REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1995	Proceedings

4. TITLE AND SUBTITLE

EVALUATION OF FLOW BIOSENSOR TECHNOLOGY IN A CHRONICALY INSTRUMENTED NON-HUMAN PRIMATE MODEL

5. FUNDING NUMBERS

PE- 6220F
PR- 7755
TA- 25
WU-C6

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AL/AO-PC-1995-0057

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Life and Biomedical Sciences and Applications Division
Mail Stop ULR
National Aeronautics Space Administration Headquarters
Washington, DC 20546-0001

10. SPONSORING/MONITORING

11. SUPPLEMENTARY NOTES

ARMSTONG LABORATORY TECHNICAL MONITOR: DR. VICTOR A. CONVERTINO

12a. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Physiology Research Branch of Brooks AFB conducts both human and non-hiuman primate experiments to determine the effects of microgravity and hypergravity on the cardiovascular system and to indentify the particular mechanisms that invoke these responses. Primary investigative research efforts in a non-human primate model require the calculation of total peripheral resistance (TPR), systemic arterial compliance (SAC), and pressure-volume loop characteristics. These calculations require beat-to-beat measurement of aortic flow. We have evaluated commercially available electromagnetic (EMF) and transit-time flow measurement techniques. In vivo and in vitro experiments demonstrated that the average error of these techniques as less than 25 percent for EMF and less than 10 percent for transit-time.

14. SUBJECT TERMS			15. NUMBER OF PAGES 4
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

EVALUATION OF FLOW BIOSENSOR TECHNOLOGY IN A CHRONICALLY-INSTRUMENTED NON-HUMAN PRIMATE MODEL

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Abstract-- **The Physiology Research Branch at Brooks AFB conducts both human and non-human primate experiments to determine the effects of microgravity and hypergravity on the cardiovascular system and to identify the particular mechanisms that invoke these responses. Primary investigative research efforts in a non-human primate model require the calculation of total peripheral resistance (TPR), systemic arterial compliance (SAC), and pressure-volume loop characteristics. These calculations require beat-to-beat measurement of aortic flow. We have evaluated commercially available electromagnetic (EMF) and transit-time flow measurement techniques. *In vivo* and *in vitro* experiments demonstrated that the average error of these techniques as less than 25 percent for EMF and less than 10 percent for transit-time.**

I. INTRODUCTION

The Physiology Research Branch has developed and refined a chronically instrumented human surrogate model for evaluation of cardiovascular responses that control mechanisms during alterations in gravity such as parabolic flight (micro-Gz), head-down tilt (micro-Gz), and centrifugation (high-Gz) [1-2]. The measurement of flow through the ascending aorta and/or pulmonary artery is critical to understanding cardiovascular responses and mechanistic behavior in these environments. Specific requirements of the flow biosensor are accuracy, biocompatability, minimal size and weight, and minimal subject trauma.

An implanted electromagnetic flow probe surrounds the target vessel with an encased inductive coil that generates a magnetic field when excited by a current source. Blood flowing perpendicular to this magnetic field induces a voltage across electrodes imbedded in the flow that is proportional to the flow rate [3]. A transit-time probe contains four piezoelectric crystals designed in an "X" pattern configuration, acting as both transmitters and receivers. Blood flow is then measured by the difference in time between upstream and downstream propagation [4]. The quantity and sources of errors associated with EMF technology have been reported, specifically a zero-flow baseline drift and alteration in vessel compliance [5].

II. METHODS

Our laboratory tested and evaluated commercially-available flow probes utilizing the EMF and transit-time techniques. Specifically, we evaluated In Vivo Metrics and Zepeda EMF probes, and Triton Technologies transit-time flow probes. These technologies were evaluated based upon desirable flow probe characteristics.

These characteristics were evaluated using both *in vivo* and *in vitro* test models. *In vivo* testing and evaluation of the electromagnetic flow probes were accomplished by chronically implanting EMF probes on the ascending aorta of three rhesus monkeys (Macaca mulatta). Testing consisted of performing a series of thermal dilution (TDL) tests one month post-surgery. The TDL tests were performed at baseline, decreased (acetylpromazine), and elevated (epinenphrine) cardiac output levels. The cardiac output computed from the EMF measurement was compared to that of the TDL computer. Immediately following the TDL procedures, subjects were euthanized and the aortas were harvested with flow probes intact. The *in vitro* testing consisted of inserting harvested aortas into steady and pulsatile closed flow loops where pressure level and flow rates were controlled. Flow measured by EMF was then compared to the set-controlled flow rate.

Triton active-redirection transit-time (ART^2) flow transducers were chronically implanted around the ascending aorta of two rhesus monkeys (Macaca mulatta). *In vivo* testing was accomplished by performing a series of TDLs at surgery, and two weeks, one month, two months, and three months post-surgery. The TDL tests were performed at baseline, decreased (acetylpromazine), and elevated (epinenphrine) cardiac output levels. The cardiac output computed from the ART^2 measurement was compared to that of the TDL computer. *In vitro* testing was accomplished by mounting the probe "in-line" with the steady and pulsatile closed flow loops. Cardiac output computed from the ART^2 probe was then compared to the controlled steady and pulsatile flow rates.

