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A Novel Total Artificial Heart for Destination Therapy: In-Vitro and In-Vivo Study

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Abstract:
Total Artificial Hearts (TAHs) could be used as an alternative to heart transplantation for patients with terminal heart failure. A fully implantable TAH is under development at our institute. Some critical aspects in TAH development are a) sufficient cardiac output, b) adequate left-right flow balance, c) measurement and control of pump performance and d) hemocompatibility.
In this paper, the results of the validation process including in vitro, acute and first chronic in vivo experiments are presented.

Keywords: *Total Artificial Heart TAH, in-vitro, in-vivo validation, animal experiment*

Introduction

Cardiovascular diseases are the leading cause of death worldwide [1]. For many patients suffering from terminal heart insufficiency, a transplantation of a donor heart is the only therapy option. However, there is a severe shortage in donor organs [2]. As a result, many patients die while waiting for the lifesaving organ.
Total Artificial Hearts (TAHs) could serve as an alternative to heart transplantation and thus compensate the lack of donor hearts [3]. In an interdisciplinary collaboration we develop the fully implantable TAH *ReinHeart* [4]. This device is intended to act as a destination therapy device. The *ReinHeart* is a pulsatile blood pump consisting of two pump chambers and a linear direct drive in between them (Fig. 1). Flexible membranes separate the blood from the drive unit. Two pusher plates move the membranes into the chambers and eject the blood alternately with concurrent filling of one chamber and ejection from the other (Fig. 2).

Figure 1: *ReinHeart* Total Artificial Heart

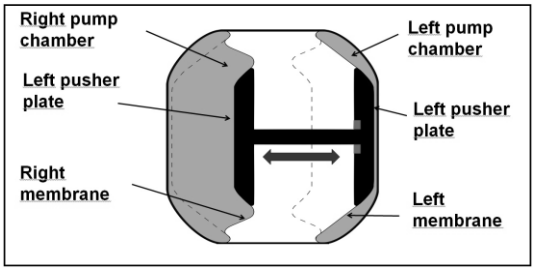

Figure 2: *ReinHeart* Total Artificial Heart

The system must function completely maintenance-free for many years within the human body, and it must also be small enough to be implanted in the majority of patients.
This study presents the in-vitro and in-vivo validation of: a) pump performance regarding sufficient Cardiac Output (CO), b) adequate left-right flow balance with higher left output due to the bronchial shunt flow, c) sensorless measurement of preload, afterload and CO using intrinsic pump parameters and d) hemocompatibility.

Methods

For in vitro validation, the device was extensively tested at a mock circulation loop (MCL) simulating the human blood circuit (Fig. 3). This MCL used electrically adjustable elements to simulate physiological, pathological and especially changing blood circuit conditions. The bronchial shunt flow, which in-vivo requires a higher left CO compared to the right CO, was simulated by a bypass in the MCL. Using this setup, the overall pump performance was tested in-vitro. Additionally, different concepts to achieve adequate left-right flow balance were investigated in-vitro before implemented in the in-vivo trials.
To avoid the need of additional pressure sensor and flow measurement equipment, a correlation between intrinsic pump parameters and different pre- and afterload conditions and filling volumes of the pump chambers was performed both in-vitro and in-vivo.
The in-vivo experiments utilized bovine models to further test the device. After nine acute trials, the TAH was suc-

cessfully implanted in four chronic trials by now. Histological analyses were performed to investigate potential thrombus formation.

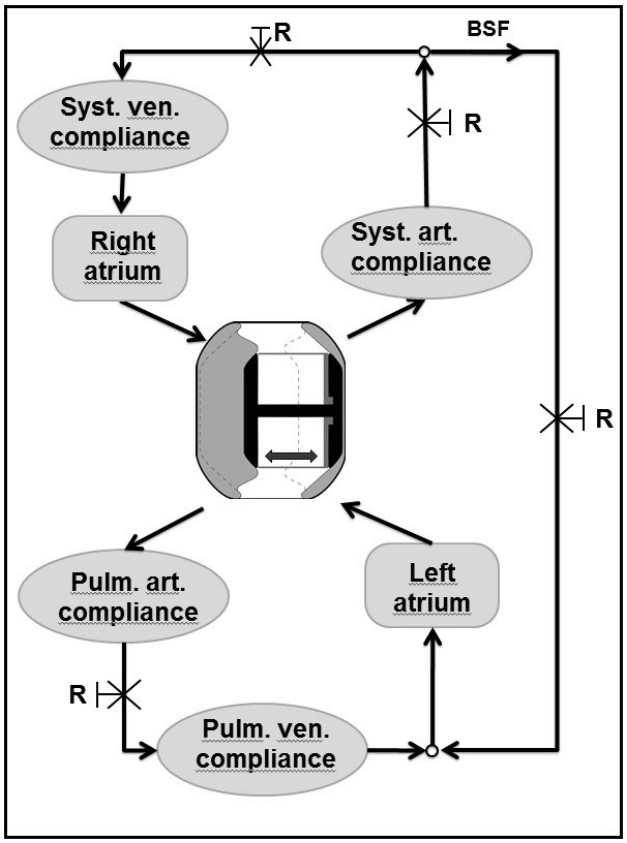

Figure 2: ReinHeart Total Artificial Heart

Results

Sufficient cardiac output of up to 7 l/min and adequate left-right flow balance (left atrial pressure <15mmHg) was validated both in-vitro and in-vivo.

The correlated intrinsic pump parameters to pre- and afterload allowed an estimation of aortic, pulmonic and both atrial pressures. Furthermore, the filling volume in each pump cycle could be determined. By multiplying the filling volume and the pump frequency, the CO can be determined.

During the animal trials, the implantation procedure was changed from median to lateral thoracotomy resulting in improved venous return during implantation and simplified closing of the thorax. Still, an adequate fitting of the device is crucial for undisturbed and sufficient inflow into the pump chambers. In the longest chronic in vivo experiment, the calf´s blood circuit was maintained for 50 hours with adequate pump performance. The animal was successfully weaned from artificial ventilation and was able to stand up and resume normal behavior. The trial was terminated due to a partial obstruction of the left ventricular inflow tract resulting from small chest size. Histological analysis showed no thrombus formation in lung or pump chambers.

Discussion

The TAH demonstrated sufficient pump performance with no thrombotic complications. The correlation of intrinsic pump parameters to pre- and afterload and filling volume may eliminate the need for pressure and flow sensors in the future. These promising results raise the hope that the device may be used in future as an alternative to heart transplantation and compensate the lack of donor hearts. Further chronic animal trials are on-going.

Acknowledgement

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Bibliography

[1] S. Mendis, P. Puska, and B. Norrving. *Global Atlas on cardiovascular disease prevention and control*, World Health Organization, 2011.

[2] Eurotransplant International Foundation. *Annual report 2011*, 2012.

[3] A. Meyer and M. Slaughter. *The total artificial heart*. Panminerva Med, 53(3):141–154, Sep 2011.

[4] T. Finocchiaro. *Investigation of a linear drive concept for a fully implantable total artificial heart*. Shaker Verlag, ISBN 978-3-8440-1636-9, 2013.