Ventricular Assist Devices in Advanced-Stage Heart Failure

Shunei Kyo
Editor
Ventricular Assist Devices
in Advanced-Stage Heart Failure
Ventricular Assist Devices in Advanced-Stage Heart Failure
At the end of the nineteenth century, the English surgeon Stephen Paget surmised: “Surgery of the heart has probably reached the limits set by nature; no new methods and no new discovery can overcome the natural difficulties that attend a wound of the heart,” expressing how difficult heart surgery was. Doctors as well as average citizens in those days considered the heart to be an untouchable internal organ and believed that a heart operation was impossible. However, Alexis Carrel, who performed a fundamental study of vascular anastomosis at the University of Chicago and established vascular anastomosis technology, transplanted the heart of a young dog to the cervix of an adult dog in 1905 and proved the possibility of recovery of the heartbeat after heart transplantation. Furthermore, Carrel transplanted the heart and lungs of a kitten to the cervix of an adult cat in 1907 and established the fundamental technology of today’s heart and heart–lung transplantation. Carrel was awarded the Nobel Prize in physiology or medicine for these achievements in 1912. Additionally, Carrel studied organ preservation and co-authored The Culture of Organs with the aviator Charles A. Lindbergh, famous for his solo trans-Atlantic flight of The Spirit of St. Louis. Carrel went on to develop the Carrel–Lindbergh Pump, a prototype of today’s pump oxygenator, an achievement that was an important step eventually leading to open heart surgery.

By pursuing the possibility of vascular anastomosis and heart transplantation, Carrel introduced the concept that the heart is a repairable and replaceable internal organ, and he was responsible for the concept of mechanical circulatory assist by developing the Carrel–Lindbergh Pump. With these two concepts Carrel established the basis for the fundamental technology that makes today’s open heart surgery possible. Open heart surgery is technology that restores valve function and coronary circulation or repairs a congenital defect or structural anomaly of the heart. In open heart surgery, native cardiopulmonary function stops with a surgical operation to the heart. A means (cardiopulmonary bypass) is needed to substitute for systemic circulation normally maintained by the natural heart and lungs.

Clinical introduction of open heart surgery began in the middle of the twentieth century and was carried out through such means as cardiopulmonary bypass, prosthetic valves, and prosthetic grafts, most of which had completely entered the realm of
possibility by the end of the century. Artificial heart treatment extends the concepts of surgical repair of the heart by using prosthetic materials and the replacement of the heart by a heart transplant. The artificial heart is in a developmental stage currently, of course, and only ventricular assist devices (VADs) have actually been put into practical use, while the total artificial heart (TAH) is still in the clinical investigation stage. Many functions considered to be “natural” in the natural heart have not yet been completely achieved in the artificial heart. Therefore, long-term survival for more than 10 years for patients supported by VADs has not yet been attained.

In the USA, nearly 2.8% of the total adult population suffer from heart failure. About 1,100,000 people have been hospitalized every year due to worsening heart failure, and some 280,000 deaths have occurred as a result of heart failure. Approximately 40 billion dollars are spent on medical treatment for heart failure every year in the USA, and it is predicted that heart failure patients and the costs of heart failure treatment will continue to rise. For these reasons, a more effective and efficient treatment strategy for heart failure in medical and surgical treatment must be developed. Although a heart transplant is considered the ultimate therapeutic strategy for heart failure, a heart from a brain-dead donor is not always available at the time it is needed, and their absolute numbers are also extremely limited. The establishment of a medical environment in which end-stage heart failure patients can be assured of treatment when necessary is our mission, and it will be the challenge of the twenty-first century.

Clinical use of the first-generation pulsatile flow implantable left ventricular assist device (LVAD) was introduced in the 1990s and spread during that decade mainly to provide a bridge device to heart transplantation. In 2000, the second-generation continuous flow (CF) implantable LVAD was introduced clinically, and destination therapy was established as a therapeutic alternative to a heart transplant. The main issues to be solved are thrombotic embolism, infection, right heart failure, and a tendency for bleeding. The solution of these challenges is closely connected with improvement in long-term clinical outcome and the improvement of a patient’s QOL. With continuous flow implantable LVAD treatment in 2013, we achieved a better prognosis in improving the patient’s life for an average of more than 2 years, with the longest survival being more than 8 years. We can predict that the day will soon come when 10-year survival can be achieved with the present devices. Competition is intensifying in the development of the fully implantable LVAD using the percutaneous energy transmission system with which a driveline is not needed. Clinical introduction of the fully implantable LVAD is predicted to be possible by 2020. Improved prognosis, with an expected survival for an average of more than 10 years, will be made possible by clinical introduction of the fully implantable LVAD, and it is predicted that survival for a maximum of 20 years can be achieved by replacing part of the device.

