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INNOVATIVE DESIGN OF REFINING MUSCULAR INTERFACES FOR IMPLANTABLE POWER SYSTEMS

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Abstract

Today all have been committed to the enhancement of a bio-implantable energy generation system that capitalizes on muscle contractions elicited through electrical stimulation to serve as a renewable energy resource for compact implantable medical equipment. Yet, excessive stress applied to the muscle tissue for power generation may result in tissue rupture or compromised vascular flow. This work has developed an innovative muscle-connecting mechanism that effectively addresses these issues. The innovative connection apparatus consists of three rods that are secured to the muscle Fibers, enabling the transformation of force applied for muscular Fibers, and the orientation transitions from vertical to horizontal during the process of muscle contraction. In this context, the simulations are conducted utilizing a three-dimensional framework. Furthermore, in addition to that, muscle evaluations and assessments are undertaken through the incorporation of actual muscle tissue. Assessment of the pulse wave is done with the help of muscle surface without obstructing the blood flow. Simulations done with the help of 3D models help for stress distribution which is quite useful in comparison to the insertion of rod in the surface. As a result, the connecting component exhibited stability and integration with the muscle, with no observable damage to the muscle tissue. Despite the absence of extended or histological assessments, the device indicates significant potential for power generation within muscle tissue owing to the negligible load exerted on the muscle-connected segment.

Index Terms – Muscular Power, AIMD, Simulation, Power Generation ,Energy System.

I. INTRODUCTION

All The design and optimization of muscular connection components for implantable power generation systems involve leveraging the mechanical energy produced by muscle contractions to generate electrical energy for powering medical devices. This approach is particularly relevant for devices like cardiac assist systems, where a reliable and sustainable power source is crucial. The integration of muscular energy conversion systems into implantable devices requires careful consideration of muscle configuration, energy conversion efficiency, and device compatibility with biological tissues. Fluid Pressure Transfer: Systems like those described by Mclean et al. utilize fluid pressure transfer to convert energy from heart muscle contractions into electrical energy, providing a sustainable power source for devices such as pacemakers(Neil et al., 1968).Skeletal Muscle Linear-Pull Convertors: Farrar and Hill developed a linear-pull energy convertor using skeletal muscles like the latissimus dorsi, which converts mechanical force into hydraulic energy to power circulatory support devices(Dj & Jd, 1992).Optimal Muscle Configurations: Research by Badhwar et al. identified that linear configurations of the latissimus dorsi muscle yield the highest power output, essential for designing efficient muscle-powered cardiac assist devices(Badhwar et al., 1997).Chronic Stimulation: Frey highlights the potential of chronically stimulated striated muscles as internal generators, emphasizing the need for automatic operation through electric stimulation similar to pacemakers(Frey, 1981).Remote Communication and Control: Mussivand et al. discuss a transcutaneous energy and information transfer system that allows for remote monitoring and control of implantable devices, enhancing the functionality and adaptability of muscular power systems(Mussivand et al., 1995).Neuromuscular Stimulation: Arabi and Sawan's microstimulator system provides programmable neuromuscular stimulation, adaptable to patient needs and future developments, which is crucial for optimizing muscle power output(Arabi & Sawan, 1995).While muscular power generation systems offer promising alternatives to traditional power sources, challenges remain in optimizing energy conversion efficiency and ensuring long-term biocompatibility. The integration of advanced control systems and chronic muscle stimulation techniques can enhance the performance and reliability of these systems. However, further research is needed to address the limitations of current technologies and to explore new configurations and materials that could improve the efficiency and sustainability of implantable power generation systems. Active medical devices that are implanted, including pacemakers for the heart, fulfill an essential function in boosting bodily activities and managing a range of health problems. Considering the swift progressions in medical technology, it is anticipated that the forthcoming era will unveil innovative devices, encompassing artificial organs such as artificial pancreases and retinas, in addition to advanced monitoring systems. These devices fundamentally rely on internal batteries for their operational energy, which engenders challenges associated with energy efficiency, longevity, and sustainability. To tackle these obstacles, scientists are exploring different methods for generating power, such as capturing energy from bodily functions, systems for transferring energy without wires, and improved battery innovations. Such advancements are imperative for bolstering the expanding functionality of AIMDs and for safeguarding their enduring performance and the safety of patients, necessitating surgical intervention for replacement when depleted. Accordingly, this obligation creates both physical and psychological pressure on the patient. Additionally, the constrained energy capacity of batteries results in inherent limitations on their practical applications. In the present system, it is imperative to affix the force extraction component. Direct interaction with muscular tissue during the contraction process elicits a responsive force upon the adjacent anatomical structures. Nonetheless, subjecting soft tissues, especially muscular systems, to mechanical loading may result in potential adverse outcomes. Muscle tissue is composed of Fiber oriented in accordance with the contraction direction, thereby rendering it susceptible to forces that may induce tearing among these fibers. Moreover, the orientation of blood vessels in relation to muscle Fibers raises apprehensions that the attachment of components could interfere with blood circulation to fibers situated either upstream or downstream of the vascular supply. There have been no recorded occurrences of lasting impairment in practical scenarios.

