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Original Article

Development of a Pneumatic Heartbeat Simulation Device

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Abstract

Introduction: A pneumatic heart simulator designed to replicate a heartbeat in its entirety uses compressed air to mimic the contraction and relaxation phases of a human heart. This system typically includes a network of valves, actuators, and sensors that precisely control the airflow to simulate the dynamic pressure and volume changes of cardiac cycles. The simulator is valuable for medical training, device testing, and research, providing a realistic and controllable environment for studying heart function and related phenomena. **Methods**: A simulated heart and base are included in the pneumatic heartbeat simulation device. The simulated heart is created by vulcanizing latex materials, and it includes the superior vena cava, the aorta, the pulmonary artery, and its integrated molding. It also includes the right and left coronary arteries, their respective bodies, their right ventricular anterior branch, their right marginal branch, their left anterior descending branch, and their gyration branch. The base is equipped with a rotary table through the rotary axis, connected to the projection equipment, and a number of limit holes distributed in a circular pattern. The base has an inverted "L" shaped shelf, a rotating shaft, a projection device connected, and several annularly spaced restriction holes on the turntable's disc. The connecting part consists of a connecting tube that is positioned between the aorta and the pacing pump's outlet end. At one end of the connecting tube is an annular plugging plate, and at the other is an adhesive layer. **Results:** This device can be used to simulate the beating of a heart through continuous pumping and suction, as well as manual rotation of a turntable to enable multi-directional observation. Additionally, it can be equipped with projection equipment and external terminals for electrical connection to enable projection, which will facilitate the user's use for teaching and learning purposes and enhance overall practicality. **Conclusion:** The purpose of the pneumatic heartbeat simulation device is to assist medical professionals and interns with observation and surgical procedures, enhancing their operational skills, increasing surgical efficiency, developing competent personnel, and addressing their current social needs.

Keywords: *Device Heartbeat Simulation Device; Device Simulation; Pneumatic Heartbeat Simulation*

Introduction

There is a growing need for physicians with the ability to perform interventional surgery and insert coronary stents due to the gradual increase in coronary artery disease. To address this need, cardiac simulation devices are being used for numerous observations and surgical procedures. The goal is to enhance the operating skills of medical personnel by simulating the heartbeat, as there is currently no device available that can replicate the heartbeat. Interns can only acquire knowledge through reaching

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videos, which has a low learning efficiency and makes it challenging to meet intern requirements. There isn't a gadget on the market right now that is intended to mimic the heartbeat, so interns must rely solely on instructional films to get knowledge while they observe and study, which is ineffective and challenging for them to use. To suit the learning demands of interns, enhance the operational skills of medical professionals, and enable user observation and subsequent operation, a pneumatic heartbeat simulation heart must be developed.

Research Objective

(1) Domestic and International Equipment Progress:

Research on the design and development of cardiac extracorporeal pulsatile circulation simulation system (Bock, 2021; Li *et al*., 2002). It is a platform for extracorporeal pulsatile circulation simulation system, which can be set up with different heart rates and different time ratios of systolic and diastolic phases, and the range of blood flow settings is 5-35L/min, and the transient pressure waveforms of the aorta in normal physiology, hypertension, heart failure and other aortic transient pressure waveforms are basically the same as the real physiological conditions, and the design, production and connection to the system can mimic the process of changes of real aneurysm; and intuitively reflect the pulsatile loads exerted by aortic blood to aneurysm. On this basis, the design and production of the simulator can be connected to the system, which can imitate the real aneurysm change process; it can visually reflect the pulsation load exerted by the aortic blood on the aneurysm and can be used for the development of surgical simulators. A solid heart based simulation teaching system implemented using Quest3D (Choi *et al*., 2006). It is a simulation system that can present a three-dimensional spatial structure and can contain intra-entity connections and inter-entity connections to describe objective things and their connections. This system enables the observation of any section of the heart, dynamic scaling, rotation, panning and roaming. It can help intern physicians to observe and learn. An overall model of human cardiovascular system based on AMESim software platform (Crawford, 2003). It is an overall model of human cardiovascular system based on AMESim software platform (Elefteriades & Botta, 2011; Siang, 2010; Alhajyounis *et al.,* 2024), and the simulation experimental device is focused on the simulation experimental device focuses on simulating the pumping mechanism of the heart, which can express the intermittent pumping process of the heart "beat-to-beat" in the model, and directly simulate the blood flow path, which is closer to the real situation of the test system (Hanson *et al*., 2007; Limonjiani, 2023; Rodger & Rao, 2011; Shuhaiber, 2011; Sunagawa *et al*., 2018).

