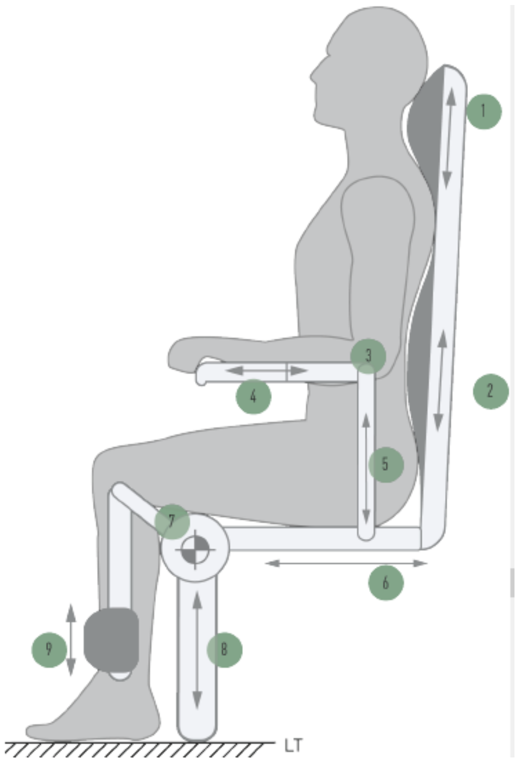
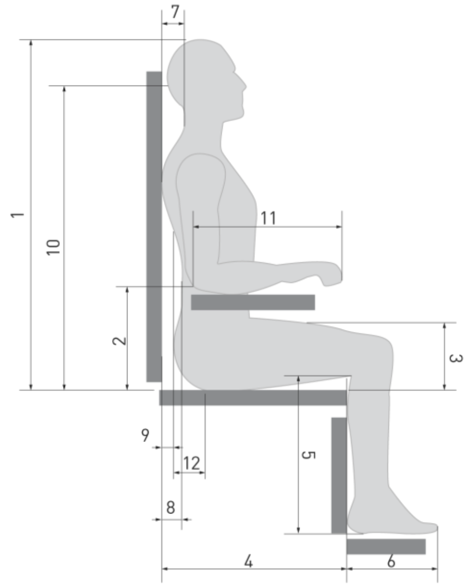



*Figure 5.9: chair overview functional scheme.*



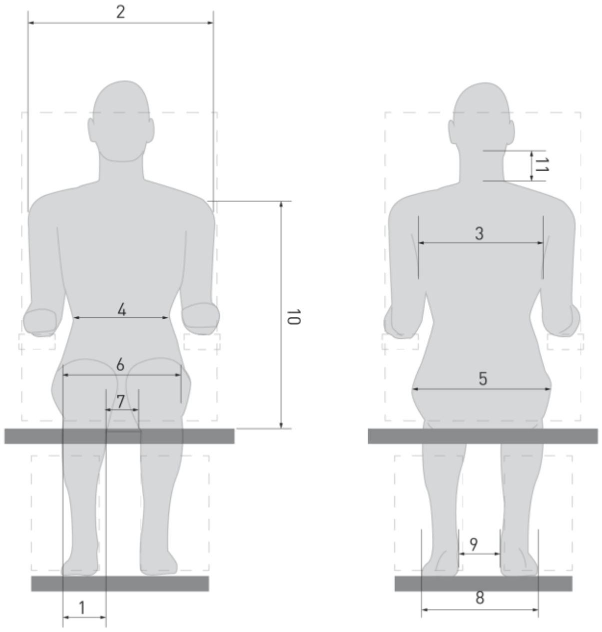




*Figure 5.10: dimensions overview.*

# Chapter 6
# Dynamics

The analysis is developed to obtain all the principal parameters in function of the range of motion angle of the knee and the elbow expressed with $\alpha$ parameter. With the dynamics the forces exchanged between patient and the components of the machine are estimated.
Finally, an actuation possible solution is proposed.
The used instrument to perform this analysis have been:

- Matlab for the mathematical model,
- SolidWorks for the 3D modelling.

## 6.1 Armrest mechanism

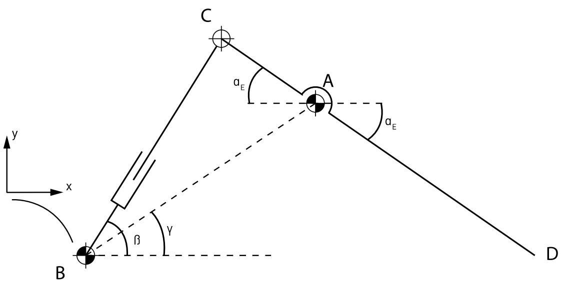



*Figure 6.1: functional scheme of armrest.*

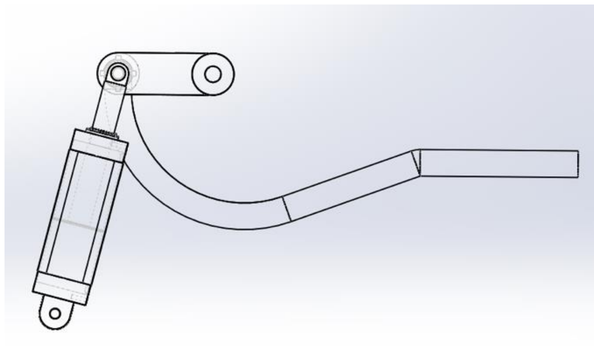


*Figure 6.2: Right view of the 3D armrest model.*

In figure 6.1 the functional scheme is represented. It is composed by the rod CD which is capable to rotate around the point A. The prismatic coupling connecting the point CB is in reality a pneumatic piston. In figure 6.2 the same geometry is represented in the 3D model.
Analysing the geometry, it is possible to get the angle $\beta$ as a function of angle $\alpha$, considering the vectoral equation:

$$\begin{cases} AB_x = BC_x + AC_x \\ AB_y = BC_y + AC_y \end{cases}$$

The given data AB, AC e $\alpha$ are known by geometry construction, BC e $\beta$ are unknown. Dividing the first equation by the second one it is possible to obtain:

$$\tan\beta \; = \frac{\overline{AB}_y - \overline{AC}\sin\alpha}{\overline{AB}_x - \overline{AC}\cos\alpha}$$

$$\beta = \; \tan^{-1}\left(\frac{\overline{AB}_y - \overline{AC}\sin\alpha}{\overline{AB}_x - \overline{AC}\cos\alpha}\right)$$

In figure 6.3 the diagram representing the value of $\beta$ as a function of $\alpha$, with a selected range of $\alpha$ between -30° and 30°.

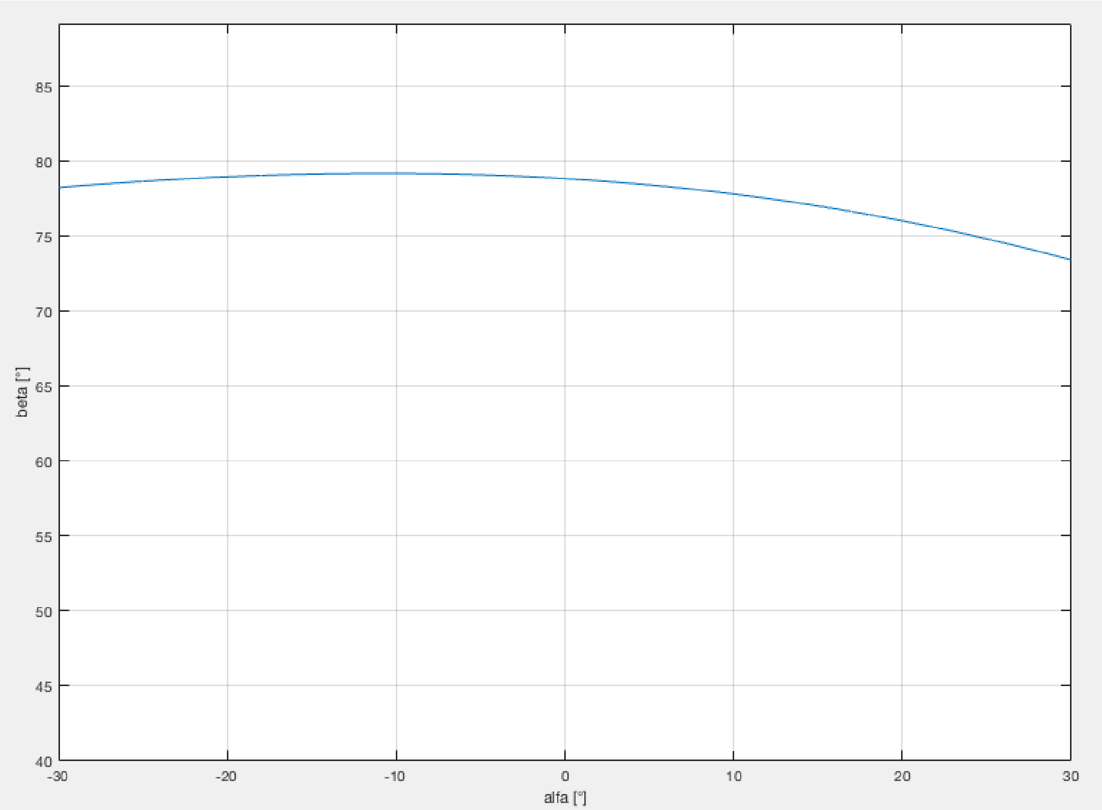



*Figure 6.3: $\beta$ as a function of $\alpha$.*

The final aim is to obtain the force that the piston must develop in order to get the user perceive and experience a constant load during the exercise of biceps curl and triceps push down.

The force applied by the user in point D is set as an entry value. For sake of simplicity, the force is considered constant and perpendicular to the segment AB along al the motion range. The masses of the components are considered negligible as well as the inertia. The free body motion indeed should be as light as possible.
The torque around A is then analysed in figure 6.4:

$$F\overline{AD} - \overline{AC}F_P \sin\beta\cos\alpha - \overline{AC}F_P \sin\alpha\cos\beta = 0$$

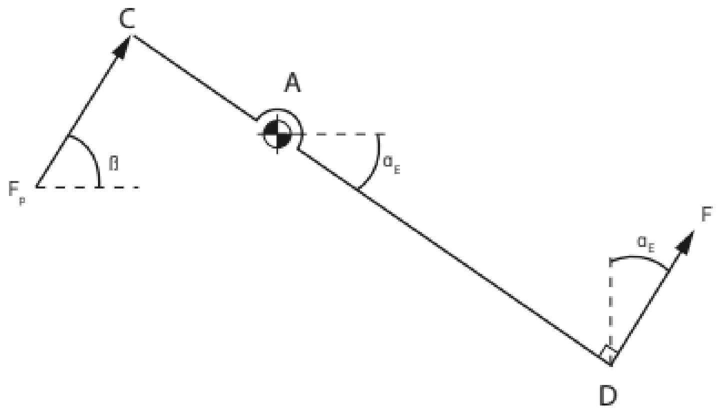



*Figure 6.4 rod CD for biceps curl.*

As a consequence, the $F_P$ force the piston must exert is:

$$F_P = \frac{F\overline{AD}}{\overline{AC}\sin\beta\cos\alpha + \overline{AC}\sin\alpha\cos\beta}$$

In the case of triceps pushdown, the mass of forearm should be considered since it develops a force along the Y direction. The actuation system should, indeed, be capable of sustain the armrest if no force is applied to it, maintaining the same in equilibrium position. Indeed, the cushion must be still if no force, but gravity force is applied. Thus, the force $F_{py}$ that the system must guarantee to have the armrest fixed in position when no force is applied is:

$$F_{py} = \frac{m_a g}{\cos\beta}$$

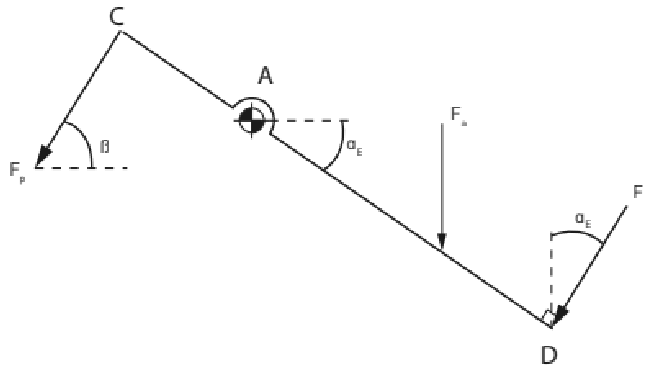


*Figure 6.5 rod CD for triceps push down.*

In which:

- $m_a$= arm mass,
- g= gravitational constant.