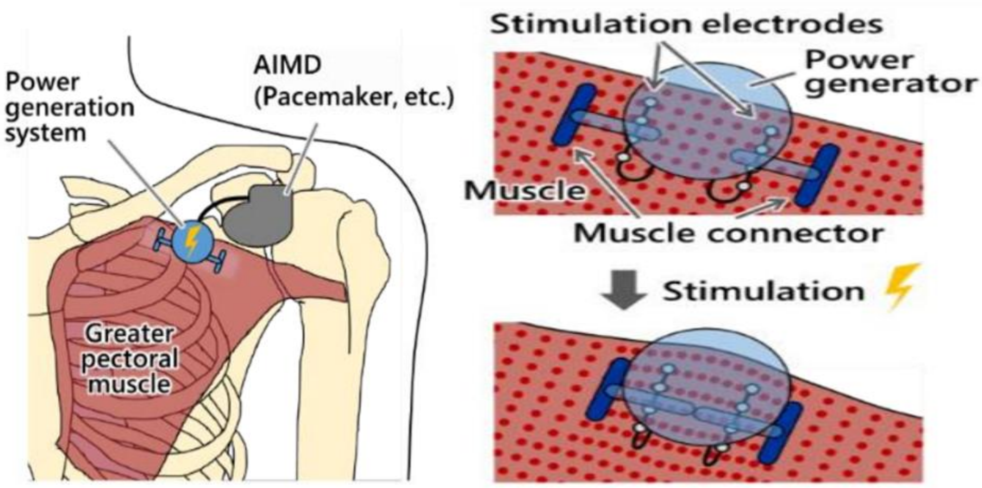

Figure 1: Representation of an Implantable Active Power Generation System.

Fig.1 is the representation of Implantable Active Power Generation System
a)The apparatus is placed in a subcutaneous position within the anterior thoracic region near the Active Implantable Medical Device (AIMD) and is anatomically linked to the greater pectoral muscle.
b)The apparatus is attached to a considerable muscle at two separate positions, purposefully located away from the skeletal elements, such that solely the muscle tissue located between the connection points contracts upon stimulation to promote the power generation mechanism.
The updated connecting component designated as the muscle connector, is meticulously designed with three rods systematically arranged orthogonally to the orientation of the muscle fibers. One rod operates to elevate the muscle, thus facilitating a stable connection point, while the remaining two rods are judiciously situated on either side to ensure structural support and equilibrium(Fig. 2). Throughout muscle contraction, the tissue that encases the central rod applies force perpendicular to the alignment of the muscle fibers, promoting effective force conveyance. To integrating the central rod, the muscle must undergo penetration at two separate sites, thus permitting stable extension beneath the muscle architecture. Despite the penetration, blood perfusion is preserved as the configuration of the component guarantees lateral displacement of the blood vessels, consequently averting obstruction to the flow in both upstream and downstream areas associated with the contraction. This careful design substantially lessens the risk of ischemia or harm to the vascular network while ensuring optimal performance. To comprehensively validate the muscle connector, a thorough evaluative process was undertaken. Pulse wave measurements were utilized to observe and ensure the continuity of blood flow. The analysis of stress distribution was conducted using sophisticated three-dimensional simulations to pinpoint and rectify potential weak points or zones of excessive loading within the tissue. Furthermore, mechanical load assessments during muscle contraction were executed to quantify the forces imposed on the component, thereby corroborating its durability and efficacy under physiological conditions. These assessments collectively highlight the muscle connector's ability to achieve robust and reliable integration with minimal disruption to the surrounding tissue, establishing it as a noteworthy advancement for implantable power generation systems.

