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Research review

# Physiologic effects of continuous-flow left ventricular assist devices

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ABSTRACT

*Background:* Within the past 10 years, continuous-flow left ventricular assist devices (LVADs) have replaced pulsatile-flow LVADs as the standard of care for both destination therapy and bridging patients to heart transplantation. Despite the rapid clinical adoption of continuous-flow LVADs, an understanding of the effects of continuous-flow physiology, as opposed to more natural pulsatile-flow physiology, is still evolving.

*Materials and methods:* A thorough review of the relevant scientific literature regarding the physiological and clinical effects of continuous-flow physiology was performed. These effects were analyzed on an organ system basis and include an evaluation of the cardiovascular, respiratory, hematologic, gastrointestinal, renal, hepatic, neurologic, immunologic, and endocrine systems.

*Results:* Continuous-flow physiology is, generally speaking, well tolerated over the long term. However, several changes are manifest at the organ system level. Although many of these changes are without appreciable clinical significance, other changes, such as an increased rate of gastrointestinal bleeding, appear to be associated with continuous-flow physiology.

*Conclusions:* Continuous-flow LVADs confer a significant advantage over their pulsatile-flow counterparts with regard to size and durability. From a physiological standpoint, continuous-flow physiology has limited clinical effects at the organ system level. Although improved over previous generations, challenges with this technology remain. Approaching these problems with a combination of clinical and engineering solutions may be needed to achieve continued progression in the field of durable mechanical circulatory support.



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## Introduction

Heart failure affects 5.7 million Americans and is responsible for >1 million hospital admissions and 58,000 deaths annually [1]. As means of treating heart failure, efforts to replicate and perfect artificial human circulation have been underway for several decades. The first successful use of mechanical circulation was by John Gibbon in 1954 when he used a heart-lung machine to repair an atrial septal defect [2]. Mechanical circulatory support evolved over the next 30 years to include left ventricular assist devices (LVADs) and permanently implantable artificial hearts [3,4]. In subsequent years, LVADs have advanced to become the predominant form of long-term mechanical circulatory support in use today [5].

The first several iterations of LVADs were volume displacement pumps. These devices were the workhorses of the field for many years and reached their clinical peak when they were approved for use in patients who were ineligible for heart transplantation also known as destination therapy. The landmark REMATCH trial, published in 2001, demonstrated a profound survival benefit at 1 (52% vs 25%) and 2 years (23% vs 8%) after device implant compared to patients receiving optimal medical management [6].

Despite the dramatically improved survival offered by the use of these pulsatile-flow devices, there were several disadvantages associated with their use. First, the use of various bearings and valves used in pulsatile designs was associated with limited durability, requiring many patients to undergo LVAD replacement surgery [7–9]. Second, pulsatile LVADs used the use of a volume displacement chamber, resulting in a relatively large device. In turn, this required both a patient with a large body habitus and extensive dissection to accommodate implantation [10,11]. Third, owing to the mechanism of the volume displacement chamber, these pumps were often noisy.

In large part due to the limitations of pulsatile-flow designs, the clinical use of LVADs with continuous-flow mechanisms has been widely adopted over the last decade (Fig. 1). Research into the use of continuous-flow designs, however, has been underway for >50 years. The first report on the development of a continuous-flow device occurred in 1960 where it was described as "an ideal heart pump [12]." This claim has since been questioned, in part, because of the lack of pulsatile flow. Despite vastly improved pump designs and ever-increasing human experience, the controversy over the efficacy of continuous-flow devices has remained. At one level, the rapid adoption of continuous-flow pumps in the last 10 years makes sense. For anyone who places these devices, the ease of insertion and simplicity of patient management is greatly welcomed. Overlooked in this enthusiasm, however, is deference for the pulsatile circulatory system honed by nature. After a decade of experience with continuous-flow devices, we can conclude that continuous-flow circulation is generally safe and that challenging a human physiology designed for pulsatile flow with a continuous-flow LVAD is appropriate. Herein, we seek to summarize the evidence regarding continuous-flow pumps at the level of each organ system to determine if Saxton was correct in his description of "an ideal heart pump." To accomplish this, we thoroughly reviewed the available literature comparing pulsatile-flow and continuous-flow LVADs on an organ system basis. The results of these searches are summarized in the following sections.

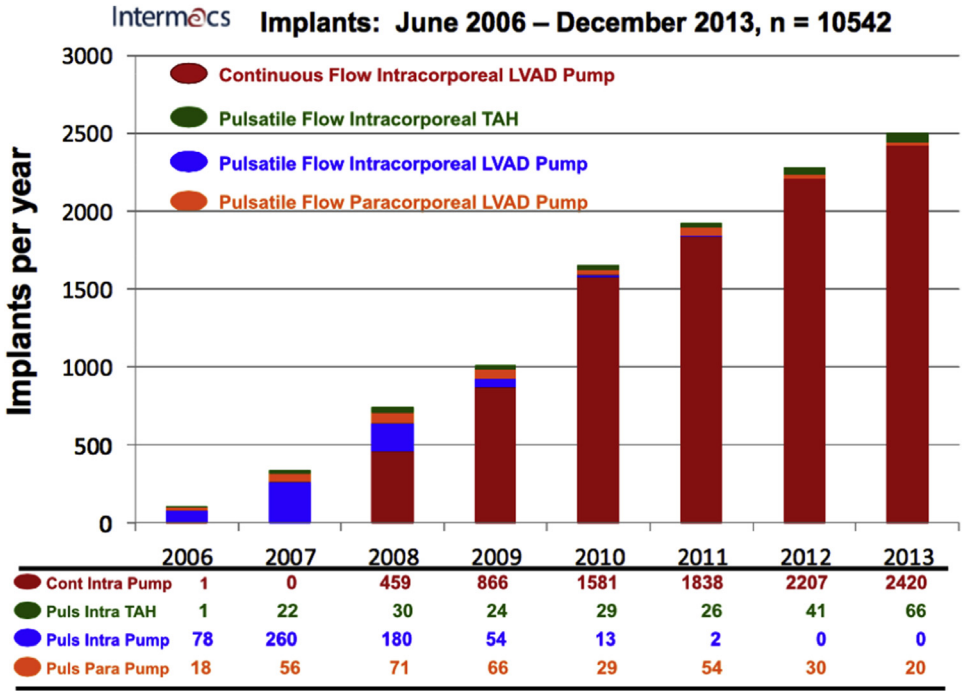


**Fig. 1 – Use of durable mechanical circulatory support devices in adults by type over time. Reproduced from Kirklin, *et al.*, [5] with permission. (Color version of figure is available online.)**