The pressure is then computed as:

$$P_{triceps\_min} = \frac{Fpy + 101425\, Area}{(Area - area)}$$

- Area = base area of cylinder [$m^2$]
- area = base area of the stem [$m^2$]
- 101425 = atmospheric pressure [Pa].

If the force $F_{py}$ varies with beta angle, then also $P_{triceps\_min}$ will experience a variation during the motion of the armrest which is described in figure 6.6 The pressure variation results to be not so high so that it is allowed to consider it constant along the range of motion with a value of 3.6476 bar.

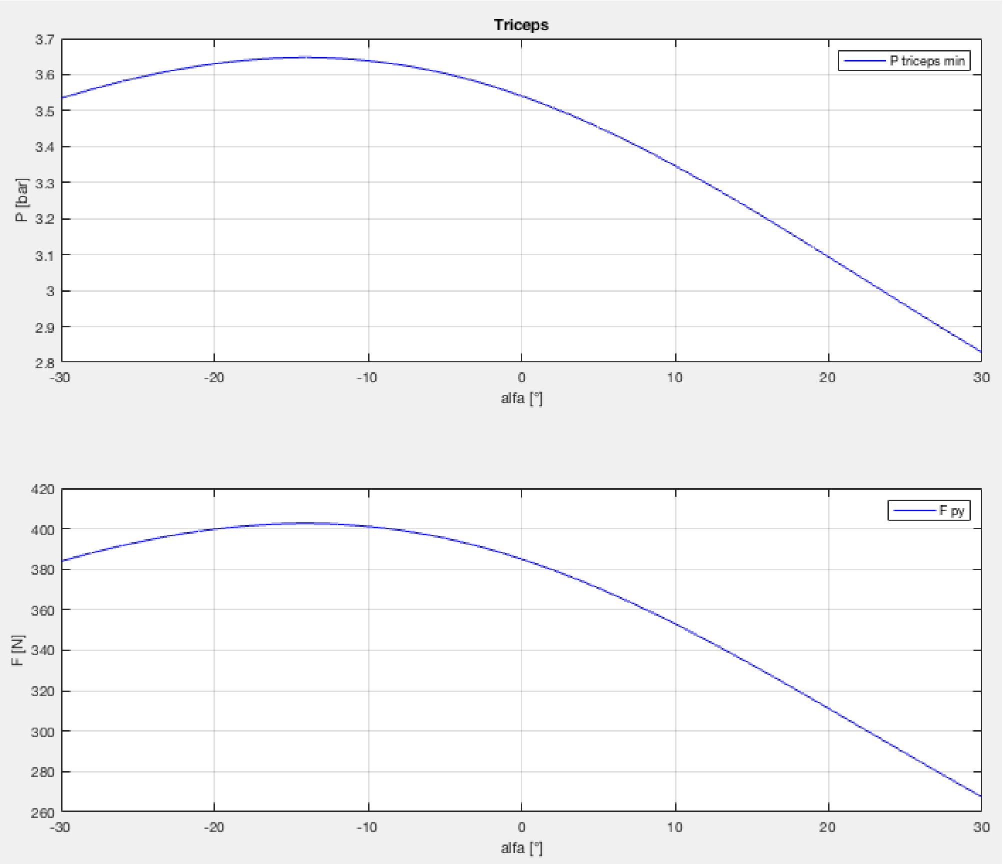



*Figure 6.6: $P_{triceps\_min}$ and $F_{py}$ as a function of elbow angle.*

## 6.2 Leg support Mechanism

In the same way, the leg support mechanism is analysed with the functional scheme showed in the following figure:

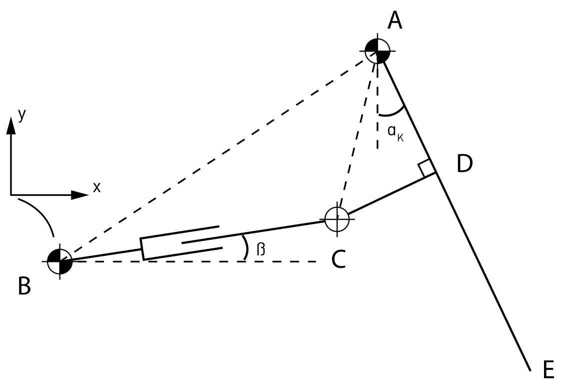



*Figure 6.7: functional scheme of leg support mechanism.*

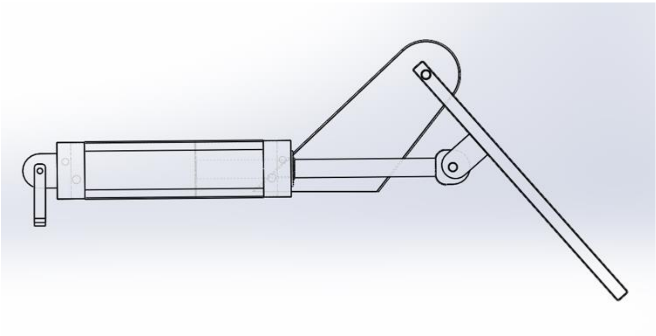


*Figure 6.8: leg support mechanism in 3D view.*

Once the geometry is known, in particular AB, AD, DC and AE distances, the angle $\gamma$ and the AC segment of the triangle ACD are investigated:

$$\overline{AC} = \sqrt{\overline{AD}^2 + \overline{DA}^2}$$

$$\gamma = \tan^{-1}\frac{\overline{CD}}{\overline{AD}}$$

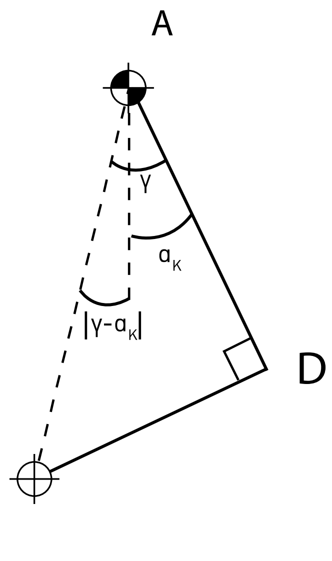



*Figure 6.9: leg mechanism geometry focus.*

The AC components along x and y axis can be expressed as a function of $\alpha$:

$$\overline{AC}_x = \overline{AC}\sin(|\gamma - \alpha|)$$
$$\overline{AC}_y = \overline{AC}\cos(|\gamma - \alpha|)$$

Even in this case, the angle $\beta$ as a function of $\alpha$ is investigated considering the vectoral equation of polygon ABC:

$$\begin{cases} AB_x = BC_x + AC_x \\ AB_y = BC_y + AC_y \end{cases}$$

Putting in evidence the unknown:

$$\begin{cases} BC_x = AB - AC_x \\ BC_y = AB_y - AC_y \end{cases}$$

The angle can be expressed as:

$$\beta = \tan^{-1}\left(\frac{\overline{AB}_y - AC_y}{\overline{AB}_x - AC_x}\right)$$

In figure 6.10 the results are showed considering a range of motion for alpha angle from 0° to 110°.

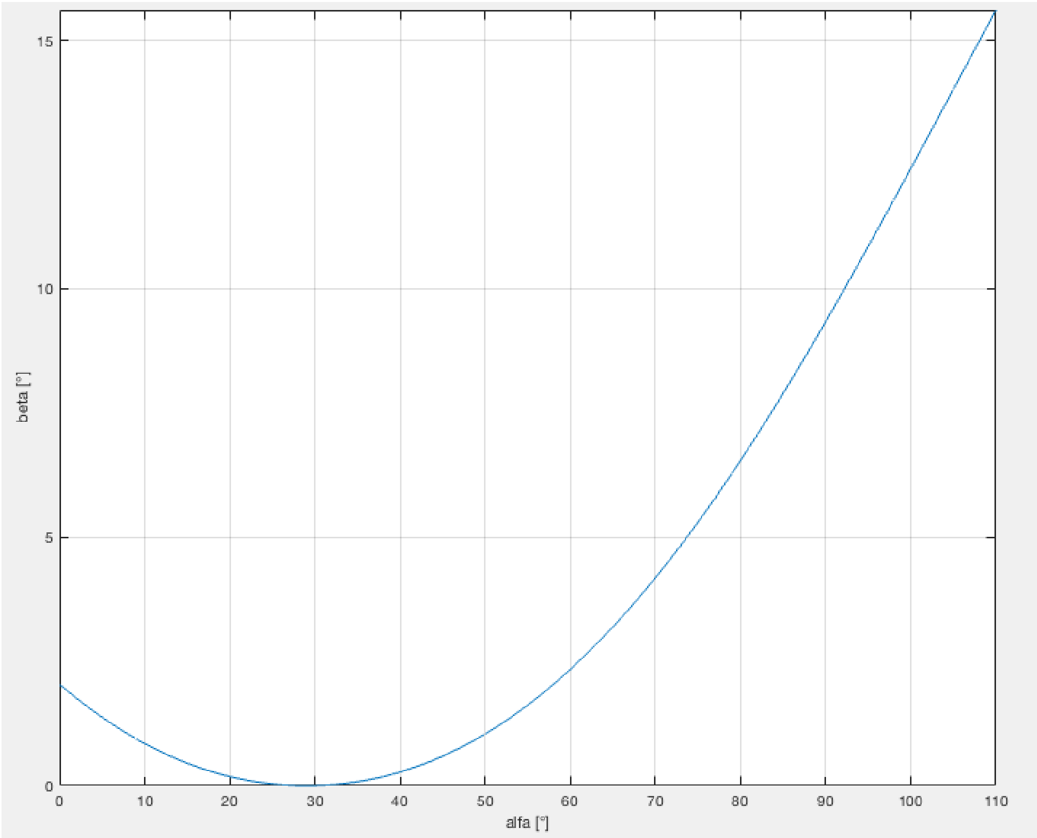



*Figure 6.10: leg mechanism angle behaviour.*

It is now possible to study the behaviour of the force $F_p$, exerted by the piston in order to get an isotonic kind of exercise. Analysing the torque equilibrium around point A, the masses of the bodies are considered negligible as well as the inertia and friction as stated before. The force is constant and perpendicular to the rod AE along the range of motion. It is obtained the relation:

$$F\overline{AE} - \overline{AC}_y F_P \cos\beta - \overline{AC}_x F_P \sin\beta = 0$$

$$F_P = \frac{F\overline{AE}}{\overline{AC}_y \cos\beta + \overline{AC}_x \sin\beta}$$

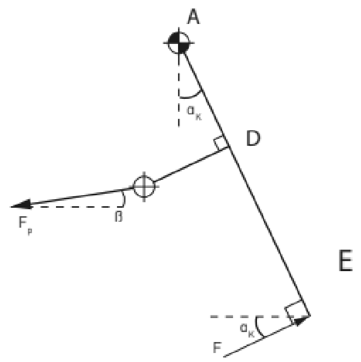



*Figura 6.11: rod AE focus.*

In the case of leg curl exercise, as in the triceps push case, the mass should be considered as applied to the cushion, developing an Y direction component. Even in this case, the system should be capable of sustain the leg when no further force is applied. For the same reasoning the force $F_{py}$ is investigated:

$$F_{py} = \frac{m_l g}{\cos\beta}$$

- $m_l$ = leg mass
- g = acceleration of gravity

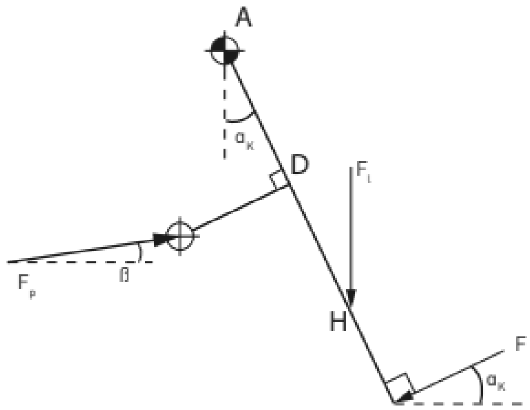



*Figure 6.12: leg curl functional scheme.*

The associated pressure will then be:

$$P_{legcurl\_min} = \frac{Fpy + 101425\,(Area - area)}{(Area)}$$

- Area = base area of cylinder [m$^2$]
- area = base area of the stem [m$^2$]
- 101425 = atmospheric pressure [Pa].

