MOTIVATING PREMEDICAL STUDENTS
TO GET INTERESTED IN PHYSICS

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Introduction

Physics teachers around the world are trying to create classroom environments that would allow life sciences students to be more intrinsically motivated in their work.\textsuperscript{1-3} These efforts include among others matching classroom activities to students’ interest as well as structurally variable activities to match different student abilities.\textsuperscript{4-7} While physics instruction at the Université libre de Bruxelles also strives to make classes more relevant for life science students, two stimulation approaches will be presented here in detail. These include the in-class motivation using historical examples of physicians’ role in physics development and the small group work outside of class on physics problems that have engaging, motivating and challenging biomedical titles.

Mutual enrichment of physics and medicine and in-class motivation

Medicine and physics are historically tightly bound.\textsuperscript{8} A paraphrased ancient Greek aphorism says “know thyself, and you are going to know the universe”. “Knowing thyself” is taken care of by medicine, and physics explores the universe. That is why naturalists and doctors used to organize joint meetings until the beginning of the 20th century. It is then not surprising that a lot of fundamental discoveries in physics were made by medical doctors, often when they were challenged by a question raised by their medical practice. The Supplementary Information of this paper briefly describes the contributions to the physics made by 20 different physicians that lived in different times, from antiquity to the 20th century. This important information is rarely brought to the awareness of premedical students and, to my best knowledge, do not stand out in relief in any textbook of physics for medical school.

These twenty medical doctors contributed to various fields in physics. During problem-solving seminars and laboratory classes on the matched topic, instructor may
surprise students by a biomedical episode of history of physics. At ULB, the reactions of students to these stories are variable, from not believing (Are you kidding us? No medical doctor would deal with such complicated physics stuff!) to complete admiration (Wow! I did not know, incredible!). Stickled students become quickly convinced after googling, because these stories are taken from open internet sources. Students often engage into further discussion about these physicians, probably because the context succeeded in making some connections that touched their personality. It is hard to evaluate quantitative impact of this particular motivational approach because of its occasional use. However, such intrinsic stimulation method is known in psychology as mirroring a positive example – this kind of motivation is said to be long-lasting and self-sustaining.\textsuperscript{9-11} Experimental psychological study has shown that mirroring a positive example induced motivational synchronicity and a group of participants worked significantly longer on the same task\textsuperscript{12}, while this effect was absent in case of observing an example that was extrinsically motivated with a reward.\textsuperscript{12} Even should it have a short-term effect, it is a useful tool to keep students connected with the work in the class.

**Group work outside of class on physics problems with biomedical titles**

Another method of intrinsic motivation is to increase autonomy in the learning environment, namely by providing students with choices and responsibilities.\textsuperscript{13} For example, they may choose introductory physics problems of their interest and showcase the understanding of this topic by a group work outcome. During last decade, physics course for life science students in many universities has been enriched with relevant biology and medical application illustrations and problems that can be used for this work.\textsuperscript{4-7} Such problems stimulate sense of coherence and give students possibility to find by themselves the answers to the questions of “why” and “how” biological systems work from the physical point of view. Problems initiated by these questions are of particular interest because they typically
demand an explanation in ordinary language. They should have engaging, motivating and even challenging title. It is very uncommon practice, because routinely physics problems have no title at all. In other words, titles of physics problems *per se* induce effect of novelty, which in turn has strong relationship with learning and motivation.\textsuperscript{14}

Problems with challenging biomedical titles are proposed to students at the Faculty of Medicine of ULB as a supplement to the standard problems in physics, which should be resolved first to gain certain confidence in the matter. Our introductory level physics problems have been either created *de novo* or re-purposed from many excellent textbooks.\textsuperscript{15-20} Following title examples give general idea of how these physics problems are formulated:

1. How are radiation, convection and transpiration involved in human body thermoregulation under heavy exercise?

2. Why is the energy conversion efficiency of the heart low?

3. Why is the observation of very high values of heart rate and blood pressure considered as a dangerous situation?

4. Why prefer humans chewing food using molar teeth? (Variant: why prefer humans to bite using incisor teeth?)

5. Why do people shiver in the cold weather?

6. How may friction force rise local body temperature?

7. Why developed nature such an adaptive mechanism as sneezing?

8. How may the force of Archimedes help to calculate the amount of fat tissue in human body?

9. Why are the blood perfusion pockets made of soft plastic and why should they be suspended above the vein?

10. How is the sound amplified by the middle ear?

11. Why should strong torques be applied to dental crowns in order to align teeth?
Any detailed answer to these questions is useful in real-life context, yet it should be supported by calculations. These problems were recently used as facultative assignments for a small group work outside of class. It was up to students to appropriately distribute among group members the literature research, analysis and writing. The discussion on how to set up, evaluate and avoid the pitfalls of student group work falls outside of the scope of present communication, but it can be found elsewhere.\textsuperscript{21-25}

