

**ȘCOALA DOCTORALĂ INTERDISCIPLINARĂ**

**Facultatea de Educație Fizică și Sporturi Montane**

**Drd. Iulia Găinariu**

**Dezvoltarea capacității de efort a alergătorilor montani prin intermediul tehnologiei noninvazive și invazive de actualitate**

**Developing mountain runners effort capacity through invasive and noninvasive modern technologies**

**ABSTRACT**

**Conducător științific**

**Prof. Univ. Dr. Răzvan Sandu Enoiu**

**BRAȘOV, 2023**



The thesis respects the methodological indications specific to the doctoral field, being structured in three parts. The first part deals with its theoretical foundation, based on the bibliographic references identified and studied. In the second part of the thesis are presented the premises, objectives, purpose, tasks and hypotheses of the preliminary research. The third part of the thesis contains the methodological approach of the final research, starting from its premises, goals, purpose, tasks and assumptions. The control test battery used in the research is structured on two categories, including non -invasive evaluation samples and invasive evaluation samples.

In the introduction, it was described the athletics discipline and the mountain running test. It has been observed that athletics is one of the oldest Olympic disciplines, a sports discipline mentioned since ancient times, which enjoys great spectacularity and attractiveness. Long distance runs have evolved from classic ones (10,000meters, marathon) to modern ones, such as long distance running, road running, mountain running or even ultrarunning. The mountain running, although it is a relatively young discipline, enjoys great popularity, both among the consecrated athletes and in the amateur athletes. The first national mountain running championship organized by the Romanian Athletics Federation was in Piatra Arsă, in the Bucegi Mountains, in 2008. The athletes were not consecrated on this test, so they were allowed to participate with the proof of them being legitimized at a sports club affiliated at the Romanian Athletics Federation. At the first edition of the National Mountain Running Championships, 76 athletes participated, the competition having a favorable evolution because their number increased significantly. Currently, in Romania are many mountain running races, enjoying a generous audience with interest for movement, outdoor sports, mountains and nature. Romania manages to achieve international results at renowned competitions and even holds a gold medal at the World Long Distance Mountain Championships from Argentina and three bronze medals obtained by the national team of the girls at the World Long Mountain Championship from Italy 2017, Poland 2018 and Argentina 2019.

The continuous development of the international mountain running test, the lack of specialists in the field at national level but also the notable performances of Romania at this discipline, requires the initiation of a preliminary study to highlight the influences that a right approach and conduct of the sports training, correlated with a feasible medical study of physiological, cardiological, biochemical and neuromotor indicators, may have on sports performance.

The prerequisites of this research consist in identifying and selecting a set of non -invasive and invasive tests and implicitly their application to the subjects. For these reasons, the subjects from the preliminary research consists of high performance senior athletes, with significant results at national and international level. Being approached senior athletes, the contribution of the research consists in the continuous improvement of the sports

performances through the optimal directing of the sports training according to the biochemical, cardiological, biochemical and neuromotor parameters. The qualitative jump regarding this research consists in the introduction in the sports training of the consecrated athletes of a set of non -invasive and invasive tests that reflect the health of the athletes, the biochemical status of the body and the dynamics of the functioning of the most important systems: cardiological, renal or neurological; this being a small used approach at national level and even less, for mountain runners.

Another important aspect is the multidimensional knowledge of the subjects, because aspects such as: age, physical training, concentration capacity, running technique, skills but also general and mental physical resistance are the fundamental key elements that dictate the possible sports performances that may be achieved.

Regarding the current stage of preparation for senior athletes, the following basic features are particularly important:

- Continue improvement of the mountain running technique, with the improvement of the descent technique and facilitating the breathing process during the climbs;
- Improving the biomechanics of flat running in order to increase speed on portions without elevation during specialized competitions;
- Using modern techniques for recording the parameters of physical effort;
- Using non -invasive and invasive technology correlated with sports training in order to increase sports performance;
- Motivating the athletes and maintaining the seriousness attitude, for a normal development of the research and for the development of their sports career, in order to obtain higher performances at the specialized competitions.

The most important component of this research is to perform non-invasive and invasive tests on the research subjects, program orientation of the sports training in close collaboration with their coach based on the obtained data and participating in the specialized competitions where it can be accurately certified whether the performance of the subjects increases.

The biggest part of the invasive and non-invasive technology used in this research has a wide medical applicability, being used for screening and diagnosis of multiple conditions. Their integration in the mountain running test is supposed to be a new approach that can bring particularly important informations about the general state of the athletes and maximize their sports performance at national and international level.

In order to achieve the objectives and tasks of the mountain running test, the training requires a correct periodization and planning based on well-established scientific principles. For these reasons, this doctoral thesis wants to highlight the importance of the methodology of mountain running sports training supported by invasive and medical and non-medical tests, in order to increase sports performance. All invasive and non-invasive tests used in the present research are widely used to investigate the health status of patients in medical

institutions, however, they have never used grouped, to include a complex series of the parameters that can reveal the actual level of preparation of performance athletes and predict by precise calculations the performances that can be achieved by them. In order to go through all the stages of this research, a series of specialized publications were studied in order to explore the selected topic. Following all the researched studies, all valuable informations for present research has been used and interpreted in order to create a coherent theoretical foundation in the specificity of the work, to establish a strategy for carrying out and applying preliminary research and to carry out efficiently and precisely the final experiment.