If the force $F_{py}$ varies with angle beta, then $P_{legcurl\_min}$ will change during the motion of the rod as described by figure 6.13

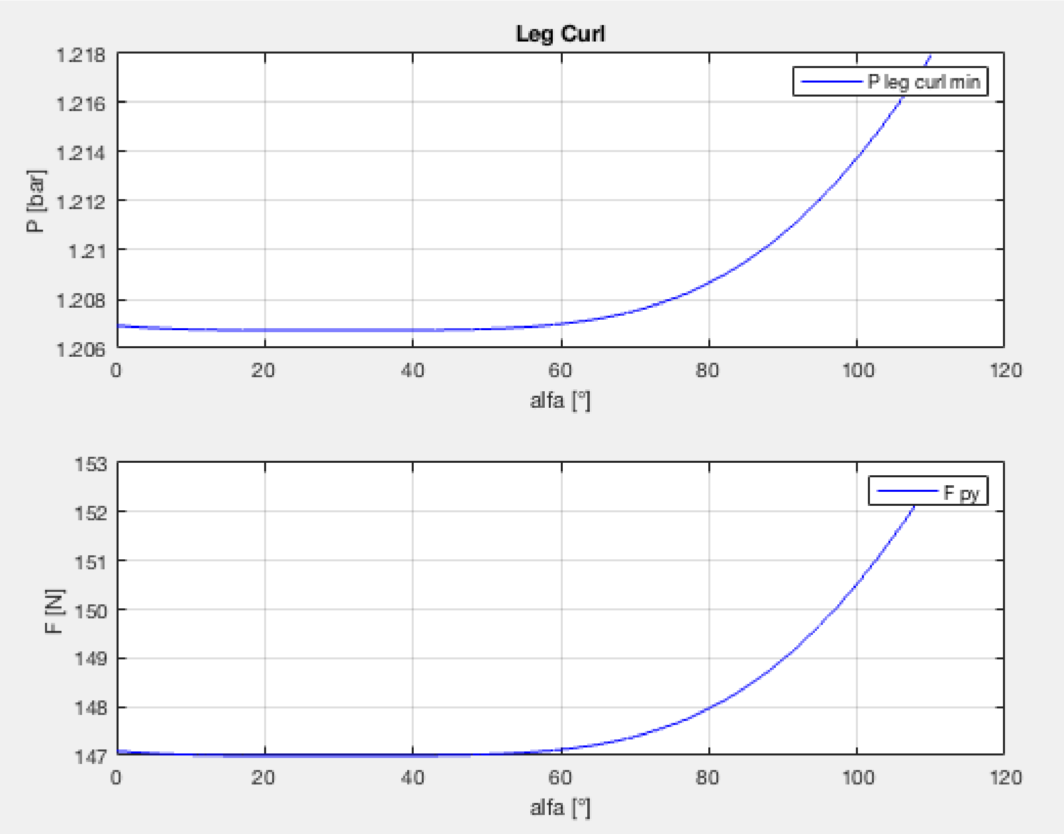



*Figure 6.13: $P_{legcurl\_min}$ and $F_{py}$ behaviour as a function of the knee angle.*

Again, the pressure can be considered constant along the range of motion equal to 1.2179 bar.

### 6.3 Actuation system

Trying to find the best trade-off between technological solution and anthropometric needs, a range of capable values for the segments have been selected.

At this point, the main task is finding the pressure output compliant with available solution already present in the market. Finally, a dimensioning for cylinders is provided fixing the maximum load to be lifted by the patient.

In particular, 2 values have been selected:

- 10 kg for arms;
- 40 kg for legs.

For the sake of the analysis, for the AD and AE segments that are adjustable, the maximum values have been considered.
The technological solution which better suits the need of the chair is a system of pneumatic piston dual-chamber electronically controlled. According to the catalogues present in the nowadays market, the maximum available pressure is 10 bar as a consequence:

| Cylinder diameter [mm] | Stem diameter [mm] | Maximum Force [N] with 10 bar pressure | |
|---|---|---|---|
| 50 | 20 | Biceps = 1963,5 | Triceps = 1649,3 |
| 80 | 25 | Leg Curl = 5026,5 | Leg Etension = 4535,7 |

*Figure 6.13 Maximum forced developed in traction and compression by cylinders.*

In addition, a safety factor accounting for pressure losses and friction has been included.
Once the commercial pressure is selected as the 70% of the maximum available pressure, the force that the system can actually provide is computed. It is underlined the fact that the forces are increasing when AD and AE segments are decreasing.

