## "Hearts will never be practical until they can be made unbreakable."

## The Wizard of Oz to the Tin Woodsman



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## The Artificial Heart: a new ending?



### Martin Elliott 37<sup>th</sup> Gresham Professor of Physic

Professor of Cardiothoracic Surgery at UCL Consultant Paediatric Cardiothoracic Surgeon The Great Ormond Street Hospital for Children





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## plumbing meets ethics



## the heart

## CO 1 5-6 times HR 40 → 200 bpm SV 50 $\rightarrow$ 220 ml/beat

## and most of the time you don't notice it's there



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starts working within days of conception works ceaselessly beats 100k/day, 40m/year 3 billion in average lifespan supplies distribution network of 97,000 km of vessels







# The Heart can Fail

## Congenital

## non-compaction

## cardiomyopathy (genetic)

## metabolic anomalies

## dysrhythmias





## coronary artery disease

hypertension

infective myocarditis

dysrhythmias

## substance abuse



## Good LV





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### dilated cardiomyopathy







## Law of Laplace

For a thick-walled structure such as the ventricle, the <u>law of Laplace</u> can be expressed as:

$$T = (P \times r)/h,$$

where:

- T wall tension,
- P pressure difference across the ventricular wall,
- r radius of the ventricle,
- h ventricular wall thickness.



Normal heart

## Myocardial tagging



### McVeigh et al. Circ. 2000



## hypertrophic (restrictive) cardiomyopathy







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### hydraulic consequences, up stream





### delivery problems, downstream







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## Heart Failure "a staggering clinical and public health problem"

Veronique Roger, 2013



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In the United States, cases of heart failure now exceed 5.8 million Each year > 670,000 new cases are diagnosed. Survival estimates are 50% and 10% at 5 and 10 years, respectively

> Circ Res. 2013;113:646-659 *Circulation.* 2012;127:743-748

## >25 million people living with heart failure worldwide



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# Advanced (Stage D) Heart Failure

**Goals of Therapy** 



- control symptoms
- improve Quality of Life
- reduce hospital admissions
- define end of life goals



## Options

- heart transplant
- IV drugs via pump
- mechanical support
- palliative care
- deactivate implanted devices





## surgical therapies for heart failure

### effective support

- resynchronisation therapy (pacing)
- revascularisation
- 'restoration'
- remove aneurysms
- repair leaky valves

### replacement

- transplantation
- total artificial heart

abandoned procedures (aimed at reducing dimension & wall stress)

- dynamic cardiomyoplasty
- passive cardiomyoplasty
- partial ventriculectomy



Delmo Walter and Hetzer 2013

### effective support

ventricular assist devices





### **Christiaan Barnard**



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## Cape Town, 1967



## **Cardiac Transplantation**





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**Adult and Pediatric Heart Transplants Kaplan-Meier Survival** (Transplants: January 1982 – June 2013)



## Adult and Pediatric Heart Transplants Number of Transplants by Year and Location



## Mechanical Support

 Bridge to recovery Bridge to bridge Destination therapy



## Bridge to transplant (majority of pts)



### John & Mary Gibbon (Boston)









1931





## a little history...1950's



### Paul Winchell



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## Henry Heimlich



Early one morning, I watched a sad George Robinson lose a patient during open-heart surgery and an idea struck me that sent me running to Heimlich.

"Hank", I began excitedly, "I just watched poor George lose his patient and I got to wondering if an artificial heart with its own power source were available, could it keep a patient alive during a crucial period?"



## Paul Winchell





Paul Winchell and the Artificial Heart

JULY1ST,2005 NICHOLASGENES(HTTP://WWW.MEDGADGET.COM/AUTHOR/NICHOLAS)



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"Odd as it may seem, the heart wasn't that different from building a dummy; the valves and chambers were not unlike the moving and eyes and closing mouth of a puppet."





THE ANNALS OF THORACIC SURGERY

Journal of The Society of Thoracic Surgeons and the Southern Thoracic Surgical Association

VOLUME I

The Implanted Bypass Heart

An Experimental Study

N. Zuhdi, M.D., C. Ritchie, B.S., J. Carey, M.D., and A. Greer, M.D.



NUMBER 3 MAY 1965

# Assisted Circulation–The Concept of



### EXPERIMENTAL CIRCUITRY AND PROTOTYPE

### CRITERIA FOR TOTAL BYPASS IMPLANTABLE HEART

- 1. Inert
- 2. Deters clot formation
- 3. Does not destroy blood elements
- 4. Capable of reproducible performance over long periods of time, 20 years, for instance
- 5. Size is such that it could be placed within one of the pleural cavities
- 6. Source of energy is small, portable, preferably implantable, reliable, and lasting (atomic capsule, blood or urine)









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FIG. 2. Photograph of the portion of the bypass heart to be implanted.



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## **Pneumatic Mechanism**





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### **Cleveland Clinic**



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![](_page_32_Picture_4.jpeg)

martin.elliott@gosh.nhs.uk

### History Movies

![](_page_33_Picture_0.jpeg)

![](_page_33_Picture_1.jpeg)

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![](_page_33_Picture_3.jpeg)

# a donor heart became available and replaced the Liotta heart after just 64hrs

# Haskell Karp died 34 hrs after the transplant

![](_page_34_Picture_2.jpeg)

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![](_page_34_Picture_4.jpeg)

![](_page_35_Picture_0.jpeg)

### 1970

![](_page_35_Picture_2.jpeg)

![](_page_35_Picture_3.jpeg)

![](_page_35_Picture_4.jpeg)






# he hoped that what the doctors learned might help save the lives of others someday.



### Barney Clark









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# Barney Clark lived for 112 very difficult days

# 236 Jarvik 7 pumps inserted over the next decade



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late 1980s

# The New York Times dubbed artificial-heart research:-



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'a kind of "Dracula" that was sucking money away from more worthwhile programs'.