Regarding the mountain running training, the establishment of the main objectives is done according to several factors. Among these factors, in the case of consecrated athletes, the most important are to keep a position in the national team, qualifying and participating in international competitions, obtaining places on the podium in competitions and implicitly, maintaining collaboration contracts with the employer and sponsors. In order to achieve these objectives, the specific physical training must present key elements such as speed or strength resistance. High performance athletes have a considerable skill of the technical processes specific to the evidence in which they participate, have tactical skills, have a continuous and sufficient psychological training, are constantly interested in their own health by participating in periodic medical controls and approaches a continuous theoretical training for the purpose of increase the basis of their theoretical knowledge about the physiological, anatomical and biochemical foundations of the human body in relation with sports training.

During the period of preparation for the mountain running test, for 1-3 months, oxidative resistance is educated through moderate intensity exercises, such as high-molded distances. Developing aerobic resistance, athletes benefit from a number of cardiorespiratory advantages, such as high aerobic ( $VO_2\max$ ) or musculoskeletal capacity, increased type I of muscle fiber and muscle resistance. These adaptations from the preparatory period aim to increase the aerobic resistance in response to the training load performed. During the specific preparatory period, the resistance in speed regime and the strength in resistance regime is educated through the specific exercises of the mountain running sample. The competitive period refers to the participation in the specialized competitions set as an objective, a stage that aims to achieve the proposed objectives, to maintain the strength, resistance and speed acquired in the previous stages. The transition period is a period of relaxation, active-passive, in which complementary sports can be performed to maintain the muscle tone, provided that they are practiced for recreational purposes.

In order to ensure the achievement of the proposed objectives within the competitive season, an efficiently designed training plan, an experienced coach and motivated athletes are required. However, in order to be able to maximize the entire training process, a good strategy known by both athletes and its entire monitoring and support team, is particularly important. The main means of specific training in mountain running are: vertical running,

down running and off road running. During the preparatory period, the coach must integrate specific running training. The coach and the athlete will have to monitor in addition to the classic running parameters: distance, speed and duration, including the elevation. The elevation represents the positive level difference that the athletes accumulate at the specific mountain running training, when the running is carried out on rough terrain, in mountain areas or hills. The improvement of these techniques is particularly important, because the off road from the mountain running test creates a major advantage for the athletes who have a very good climb and descent technique. The resistance capacity of mountain runners is determined by different essential aspects, such as the pulmonary system, aerobic power, cardiac flow, oxygen transport capacity, skeletal muscles, mitochondrial and capillary density, lactic threshold and movement economy.

The consequence of the intensely increased cardiac flow during maximum physical activities, is the decrease of the time of oxygen blood saturation, which is why oxygen desaturation appears and limits as well the sports performance. These similar limitations can be observed including in the workouts carried out at moderate altitudes. Due to the limited gas exchange, this limitation causes a decrease in  $VO_{2max}$  value. The aerobic power is represented by the maximum speed with which  $O_2$  is taken over and used by the body during maximum physical exercises, being viewed by many authors a key element for success in resistance sports. In response to the long-term aerobic effort in the mountain running test, mountain runners tend to have a higher percentage of type I muscle fibers, fibers that are characterized by a higher oxidative capacity, also presenting a larger number of capillaries surrounding these fibers. Physical effort stimulates the mitochondrial biogenesis of the skeletal muscles, which is why the mitochondrial density will increase. Also, mitochondrial enzymes will in turn increase effort resistance through a complex mechanism that decreases lactate production and favors fat oxidation, thus saving glucose and muscle glycogen.

The theoretical foundation of the thesis focused on the observation of the main physiological and biochemical aspects involved in intense physical effort. Thus, considering the fact that human physiology deals with the study of factors of physical or chemical origin, responsible for the genesis, development and evolution of life, since each human being is a completely unique entity with completely individual characteristics, its purpose was to explain these characteristics and the specific mechanisms that define the human organism in its essence. However, human physiology deals with the study of all these parameters in ordinary life conditions, the studies being done from the perspective of basal metabolism and normal effort. Regarding the intense physical effort, many of these parameters are intensely modified, because the human body adapts perfectly perfect mechanisms to cope with the changes that occur. Intense physical effort represents an extreme stress on the human body. It is believed that continuous extreme physical exertion can be lethal. So, the science that deals with the study of the changes that occur during intense physical effort is effort physiology which studies the maximum limits to which certain mechanisms and

characteristics of the human body can be pushed. For example, the difference in body metabolism between a sedentary man and one trained in a marathon is up to 2000% more, in favor of the trained one, while in fever, body metabolism increases by only a maximum of 100%. Addressed in the present study were the aspects related to the locomotor compartment, respiratory function, cardiac and renal function.