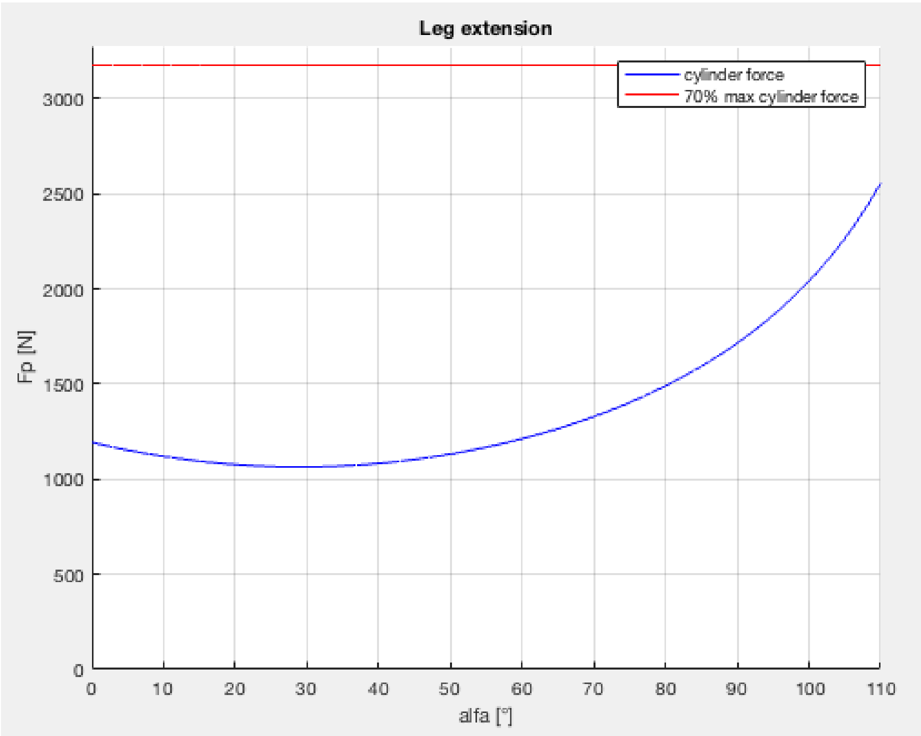



*Figure 6.14 (a): forces behaviour as a function of angles in leg extension.*

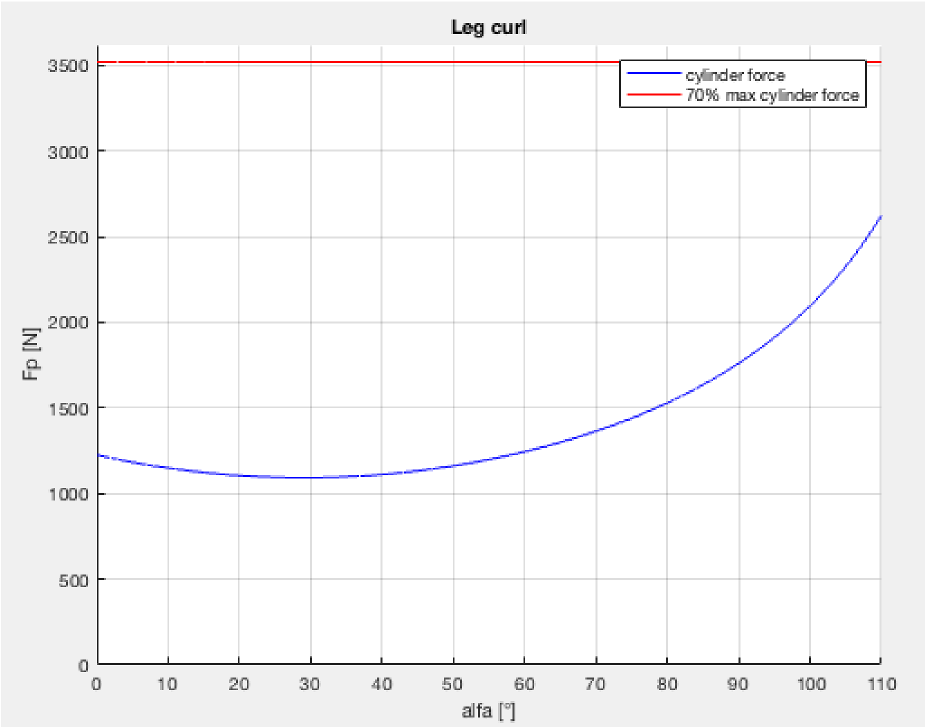



*Figure 6.14 (b): forces behaviour as a function of angles in leg curl.*

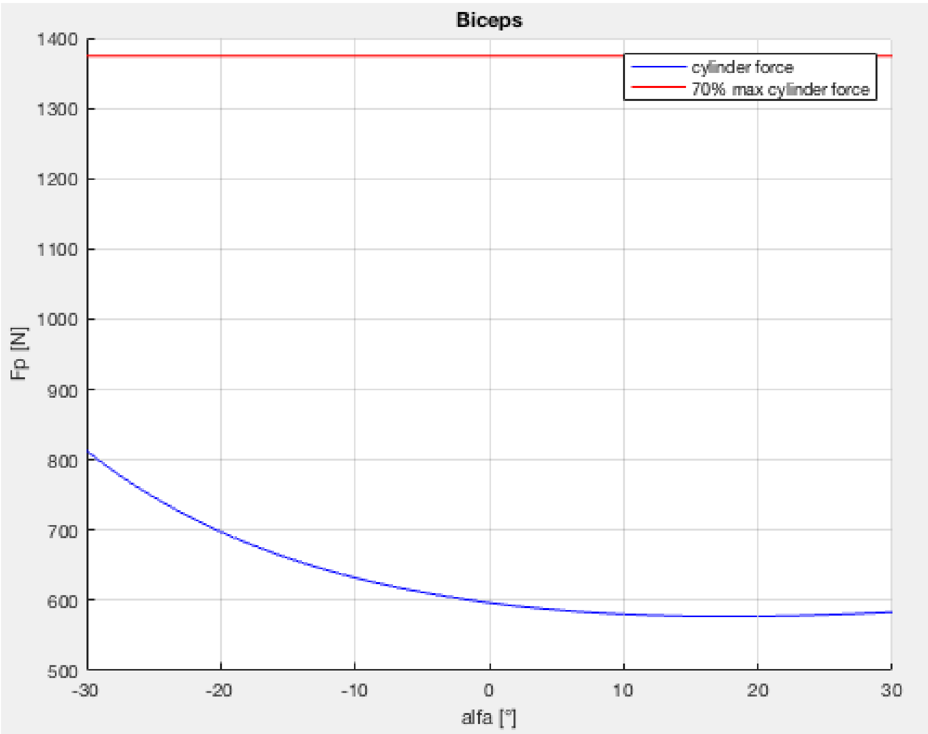



*Figure 6.14 (c): forces behaviour as a function of angles in biceps curl.*

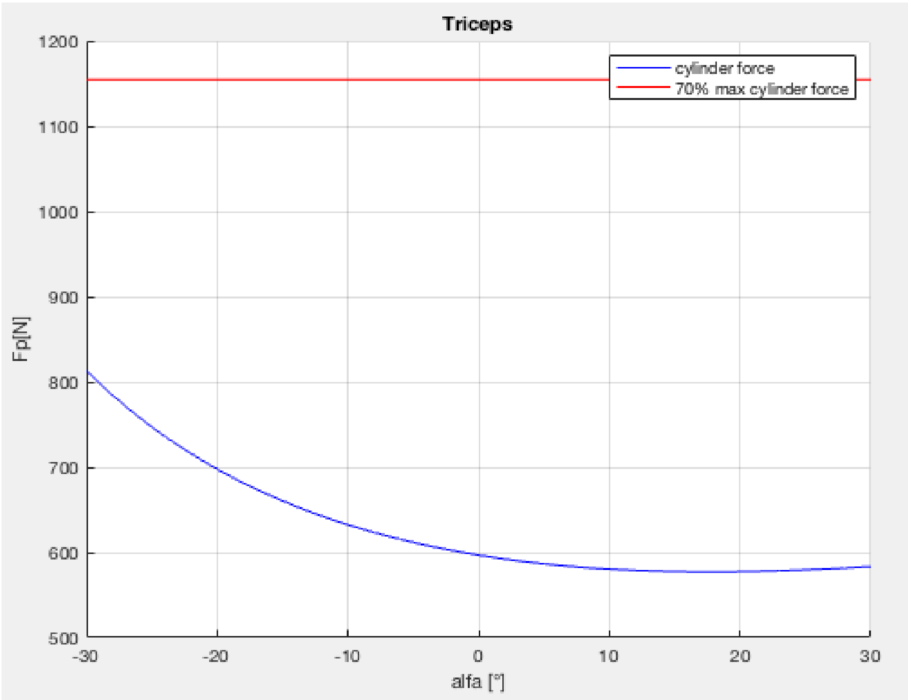


*Figure 6.14 (d): forces behaviour as a function of angles in triceps pushdown.*

Assuming that the non-working chamber is at atmospheric pressure, the pressure in the working chamber is then calculated in the following way:

$$P_{biceps} = \frac{F_p + 101425(Area - area)}{Area}$$

$$P_{leg\ curl} = \frac{F_p + 101425(Area - area)}{Area}$$

$$P_{triceps} = \frac{F_p + 101425\ (Area)}{Area}$$

$$P_{leg\ extension} = \frac{F_p + 101425(Area)}{Area - area}$$

The pressure behaviour in function of the main angle alpha is then showed in the following diagrams.

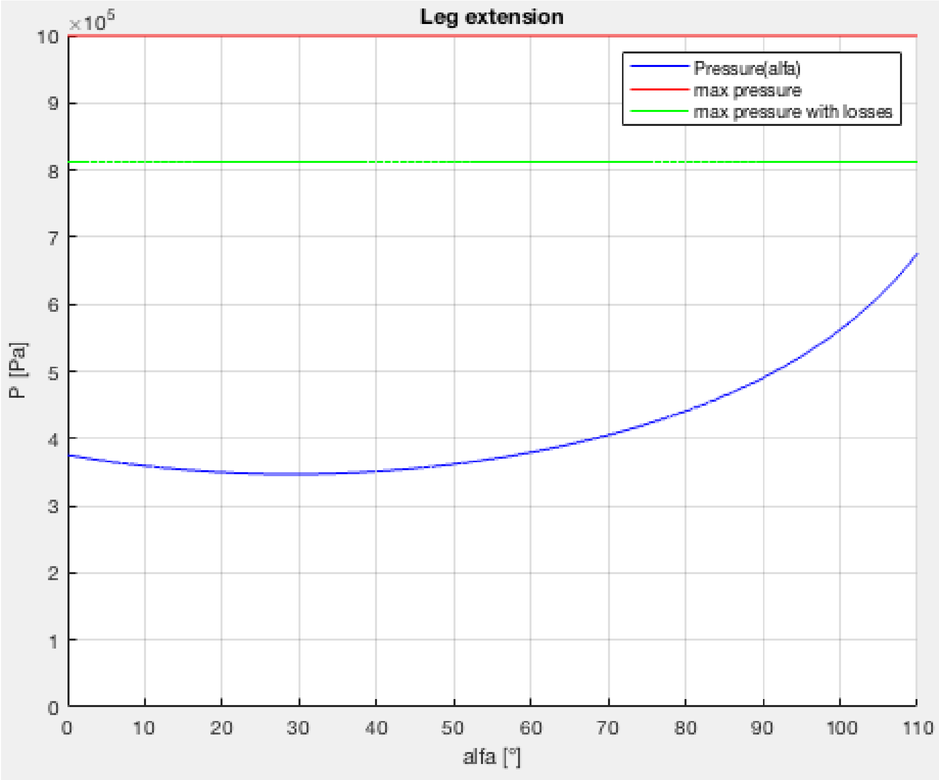



*Figure 6.15 (a): pressure behaviour in the working chamber of the cylinder as a function of the angle alpha for leg extension.*

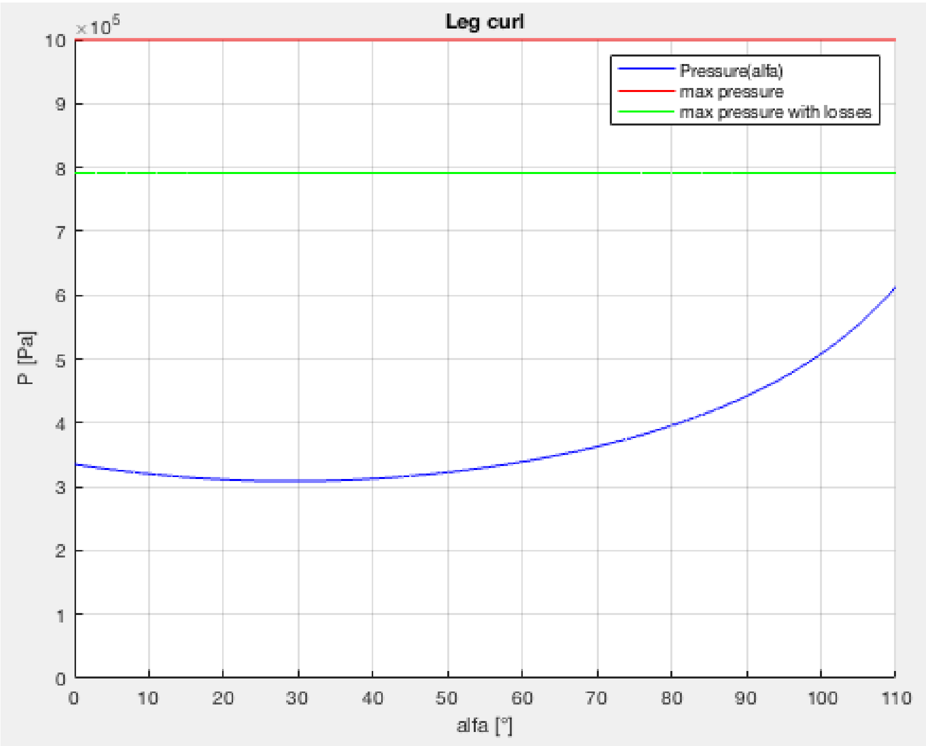



*Figure 6.15 (b): pressure behaviour in the working chamber of the cylinder as a function of the angle alpha for leg curl.*

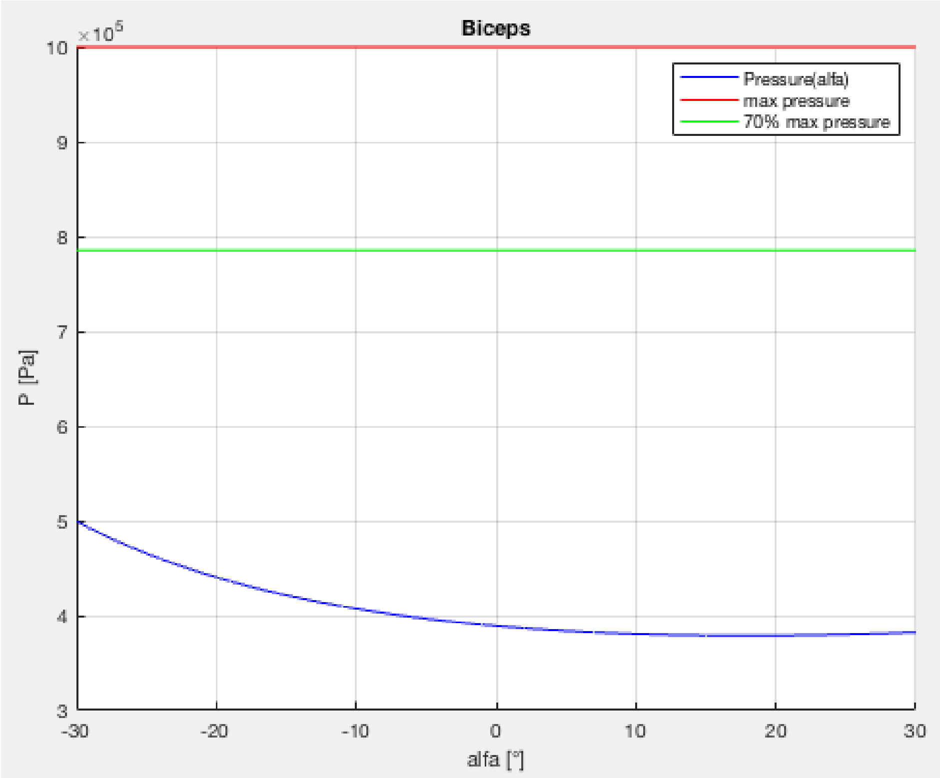



*Figure 6.15 (c): pressure behaviour in the working chamber of the cylinder as a function of the angle alpha for biceps curl.*

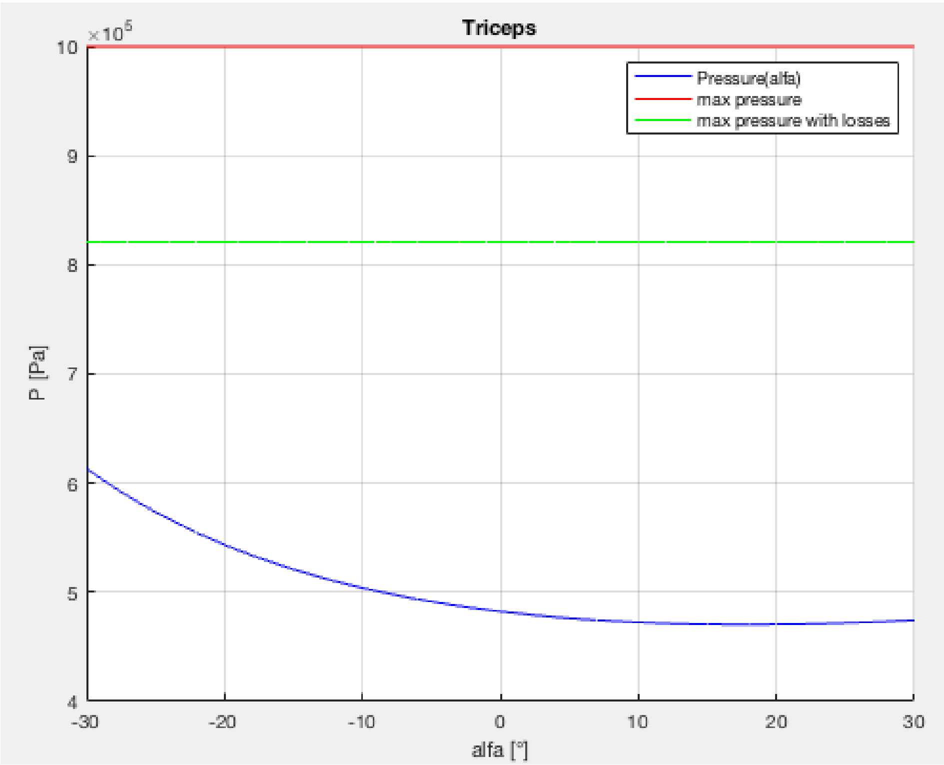



*Figure 6.15 (d): pressure behaviour in the working chamber of the cylinder as a function of the angle alpha for triceps pushdown.*

As showed in the plot, the piston should exert different pressure according to the angle alpha for both knee and elbow. For arm mechanism the value should vary of 1 bar (biceps) and 1.5 (triceps). For leg mechanism, the difference in pressure should be even greater around 3 bar for both the exercise. Anyway, considering that the greatest variation is between 90° and 110°, the range of motion can be reduced to a maximum of 90° which is realistic for bariatric patients with reduced mobility.