II. LITERATURE REVIEW

[1] The paper discusses a power supply unit that utilizes fluid pressure transfer from heart muscular contractions to generate electrical energy, but it does not specifically address the design and optimization of muscular connection components for implantable power generation systems.[2] The paper does not address the design and optimization of muscular connection components for implantable power generation systems. It focuses on movement control for powered prosthetic devices using externally detectable articles and muscle tension to generate control signals.[3] The paper emphasizes the need for internal energy sources in artificial organs, highlighting the potential of chronically stimulated striated muscles as power generators. However, it does not specifically address the design and optimization of muscular connection components for these systems.[4] The paper discusses a new skeletal muscle-powered linear-pull energy converter, focusing on reattaching the latissimus dorsi muscle to a hydraulic energy converter. This design optimizes direct tension force conversion into hydraulic energy for powering implantable circulatory support devices.[5] The paper focuses on a transcutaneous energy transfer system for implantable medical devices, emphasizing energy delivery and remote communication rather than the design and optimization of muscular connection components for power generation systems.[6] The paper focuses on a programmable implantable microstimulator for neuromuscular, stimulation, emphasizing the usage and adaptability, power efficiency, and a telemetry system, but does not specifically address the design and optimization of muscular connection components for implantable power generation systems.[7] The paper focuses on a device that converts muscle movement into electrical energy using a generator and variable conversion gearing, but it does not specifically address the design and optimization of muscular connection components for implantable power generation systems.[8] The study identifies optimal latissimus dorsi muscle configurations for power generation, highlighting that linear oriented configurations yield the highest power output. These findings are crucial for designing efficient muscular connection components in implantable power generation systems for cardiac assist devices.[9] The paper focuses on an implantable stimulator and telemetry system for neuromuscular stimulation, detailing biocompatible packaging, lead systems, and electrodes (epimysial and intramuscular) for effective long-term performance, but does not specifically address muscular connection components for power generation systems.[10] The study focuses on developing an energy convertor that connects skeletal muscle to cardiac assist devices, emphasizing muscle conditioning and biomechanical characterization to optimize power output. This research aims to enhance the design of muscular connection components for implantable systems.[11] The paper focuses on BIONs as implantable devices for functional electrical stimulation, emphasizing their hermetically sealed design and integration with external power sources, but does not specifically address the design and optimization of muscular connection components for power generation systems.[12] The paper focuses on a custom ASIC for controlling implantable stimulators and telemetry systems for paralyzed muscles, rather than the design and optimization of muscular connection components for implantable power generation systems.[13] The paper focuses on a device generating electrical supply for pacemakers or muscle stimulators, utilizing elastic membrane pillows that pump oil as the artery pulsates, driving a crank connected to a permanent magnet alternator for power generation.[14] The paper focuses on evolutionary structural optimization for connection topology in multi-component systems, but does not specifically address the design and optimization of muscular connection components for implantable power generation systems.[15] The paper does not specifically address the design and optimization of muscular connection components for implantable power generation systems. It

focuses on a magnetic coupling and generator system for power supply to deeply implanted medical devices.