The locomotor compartment refers to all the structures, mechanisms and functions that have locomotion as an end product. Among the particularly important anatomical structures, we mention the following: bones, joints and striated muscles. The most important qualities of the material from which the bone is structured are the possibility of bone of remodeling, the strength and the flexible structure. Recovery after an injury is possible precisely because the bone is made up of specialized cells and protein fibers, being a living and mobile tissue that is in constant destruction and regeneration. The organic matrix of bone is made up of 90-95% collagen fibers and 5% fundamental substance. Joints are represented by the place where two bones come into contact, that is, where they join. Following their classification, they are of several types, the most important being synovial joints. They have the highest degree of flexibility, being represented by a complex joint consisting of joint capsule, synovial membrane and synovial fluid. A percentage of approximately 40% of body mass is made from skeletal muscle. Skeletal muscle has a number of specific characteristics and properties, and skeletal muscle contraction is a particularly important mechanism. Striated muscle is made up of a multitude of muscle fibers, and in turn, muscle fibers are made up of a multitude of successive subunits progressively diminished in volume. Most skeletal muscles have muscle fibers along almost the entire length of the muscle, and the muscle fibers are generically innervated by a single nerve ending located in the central portion of the fiber. One of the essential factors that condition competitive success is skeletal muscle performance. Skeletal muscle performance can be classified by the force they produce; the power they can reach during physical effort and the duration. Endurance is a very important effort parameter in long time sports. This parameter depends mostly on the nutritional support of the muscle: glycogen and carbohydrates from the diet. A person on a high-carbohydrate diet stores more glycogen in the muscles. The metabolic systems of the skeletal muscle under conditions of intense physical effort are: the phospho-creatine system; the glycogen-lactic acid system and the aerobic system. Important to the present study and relevant, is the aerobic system, which represents the oxidation of food principles at the mitochondrial level, with the purpose of producing energy. The aerobic system produces unlimited energy, unlike the other two energy systems, as long as are provided nutritional reserves. During the effort of about 4-5 hours duration similar to long-distance mountain running races, glycogen stores are almost completely used, and their usefulness in muscle contraction is insignificant. Therefore, supplementation with carbohydrate solutions used by athletes during endurance exercise covers approximately 30-40% of the energy requirement of physical effort, energy requirement supported by means of blood glucose and muscle

glycogen. Respiration is a fundamental physiological process through which organisms exchange respiratory gases:  $O_2$  and  $CO_2$  with the environment. Respiratory physiology studies the exchange of respiratory gases and the mechanisms by which this exchange occurs. In endurance sports, the efficiency of respiratory function is particularly important for achieving superior sports performance. The relationship between  $O_2$  consumption and total pulmonary ventilation is a linear relationship that increases 20 times in the interval between resting and maximal intensity exercise. The maximum respiratory capacity increases by approximately 50% more than pulmonary ventilation during maximal effort, being a safety element for maximizing sports performance, as it provides a surplus of ventilation that can be useful in conditions of physical effort at elevated temperatures, at high altitudes or in case of abnormalities of the Respiratory System.  $VO_{2max}$  represents the rate of  $O_2$  consumption under conditions of maximal aerobic metabolism, being a parameter on which sports training has a direct effect. The  $VO_{2max}$  of a marathon runner is 45% higher than that of an untrained person, a fact also conditioned by genetics. During exercise, the  $O_2$  requirement can exceed 20 times the normal value. As cardiac output increases, the duration of blood circulation through the pulmonary capillary is reduced by less than half, and yet the blood remains nearly 100% saturated with  $O_2$ . The  $pO_2$  value in blood Hb is 15-40 mmHg and ensures the automatic exchange of  $O_2$  to the tissues.  $O_2$  transportation is made through the  $O_2$  bound with the hemoglobin in proportion of 97% and the rest physically dissolved in the  $H_2O$  from plasma and red blood cells.

At altitude, the difference in atmospheric pressure is significant compared to the sea level. Atmospheric pressure at altitude decreases because there is literally less atmosphere above. The decrease in atmospheric pressure comes with a series of consequences, such as a decrease in the ambient temperature or other changes in the human body. Among these changes are identified the increase in pulmonary arterial pressure, the size of the right heart, the number of red blood cells and the hematocrit. Hypoxia is a first sign that appears at altitude, and depending on the adaptation of each organism to the new conditions, this may be a trigger in the appearance of other symptoms. Decreased muscle capacity is one of the adverse effects of hypoxia, and the depression may also appear.

The heart is the main organ from the cardiovascular system. The specific anatomical composition of the heart ensures the proper circulation of blood and lymph in the body. Without this function, the distribution of oxygen and nutrients to the cells of the body or the collection of waste products could not be possible. The electrical activity of the heart consists in the generation of action potentials, functioning as a cardiac impulse generator (pacemaker). The musculature of the ventricles and atria can contract spontaneously due to the excitoconductive system of the myocardium. The cardiac cycle is the sum of systoles and diastoles. At a rate of 75 beats/minute, the cardiac cycle lasts 0,8 seconds. The cardiac cycle is accompanied by acoustic manifestations such as systolic and diastolic murmur; electrical, represented by the variations in the biocurrents of depolarization and repolarization of the

myocardium that can be recorded in the form of an electrocardiogram (ECG) and mechanical, represented by the arterial pulse.