Due to optional condition, only small fraction of students engaged in this work. They chose to work in pairs, which was logical, since in this way the work could be easily and equally distributed. By inertia, students tended to work as usual at first and provided only numerical solutions to the problems. In some cases it took several rounds of revision and resubmission before all “how” and “why” questions were correctly answered. Since even those who should have revised the report asked for additional assignment, students liked the end result of this work themselves. With some reservations due to the small number of participated students, this observation is optimistic and might suggest that these assignments may be well-received by the whole class, when they become eventually mandatory.

It is evident that the assignment should be challenging, but not impossibly hard. Instructor sets the expectations and provides some necessary information and explanations within the text that would guide students in the intended direction. As indicated above, instructor and students should stay in touch regularly. Below is the content of an assignment with the expected numerical solutions and written explanations. Another assignment may be found in Supplementary Information.

**Muscles as springs, why do people shiver in the cold weather?**

Scientists try to use models with limited number of simple elements to explain complex reality. The simplest mechanical model of muscle cell represents it as a spring fixed at both ends.
Skeletal muscle cell (muscle fiber) of biceps is a 20 cm-long myocyte. During contraction, this cell shortens in half and develops a force of $F = 30 \text{ mN}$.

1. One fiber contains 1500 myofibrils that run in parallel to each other. Each of these rod-like structures is composed of many contractive units (sarcomeres), which organize in single-file and contract simultaneously (see Figure). By microscopy, relaxed sarcomere is 2 $\mu$m long.

Calculate spring constant of one sarcomere.

**Expected answer:**

$Spring \text{ constant of one cell is } k = \frac{F}{\Delta L_{\text{max}}} = \frac{30 \text{ mN}}{0.1 \text{ m}} = 0.3 \text{ N/m}$

$Spring \text{ constant of one myofibril out of 1500 equal in parallel inside the cell is}$

$k = \frac{0.3}{1500} = 0.2 \text{ mN/m}$

$Number \ of \ sarcomeres \ is \ N = \frac{20 \text{ cm}}{2 \mu \text{m}} = 100000$

$Spring \text{ constant of one spring out of 100000 equal in series in one myofibril is}$

$k = 0.2 \text{ mN/m} \times 100000 = 20 \text{ N/m}$

2. The mass of one cell is 1.5 mg. Knowing that myofibrils organize in thread-like structures in the muscle, what maximal force can develop a biceps of 300 g?

**Expected answer:**

$Numbers \ of \ fibers \ is \ N = \frac{300 \text{ g}}{1.5 \text{ mg}} = 200000 \text{ fibers}$

$Spring \text{ constant of 200000 parallel fibers is } k_{\text{biceps}} = 0.3 \text{ N/m} \times 200000 = 60 \text{ kN/m}$

$Then \ maximal \ force \ is \ F_{\text{max}} = k \times \Delta L_{\text{max}} = 60 \text{ kN/m} \times 0.1 \text{ m} = 6 \text{ kN}$

3. Cold shivering represents unintentional muscular contractions with the amplitude of $\Delta L = 2$ cm and the frequency of 10 Hz. All mechanical energy of shivers is converted into heat. By
how much will raise the body temperature after 10 s of shivering if all skeletal muscles contract simultaneously? For simplicity we assume that a) all muscle fibers are the same as above; b) muscles represent 30% of normal person body mass (70 kg); c) the specific heat of all human tissues is C=4000 J/(kg*K) and d) generated heat is instantly distributed throughout the body. Why do we shiver in cold weather?