III. PROPOSED METHODOLOGY

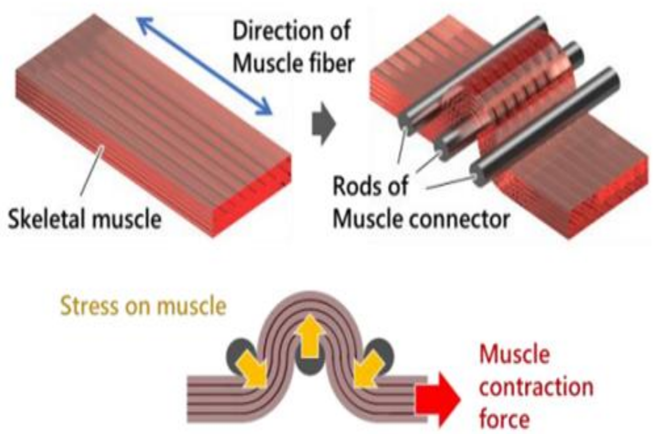

Figure 2: Conceptual Framework of Muscle Connector. (a) Identification of a segment of the muscle with three rods oriented orthogonally to the direction of the muscle fibers. (b) The orientation of the stress exerted on the muscle varies throughout the process of muscle contraction.

The principal characteristics of adaptability associated with thermal power stations. All experimental protocols involving caprine species were conducted at Tohoku University, following prior authorization from the institution's Ethics Committee (approval ID: 2017AcA-052). The study employed a male goat (Capra aegagrus hircus) weighing 76 kg, selected for its representation of the Japanese Saanen breed. Contemporary practices within power systems continue to favour deterministic scheduling; however, the increasing prevalence of variable energy resources is anticipated to drive the sector toward the adoption of stochastic scheduling methodologies. For the intervention, the goat was meticulously positioned laterally on a surgical table to ensure both optimal accessibility and safety during the procedure. As the research unfolded, the entire methodology was performed in accordance with extensive ethical considerations to uphold the welfare of the animals. Sedation was achieved through a 0.012 mg/kg intramuscular injection of medetomidine, which was then followed by anaesthesia induction via 2% isoflurane inhalation. To simulate conditions in which muscle connectors were affixed to muscle tissue, components manufactured from three-dimensional-printed polylactic acid (PLA) resin were employed. The assembly encompassed three screws, each exhibiting a diameter of 3.9 mm, alongside two metal tubes with diameters of 5.3 mm. Fig.2 Represents the Conceptual Framework of Muscle Connector. (a) Identification of a segment of the muscle with three rods oriented orthogonally to the direction of the muscle fibers. (b) The orientation of the stress exerted on the muscle varies throughout the process of muscle contraction. These items were decisively fixed to the latissimus dorsi muscle (Fig. 3). The central screw was implanted through the muscle's surface, traversing its interior, and subsequently re-emerged along its exit trajectory. The two lateral screws, enhanced with metal tubing to a diameter of 5.3 mm, were meticulously engineered to interact gently with the muscle surface to avert undue compression of the tissue. Pulse wave measurements were acquired at the

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proximal and distal regions of the muscle connectors, employing the central screw as a reference, along with measurements taken from the muscle surface situated between the two connection points.

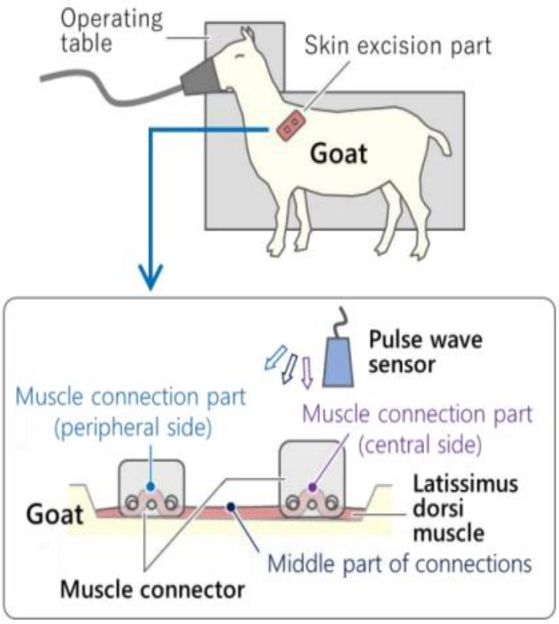

Figure 3: Methodology for Assessing Muscle Blood Flow. The latissimus dorsi muscle of the caprine species was surgically exposed, and the perfusion within the superficial stratum of the muscle at the locations of the connector installation and their intervening regions was quantified utilizing photoelectric pulse wave technology.