In this way, the hypothesis of constant pressure can be considered still valid. The force will not be constant anymore, but its variation will be negligible.

The constant pressure inside the cylinder has been selected as the average value between the pressure curve obtained. A correlation map has been then built correlating the weight lifting for the exercise and the pressure value the cpu must force to the cylinder.

| Biceps | | Triceps | |
|---|---|---|---|
| Weight [kg] | Pressure [bar] | Weight [kg] | Pressure [bar] |
| 0 | 0,99 | 0 | 0,99 |
| 1 | 1,17 | 1 | 1,59 |
| 2 | 1,49 | 2 | 1,97 |
| 3 | 1,81 | 3 | 2,35 |
| 4 | 2,13 | 4 | 2,73 |
| 5 | 2,45 | 5 | 3,11 |
| 6 | 2,77 | 6 | 3,50 |
| 7 | 3,10 | 7 | 3,88 |
| 8 | 3,42 | 8 | 4,26 |
| 9 | 3,73 | 9 | 4,64 |
| 10 | 4,06 | 10 | 5,02 |

*Table 2: selected weight vs cylinder pressure in arms exercise.*

| Leg Extension | | Leg Curl | |
|---|---|---|---|
| Weight [kg] | Pression [bar] | Weight [kg] | Pression [bar] |
| 0 | 0,99 | 0 | 0,99 |
| 2.5 | 1,29 | 2.5 | 1,07 |
| 5 | 1,46 | 5 | 1,23 |
| 7.5 | 1,63 | 7.5 | 1,38 |
| 10 | 1,79 | 10 | 1,54 |
| 12.5 | 1,96 | 12.5 | 1,69 |
| 15 | 2,13 | 15 | 1,85 |
| 17.5 | 2,30 | 17.5 | 2,00 |
| 20 | 2,46 | 20 | 2,16 |
| 22.5 | 2,63 | 22.5 | 2,31 |
| 25 | 2,80 | 25 | 2,47 |
| 27.5 | 2,97 | 27.5 | 2,62 |
| 30 | 3,14 | 30 | 2,78 |
| 32.5 | 3,30 | 32.5 | 2,93 |
| 35 | 3,47 | 35 | 3,09 |
| 37.5 | 3,64 | 37.5 | 3,24 |
| 40 | 3,81 | 40 | 3,40 |

*Table 3: selected weight vs cylinder pressure in legs exercise.*

In the following pictures 6.16 a and b, the pneumatic logical scheme is presented.

The constitutive components and the relative identification codes are:

- K = air pressure production system with compressor, tank, pressure safety valve, backpressure regulator and pressure sensor$_{(1)}$;
- PPR=proportional pressure regulator$^{(4)}$;
- EV = normally closed electro valve with spring back$_{(5)}$;
- Silencer$_{(6)}$;
- C = chamber of cylinder;
- PX=position sensors.

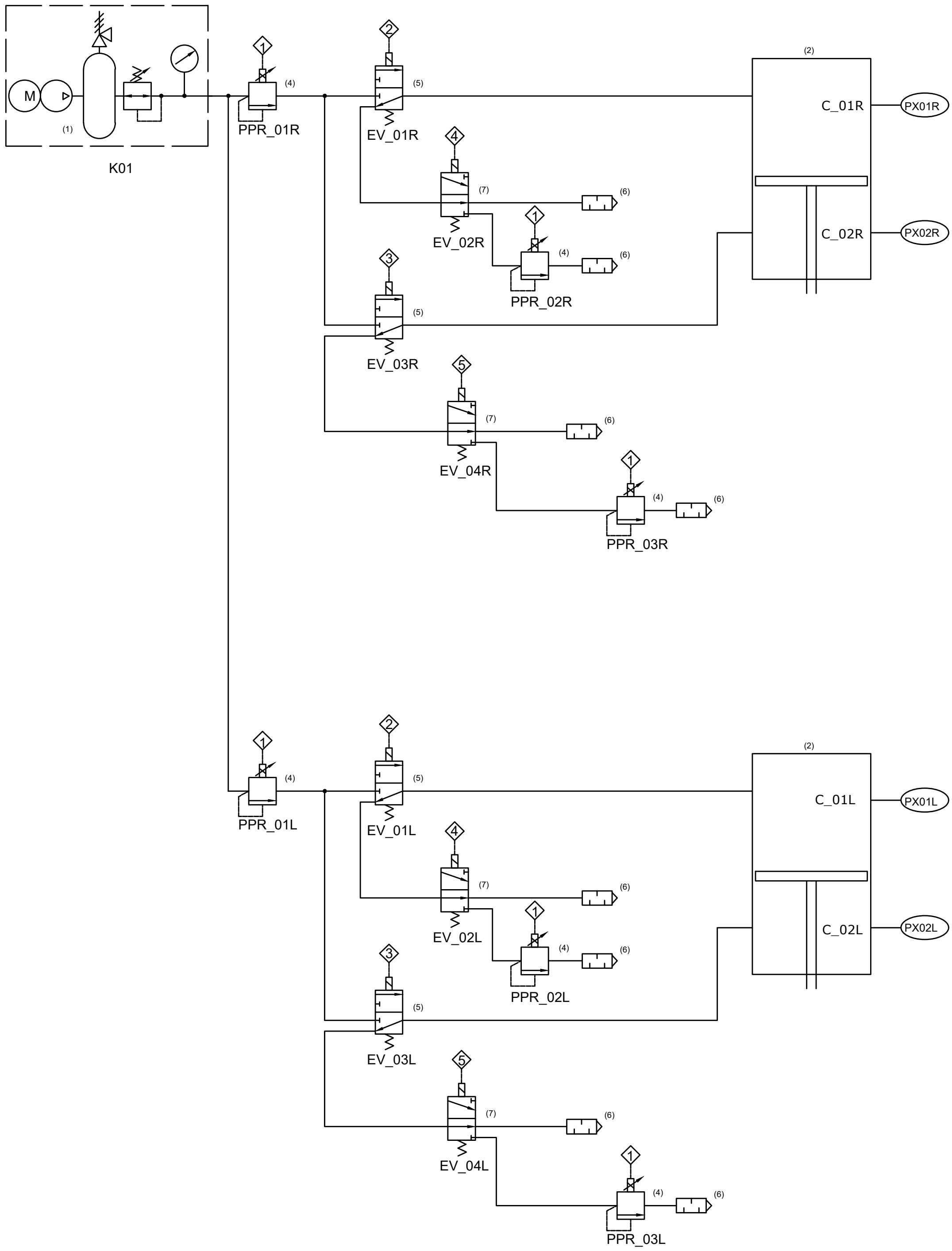



*Figure 6.16 (a): pneumatic functional scheme for arm exercises actuation system.*

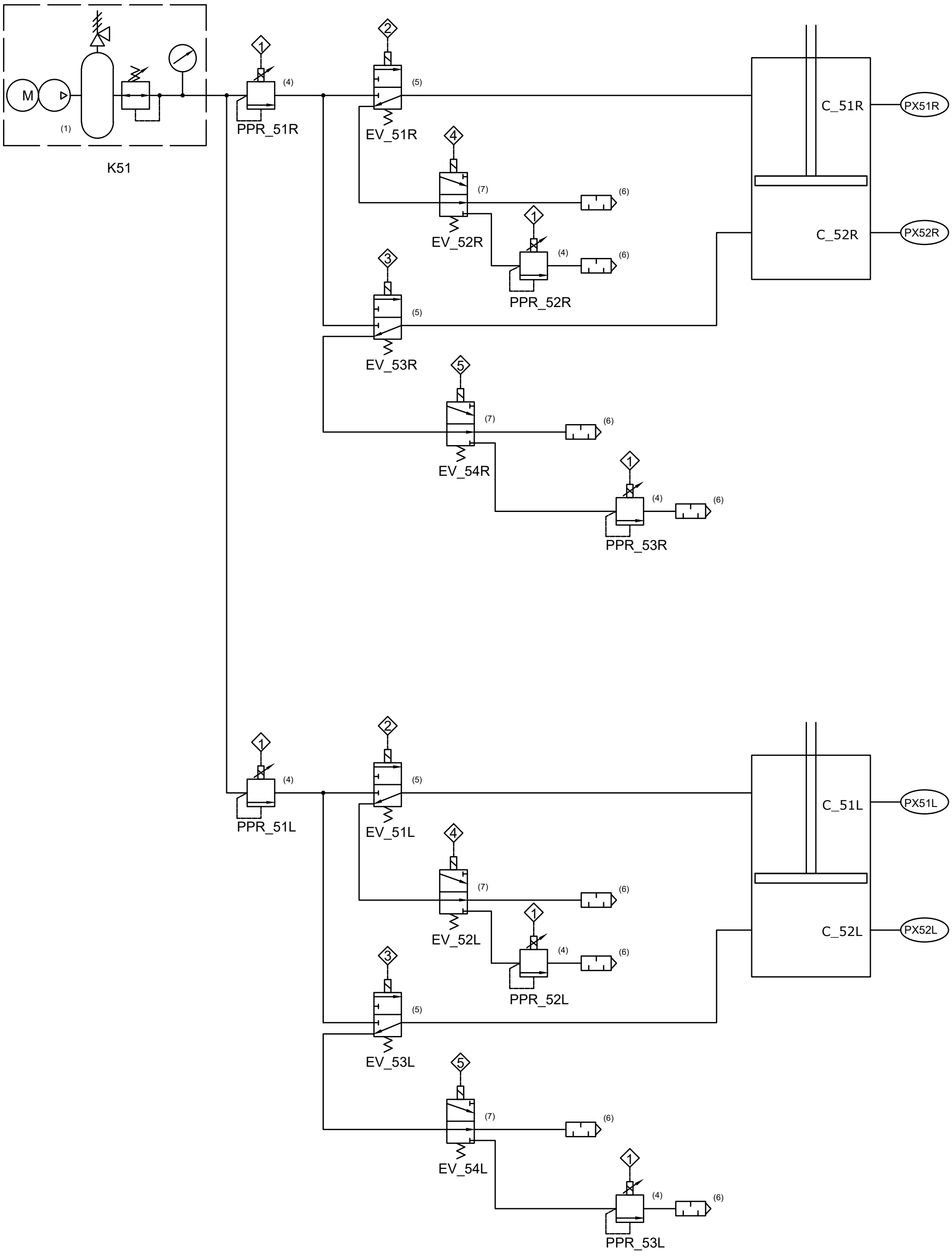



*Figure 6.16 (b): pneumatic functional scheme for leg exercises actuation system.*

The functional scheme components have a code to indicate if the components are constituting the arm exercise system or the leg one. Moreover, after a number there are letters to indicate if it refers to the right limbs or the left limbs:

- component_0xR: refers to components which are integrated in the right arm exercise system;
- component_0xL: refers to components which are integrated in the left arm exercise system.
- component_5xR: refers to components which are integrated in the right leg exercise system.
- component_5xR: refers to components which are integrated in the right leg exercise system.