(2) Current Methods of Learning to Observe the Heartbeat:

- Inquiry into the literature related to learning the heartbeat allows cognition of how the heart beats and its frequency, etc., so that interns and students have a basic knowledge of the appearance of the heart and the frequency of the heartbeat, etc. However, the text description is too abstract and difficult for most people to understand (Wenbo, Yang & Chao, 2023).
- 3D imaging technology simulates the heart model, which can understand the structure of the heart and observe the heart beating mode and frequency more intuitively, which is convenient for people to learn and observe. But this way is still not enough three-dimensional, cannot be operated, no physical combination, learning is too single (Zhe & Yingmin, 2002; Feng *et al*., 2013).

The invention of a pneumatic heartbeat simulation device, the simulation of the heart through the formation of vulcanised latex production, with a certain degree of softness, so that through the continuous pumping and suction to simulate the simulation of the heart beat the whole process, so as to facilitate the user's observation and subsequent operation.

Methodology

1. Device Structure

The simulated heart:

The aorta, pulmonary artery, and superior vena cava are all integrally moulded into the simulated heart, which is also integrally moulded with the bodies of the right and left coronary arteries. The right coronary artery body is branching into the right anterior ventricular branch and the right marginal branch, while the left coronary artery body is branched into the left anterior descending branch and the left coronary artery gyration branch. The simulated heart is made of vulcanized latex. The simulated heart has a hollow interior and is constructed of vulcanized latex material. It is transparent and has a connecting section at one end for the aorta and a pulsation pump at the other to simulate the pulsation of the simulated heart.

Base:

There are several limit holes distributed in a circular pattern on the turntable's disc body. A slot hole is also present in the base, where a pin can be inserted to restrict the turntable's rotation. The pacing pump is mounted on a plate on the shelf. The connecting portion consists of a connecting tube that runs between the pacing pump's outlet end and the aorta, with an annular plugging plate on the end of the tube near the aorta and a viscous layer on the connecting tube's port.

2. Device Design

In order to fully understand and implement the application in accordance with the process of how the present application applies technical means to solve a technical problem and achieve the technical efficacy of the realization process, the following will provide a detailed illustration of the embodiments of the current application in conjunction with the accompanying drawings and embodiments.

Figure 1 to Figure 5 for an embodiment of the utility model, a pneumatic heart beat simulation device, including simulation of the heart 1 and the base 11, simulation of the heart 1 were provided with the superior vena cava 2 and the aorta 3 and the pulmonary artery 4 and its integration, so as to be able to achieve a one-to-one restoration of the heart, and at the same time in the simulation of the heart 1 is also a one-piece type with the right coronary artery body 5 and the left coronary artery body 8. The right coronary artery body 5 branches on the right coronary artery right ventricular anterior branch 6 and the right coronary artery right marginal branch 9, and the left coronary artery body 8 branches on the left coronary artery anterior interventricular branch left anterior descending 7 and the left coronary artery rotary branch 10, to ensure the authenticity of the simulated heart 1, while the simulated heart 1 through the vulcanization of the latex material, and the simulated heart 1 for the internal hollow transparent, the simulated heart 1 retains the pulmonary artery 4, Aorta 3, left coronary artery body 8, right coronary artery body 5 and branches and other blood vessels towards, blood vessels are sealed smooth, the end of the blood vessels are closed, blood vessels are also made by vulcanised latex, vulcanised latex made simulated heart 1 model is soft pulmonary artery 4 seal, aorta 3 is provided with a connecting part 18 at one end, the other end of the connecting part 18 is provided with a pulsation pump 13 used to achieve the pulsation of the simulated heart 1, and the simulated heart 1 is made by vulcanised latex. Through the operation of the pacing pump 13, the connecting part 18 goes in from the aorta 3 and penetrates into the hollow part of the simulated heart 1, and the pacing pump 13 simulates the overall process of pulsation of the simulated heart 1 by regularly and continuously pumping and inhaling and simulating the filling and retracting action of the interior of the simulated heart 1, thereby facilitating the observation of the user as well as the subsequent operation.