The kidneys have an essential role in maintaining the body's homeostasis, fulfilling multiple roles, such as: regulating the water and electrolyte balance; excretion of end products of metabolism or exogenous substances; regulates osmolarity; regulates blood pressure; maintain the acid-base balance; secrete and excrete hormones etc. Water regulation participates in maintaining body homeostasis by achieving a balance between the intake and excretion of H<sub>2</sub>O and electrolytes. If for a certain substance the intake is greater than the elimination, that substance will accumulate and can cause severe imbalances in the body. A supplement of certain electrolytes causes the kidneys to increase the excretion of that product until equilibrium is reached. All exogenous chemicals, drugs and end products of metabolism are excreted through the kidneys. Urine is formed through glomerular filtration. The glomerular membrane consists of three layers represented by the capillary endothelium, the basement membrane and a unicellular layer of podocytes (epithelial cells). This structure makes up the filtration barrier being different from the membranes of other capillaries in that it contains three layers and not two. This structure has increased permeability to water and solutions, but is normally impermeable to proteins. Fenestrations at the capillary endothelium contain negative electrical charges that oppose the passage of plasma proteins. At the level of the basal membrane there is a network of collagen and proteoglycans that allows filtering an increased amount of H<sub>2</sub>O and the existence of pores, spaces between podocytes, represents a third barrier for the glomerular filtrate due to the charge with negative electrical charges. Due to the processes of reabsorption and excretion from the proximal tubule, loop of Henle, distal tubule or collecting tubules, the urinary excretion rate consists of the filtration rate together with the secretion rate, from which the rate of reabsorbed products is subtracted. Initially, the primary filtrate is formed which consists of the passage of a large amount of fluid through Bowman's capsule to the proximal tubule. In primary urine, almost all plasma substances are filtered, except for proteins. Following the processes of secretion and reabsorption, the composition of the filtrate will change, resulting in the final urine, which will be finally eliminated.

The second aspect studied in the present research was related to the biochemical processes involved in maintaining the homeostasis of the bodies of performance athletes. Biochemistry is a discipline that studies all the chemical substances that participate in the formation of the human body and that maintain their biosynthesis and degradation processes. For these mechanisms to exist and function, they need numerous compounds of an organic or inorganic nature. These compounds fulfill distinct roles, such as participating in material necessary for survival or processes for providing metabolic energy. By knowing the structure and properties of organic chemicals, we can better understand the metabolic reactions in the human body and their influences to our advantage. Water in the human body is approximately 43–75%. Water has a complex role due to its structure, its special properties



determining the intensity of some metabolic processes. The daily water requirement of an adult is on average 30 mL/kg , being directly influenced by external factors, such as physical effort, ambient temperature or various pathological conditions. Performance athletes practicing endurance sports have an intense liquid consumption. In order to maintain an optimal ratio, these athletes must very well balance the amount of fluids ingested with those eliminated, because excessive hydration will not have a beneficial role in the hydration process, but on the contrary, it can lead to hyponatremia which will implicitly decrease sports performance. Therefore, it is important that the ingested substances are in limited quantities, in relation to the needs of the body and the level of effort. pH is the hydrogen exponent and is mathematically defined as the signed decimal logarithm of the H<sup>+</sup> ion concentration. Thus, through pH we can express the alkalinity or acidity of an environment. Disturbance of acid-base balance induced by exercise and accumulation of extracellular potassium causes fatigue. Exercise under hypoxic conditions may enhance exercise-induced changes in these two factors compared with exercise under normoxia. Under conditions of hypoxia, the concentration of lactate in the blood increases significantly. Also, bicarbonate ion concentrations and blood pH during the exercise and post-exercise periods are significantly lower under normoxia conditions. The regulation of the acid-base balance is done by two physiological mechanisms: the physiological buffer systems that act in the very short term, but whose capacity is limited by the concentrations of different compounds in the blood, and the physiological regulation, initially pulmonary, then renal, which has a trigger mechanism slower but with superior efficiency. Acid-base imbalances occur by changing the pH in the blood and have four forms of manifestation:

- Metabolic acidosis involves the accumulation of excess acids or the drastic loss of bases. This can be found in the case of short-term intense efforts in the form of lactic acidosis or in the case of an intense muscular effort typical of athletes.

- Respiratory acidosis consists in lowering the pH by decreasing the elimination of CO<sub>2</sub>. In the case of athletes, it can occur in the case of excessive fatigue due to long-term exertion by abolishing the movements of the ribcage.

- Metabolic alkalosis is rare and is caused by an excess of bicarbonate or in case of a massive loss of hydrogen ions. It can be found in athletes who have made too intense efforts that have caused prolonged episodes of vomiting.

- Respiratory alkalosis occurs due to the decrease in pCO<sub>2</sub>, occurring in case of hyperventilation or anxiety states such as starting fever or the psychological factor of little training.

Mineral salts do not represent a source of energy for the body, but they constitute 4% of the body's weight, being indispensable for physical effort. The human body requires a daily intake of mineral salts through food, because they are eliminated daily, especially through urine. They have particularly important roles in the body, including:



- Participation in the morphogenesis processes of bone tissue, connective tissue, cartilage, etc.;
- Inhibitors or activators of certain enzymatic reactions;
- Participates in the formation of physiological buffer systems;
- They maintain the physical-chemical state of colloids in the body and colloid osmotic pressure;
- It is included in the composition of chemical effectors such as iodine in the synthesis of thyroid hormones, etc.

A balanced and carefully designed diet ensures the daily requirement of mineral elements. That's why knowing their roles and food sources is extremely valuable information that ensures the necessary essential intake for the good functioning of the athletes' body and the achievement of the performances proposed in the annual training plan.