As can be seen, all the 4 cylinders have been taken into consideration, to realise all the actuated exercises.
Analysing the schemes from left to right, the firsts component are ensembles: K51 for legs system and K01 for arms system. It works as follow: when compressor is on, it takes air from environment. The air is then stored in the tank in which a safety valve is present.
Usually, compressors are equipped with sensors capable of detecting pressure under which the compressor shout off automatically. In this way, a pressure of 10 bar can be granted inside the tank and at the same time there is no need of keeping the compressor activated for the whole working time. A pressure reducer also is present to set a safety pressure, in such a way the pressure will not exceed safety values.
Then to modify in a dynamic way the pressure, proportional pressure control is implemented(4). Inside them a transducer is present which is emitting a continuous analog signal to the inner CPU, in such a way the pressure can be regulated.
The reference value as an input is forced by selector 1, this is just the value of pressure correspondent to the selected weight with whom it is decided to perform the exercise.

It must be set an offset of value to the following PPR:

- PPR_03R and PPR_03L offset corresponding to 3,6476 bar
- PPR_53R and PPR_53L offset corresponding to 1,2107 bar

In this way the chair elements, while performing exercises of triceps and leg curl, they are not facilitated by the user's weight force and remain in the initial position. An optimal solution could be provided computing dynamically this value due to the limbs length and weight applied on cushions, so more sensors could be integrated. Otherwise this value could be too much or too little based on user, that will perform an harder or easier exercise.

In the following picture the block diagram of the functioning scheme is presented:

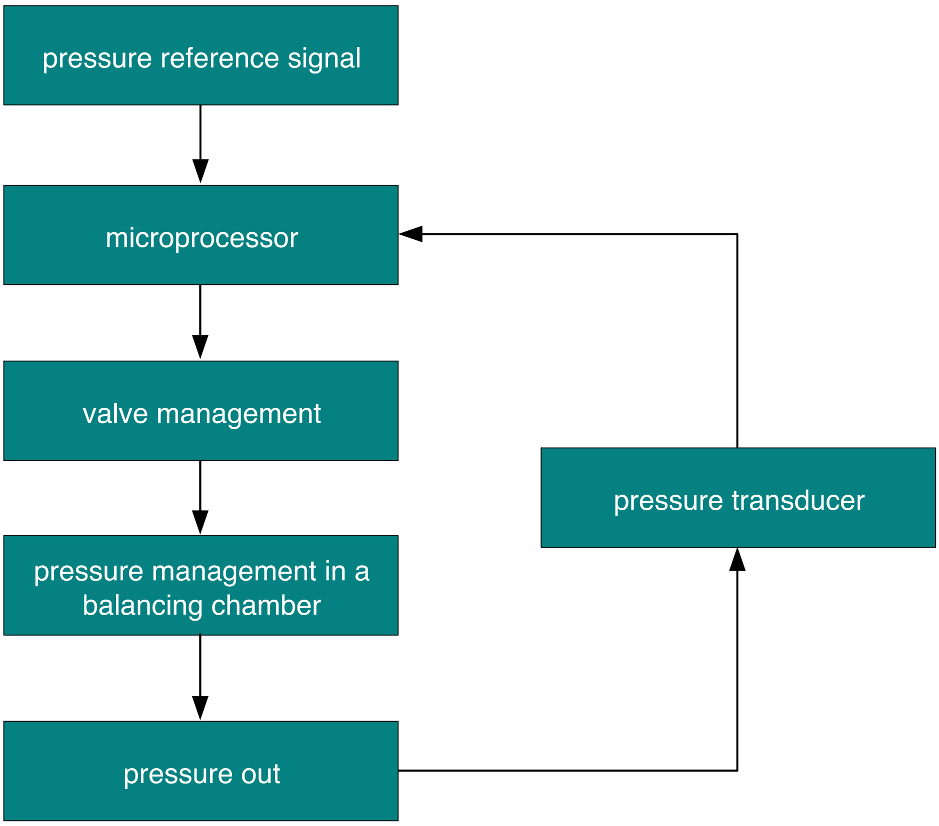



*Figure 6.17: logic of the proportional pressure regulator.*

### 6.3.1 Actuation system logic

First of all, it can be said that, biceps and leg extension is the same as well as triceps and leg curl.

For what concern the logic of leg extension and biceps: once the exercise is selected, the chamber C_x1x must be carried under pressure, the value is chosen by the user. The patient should wait some seconds until the system reaches the nominal working pressure. A signal is then transmitted to the pressure regulator PPR_01, PPR_02 and PPR_03 plus the offset at the same moment.

The electro valve EV_x2x is permanently in excited status during the whole exercise by means of the selector 4.

Since C_x1x must be under pressure, the compressed air should flow from the tank to the cylinder through EV_x1x that must be on (energized) through the selector 2 to move the leg cushions and the armrests downwards in the exercise initial position.

The cylinder stem is pushed towards PX02L/PX02R/PX52L/PX52R and the C_x2x volume is reduced until PX02L/PX02R/PX52L/PX52R is reached. In the meantime, C_x1x volume grows up. At this point the initial position for the exercise is reached and EV_x1x must be deenergized to stop the air compressed flow and to allow the beginning of the exercise. So, the C_x1x can be compressed by the user. As a consequence, the volume of C_x1x is decreased and the air should flow out, otherwise the pression grows and the exercise is not functional.

If EV_x2x had not been previously energized, the reached pression in C_x1x should naturally go away from this cylinder chamber, because of the pressure difference between the chamber and the atmospheric pressure without a user effort.

In this way, instead, the air passes through PPR_x2x and the C_x1x stays under pressure until an effort is accomplished that is when the patient starts the movement and it reaches a pressure to flow air out

When PXx1x is reached, EV_x1x is energized again and C_x1x tends to be again under pressure and the arm/leg of the patient is driven slowly through the initial position to start again the movement.

During all the exercise C_x1x stays at a constant pressure, meanwhile C_x2x is at a constant atmospheric pressure, because EV_x3x and EV_x4x are not energized. In figure 17 there's a flow diagram to describe this logic.

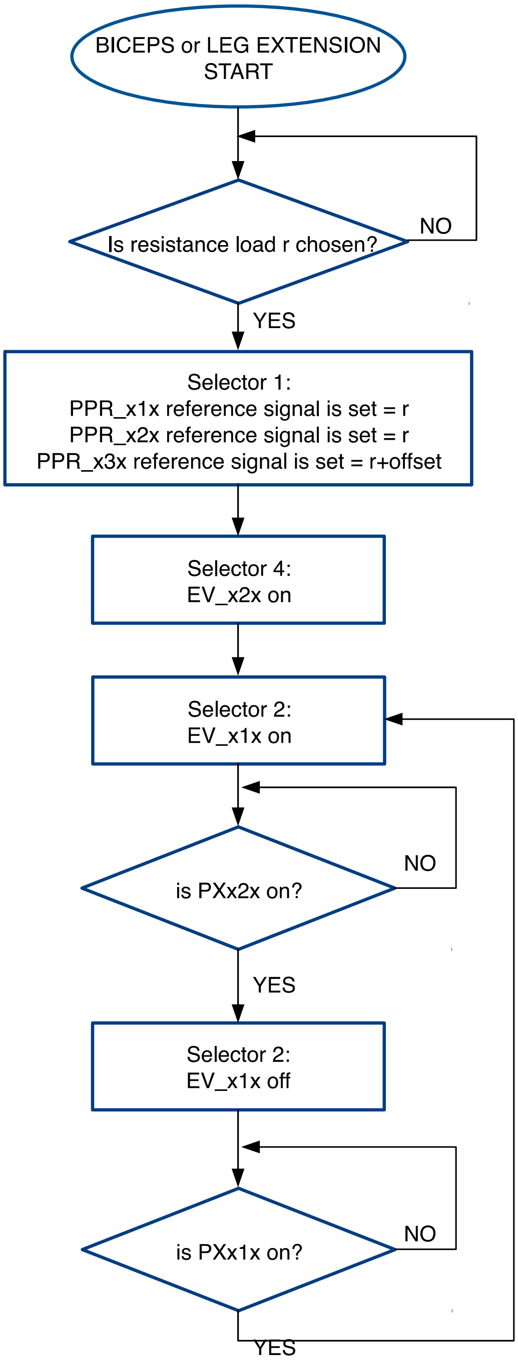



*Figure 6.18: logic of pneumatic system leg extension and biceps*

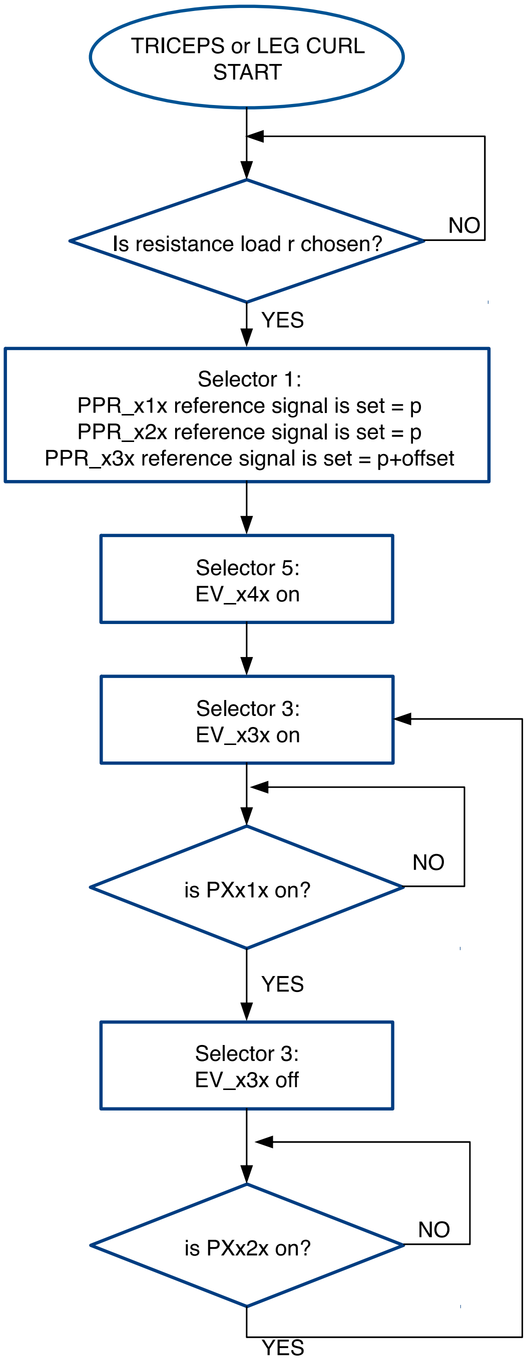



*Figure 6.19: logic of pneumatic system leg curl and triceps*

Triceps/ leg curl exercises have a similar logic. Once the exercise is selected, the chamber C_x2x must be carried under pressure, the value is chosen by the user. The patient should wait some seconds until the system reaches the nominal working pressure. A signal is then transmitted to the pressure regulator PPR_01x, PPR_02x and PPR_03x plus the offset at the same moment.

The electro valve EV_x4x is permanently in excited status during the whole exercise by means of the selector 5, its purpose is similar of what is has been said about EV_x2x in the biceps/leg extension case.

Since C_x2x must be under pressure, the compressed air should flow from the tank to the cylinder through EV_x3x that must be energized through the selector 3 to move the leg cushions and the armrests upwards in the exercise initial position.

The cylinder stem is pushed towards PX01L/PX01R/PX51L/PX51R and the C_x1x volume is reduced until PX01L/PX02R/PX51L/PX51R is reached. In the meantime, C_x2x volume grows up. At this point the initial position for the exercise is reached and EV_x3x must be deenergized stopping the air compressed flow and to allow the beginning of the exercise. So, the C_x2x can be compressed by the user. As a consequence, the volume of C_x2x is decreased and the air should flow out, otherwise the pression grows and the exercise is not functional.