This book commemorates a milestone: With the introduction of destination therapy, the current implantable LVAD has reached the clinical outcome of a 2-year survival rate, almost equivalent to that of heart transplantation for end-stage heart failure. This book is also a “declaration of independence” for the LVAD, marking the starting line from which the implantable LVAD will surpass heart
transplantation in prognosis for survival and in QOL in the near future. The time when an artificial heart is considered inferior to a heart transplant soon will come to an end. The day when the status of the artificial heart will have been established as the ultimate therapeutic strategy for end-stage heart failure is at hand.

I had the opportunity to implant a ventricular assist device (the Atsumi–Todai Pump, developed at Tokyo University) in the first Japanese patient in 1980. Thereafter, for more than 30 years, I have been engaged in clinical and research work on the artificial heart. Because performing a heart transplant in Japan was extremely difficult until 1999 due to certain social and cultural factors, a significant delay occurred in the introduction of the implantable LVAD, especially for bridge-to-transplant (BTT) use in Japan. Insurance reimbursement for the implantable CF-LVAD was started in 2011 in Japan. Although it had been delayed for almost 20 years, the artificial heart therapy of Japan with the implantable CF-LVAD ultimately approached the American and European level.

I would like to dedicate this book to the many pioneers in the world who have promoted the development of the artificial heart. Willem J. Kolff, Adrian Kantrowitz, and Michael E. DeBakey in particular are the real parents of the artificial heart. William S. Pierce, Peer M. Portner, and Victor L. Poirier contributed immensely to the development of the ventricular assist device. The Japanese researchers Tetsuzo Akutsu, Yukihiko Nose, and Kazuhiko Atsumi had many great achievements in artificial heart development, and they nurtured numerous researchers who today are playing an active role in Japan and other parts of the world.

Tokyo, Japan

Shunei Kyo
Contents

1 Opportunities and Challenges for LVAD Therapy Now and in the Future ................................................................. 1
   Walter P. Dembitsky and Robert M. Adamson

2 The State of Ventricular Assist Device Therapy Today ...................... 23
   Erskine A. James and John B. O’Connell

3 Older Destination Therapy Patient Selection .................................. 41
   Robert M. Adamson and Walter P. Dembitksy

4 The Economics of Long-Term Ventricular Assist Device
   Therapy for Patients with End-Stage Heart Failure ...................... 61
   Robin R. Bostic

5 Improving Clinical Outcomes: A Targeted Approach ....................... 73
   Mark Jay Zucker and Hassan Baydoun

6 Transplant Versus VAD: Evolving and Future Perspectives ............... 97
   Hiroo Takayama, Sunu Thomas, and Yoshifumi Naka

7 Strategies to Assess and Minimize Right Heart Failure
   After Left Ventricular Assist Device Implantation ....................... 113
   Michihito Nonaka and Vivek Rao

8 Innovation Update ...................................................................... 131
   David J. Farrar, Kevin Bourque, Steven H. Reichenbach,
   Paul Muller, and Laxmi Peri

Index .............................................................................................. 143
Abbreviations

ACC    American College of Cardiology
ACGME Accreditation Council in Graduate Medical Education
ACHF Advanced chronic heart failure
ADL Activities of daily living
AHA American Heart Association
AHF Advanced Heart Failure
ALVAD Intra-abdominal left ventricular assist device
AST Aspartate aminotransferase
AST/SGOT Aspartate Aminotransferase/serum glutamic oxaloacetic transaminase
BCBS Blue Cross Blue Shield
BiVAD Biventricular assist device
BNP Brain natriuretic peptide
BP Blood pressure
BTT Bridge to Transplantation
BUN Blood urea nitrogen
CAV Coronary allograft vasculopathy
CDC Centers for Disease Control and Prevention
CEA Cost effective analysis
CFD Computational fluid dynamic
CF-LVADs Continuous flow left ventricular assist devices
cGMP Cyclic guanine monophosphate
CHF Congestive Heart Failure
CMS Center for Medicare and Medicaid Services
CO Cardiac output
CPB Cardiopulmonary bypass
CPR CardioPulmonary Resuscitation
CRT Cardiac resynchronization therapy
CTICU Cardiotoracic Intensive Care Unit
CVP Central venous pressure
DT Destination Therapy
DTRS Destination therapy risk score
Abbreviations