An important biochemical aspect studied in the present research is carbohydrate, protein and lipid metabolism. Metabolism is the set of all chemical transformations that take place in the living organism, from the level of the cell to the tissue and organ. The two essential processes of metabolism are: the production of energy, respectively, the production of ATP and the synthesis of macromolecules necessary for the body, respectively the consumption of ATP. Practically, all the reactions that release energy are degradation reactions, the process being called catabolism, and the reactions that consume energy are biosynthesis reactions, thus participating in the anabolism process. The release of energy through catabolic reactions is carried out by the breakdown of molecules, originating from food or from the body's reserves, into even smaller molecules that can be directly used in biochemical reactions. The mitochondrial stage of energy production takes place only in cells provided with mitochondria, intensely vascularized, such as striated muscle fiber, because mitochondria play the fundamental role in energy metabolism. At its level, metabolic intermediates are degraded to the molecule called acetyl coenzyme A. Through the mitochondrial respiratory chain and the Krebs Cycle, it is produced energy, Hydrogen under water form and the carbon is eliminated through the form of CO<sub>2</sub>. Mitochondria regenerate over 90% of the ATP requirement. Carbohydrate metabolism begins with intestinal digestion and absorption, the main role in this process being that of the liver. Carbohydrate digestion begins in the oral cavity, under the action of alpha-amylase, and continues in the stomach, where it is stopped due to gastric acidity. The process continues at the level of the duodenum under the action of pancreatic alpha amylase, the carbohydrates being hydrolyzed to the stage of monoglycerides, which are then absorbed in circulation from the intestine. Lipids are highly hydrophobic substances and insoluble in water, therefore, they cannot be transported in circulation in free form. The amount of lipids consumed daily varies between 60 g and 100 g per day. Despecification of these food constituents to absorbable compounds such as free fatty acids , glycerol, monoglycerides and free cholesterol takes place at several levels along the digestive tract under the action of lipases (hydrolytic enzymes that facilitate the

deesterification of lipids). Proteins have an energy value of 4 kcal/mol and represent 10-15% of the caloric intake required by the body to maintain a healthy and balanced diet. Protein digestion begins in the stomach under the action of gastric acid and pepsinogen. In the intestine, the digestion process continues under the action of enzymes from the pancreatic juice, more precisely chymotrypsin, trypsin and elastase. The purpose of this digestion process is the despecification of proteins down to amino acids. Resistance training stimulates the recycling of protein throughout the body through the processes of synthesis and breakdown, although it is not yet known exactly whether this translates into a net increased protein oxidation or a nutritional need for protein. Skeletal muscle is the primary energy consumer during exercise, and branched-chain amino acid (BCAA) oxidation is increased several-fold, suggesting an increased fuel requirement.

The preliminary research objectives aimed in two main directions: the use of a complex system of noninvasive and invasive techniques through which we can optimize the physical training of senior mountain runners and the analysis of specialized parameters and the effective control of training means to determine an optimal screening model mountain running tests. The purpose of the preliminary research is the study of modern invasive and non-invasive techniques and their application in correlation with sports training, with the aim of superior management of physical training, obtaining superior results at specialized competitions and achieving an optimal and efficient screening model of sports performance at senior mountain runners. We assume that through the use of invasive and noninvasive techniques, we can select a category of samples that will evaluate subjects from a physical, functional, biochemical, cardiological and cognitive point of view in order to develop an effective means of monitoring and intervention that will increase their sports performances and also; we assume that through the use of selected invasive and noninvasive techniques, a screening protocol and individual monitoring of research subjects can be created, with the aim of preventing the main ailments that can be caused based on the increased level of stress that performance sports exert on their body.

The preliminary research consisted of testing the national mountain running team during 2021. The subjects involved in the research are part of the components of the men's national mountain running team from the period 2020 -2021, over 20 years. The preliminary research consisted of the initial testing at the beginning of the preliminary research period with the role of determining the initial performance level of the subjects and the final testing, at the end of the preliminary research with the aim of highlighting the evolution of the studied parameters. In the middle period of the preliminary research, namely the specific, pre-competition and competition preparation of the annual training plan, two training macrocycles were carried out designed by the subjects' trainer according to our medical indications, through which it was possible to interpret the effectiveness of the invasive and non-invasive techniques applied in research. The sports trials took place within the national mountain running competitions organized at Câmpulung Moldovenesc by the Romanian

Athletics Federation, while the invasive and non-invasive tests were carried out at the National Sports Research Institute in Bucharest, at the private biochemical analysis laboratories of blood and at the private cardiology office. By means of the scientific experiment method, the sequence of events proposed for the research could be realized. From a practical point of view, the scientific experiment consisted of applying an initial and final test, each of which consisted of a group of specific and carefully selected tests. By means of these tests it was possible to appreciate the quality of the training method and the effectiveness of the monitoring methods on the physiological, biochemical and cognitive status of the athletes. All the samples used in the preliminary research are tests widely used by the medical society for conducting preventive or diagnostic investigations and sports tests conducted according to the regulations in force of the International Association of Athletics Federations. Basically, the initial testing took place at the beginning of the experimental program of the preliminary research and the final testing took place after the last sports test, in order to be able to appreciate the dynamics of the individual and group sports performance of the research subjects. The method of measurements through control tests included: physical assessment (the specific sports test of short-distance mountain running race and the sports test for determining  $VO_2$ max values); cardiological assessment which consisted of electrocardiogram and cardiac ultrasound; biochemical test of urine, capillary blood by the MicroAstrup method; hematological blood analysis; determination of lactate concentration and cognitive assessment by using the Neurotracker device. During the preliminary experiment, several categories of parameters were investigated, classified by group, as follows:

- a. Parameters specific to sports training: Speed, Volume and Elevation;
- b. Medical parameters grouped into two subcategories:
  - b.1. Parameters obtained by noninvasive methods: EKG, ECO,  $VO_2$ max, Neurotracker, Urine summary;
  - b.2. Parameters obtained by invasive methods: Astrup, Hematology, Lactate concentration;

The research focused on the results obtained after the application of the investigation methods on the subjects of the mountain running test, from the point of view of the parameters selected in the preliminary experiment. Medical data interpretation discussions are based on the fact that gathering medical information from tests performed becomes an easy process when a close communication relationship is established between the clinician, athlete and coach. However, in order to be able to interpret and provide medical opinions, the clinician must have specific medical training and a minimum of information, which they have the ability to interconnect with each other, in order to establish a diagnosis and a method of treatment. Although performance athletes are generally healthy people, prevention is extremely important in their case, because, without it, the intense stress produced by the effort can trigger conditions that not only affect their sports performance, but also put them life in danger. For these reasons, the American Society of Cardiology recommends, for

example, to perform cardiological tests at least annually in performance athletes. In addition, the American Academy of Family Physicians recommends that ECG, ECHO, and referral to a cardiologist be considered for performance sports patients who have an abnormal cardiac history or abnormal physical examination findings, or a combination of them.

Primary prevention aims to intervene before injury or disease occurs through screening programs, such as neuromuscular programs to prevent knee injuries; secondary prevention focuses on intervention immediately after an injury or disease has occurred, referring to early treatment to slow the disease; and tertiary prevention focuses on improving outcomes for those with long-term injuries or illnesses (eg, knee or ankle osteoarthritis developed in former high-performance athletes of above-average age). Often, despite efforts to prevent injuries, this situation becomes inevitable for any athlete at some point. Two-thirds of performance athletes in track and field experience at least one injury during a competitive season, and nearly all athletes have been injured at least once during their years of athletic practice. An injury has direct negative consequences on sports training and participation in competitions, reducing the ability to perform optimally. During major sporting events, athletes have been found to be at increased risk of symptomatic infections especially from viruses in the general population. Symptoms are usually mild and self-limiting, which is why many of these athletes compete while having a viral respiratory infection. However, among the most common conditions associated with sports training and endurance competitions, excluding respiratory tract infections, are neuromuscular injuries of tendons and bones, dehydration, acute kidney injury, gastrointestinal problems, rhabdomyolysis, epithelial injuries, cardiovascular injuries, changes in liver function and collapse associated with particularly intense physical exercise. The main areas prone to injury are the lower extremities, most of which occur during training. In a study conducted on athletes, the most common injury was muscle the cramp, having the main cause the overtraining. Considering that the practice of endurance sports is becoming more and more popular, it must be taken into account that they can cause injuries or even major adverse effects. In addition to the well-known beneficial effects of practicing long-term endurance sports on health, especially for the cardiovascular, pulmonary and musculoskeletal system, the main conditions that appear in these runners must also be taken into account, such as: Achilles tendinopathy, plantar fasciitis, patellar tendinopathy, tibial stress fracture, hamstring tendinopathy or Iliotibial Band Syndrome. The main homeostasis disorders identified through noninvasive techniques consist of proteinuria and changes on the ECG path, while the homeostasis disorders identified through invasive techniques consist of potassium, magnesium, calcium concentration disorders; anion gap acidosis and respiratory acidosis. The conclusions drawn from the preliminary research are that the use of modern medical technology, such as the Radiometer automatic blood gas analyzer, the Medonic M-Series hematology analyzer, the Lactate Pro-2 lactate analyzer is an easy and effective procedure that provides real values of the most significant biochemical parameters. The use of these means aims to provide an

overview of the biochemical status of each athlete's body and which, in turn, provides the opportunity to modify the training program according to the identified values. Despite the fact that this technology could be expensive and requires a medically trained person to perform the tests and interpret them, they are undoubtedly the most significant contribution that can be made to improving sports performance, health athletes' health and to prevent the main injuries that can occur in high-performance sports. Performing the Paired T-Test demonstrated that the results obtained in the final testing are statistically significant, in contrast to those obtained in the initial one, the conclusion being that the subjects improved their results during the annual training plan achieving superior sports performances.

Because of the researchers intervention and the close collaboration with their coach, the results recorded in all tests were superior in the final test compared to the initial one, this statement being confirmed by the values recorded in Tf for the main parameters:  $VO_2\max$ , LDH, CPK,  $SpO_2$ , proteinuria, Neurotracker and most importantly, the time to complete the sports test in Tf. The electrocardiogram captured a normal electrical activity of the heart, with a superior adaptation of the myocardium to exercise conditions, and the resting ultrasound revealed all heart parameters within normal limits, with minimal left ventricular hypertrophy for all athletes. This left ventricular hypertrophy represents nothing more than the adaptation of the myocardium to the effort due to the increase in the thickness of the left ventricular wall, implicitly the excito-conduction capacity and the pumping force. Neurotracker training proves that perceptual-cognitive skills are perfectly trainable and can improve sports performance by developing attention and concentration.