If EV_x4x had not been previously energized, the reached pression in C_x1x should naturally go away from this cylinder chamber, because of the pressure difference between the chamber and the atmospheric pressure without a user effort.

In this way, instead, the air passes through PPR_x3x and the C_x2x stays under pressure until an effort is accomplished that is when the patient starts the movement and it reaches a pressure to flow the air out.

When PXx2x is reached, EV_x1x is energized again and C_x2x tends to be again under pressure and the arm/leg of the patient is driven slowly through the initial position to start again the movement.

During all the exercise C_x2x stays at a constant pressure, meanwhile C_x1x is at a constant atmospheric pressure, because EV_x1x and EV_x3x are not energized. In figure 18 there's a flow diagram to describe this logic.

### 6.3.2 Air consumption

To get the tank dimension as well as the power of the compressor, the air consumption in litres x minute is needed.
As a first approximation, it can be calculated as litres necessary for 1 serie:

$$Q_{biceps} = \frac{\pi D^2}{4}\, C\, P_{mean}\, n_{arm} \quad [l/serie]$$

$$Q_{triceps} = \frac{\pi}{4}(D+d)(D-d)\, C\, P_{mean}\, n_{arm} \quad [l/serie]$$

In which:

D = cylinder diameter [dm]
d = stem diameter [dm]
C = cylinder displacement [dm]
$P_{mean}$ = absolute pressure [bar]
$n_{arm}$ = number of stroke equal to the repetition each series

For this computation, it is necessary to make an assumption about the number of series as a relation of the average selected pressure. The more the number of repetitions, the less will be the lifting weight. This factor is strictly related to the patients himself and his training level. Nevertheless, the focus of this study is to make possible execute exercise with low weight but large number of repetitions. So, a $n_{arm}$ equal to 25 is selected, as a result:

- $Q_{biceps}$= 4.9276 l/serie,
- $Q_{triceps}$= 5.6094 l/serie.

With a weight of 5 kg instead, a $n_{arm}$ of 8 is considered, the results are:

- $Q_{biceps}$= 3.3024 l/serie,
- $Q_{triceps}$= 3.5206 l/serie.

Finally, a 6-litre tank for each pneumatic circuit of arms can be used, the main objective is having the activation of the compressor not more then 1 time each exercise.

As well for the leg:

$$Q_{leg\ curl} = \frac{\pi D^2}{4}\ C\ P_{mean}\ n_{leg} \quad [l/serie]$$

$$Q_{leg\ extension} = \frac{\pi}{4}(D+d)(D-d)\ C\ P_{mean}\ n_{leg}\ [l/serie]$$

With weight equal to 2.5 and n equal to 8 the results are:

- $Q_{extension}$= 9.0765 l/serie
- $Q_{legcurl}$= 8,3364 l/serie.

The tank for the legs exercise should be around 10 l for each leg circuit.
As an assumption the unit measure of l/series can be considered equal to l/min if we consider that no more than 1 min for each series is needed, followed by a rest time of at least 1 min. It is now possible to go throw the compressor choice, taking a look into the nowadays market, summarizing the data a machine like that can be selected:

- 40 l/min
- 10 bar
- 120 W
- 12 V

With this feature, the compressor can feed in 1 minute all the 4 tanks at a time, if 2 compressors are included, then the charging time is scaled.

Considering now a domestic plant in which the available current is of 220 V, it is necessary to connect the compressor by means of an external power supply. For 120 W, with 12 V a 10 A current is needed, considering a safety factor of 10%, a commercial model with these characteristics is selected:

- 220 V AC to 12 DC
- 12 A nominal current

# Chapter 7
# Final concept

## 7.1 3D model

A 3D layout has been realized in Rhino environment, putting together all mechanical parts realized with Solidworks. This software has been particularly helpful to cover what was necessary to make the seat more pleasant to a bariatric user. All the mechanisms and systems implemented are hidden at the eye for a better sensation and greater security. The goal is to camouflage the machine to avoid associations with the gym environment.

For greater comfort, the frame was almost completely covered with a thin one layer of padding to cover any edges or dangerous protrusions of the frame in steel.

All ergonomics and anthropometrics details have been considered. Support surfaces (seat, backrest, leg cushions and armrests) are designed to sustain the user while performing the training.

The limbs surfaces appear shaped to comfort arms and legs but also appear suitable to perform exercises without remembering a gym machine, so that cognitive design is also considered.

The seat has 3 possible configurations:

- totally closed, while all the anthropometric regulations are minimum;
- totally open, while all the anthropometric regulations are maximum;
- inclined one to better perform the leg exercises.

In this way the seat is adequate for all bariatric users

Two details have been taken into account while realizing the structure:

- maximum depth in closed configuration is less than 90 cm to allows the passage through hospital doors, because the minimum is of 95 cm(1). A width of 80 cm is considered to allow the passage through normal doors;

- the transport is eased leaving a space of 8 cm high and a 20 cm wide at the base of the structure. So, a trans pallet may move it if necessary.

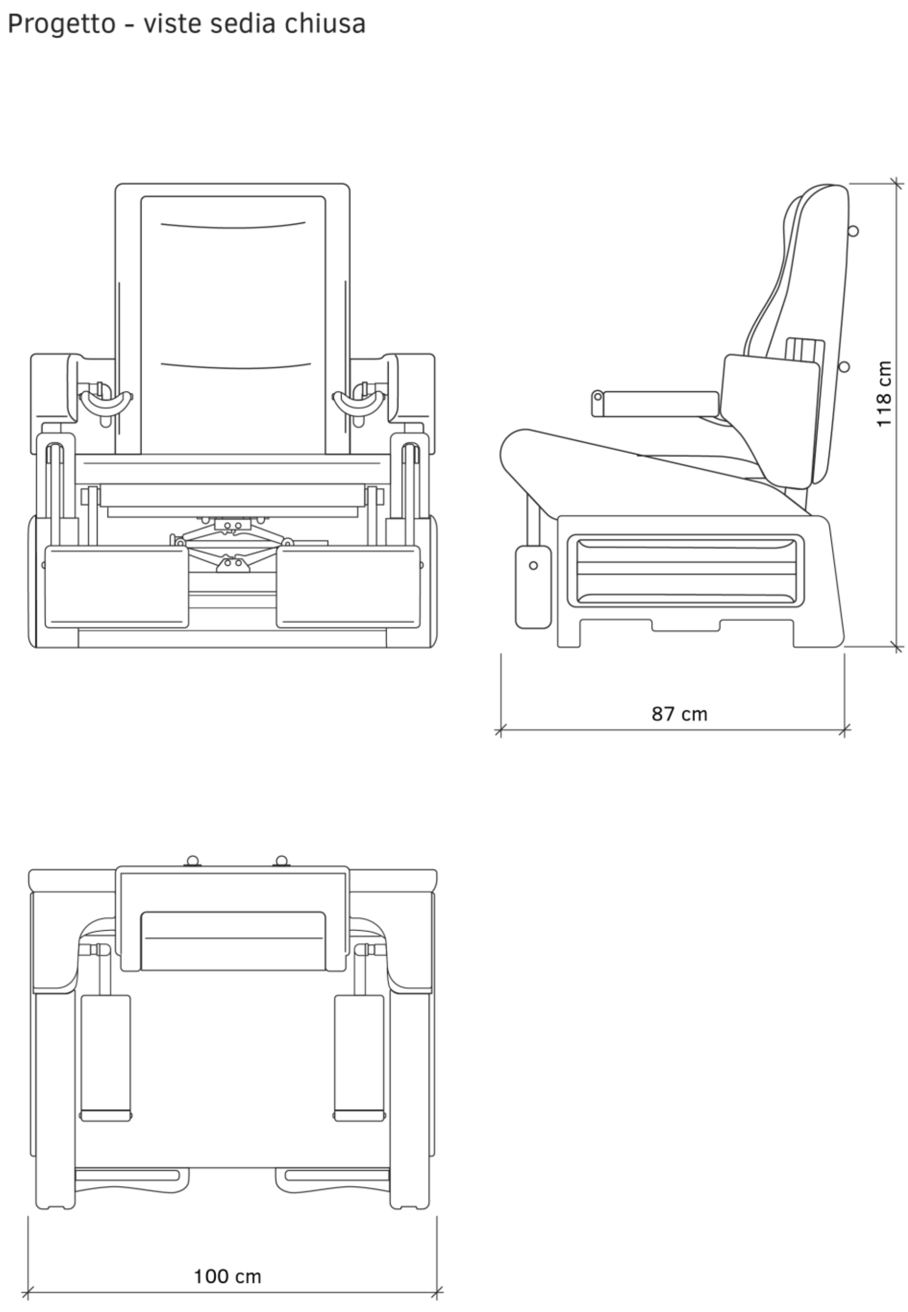



*Figure 7.1: the different sides of the seat are shown in the closed configuration.*

## Progetto - viste sedia aperta

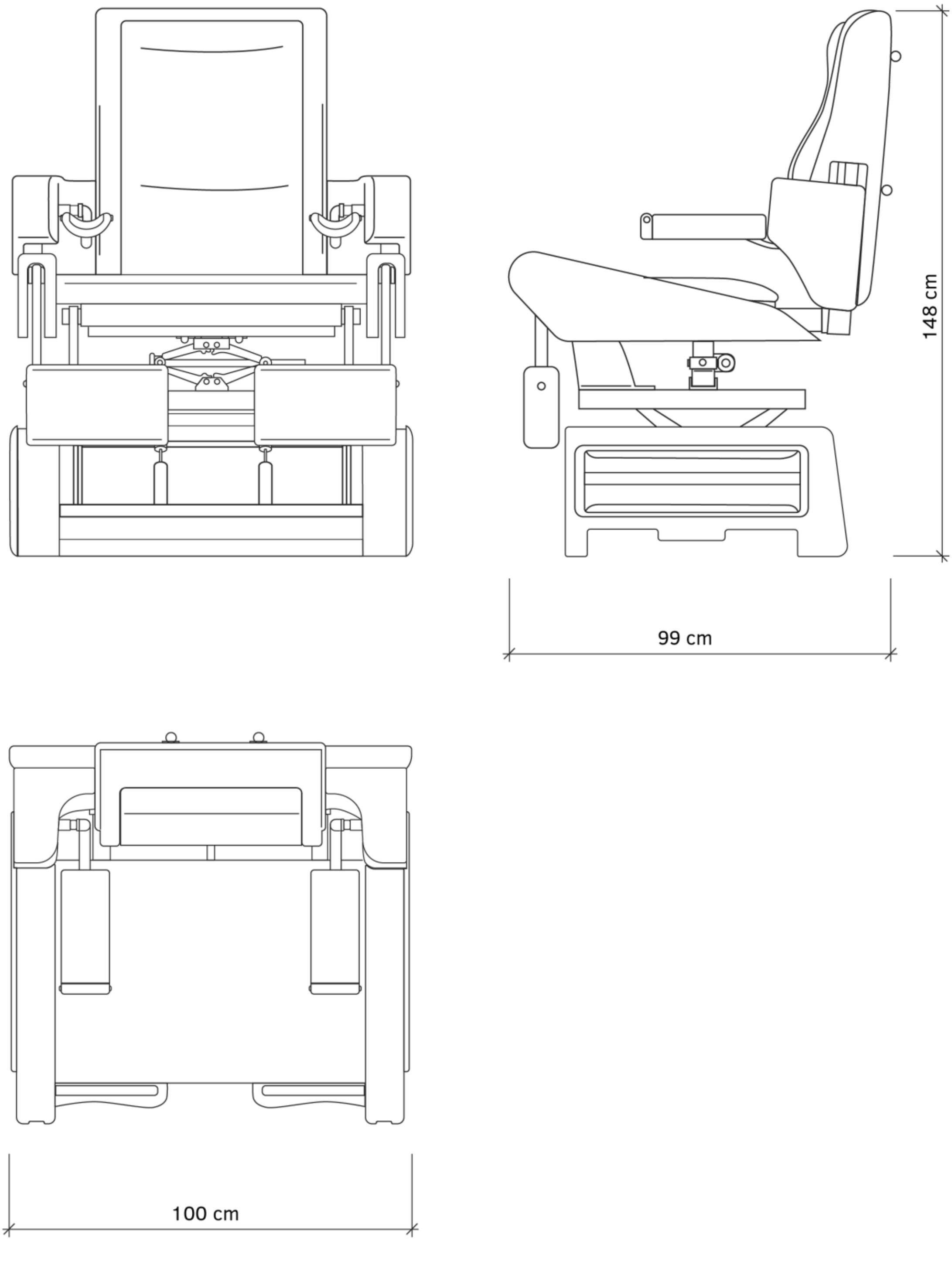



*Figure 7.2: the different sides of the seat are shown in the opened configuration.*