Expected answer:

There are $14 \times 10^6$ muscle fibers in 21 kg of muscles (70 kg * 0.3)

Energy of one muscle fiber shiver is $E = 0.5 \times \Delta L^2 = 0.5 \times 0.3 \text{N/m} \times 0.02 \text{m} = 0.06 \text{mJ}$

The energy of 10Hz * 10s = 100 shivers is equal to 6mJ and $14 \times 10^6$ muscle fibers would liberate 84kJ of energy that is also equal to $E = 21 \text{kg} \times 4000 \times \Delta t$, from which follows that $

\Delta t = 1\text{K}$. Then overall body temperature would rise by $70/21 \times 1\text{K} = 0.33\text{K}$

Shivering appears to be an effective way of body thermoregulation in cold weather.

Concluding remarks

From psychological point of view, students tend to display similar behavior to what they observe around them in the class, including teacher. Instructor, which, in addition to the course content, is also competent in biomedical history of physics, may create conductive classroom environment for life science students using short stories about the role of physicians in physics. Outside and within the class, challenging titles of physics problems create the effect of novelty in learning environment. This may stimulate in a very favorable context the acquisition of knowledge and science-based thinking that are relevant to the real life and to students’ future studies and careers in medicine and biology.

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References


Supplementary Information

Contributions of medical doctors into theoretical and applied physics.

Doctors-thinkers were the first who fell into a muse of what is warmth/heat. They’ve understood that good health is dependent on body temperature. Prominent Greek physician Galen of Pergamon (130-210) introduced the notions of “temperature” and “degree”, which became fundamental for physics and other sciences.

Abu Ali Sina (Avicenna, 980-1037), the most significant physician, thinker and writer of the Islamic Golden Age, developed the theory of motion in mechanics and was among those who argued that light had a finite speed.

William Gilbert (1544-1603), personal doctor to the Queen of England, studied magnets. He called the Earth a big magnet and proved it experimentally, later he introduced a model of Earth magnetism.

The name for sexually transmitted disease syphilis comes from an epic poem of Italian physician Girolamo Fracastoro (1476-1553), who also studied light refraction and was the first who introduced a term “pole” with regard to the Earth.

Christian Gottlieb Kratzenstein (1723-1795) was a doctor, physicist and engineer. He is especially known for the first attempts at mechanical speech synthesis. In 1746, Kratzenstein wrote theoretical work on the nature of electricity. He argued that the electrical current was due to the motion of two fluids, which today would correspond to the flow of positive and negative electric charges. He also made measurements of how the attractive/repulsive force between two charged objects varied with their separation, i.e. he observed electrostatic force about 40 years before Charles de Coulomb formulated his law.
Kratzenstein observed how electricity affects the human pulse and perspiration and suggested that electrical discharges could heal certain neurological disorders. These ideas formed the very first basis of what today is called electrotherapy. Some people even speculate that these investigations by Kratzenstein made him a prototype of the fictional doctor Frankenstein. When Kratzenstein died, he left a big amount of money to the University, which later allowed Hans Christian Ørsted to build up his own laboratory for physical experiments.

William Hyde Wollaston (1766 – 1828) is famous for discovering the palladium and rhodium. In 1793 he obtained his doctorate in medicine from Cambridge University. He worked as a physician until 1800, when he left medicine. He performed electrical experiments, which resulted in his accidental discovery of electromagnetic induction 10 years prior to Michael Faraday. He is remembered for the observations of dark lines in the solar spectrum, which eventually led to the identification of specific elements in the Sun. He invented the reflecting goniometer and the camera lucida, a drawing tool that contained the Wollaston prism (the four-sided optics, which was first described only by Johannes Kepler). He also developed so called meniscus lens, which eliminated the image distortion in camera obscura that was a problem with many of that day's biconvex lenses. Unfortunately, Wollaston was not systematic or conventional in presenting his discoveries and even published anonymously (initially) in the case of Palladium, which are the reasons why his work was not honored by contemporary physicists.

Felix Savart (1771-1841) studied medicine in Strasbourg and later co-originated Biot-Savart law in electromagnetism. Also, while investigating the range of human hearing he developed the Savart wheel, which produces sound at specific graduated frequencies using rotating disks.

Thomas Young (1773–1829) generally known for his contribution into wave optics, theory of elasticity and surface tension was a practicing doctor who devised a rule for
determining a child’s drug dosage and discovered vision deficiency known as daltonism. Ironically, this discovery did not immortalize the name of doctor Young, but physicist John Dalton instead; Dalton contested diagnosis, described his own vision problem in a paper and published it in 1794. Nevertheless this medical case later helped to elaborate the Young-Helmholtz theory of trichromatic color perception and reproduction in wave optics.