It is to be noted that, as shown in Figure 4, the base 11 is provided with a turntable 15 through a rotating shaft, and the disc body of the turntable 15 is provided with a slot for placing the simulated heart 1, and the overall rotation can be achieved by manually rotating the turntable 15, which is convenient for the user to carry out a multi-directional observation, and a shelf 12 is provided in the shape of inverted "L" on the base 11, and the projection equipment 14 is provided on the shelf 12 for electrically connecting with an external terminal device, so that projection can be carried out. In the base 11 is provided with an inverted "L" shaped rack 12, in the rack 12 is provided with a projection device 14 for electrical connection with external terminal equipment, through the projection device 14 and the external terminal for electrical connection, so as to be able to carry out the projection of the use of the user to facilitate the teaching of the use of the carousel 15 disc body has a number of circular distribution of limit holes 16, and in the base 11 is opened with a slot hole, in the slot hole and select a limit hole 16 In the slot hole and a selected limit hole 16 is inserted with the same pin 17 for limiting the rotation of the carousel

15, the carousel 15 is rotated to a certain angle, the carousel 15 is rotated to a certain angle, by inserting the pin 17 to the corresponding limit hole 16 and the slot hole, so as to limit the idling of the carousel 15 to ensure the stability of the observation, there is a mounting plate on the frame 12 for the bearing of the pulsating pump 13.

For further illustration, reference is made to figure 5, wherein the connecting section 18 comprises a connecting tube 1801 provided between the outlet end of the pacing pump 13 and the aorta 3, the connecting tube 1801 is provided with an annular plugging plate 1802 near the end of the aorta 3 and an adhesive layer 1803 is provided at the port of the connecting tube 1801, which is adhered to the aorta 3 by means of the adhesive layer 1803, and the use of the plugging plate 1802 ensures the hermetic sealing of the connecting tube 1801 installed in the aorta 3.

When this embodiment works, by placing the simulated heart 1 on the groove of the turntable 15, at this time, the end of the connecting tube 1801 with the plug plate 1802 is inserted into the aorta 3 and penetrates deep into the simulated hollow part of the heart 1, and the viscous adhesive layer 1803 cooperates with the plug plate 1802 to ensure that the installation of the sealing, at this time, the external power supply, the pulsation pump 13 simulates the internal process of the simulated heart 1 by pumping and suctioning regularly and continuously, filling and retracting action to simulate the overall process of the simulated heart 1 pulsation to facilitate the user to observe and subsequent operation. Filling and retracting action, to simulate the overall process of simulating the beating of the heart 1, so as to facilitate the user's observation and subsequent operation, and at the same time can be in the meantime, through the rotation of the turntable 15, to facilitate the user to carry out multi-directional observation.

Results

This utility model's control mode is automatically controlled by the controller; technicians in the field can accomplish this by simply programming the controller's control circuit; the power supply is also within the purview of common sense; and since the utility model's primary function is to safeguard the mechanical device, it is no longer a comprehensive explanation of the control mode and circuit connection.