The essential characteristics of flexibility pertaining to thermal energy facilities. The isolated muscle exhibited an unloaded length measuring 49 mm, accompanied by a cross-sectional area of 506 mm^2. A strain gauge was utilized to quantify the displacement throughout this procedure, thereby yielding precise measurements of the muscle's deformation in response to stress. To augment the accuracy of our measurements, a laser displacement meter was employed, facilitating high-resolution monitoring of the muscle's elongation with minimal disruption or mechanical contact. For each recorded length, the mean stress was computed utilizing the muscle's cross-sectional area, thereby enabling the formulation of a strain-stress curve that authentically depicted the muscle's mechanical characteristics. This curve was subsequently subjected to linear approximation via the least squares method, from which the elastic modulus was derived based on the slope. The elastic modulus is pivotal in assessing the stiffness of muscles, which is integral for scrutinizing their capacity to resist deformation induced by applied forces. This approach permitted an exhaustive examination of the muscle's architecture, highlighting not only the muscle itself but also the adjacent connective tissues and the orientation of the fibers. Furthermore, the application of CAD software allowed us to refine the experimental configuration, ensuring that the anatomical attributes of the muscle were accurately mirrored in our simulations. This methodology further provided a comprehensive perspective on the biomechanical facets of the muscle, elucidating regions that experience maximal stress during stretching. The integration of simulated computational models with empirical data represents an efficacious strategy to enhance the precision of biomechanical investigations and fosters new avenues for analysing muscle functionality and mitigating injury risks. This approach permitted us to analyze the stress imposed on the muscle by the connecting components. A thorough evaluation of static stress was performed using the finite element method (FEM), which facilitated a detailed understanding of the mechanical interactions occurring within the system. This thorough analysis yielded significant insights into the mechanical properties and behaviour of the muscle when exposed to external forces.

IV. RESULTS AND DISCUSSION

Figure 4 depicts the pulse waveforms obtained from the two muscle junctions and the adjacent muscular surface. Consistent pulse wave signals, in harmony with the cardiac rhythm, were observed at all measurement locations, denoting stable hemodynamic. Remarkably, the amplitude of the pulse wave signal identified at the midpoint of the muscle outstripped those logged at the two junctions. This discrepancy in amplitude implies that the mechanical properties of the muscle, along with its interactions with the connectors, may significantly influence local hemodynamic dynamics. Although the muscle was in a relaxed state during the hemodynamic assessments, the natural elasticity of the tissue retained a foundational level of tension within the muscle fibers. This intrinsic tension presumably contributed to the modulation of the pulse wave characteristics, particularly at the midpoint, where the signal exhibited the greatest intensity. Moreover, this finding underscores the muscle's capability to uphold functional blood flow even when subjected to the structural alterations imposed by the connectors. The uniformity of the waveform patterns detected throughout all locations further demonstrates the consonance of the connector design with the safeguarding of vascular integrity and physiological operations within the muscle tissue.

A. Stress distribution simulation based on a 3D model:

The highest tensile force noted exerted on the muscle within the defined experimental framework was determined to be 19 N, whereas the most significant elongation observed in the muscle reached 31.2 mm. Figure 5 depicts the strain-stress relationship, accompanied by the linear approximation derived from the empirical analysis of the goat's latissimus dorsi muscle. This graphical illustration presents an unambiguous depiction of the mechanical characteristics of the muscle when subjected to tensile stress. Considering the experimental data, the elastic modulus of the relaxed skeletal muscle—represented as the ratio of stress to strain—was assessed to be 0.047 MPa. This parameter was subsequently employed as a pivotal input in simulation models. Fig.4 is the Representation of Pulse Waveform and Comprehensive Examination of Pulse Wave Assessment. The pulse wave was quantified utilizing a photoelectric pulse wave sensor positioned at the two muscle junctions and the equidistant point. The evaluation of this modulus is essential for the accurate reproduction of the biomechanical characteristics of the muscle during simulation, thus guaranteeing that the simulated interactions between the muscle and the relevant components closely align with the observed physiological reactions. Figure 5: Calculation of the Elastic Modulus of Muscular Tissue. The strain-stress relationship was established via experimental procedures employing caprine skeletal muscle, from which the estimated elastic modulus was derived through a regression analysis. This comprehensive analysis underscores the importance of precise mechanical characterizations in the progression of reliable and effective implantable systems.