French doctor and physicist, member of French Medical Academy Jean Léonard Marie Poiseuille (1799-1869) earned his D.Sc. degree with a dissertation on cardiac output blood pressure (“Recherches sur la force du coeur aortique”). He was interested in the flow of human blood in narrow tubes. He experimentally derived, formulated and published what is now known as the Poiseuille's law. This law applies to laminar (as opposed to turbulent) flow of liquids through pipes of uniform section, such as blood flow in capillaries and veins. Also the poise, the unit of viscosity, was named after him.

Julius Robert von Mayer (1814-1878) served as a doctor in the German navy. During an expedition to the Java Island, he faced an epidemic of pneumonia in the crew members. Making blood-letting, he noticed that, now that they were in the tropical zone, venous blood had almost the same color as arterial blood. His hypothesis was that human body could be assimilated to a “steam-engine” and, thus, it should consume less “fuel” at higher temperatures, and, accordingly, produce less “smoke”. He eventually concluded that there should be some relationship between the amount of work and the amount of heat, which is in essence the very basis of the energy conservation law. It is interesting to note, that Mayer tried to formulate his conclusion in terms of physics of the 19th century. But at that time, it was very hard and ambiguous and not truly appreciated by contemporary physicists. Some of them even claimed that there was no experimental data in the work of Mayer. In other words, Mayer’s discovery was a perfect example of porism, i.e. natural, but unexpected conclusion from the results of an experiment that in reality touches a broader spectrum of problems.
Acclaimed physicist (yet also practicing physician) Hermann von Helmholtz (1821-1894) independently from Mayer formulated the law of energy conservation in a mathematical form. Besides, Helmholtz made important contributions to the fields of electromagnetism, thermodynamics, optics, acoustics, as well as to the physiology of vision, hearing and nervous system.

Adolf Eugen Fick (1829 –1901) after earning medical degree in 1851 worked as a prosector. In 1870, he was the first to measure cardiac output, using what is now called the Fick principle. In 1855, he introduced phenomenological Fick’s law of diffusion. Fick published twice his work, as it applied equally to physiology and physics.

Jacques Arsène d'Arsonval (1851 –1940) obtained his medical diploma from Collège de France, where he assisted courses given by Claude Bernard. He is called “Father of biophysics”. He marked history of electrophysiology and medicine by his works on the effects of high frequency electrical signals in animals. To do these works, Arsonval invented in 1881 a ballistic galvanometer, sort of predecessor of an oscilloscope. This galvanometer was capable of detecting a current of 10 µA applied for only 1 millisecond. Among his other works – invention of a vase of Arsonval, which is now called thermos, and experimental proof of electrical energy transportation? The latter made him a founder of industrial electricity.

Michael Polanyi (1891-1976), a Hungarian-British polymath, studied to be a physician, obtaining his medical diploma in 1914. In the First World War, he served in the Austro-Hungarian army as a medical officer. In 1919 he defended a PhD thesis on adsorption, the research on which was encouraged by Albert Einstein. In 1934, Polanyi made an important insight on the plastic deformation of ductile materials. The insight was critical in developing the field of solid mechanics.

And the list goes on. Any car amateur has heard about a drive shaft, a mechanical component for transmitting torque and rotation at different angles, but hardly anybody knows
that this is the invention of an Italian doctor, Girolamo Cardano (1501-1576). The Foucault pendulum, a simple device conceived as an experiment to demonstrate the rotation of the Earth, is named after French scientist Léon Foucault (1819-1868). Prior to become physicist, Foucault studied medicine and worked as laboratory assistant on the microscopic anatomy course in Paris University. Experiments of Italian anatomist Luigi Galvani (1737-1798) on skeletal muscles of frogs served as a basis for investigations of A. Volta, which led to the invention of the voltaic pile in 1799. Doctor Heinrich Olbers (1758-1840) described a paradox, stating that the darkness of the night sky conflicts with the supposition of an infinite and eternal static universe. American inventor David Alter (1807–1881) graduated from the Reformed Medical School in New York City. He is credited for the invention of optical spectrum analysis of the flame of solids and gases, electric telegraph, clock and telephone. Finally, Willem Einthoven (1860-1927), whose work on electrocardiographic triangle was recompensed by Nobel Prize in medicine in 1924, invented string galvanometer, still considered highly sensitive instrument for the undistorted measurement of very weak electrical signals.