III. RESULTS

Results of *in vivo* testing indicated that the EMF flow probe produced an average error of 15% ($r = 0.896$) over the varying flow ranges (figure 1). *In vitro* testing

showed a 34% (r = 0.972) error and between the controlled flow and the measured flow (figure 2). Results of *in vivo* testing of the Triton ART^2 flow probe produced an average error of 8% (r = 0.955) over the varying flow ranges (figure 3). *In vitro* testing demonstrated an average full-scale error of 1.1% (r = 0.999) between the measured and controlled flow rates (figure 4). We did not observe any degradation of signal quality or biocompatability problems in either the EMF or ART^2 flow probes at necropsy.

IV. DISCUSSION

The results of *in vivo* and *in vitro* testing showed that the Triton transit-time flow probe were more accurate in measuring flow than the EMF flow probes. In addition, the Triton probe was of smaller size and weight the EMF probe, an important feature for our hypergravity experiments since the flow probe under 10 G_z is ten times its weight at 1 G_z. Previous experience with EMF probes demonstrated an unfavorable zero-flow baseline drift that worsened significantly under high-G_z. We hypothesized that this drift was probably due to the variation in aortic pressure that caused changes in resistance between the sensing electrodes of the EMF probe and the vessel wall. Our test results indicated a directly proportional relationship between aortic pressure and zero-flow baseline drift. Due to greater accuracy and absence of zero-flow baseline drift, we selected the Triton ART^2 flow probe for future studies.

ACKNOWLEDGMENT

The views expressed herein are the private views of the authors and not to be construed as representing those of the Department of Defense or Department of the Air Force. The animals involved in this study were procured, maintained, and used in accordance with the Animal Welfare Act and the *Guide for the Care and Use of Laboratory Animals* prepared by the Institute of Laboratory Animal Resources - National Research Council. Armstrong Laboratory has been fully accredited by the American Association for Accreditation of Laboratory Animal Care (AAALAC) since 1967. This work was supported by NASA RTOP Grant #W-18,599.

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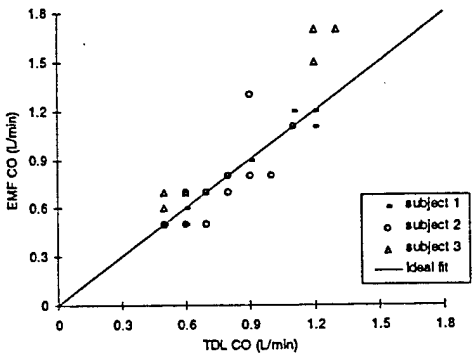

Figure 1: EMF *in vivo* study

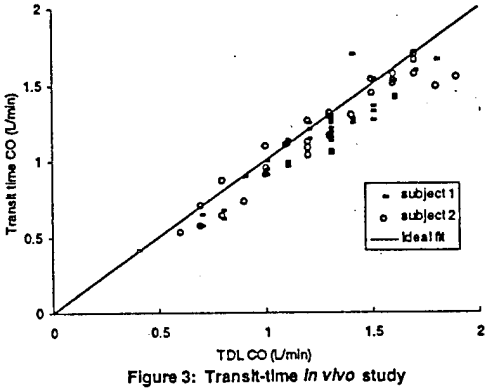

Figure 3: Transit-time *in vivo* study

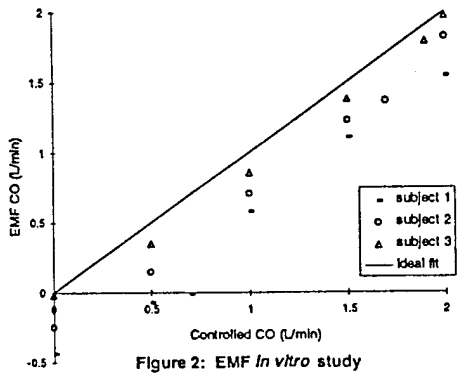

Figure 2: EMF *in vitro* study

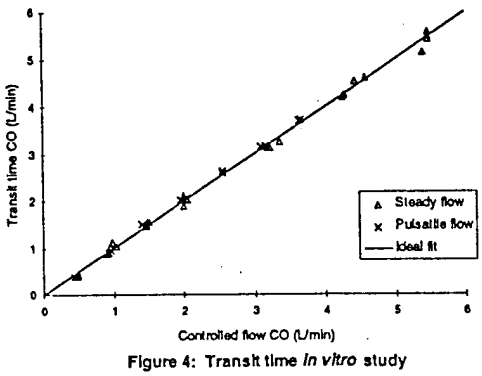

Figure 4: Transit time *in vitro* study

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