In the final experimental research, it was started from the premise that the training process of mountain runners can be optimized by using the obtained results from the applied selected non-invasive and invasive research techniques, with the aim of increasing sports performance in the 2022 competitive season. Early and correct application of some categories of noninvasive and invasive techniques allows the correction of hydro-electrolytic imbalances and lactic acidosis, the correction of vitamin deficiencies and the performance of controlled physical effort with the aim of preventing the main sports ailments that may occur. Thus, a second important premise of the research is the fact that the prompt intervention in the training program of the subjects based on the established protocol, maintaining a very good communication with their coach and performing periodic non-invasive and invasive tests, automatically determines the increase in their sports performances by the simple fact that the subjects do not get injured or show drastic deficiencies that affect their sports training. The main objective of the final experimental research is represented by the use of non-invasive and invasive techniques for the development of the physical potential of mountain runners and the identification of an intervention protocol to regulate the main imbalances in the homeostasis of the athletes' body, and the purpose of the research is to confirm the effectiveness of the research methods used in preliminary experimental research, their re-application and highlighting of the results. The hypotheses of the final experimental

research are represented by the idea that by using a set of invasive and non-invasive medical tests in the training of mountain runners, it is possible to determine the achievement of superior sports performance materialized in favorable results at specialized competitions, thus achieving an effective performance screening protocol sports and also that by using invasive and non-invasive tests selected and applied in the process of sports training, as well as by using this screening protocol in experimental training programs, we assume that we will achieve an increase in sports performance, superior values of physical indices, biochemical, cardiological and cognitive in order to monitor, evaluate and reach the maximum potential of the research subjects. The final research was initiated in April 2022 and ended in October 2022. The subjects involved in the research are identical to the subjects involved in the preliminary experimental research, all 7 subjects being subjected to all the selected samples, the data taken being interpreted in order to confirm the hypotheses of the research finals. In the final experimental research, the method of the scientific experiment consisted in applying the selected tests to the group of subjects. The results obtained were useful for the realization of an effective screening protocol that could direct and guide the training plan of the subjects in the 2022 competitive season, so that the proposed objectives are achieved.

The final scientific experiment took place in 3 stages:

- Initial test — represented by the subjects' participation in the first stage of the National Short-Distance Mountain Running Championship and the selection for CEAMLD in a long-distance mountain running competition.
- Intermediate test — represented by the PSSD simulation within the training camp in the Piatra Arsă national center and the participation of qualified subjects at CEAMLD
- Final test — represented by the final stage of the National Short Distance Mountain Running Championship and the National Long Distance Mountain Running Championship.

The control test measurement method in the final experimental research compared to the preliminary experimental research additionally evaluated in the physical evaluation, the sports testing of the long-distance mountain running test; testing by the pulse oximetry and the questionnaire method in which the opinions of athletics specialists were evaluated regarding the importance of non-invasive and invasive medical techniques regarding the effectiveness of screening on the health status of athletes and the monitoring of their sports performances. The questionnaire is composed of 30 questions with four answer options each, except for question number 1, which refers to the nationality of the person completing the questionnaire. In order to have objective answers, filling in the questionnaire was anonymous and the only personal data requested were nationality and age. The questionnaire was formulated both in romanian and english, being applied to coaches through the SURVIO platform. The results recorded in all categories of tests carried out were analyzed and interpreted (each subject was analyzed from an individual point of view, each subject was



individually intervened), and following them the final conclusions and screening protocols could be drawn up of athletes' health and intervention in sports training.

The main interventions at the level of athletes in the research group are represented by supplementation with vitamin complexes; supplemental daily consumption of isotonic drinks to prevent dehydration and acid-caused imbalances following sustained effort; increasing the specific parameter in mountain running, namely elevation; to increase the volume of effort, complementary cycling training was recommended at the expense of specific effort (running); the use of micronutrients, coenzyme Q-10 and L-carnitine to support the energy metabolism; the use of beer's enzymes to aid sports recovery and reduce CPK values and to support brain and nerve cell function, a B12-based drinkable product used for two weeks before objective competitions, has been recommended. Regarding the individual analysis of the subjects, it was found that post-exercise there are variations in the electrolyte balance; the urine summaries performed showed proteinuria; inadequate respiratory recovery; relationship of inverse proportionality between  $VO_2\text{max}$  and the position occupied in the general ranking of specialized competitions, and singular changes were also detected in terms of certain enzymes such as: TGO, TGP, CPK, LDH, etc. in response to intense physical exertion.

Through the use of noninvasive and invasive techniques, the main imbalances of the athletes' bodies were identified, based on which we created a series of intervention protocols to rebalance their homeostatic balance. The use of these protocols is simple, the strict following of the indications within them by the trainer being an extremely important stage for obtaining the expected results. In the situation where the coach applies the specific protocol for the identified imbalance and strictly respects the indicated stages, but the results are not favorable, a complementary condition may be present, which is why the best indication is a visit to a specialist sports doctor or family medicine doctor. We also recommend the application of these protocols also in the case of other sports disciplines, whose athletes present biochemical, cardiological and functional indices modified compared to physiological values. Screening protocols were thus created for: monitoring and increasing  $VO_2\text{max}$  values; of cardiological testing and interpretation of the obtained data; of non-specific laboratory diagnosis associated with infections; of diagnosis and treatment of the main anemias; interpretation, treatment and screening of the main biochemical imbalances encountered in mountain runners; calculation, evaluation and screening of lactate concentration rate and screening, interpretation and diagnosis of the main kidney diseases.