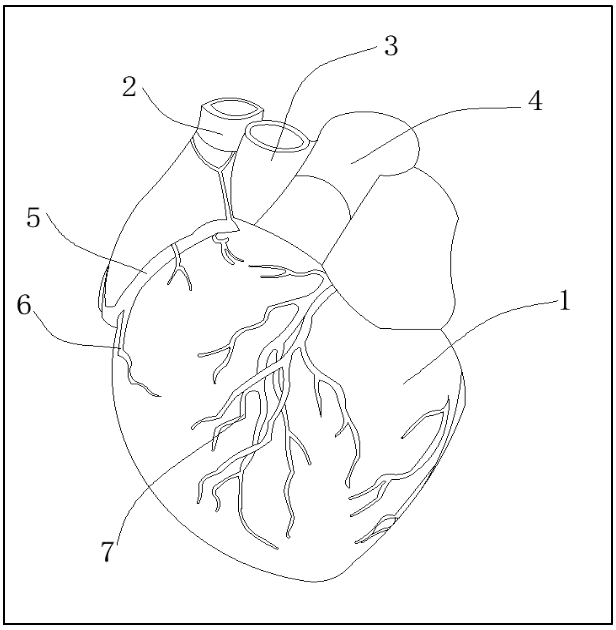

Figure 1: Schematic Diagram of the Front View Structure of the Utility Model

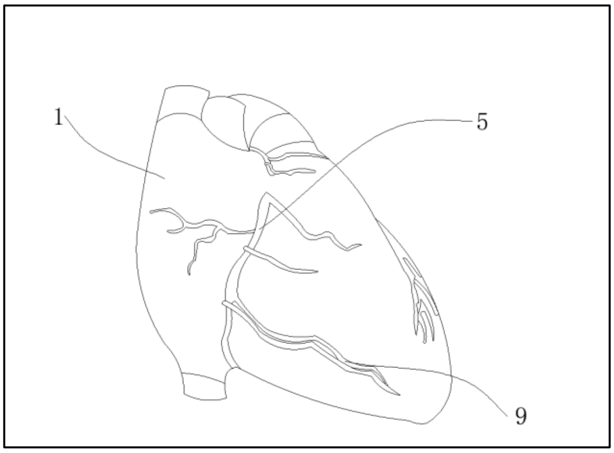

Figure 2: Schematic Diagram of the Left-View Structure of the Utility Model

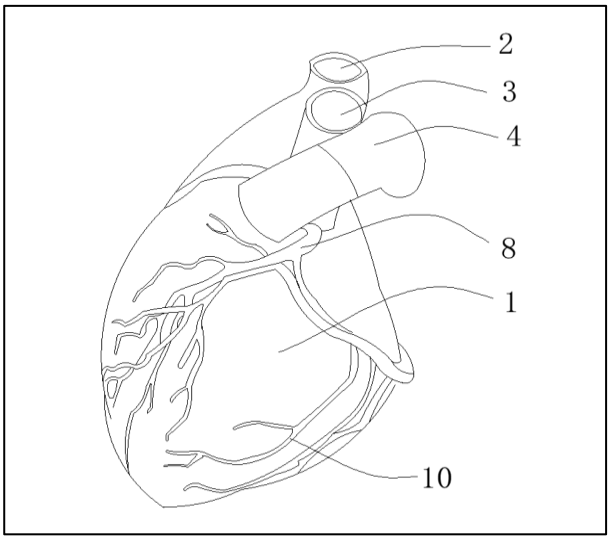

Figure 3: Utility Model Right View Structure Schematic Diagram

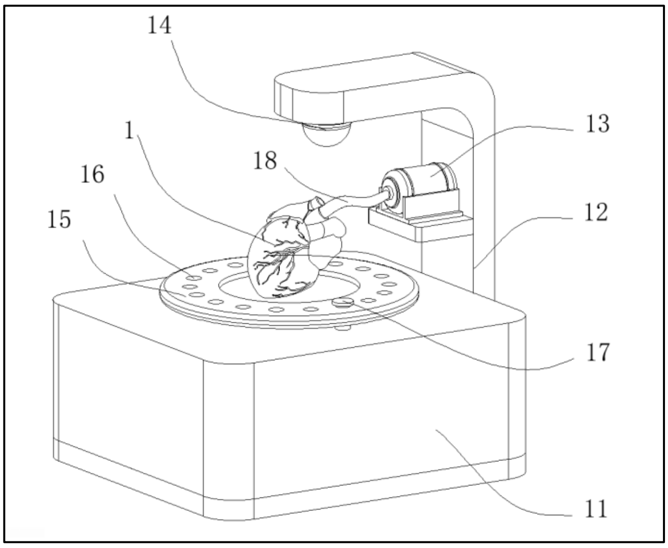

Figure 4: Working Structure Diagram of the Utility Model

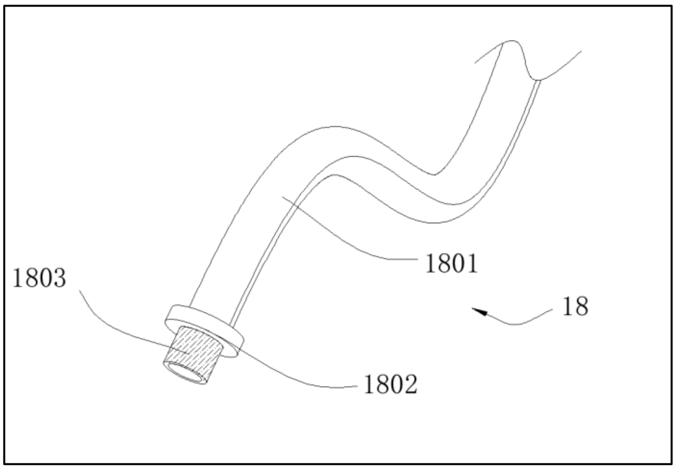

Figure 5: A Local Structural Diagram of the Connecting Part of the Utility Model

In the figure: 1. Simulated heart; 2. Superior vena cava; 3. Aorta; 4. Pulmonary artery; 5. Right coronary artery body; 6. Right coronary artery right anterior ventricular branch; 7. Left coronary artery anterior interventricular branch left anterior descending; 8. Left coronary artery body; 9. Right coronary artery right marginal branch; 10. Left coronary artery gyratory branch; 11. Base; 12. Rack stage; 13. Pulsation pump; 14. Projection equipment; 15. Turntable; 16. Limit holes; 17. Plug; 18. Connecting portion; 1801. Connecting tube; 1802. Plugging plate; 1803. Adhesive layer.

Usage of the Device:

Compared with the prior art, the utility model provides a pneumatic heart beating simulation device with the following beneficial effects:

- Through the provision of the simulated heart, the simulated heart through the vulcanised latex production formation, has a certain degree of softness, so as to be able to simulate the simulation of the whole process of the heartbeat through the continuous pumping and inhalation of the beat pump, so as to facilitate the user's observation and the subsequent operation.
- Through the provision of a turntable and projection equipment, the turntable can be manually rotated to facilitate the user to carry out multi-directional observation, and through the projection equipment and external terminals for electrical connection, so as to be able to carry out the projection of the use of the user to facilitate the user to teach the use of the user, and further improve the overall practicality.
- Through the provision of the connecting part, the connecting part near the aorta end is provided with a blocking plate and adhesive layer can ensure that when connected with the aorta closed, to ensure that the simulation of the heart in the operation of the stability of the heart.

Discussion

The study developed a pneumatic heartbeat simulation device designed to mimic the mechanical properties and behaviors of the human heart. The results show that the device accurately replicates the pressure and flow characteristics of a human heartbeat under various physiological conditions. Specifically, the device demonstrated consistent pressure waveforms, suggesting its potential for realistic simulation in medical training and research applications (So *et al.,* 2019).