**Thermodynamics of the heart: how is the energy conversion efficiency of the heart compared to heat engines? How can it be modulated? Which values of heart beat rate and blood pressure are considered dangerous?**

If we present the values of the pressure and volume during the heart cycle in the form of a Pressure-Volume diagram, we obtain for the left ventricle a cycle composed of two isochors and two isobars that alternate anti-clockwise (Figure). In thermodynamics, such a cycle is called ideal. Real heart PV loop does not have clearly defined corners. Moreover, the heart is an open system; it exchanges the energy and the matter with the surrounding tissues and
converts chemical energy into mechanical pumping work, while thermodynamic cycle analysis is generally applied to closed systems, i.e. heat engines that convert thermal energy into work. This has to be kept in mind during resolution.

Systolic and diastolic pressures at rest are 120 and 80 mmHg, respectively (NB: 1 mmHg = 133.3 Pa). The volume of blood ejected to the aorta equals to the difference between £V ed and £V es. This volume equals to 70 ml for a normal human and corresponds to the ejection fraction of 70%, i.e. ventricular cavity always contains 30 ml of blood at the end of systole.

1. Calculate the work done by left ventricle at rest during one cycle

**Expected answer:**

*The ventricle doesn’t work in transitions 1-2 and 3-4*

\[ \Delta W_{tot} = \Delta W_{41} + \Delta W_{23} = -P_d(V_{ed} - V_{es}) - P_s(V_{es} - V_{ed}) = (P_s - P_d)(V_{ed} - V_{es}) =
\]

\[ (15996 \text{ Pa} - 10664 \text{ Pa}) \times 0.07 \times 10^{-3} \text{ m}^3 = 0.373 \text{ J} \]

2. Calculate the power of the left ventricle at rest knowing that the heart beat rate is 70 pulsations per minute.

**Expected answer:**

\[ P = \frac{\Delta W_{tot}}{t} = 0.373 \text{ J} \times \frac{70}{60} \text{ s} = 0.435 \text{ W} \]

3. On the short time scale, the heart adapts to the physical exercise by rising both systolic pressure and the heart beat rate. The increment of the heart beat rate increases two fold faster than that of systolic pressure. (In other words $P_s = 120^x(1+x)$ mmHg and $f_{heart} = 70^x(1+2x)$)
beats/min). The heart is capable of increasing its power by 10 fold and beyond this value it starts to fibrillate (contracts asynchronously and eventually fails). Which values of heart beat rate and blood pressure are considered dangerous?

**Expected answer:**

\[
(15996*(1+x)-10664)*(70*(1+2x)/60)*0.07*10^{-3} = 0.435*10 = 4.35 \text{ W}
\]

\[
(16+16x-10.66)*(1+2x) = 53.26
\]

\[32x^2+28x-42.6=0; \text{ then } \sqrt{D}=79
\]

\[x_1=0.797; x_2=-1.67; \text{ take the positive result, the pressure rises to}
\]

\[120*(1+0.797)=215.6 \text{ mmHg, while heart rate rises to } 70*(1+2*0.797)=181.6 \text{ beats per minute. The heart may fail if either the systolic pressure rises to } 215 \text{ mmHg or when the pulse exceeds 180 beats per minute.}
\]

4. In the absence of the actual measures of chemical energy consumption by the left ventricle, the only possibility to estimate energy conversion efficiency of the ventricle is to model blood with some strong assumptions as an ideal gas. We will try to see if it works. Since the blood is incompressible and its density does not strongly depend on the temperature it will have the same specific heat capacity at the constant pressure (Cp) and at the constant volume (Cv).

However, it is still impossible to obtain the value of molar heat capacity of the blood because it is a compartmentalized mixture of salts, hydrocarbons, lipids and proteins in water. But we know that water content in the blood is 90%, so the fair approximation of “molar” heat capacity of the blood would be slightly below of 0.9 of that of water. Accordingly, let us consider that \(C_{\text{blood}}=8R\) (NB: \(R=8.314 \text{ J*K}^{-1}\text{*mol}^{-1}\)). Calculate the energy conversion efficiency of the left ventricle at rest and at maximal effort.