Progetto - viste sedia inclinata

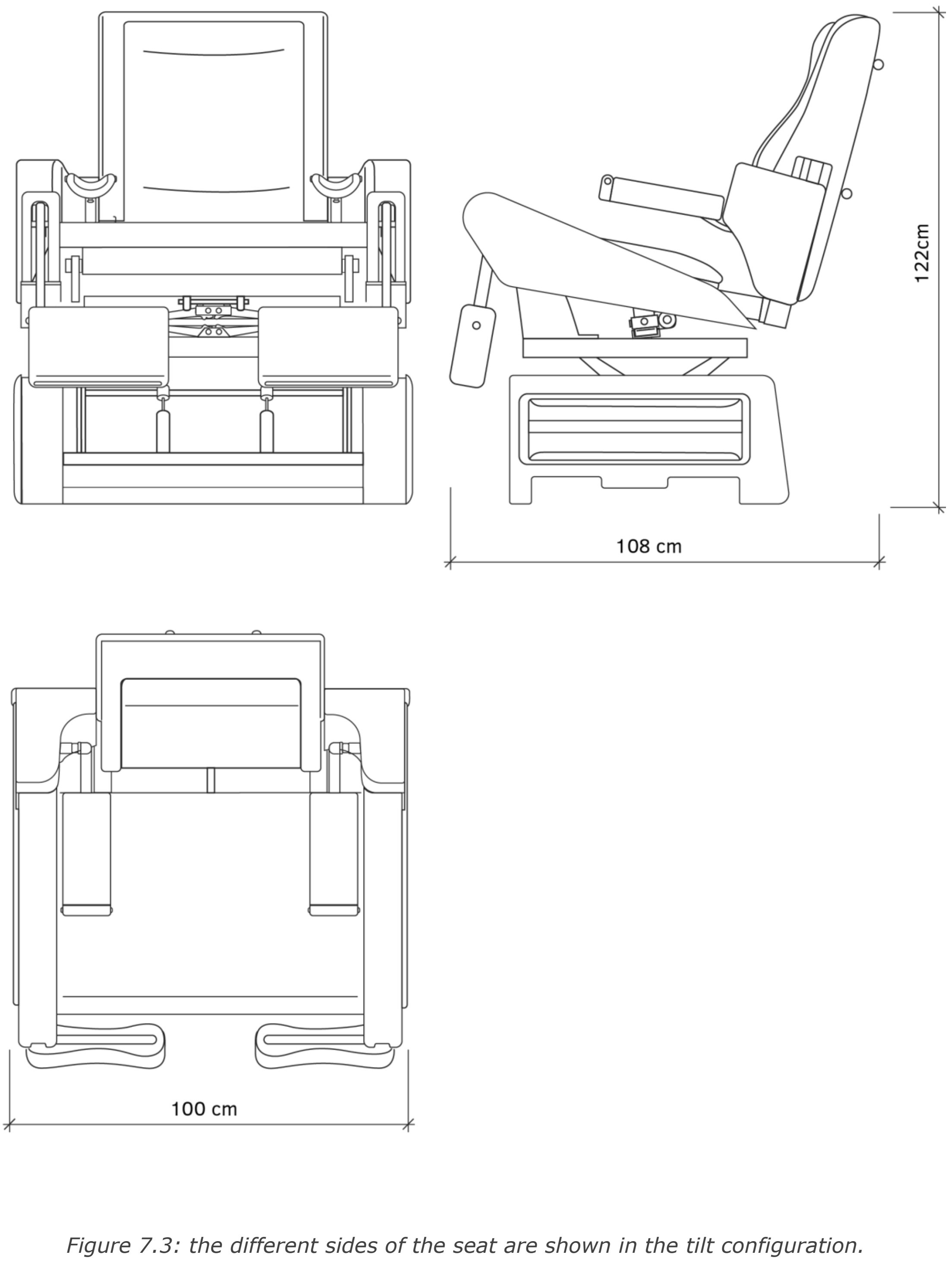



*Figure 7.3: the different sides of the seat are shown in the tilt configuration.*

*Figure 7.4: project layout.*

## 7.2 Structure overview and solutions

In the kinematic analysis all regulations have been established. The structure and mechanisms are not definitive, a test phase is needed to validate them.

Guidelines are here provided, and they may be approved or not in future, because the high weight of patients has to be taken into account.

A height regulation may be provided by a lift table that raises all the chair. The lift table is solid and capable to bear considerable loads, it also makes versatile and adaptable height adjustment to the anthropometric variability.

The knee tilt inclination of the system is realized thanks to a hinge positioned under the seat (under the user knee) such that the knee is always in correspondence of the mechanical join of the leg curl/leg extension mechanism. A pantograph electric jack is inserted to articulate the knee tilt.

Seat depth adjustment is carried out by sliding the frame of the backrest on the seat. This is achieved with a pipes system that run under the seat moved by an electric linear actuator placed in the centre and bound to the seat itself.
The same principle may be applied to regulation in height of the armrests, which must necessarily take place with the backrest. Even in this case the entire system moves by scrolling up tubes forming the backrest frame, thanks to the action of an electric linear actuator.
The height regulation of the legs supports, the depth of the armrests and the position of cervical and lumbar supports, are managed through the application of lock pins a spring that maintain the chosen position by anchoring to the sliding tubes. In this case the adjustment can be done manually by the patient or by the doctors.
A last setting concerning the position of armrests in width, is resolved through the application of a sliding system telescopic between the tubes that constitute the supporting structure. Also in this case, the adjustment is manual.

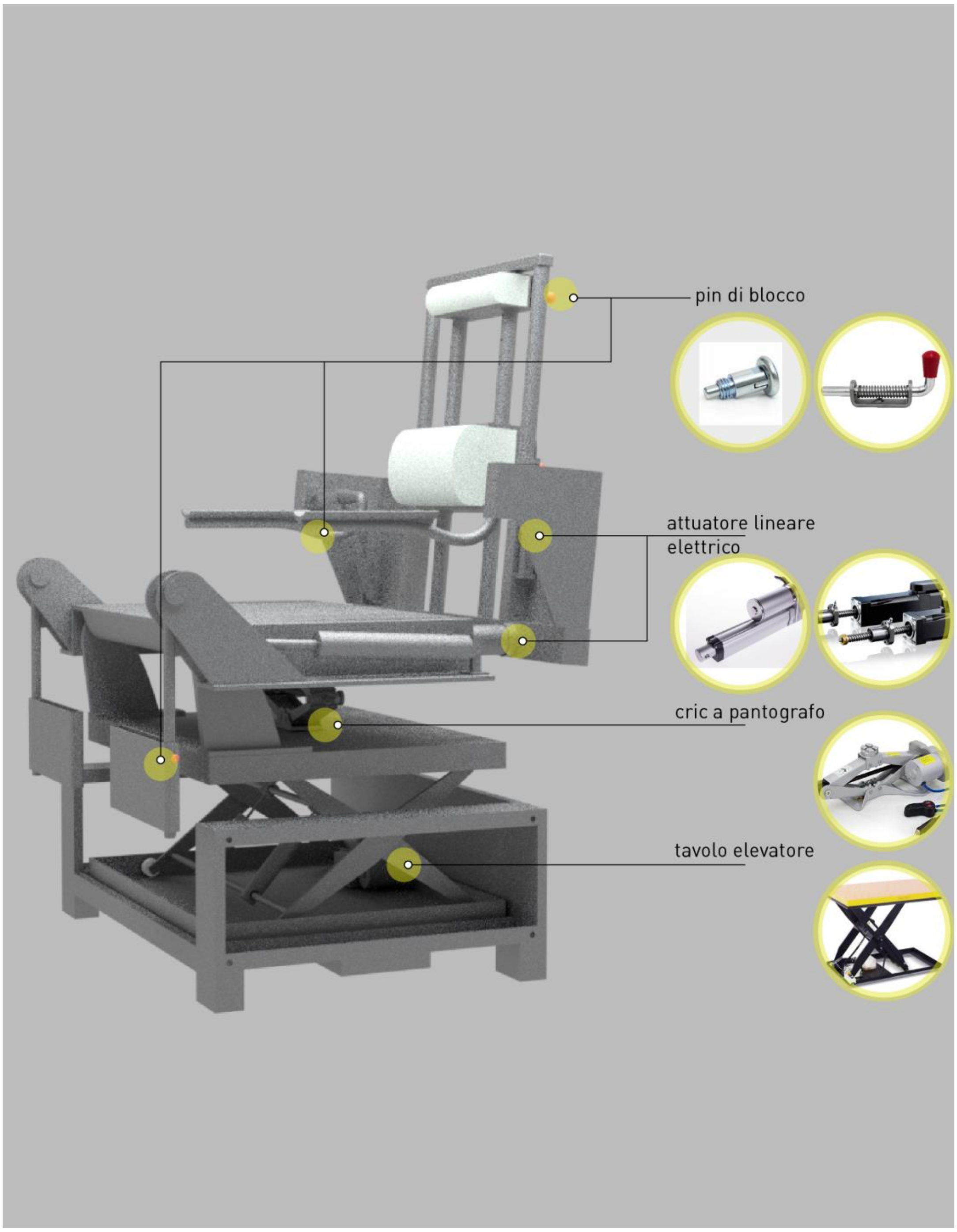



*Figure 7.5: 3D model of the frame structure integrated with the principal mechanism.*

## 7.3 Accessories

In the system some accessories are needed to the correct functioning of the product. On the floor, a frame with sensor to register the motion in some peculiar exercise is needed. Then a control display that is used to select the wanted exercise together with the non-manual regulation. Last but not least, an additional cervical support to reduce the risk in the more critical patients.

*Figure 7.6: In red colour the accessories needed for the seat.*

## Final remark

With the accessories definition, the concept phase of the chair can be considered concluded. The patient's population have been studied and appropriate physical exercise have been selected. Moreover, the particular kind of problem shows the need of introducing non-standard dimensions for the product.

Then, the project presents a detailed kinematic and dynamic analysis with a 3D software-based study on interference of components. The required exercises have been achieved and forces and pressure needed in the system have been computed by means of a mathematical model developed in Matlab. Finally, the solution for the pneumatic actuation system based on the commercially available model of components is provided. The concept is ready to enter in a verification phase which has not been developed within this thesis for sake of time.

Nevertheless, this kind of preliminary project gives the possibility of developing new different multidisciplinary scenarios.

Indeed, to reach the JOB 0 model of the chair some further analysis are needed and, of course, recommended:

- FEM verification of single mechanism,
- FEM verification of the frame structure due to the load,
- Verification of the actuation system,
- Sensor and data managing development,
- Prototyping and production.

Other field of study must also be involved:

- Materials,
- Gaming interface for integration (exergames, mirror therapy),
- Biomedical studies.

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## Overall reference

The thesis work has been developed together with the student Julia Robin, Master's degree course in DESIGN SISTEMICO in Politecnico di Torino. Two thesis work have been developed together, the current one with the engineering focus, the Julia Robin one with the designer focus.

- ***"Fidget Chair, seduta a scopo terapeutico per la cura dei grandi obesi", Julia Robin, 2019.***