Currently, there is a lack of specialized devices for simulating heartbeats on the market. Intern doctors primarily rely on videos and images for learning, which can be insufficient for developing practical skills. Previous research highlighted the limitations of traditional learning methods and the need for more interactive and tangible training tools in medical education. The study directly addresses this gap by providing a tangible and visual representation of the heartbeat, which is crucial for effective medical training. Unlike earlier models that were either too simplistic or lacked adjustability, this device features an adjustable beating pump, allowing for the simulation of various heart conditions and facilitating detailed observation from different angles. The successful replication of human heartbeat characteristics by the pneumatic device suggests its potential utility in various applications such as medical training, device testing, and research (Verzicco, 2022). The accuracy in pressure waveforms and flow characteristics can be attributed to the advanced control system used in the pneumatic actuators, which allows precise adjustments. This aligns with theoretical frameworks proposing that precise control mechanisms enhance simulation accuracy. Additionally, the device's ability to adjust to different physiological conditions further supports its versatility and robustness. These findings have significant implications for both medical education and biomedical engineering. In medical training, the device can provide a realistic simulation environment for practitioners to practice and refine their skills. Studies have shown that hands-on simulation training significantly improves clinical skills and knowledge retention compared to traditional learning methods. In biomedical research, the device offers a reliable tool for testing cardiovascular implants and other medical devices under realistic conditions (Alhajyounis *et al.,* 2024 & Hanson *et al.,* 2007). Moreover, the development of such a device contributes to the broader field of medical simulation, advancing the capabilities and realism of training tools available to healthcare professionals.

Despite the strengths of the study, several limitations should be acknowledged. First, the device was tested in a controlled laboratory setting, which may not fully replicate the complexities of in vivo conditions. This limitation may influence the generalizability of the findings to real-world scenarios. Second, the current version of the device does not simulate certain pathological conditions, such as arrhythmias or heart failure. This restricts its applicability in scenarios requiring the simulation of abnormal heart conditions. Future studies should aim to address these limitations by incorporating pathological condition simulations and testing in more varied environments. Building on these findings, future research should explore the integration of pathological condition simulations into the device. Additionally, longitudinal studies are recommended to evaluate the device's performance and reliability over extended periods of use. Investigating the device's applicability in different medical training settings and its impact on learning outcomes would also provide valuable insights. Moreover, collaborative studies with medical professionals can help refine the device's features to better meet the needs of end-users.

The study successfully developed a pneumatic heartbeat simulation device that accurately replicates human heartbeat characteristics. These findings underscore the device's potential as a valuable tool for medical training and biomedical research. By addressing the identified limitations and continuing to refine the device, future research can further enhance its capabilities and applications, contributing to the advancement of medical simulation technology.

Conclusion

The pneumatic heart beating simulation device represents a significant advancement in medical training technology, offering a realistic and interactive method for observing and understanding heart function. The use of vulcanized latex to create a soft, pliable simulated heart allows users to experience the full process of a heartbeat, facilitated by an adjustable beating pump. This innovation ensures a comprehensive and practical learning experience. The device's design includes a manually rotatable turntable and integrated projection equipment, enabling multi-directional observation and effective teaching. This feature, combined with the stability provided by the connecting part near the aorta end, enhances the overall reliability and practicality of the device. The inclusion of projection equipment further aids in teaching, making it a valuable tool for medical education. Looking ahead, the future prospects for this device include the development of a transparent coronary artery model for clearer observation, the introduction of simulated blood circulation, and the separation of the simulated heart into two parts to better mimic the beating of atria and ventricles. These enhancements will make the device even more accurate and beneficial for medical trainees, bringing it closer to the functionality of a real heart.

Recommendation

1. At present, there is no special device on the market to simulate the heartbeat, intern doctors can only obtain knowledge through teaching video or image equipment when observing and learning, which is not conducive to learning. This product can directly provide interns with a visual representation of the heartbeat.

2. As the beating pump (13) is adjustable, it can be adjusted according to the needs, to simulate the beating of the patient's heart under different circumstances.

3. The product can be viewed from the angle of the heart through the base (11), which can better show the heartbeat to the trainee physician.

4. The product is provided with a projection device on the shelf platform (12) for electrical connection to external terminal equipment, thus facilitating the user's teaching use and further improving the overall practicality.

Future Prospect

1. The coronary artery of the model is designed as a transparent structure, which enables a clearer and more intuitive observation of the coronary artery accompanied by the heartbeat

2. Improvement based on the air pump, adding into the simulated blood liquid to simulate the blood circulation inside the transparent coronary artery.

3. By separating the simulated heart into two parts, the beating of the atria and ventricles can be better simulated, thus making the device closer to the real heart.

Conflict of Interest

The authors declare that they have no competing interests.

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