ECMO    Extracorporeal membrane oxygenation
EF    Ejection fraction
ESP    Evidence-based Synthesis Program
FDA    Food and Drug Administration
FFP    Fresh frozen plasma
FILVAS    Fully Implantable Ventricular Assist System
GI    Gastrointestinal
HF    Heart failure
HMWM    Higher Molecular Weight Multimers
HRPCI    High-risk percutaneous coronary interventions
IABP    Intra-aortic balloon pumping
ICD    Implantable cardioverter-defibrillator
ICER    Institute for Continuing Education and Research
iNO    Inhaled nitric oxide
INR    International normalized ratio
INTERMACS    Interagency Registry for Mechanically Assisted Circulatory Support
ISHLT    International Society of Heart and Lung Transplantation
IVS    Interventricular septum
JCAHO    Joint Commission on Accreditation of Healthcare Organizations
J-MACS    Japanese registry for Mechanically Assisted Circulatory Support
KCCQ    Kansas City Cardiomyopathy Questionnaire
LDL    Low-density lipoprotein
LOE    Level of evidence
LV    Left ventricle
LVAD    Left Ventricular Assist Device
LVEF    Left Ventricular Ejection Fraction
MCS    Mechanical Circulatory Support
MEDPAR    CMS Medicare Provider Analysis and Review
METS    Metabolic Equivalent Task Score
MLHF    Minnesota Living with Heart Failure
MLWHF    Minnesota Living with Heart Failure
MRI    Magnetic resonance imaging
mTOR    Mammalian target of rapamycin
6MWD    6-Minute walk distance
6-MWT    6-Minute walk test
NHLBI    National Heart, Lung, and Blood Institute
NT    N-terminal
NYHA    New York Heart Association
OHC    Open heart centers
PAP    Pulmonary artery pressure
PCWP    Pulmonary capillary wedge pressure
PHP    Percutaneous heart pump
PSI    Percutaneous site infections
PVR    Pulmonary vascular resistance
QALY    Quality adjusted life year
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>QUERI</td>
<td>Quality Enhancement Research Initiative’s</td>
</tr>
<tr>
<td>RAP</td>
<td>Right atrial pressure</td>
</tr>
<tr>
<td>RCA</td>
<td>Pulmonary vascular resistance</td>
</tr>
<tr>
<td>REMATCH</td>
<td>Randomized Evaluation of Mechanical Assistance for the Treatment of Congestive Heart Failure</td>
</tr>
<tr>
<td>RV</td>
<td>Right ventricle</td>
</tr>
<tr>
<td>RVAD</td>
<td>Right ventricular assist device</td>
</tr>
<tr>
<td>RVEF</td>
<td>Ejection fraction of the right ventricle</td>
</tr>
<tr>
<td>RVF</td>
<td>Right ventricular failure</td>
</tr>
<tr>
<td>RVFAC</td>
<td>RV Fractional area change</td>
</tr>
<tr>
<td>RVOT</td>
<td>RV outflow tract</td>
</tr>
<tr>
<td>RVSP</td>
<td>RV systolic pressure</td>
</tr>
<tr>
<td>RVSWI</td>
<td>RV stroke work index</td>
</tr>
<tr>
<td>SIRS</td>
<td>Systemic inflammatory response syndrome</td>
</tr>
<tr>
<td>TAPSE</td>
<td>Tricuspid valve (TV) annular plane systolic excursion</td>
</tr>
<tr>
<td>TC</td>
<td>Transplant center</td>
</tr>
<tr>
<td>TEE</td>
<td>Transesophageal echocardiography</td>
</tr>
<tr>
<td>TET</td>
<td>Transcutaneous energy transmission</td>
</tr>
<tr>
<td>TR</td>
<td>Tricuspid regurgitation</td>
</tr>
<tr>
<td>TV</td>
<td>Tricuspid valve</td>
</tr>
<tr>
<td>UNOS</td>
<td>United Network for Organ Sharing</td>
</tr>
<tr>
<td>VAD</td>
<td>Ventricular Assist Device</td>
</tr>
<tr>
<td>VO2</td>
<td>Oxygen consumption</td>
</tr>
<tr>
<td>vWF</td>
<td>von Willebrand Factor</td>
</tr>
</tbody>
</table>