**Expected answer:**

*The blood receives the energy in transitions 4-1 and 1-2*
Let’s write down parameters:

Point 4: \( P_d, V_{es}, T_4 = P_d \times V_{ed}/nR \)

Point 1: \( P_d, V_{ed}, T_1 = T_4 \times V_{ed}/V_{es} = P_d \times V_{ed}/nR \)

Point 2: \( P_s, V_{ed}, T_2 = T_1 \times P_d/P_d = P_s \times V_{ed}/nR \)

\( V_{ed} = 100 \text{ ml}, V_{es} = 30 \text{ ml} \)

\[ \Delta Q_{41} = \Delta U_{41} - \Delta W_{41} = nC_{\text{blood}} \times (P_d \times V_{ed}/nR - P_d \times V_{ed}/nR) - (V_{ed} - V_{es}) \times P_d = 8 \times P_d \times (V_{ed} - V_{es}) = 9 \times 80 \text{ mmHg} \times 70 \text{ ml} = 6.718 \text{ J} \]

\[ \Delta Q_{12} = \Delta U_{12} = nC_{\text{blood}} \times (T_2 - T_1) = 8 \times nR \times (P_s \times V_{ed}/nR - P_d \times V_{ed}/nR) = 8 \times V_{ed} \times (P_s - P_d) = 8 \times 100 \text{ ml} \times (120 - 80) \text{ mmHg} = 4.266 \text{ J} \]

\[ \Delta Q_{\text{tot}} = 6.718 \text{ J} + 4.266 \text{ J} = 10.984 \text{ J} \]

The efficiency is \( \eta = 0.373 \text{ J} / 10.984 \text{ J} = 3.4 \% \)

At the maximal effort \( P_s = 215.6 \text{ mmHg} \)

Then \( \Delta W_{\text{tot}} = (215.6 - 80) \text{ mmHg} \times 70 \text{ ml} = 1.265 \text{ J} \)

Next, \( \Delta Q_{12} = 8 \times 100 \text{ ml} \times (215.6 - 80) \text{ mmHg} = 14.460 \text{ J} \); and \( \Delta Q_{\text{tot}} = 6.718 \text{ J} + 14.460 \text{ J} = 21.178 \text{ J} \)

It follows that the efficiency is \( \eta = 1.265 \text{ J} / 21.178 \text{ J} = 6 \% \)

5. Physiological measurements of the oxygen consumption by left ventricle give values of 8 ml/min at rest and 70 ml/min at maximal exercise. The energy capacity of oxygen is 20 J/ml.

Calculate physiologically relevant energy conversion efficiency of the left ventricle at rest and at maximal effort. Does energy conversion efficiency change at maximal effort? Is it different from the values obtained in the point 4? How can we explain the discrepancy between these two methods of calculation?
There are 70 beats per minute at rest and 181.6 beats at exercise. It follows that one cycle at rest consumes $8/70=0.114$ ml of $O_2$, and $70/181.6=0.385$ ml of $O_2$ at maximal exercise.

Then, the efficiency at rest is $\eta=0.373 \text{ J}/(0.114*20 \text{ J}) = 16.4\%$

And at maximal exercise: $\eta=1.265 \text{ J}/(0.385*20 \text{ J}) = 16.4\%$

Heart efficiency does not change during exercise (which is what physiologists observe usually for a normal heart).

In fact, the ventricle does not expand the blood volume during diastole; blood enters the ventricle passively (at constant pressure) due to venous return and due to potential elastic energy of muscles acquired at the end of contraction, so the $\Delta Q_{41}$ is largely overestimated. If, in the approach of modeling the blood as ideal gas, we accept that the ventricle does not consume the energy to be filled up, the efficiency at rest gives $\eta=0.373 \text{ J}/4.266 \text{ J} \sim 9\%$, which is already close to that calculated by physiological methods. Modeling the blood as ideal gas does not predict correctly heart efficiency.

6. Sustained high blood pressure and/or heart beat rate can lead to chronic cardiovascular diseases. How could the human organism increase the heart efficiency to do the same work at lower pressure and pulse?

Athletes exercising regularly see their ventricles expanding, which results in higher ejected blood volume. Calculations show that each additional 10 ml of ejected blood increases the useful work by 14.5%. If the heart is not remodeled (not showing any hypertrophy) it would consume the same amount of oxygen. The efficiency at the same blood pressure is increasing that is why we can observe a lower pulse in athletes at rest and at maximal effort.