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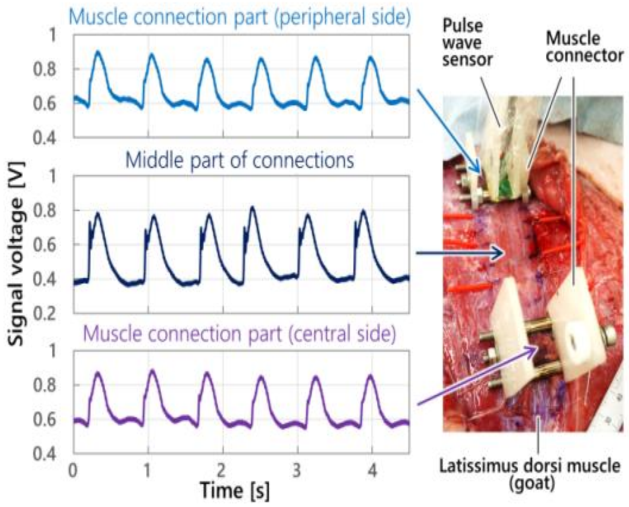

Figure 4: Representation of Pulse Waveform and Comprehensive Examination of Pulse Wave Assessment. The pulse wave was quantified utilizing a photoelectric pulse wave sensor positioned at the two muscle junctions and the equidistant point.

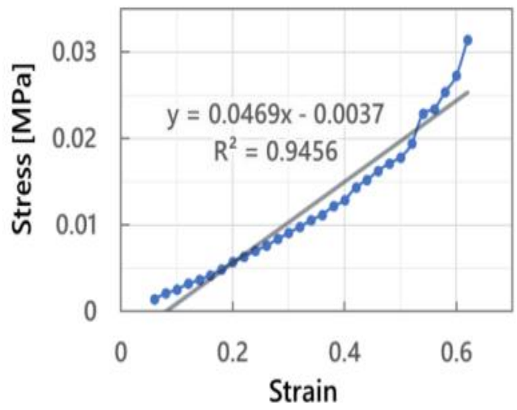

Figure 5: Calculation of the Elastic Modulus of Muscular Tissue. The strain-stress relationship was established via experimental procedures employing caprine skeletal muscle, from which the estimated elastic modulus was derived through a regression analysis.

V. CONCLUSION

An advanced muscle-attachment mechanism was devised, demonstrating the capacity for energy harvesting while preserving the integrity of both muscular and vascular structures. The investigation substantiated that the device sustains blood perfusion, even in regions experiencing structural modifications, as evidenced by the signal output recorded by the photoelectric pulse wave sensor. Empirical findings revealed that, although the muscle was subjected to stress and experienced reduced blood flow because of the rod's insertion and applied pressure, the dynamics of the vascular system were maintained, allowing for a gradual restoration of blood flow. Stress analysis underscored the potential hazards associated with tensile stress concentrations along muscle fibers; however, deliberate design alterations, such as the incorporation of horizontally aligned rods, effectively redistributed forces, thereby safeguarding the structural and functional integrity of the muscle tissue under mechanical duress. The symmetrical configuration further enhanced stability and resilience in the face of varying forces, thereby facilitating prolonged functionality.

VI. LIMITATION

Despite its promising results, the muscle-attaching element exhibited areas of concern. Stress analysis revealed uneven stress distribution, particularly in zones susceptible to augmented strain, which may increase the risk of muscle tearing and structural failure. Blood flow constraints, though minimal, were noted in regions surrounding the junctional components due to pressure exerted by the rod and potential vessel damage. Additionally, short-term blood flow interruptions during muscle contraction highlight a need for further refinement to mitigate any residual risks to tissue health. These challenges emphasize the need for optimizing the structural design to minimize stress concentration and vascular disruption.