Regarding the conclusions of the final experiment, it was found that a higher  $VO_2\text{max}$  does not automatically determine a higher position in the overall ranking of a mountain running competition, which is why it can be stated that a number of other factors are determining for obtaining a such result as physical fitness, skill, agility or mental attitude in relation to the competition. Also, at altitude, the maximal aerobic threshold of athletes is reduced, which is why the determination of  $VO_2\text{max}$  values will be lower compared to the



values obtained at ground level. Second, SpO<sub>2</sub> has been observed to decrease under exercise conditions regardless of the area in which the test is applied: ground or altitude. The effects of hypoxia on SpO<sub>2</sub> cause tissue O<sub>2</sub> concentration to decrease with altitude both under basal conditions and during exercise or after active recovery. After 15 minutes of active rest, SpO<sub>2</sub> values return to physiological values regardless of atmospheric pressure. However, each organism is unique, which is why the response to hypoxia differs from one individual to another. Thirdly, no correlations could be found between lactate production at altitude compared to sitting, and also, it was observed that altitude does not determine a lower recovery rate of lactate concentration during maximal aerobic effort. Also, the lactate recovery rate is just another parameter that contributes to the increase in sports performance, because in this research, it was observed that a better lactate recovery rate conditions the achievement of a superior performance in the specialized competition. Last but not least, it was observed that a number of values were superior in the final testing, which is why it can be concluded that in order to record superior sports performance, conducting a well-thought-out altitude training camp and using modern sports technology leads to fulfilling the main objective of mountain runners.

One of the main elements of originality of this research is the introduction of a set of non-invasive and invasive tests for screening the sports performance and health of the subjects, with the aim of maximizing sports performance and preventing injuries. The actual originality of this thesis is the intervention in the training program of the group of subjects and the use of noninvasive and invasive medical technology in the mountain running test in the athletics discipline, with the aim of achieving the goal and objectives of the research. The intervention in the training programs was carried out through close collaboration with the coach of the group of subjects through the involvement of a multidisciplinary team of specialists in the field of sports science and the medical field. They took and analyzed information and samples collected from the research subjects, by means of specialized medical equipment, such as Medonic M-series or ABL Radiometer; specialized sports equipment: Cosmed K5, Neurotracker, Garmin and sports tests specific to the mountain running event: the short and long distance event. Analyzing the results obtained by the research subjects, including the X place in the individual general ranking of the European Long Distance Mountain Running Championship by subject A1 or the IV place with the romanian team at the World Long Distance Mountain Running Championship from Thailand, we believe that the intervention in the training program of the subjects was a novelty element for the mountain running test at the national level. Also, of all the studies identified on mountain running, none were found that looked at this test of athletics from such a complex angle. Thus, this study contains a lot of novel elements, from the novelty of the test itself, to the multidisciplinary medical testing correlated with the sports performance analysis.

The research carried for the development of the effort capacity of mountain runners by modern non-invasive and invasive technology has resulted in the creation and publication of three scientific articles indexed in the international stream.

Regarding the limits of the research, it was observed that although the totality of the noninvasive and invasive methods used in the research represent modern, useful and relevant means for investigating the parameters used in order to develop the effort capacity of senior mountain runners; however, these techniques require special equipment that can not only be expensive, but also require specialized personnel who can analyze the data, formulate a diagnosis, and provide recommendations. Following the questionnaire entitled "Questionnaire regarding the importance of medical techniques in the evaluation of performance athletes" applied at national and international level, the vast majority of specialists in the field generally apply these tests only once a year, which is why this attitude in itself represents a limitation of increasing sports performances. Mountain running events have a fairly flexible set of rules set by the IAAF regarding the technical aspects of the running course, both short and long distance. For this reason, the elevation can vary from one sample to another, and often even the distance. Even if two mountain running events had exactly the same distance and elevation, the specifics of the terrain would still distinguish them from one another. For this reason, to measure the sports performance of the subjects, the only possible ways are to evaluate the position obtained in the general classification or the time obtained within an identical competition that they repeat. To be able to interpret a series of medical parameters, a wide range of knowledge in this field is needed. However, the evaluation must be related to the characteristics of high-performance athletes, which is why pathological changes must be carefully distinguished from the benign ones found physiologically in this category of subjects. The medical staff thus requires both medical and sports knowledge to be able to understand the physical effort exerted by the subjects and treat the changes occurring in relation to them. Taking into account the increased sporting value of the subjects in the group selected for the pedagogical experiment, another limitation of the research is represented by the fact that the recommendations in this paper are strictly addressed only to subjects with similar performances. The small number of national level performance athletes in this discipline influenced the small numerical selection of the research subjects, this being another limitation of the research. The costs of conducting medical investigations and the use of state-of-the-art equipment used in this scientific work are significant, which is why the financial aspect is an important limitation of the research.

The personal contributions of the author of the thesis are represented by the introduction of a set of non-invasive and invasive tests with the purpose of screening the the sports performance and the health status of the subjects, with the aim of maximizing sports performance and prevent injuries. The actual originality of this thesis is the intervention in the training program of the group of subjects and the use of non-invasive and invasive medical technology in the mountain running race, with the aim of achieving the desired goals and



objectives proposed in the research. The results of the research were capitalized by the practical implementation of the experimental intervention program at the level of the components of the national group of senior mountain runners. Analyzing the results obtained by the subjects of the research, among which the 10th place in the individual general ranking of the European long distance mountain running Championships obtained by the subject A1 or the 4th place with the romanian team at the World Championship of long-distance mountain running from Thailand, we consider that the intervention in the training program of the subjects it was a favorable novelty element for the mountain running event at the national level.