VII. FUTURE WORK

Future research should focus on refining the connector design to balance stress distribution and further reduce strain concentration in vulnerable muscle areas. Advanced simulations and experimental testing could enhance the understanding of stress dynamics and muscle integrity under various mechanical loads. Innovations in material science, such as incorporating more flexible or adaptive materials, may improve vascular preservation and reduce tissue damage. Furthermore, the integration of this technology into energy systems—particularly low-carbon frameworks—could benefit from tailored applications that account for system-specific flexibility demands, such as wind, nuclear, or natural gas-dominated energy systems. Optimizing scheduling methodologies and exploring alternative configurations would further enhance the practical application and scalability of this innovative concept.

REFERENCES

1. Mclean, Donald, Neil., Rosensweig, Jacob., Saunders, John. (1968). 1. Biologically implantable and energized power supply.
2. Edmund, B., Weis., Craig, R., Hassler., John, H., Flora. (1974). Method and system for control of a powered prosthetic device.
3. M., Frey. (1981). Stimulation of Striated Muscles for Biological Energy Supply. doi: 10.1007/978-3-7091-8618-3_12.
4. Farrar, Dj., Hill, Jd. (1992). A new skeletal muscle linear-pull energy convertor as a power source for prosthetic circulatory support devices Journal of Heart and Lung Transplantation.
5. Tofy, Mussivand., Albert, Hum., Marc, Diguer., Kevin, S., Holmes., Gino, Vecchio., Roy, G., Masters., Paul, J., Hendry., Wilbert, J., Keon. (1995). 5. A transcutaneous energy and information transfer system for implanted medical devices. Asaio Journal, doi: 10.1097/00002480-199507000-00006.

6. Karim, Arabi., M., Sawan. (1995).A monolithic miniaturized programmable implant for neuromuscular stimulation. doi: 10.1109/IEMBS.1995.579564.
7. Philipps, Werner, Dipl, Ing. (1997).Muscular powered electrical energy generation device.
8. Vinay, Badhwar., Ravinder, K., Badhwar., Joong-Hwan, Oh., Ray, C.-J., Chiu. (1997). 8. Power generation from four skeletal muscle configurations. Design implications for a muscle powered cardiac assist device Asaio Journal, doi: 10.1097/00002480-199703000-00173.
9. Brian, J., Smith., Zhengnian, Tang., M., W., Johnson., S., Pourmehdi., M.M., Gazdik., J., R., Buckett., P.H., Peckham. (1998). 9. An externally powered, multichannel, implantable stimulator-telemeter for control of paralyzed muscle. IEEE Transactions on Biomedical Engineering, doi: 10.1109/10.664202.
10. Steven, H., Reichenbach., K., J., Gustafson., K., M., Khazalpour., David, J., Farrar., Hill, Jd. (1998). Chronic implantation of a skeletal muscle energy convertor for cardiac assist devices: a preliminary report. Asaio Journal, doi: 10.1097/00002480-199809000-00091.
11. Gerald, E., Loeb., F., J., R., Richmond., D., Olney., T., Cameron., A.C., Dupont., Kevin, H., Hood., Raymond, A., Peck., Philip, R., Troyk., H., Schulman. (1998). 11. BION/sup TM/. Bionic neurons for functional and therapeutic electrical stimulation. doi: 10.1109/IEMBS.1998.744747.
12. Soheyl, Pourmehdi., Primoz, Strojnik., Hunter, Peckham., J., R., Buckett., Brian, Smith. (1999). 12. A custom designed chip to control an implantable stimulator and telemetry system for control of paralyzed muscles. Artificial Organs, doi: 10.1046/J.1525-1594.1999.06358.X.
13. Demetriou, Demetrios. (1999). 13. Implanted power generator.
14. Qing, Li., Grant, P., Steven., Yi, Min, Xie. (2001). Evolutionary structural optimization for connection topology design of multi-component systems. Engineering Computations, doi: 10.1108/02644400110387127.
15. Shin-nosuke, Suzuki., Tamotsu, Katane., Hideo, Saotome., Osami, Saito. (2002).Electric power-generating system using magnetic coupling for deeply implanted medical electronic devices. IEEE Transactions on Magnetics, doi: 10.1109/TMAG.2002.803185