# SynCardia TAH

- 1250 implanted
- 350 patient-years of support
- Iongest pre-transplant is 1374 days







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The Abiomed total artificial heart (TAH) uses a centrifugal pump to move silicone hydraulic fluid, which drives the device. A sleeved, rotating valve shuttles the fluid between the left and right blood pumps.

### **Right-side cutaway**

Woven polyester flexible tubing grafted to ascending aorta and pulmonary trunk.

Clear epoxy parts are easily \_\_\_\_\_\_ cast into irregular shapes, and allow visual inspections for proper pump function and to ensure that no air is present before the artificial heart is turned on.

Pump impeller -

Titanium-alloy case

Twist-lock quick connectors allow surgery without the artificial heart in the way.

Polyester cloth cuffs aresutured onto the remaining atria.



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🖂 ma

# "Space and the inside of your body have a lot in common; hey both present harsh and inaccessible environments" STRUM COMPANY DS

# Matthieu Dollon, Head of Business Development in Astrium





**Carmat Heart:** planned lifespan 5 years

biologic valves bio-coated surfaces demand feedback









# If your satellite stops working during the final penalty of the football world cup it's disappointing. But if a heart stops beating for five seconds, it's fatal.







Carmat's first transplant patient, a 76-year-old man, died in March last year, 2.5m post op

A second patient died on May 2, 9m post op. due to a technical problem with the controls of the motor.

A third patient, who was fitted with the device on April 8, is undertaking physiotherapy.



# total artificial hearts are heavy



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Constructed Patient Landscape

# Ollie Hirst

## www.olliehirst.co.uk







# Contour Landscape III

# Ollie Hirst

### www.olliehirst.co.uk





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# Ventricular Assist



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## **Thoratec PVAD**





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# **Thoratec IVAD**



IVAD is implanted inside the abd cavity and is attached to the same TLC II driver on the outside.





# The Berlin Heart in Children



# Great Ormond Street Hospital for Children NHS Foundation Trust



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# the swing





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# Image courtesy of Terri Pengilley, The Independent

# Elliott Livingstone 1 year on the Berlin Heart



# Image courtesy of Terri Pengilley, The Independent



# Image courtesy of Terri Pengilley, The Independent

# **Berlin Heart EXCOR complications**





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STATE OF ART

# Axial and centrifugal continuous-flow rotary pumps: A translation from pump mechanics to clinical practice

Nader Moazami, MD,<sup>a,b</sup> Kiyotaka Fukamachi, MD, PhD,<sup>c</sup> Mariko Kobayashi, MD,<sup>c</sup> Nicholas G. Smedira, MD,<sup>a,b</sup> Katherine J. Hoercher, RN,<sup>b</sup> Alex Massiello, MEBME,<sup>c</sup> Sangjin Lee, MD, MS,<sup>b,d</sup> David J. Horvath, MSME,<sup>c</sup> and Randall C. Starling, MD, MPH<sup>b,d</sup>

From the <sup>a</sup>Department of Thoracic and Cardiovascular Surgery; <sup>b</sup>Kaufman Center for Heart Failure; <sup>c</sup>Department of Biomedical Engineering, Lerner Research Institute; and the <sup>d</sup>Department of Cardiovascular Medicine, Heart and Vascular Institute Cleveland Clinic, Cleveland, Ohio.



The Journal of Heart and Lung Transplantation

http://www.jhltonline.org

# **Pump Design Differences: Impeller**



### **Axial = "PUSHES Fluid"**





### **Centrifugal = "THROWS Fluid"**





# **Pump Design Similarities**

- Rotary Blood Pump Components:
  - Inlet and Outlet
  - Single Rotating Element (Impeller)
  - Housing
  - Bearing \_\_\_\_
  - Magnetic Motor Windings









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# HeartMatell





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## **Micromed DeBakey HVAD (Reliant Heart)**





### PRODUCED BY BERLIN HEART, BERLIN GERMANY



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# **Examples of thrombus formation in axial flow LVADs**





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\* Includes RVADs implanted at time of LVAD and subsequent RVAD implantations

J Thorac Cardiovasc Surg 2012;144:584-603





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FIGURE 16. Survival after cardiac transplantation, stratified by era. NA, Not applicable. (From Stehlik J, Edwards LB, Kucheryavaya AY, Benden C, Christie JD, Dobbels F, et al. The Registry of the International Society for Heart and Lung Transplantation: Twenty-eighth Adult Heart Transplant Report—2011. J Heart Lung Transplant. 2011;30:1078-94. Reproduced with permission of the International Society for Heart and Lung Transplantation Registry.)

**FIGURE 12.** Actuarial survival among destination therapy patients, stratified by device type. Patients are censored at the time of transplant or explant due to recovery. LVAD, Left ventricular assist device. \*See notation in Figure 4.

J Thorac Cardiovasc Surg 2012;144:584-603







# The Hopkins Heart Initiative

- **Executive Board**
- Duke Cameron, Gordon Tomaselli, Ashish Shah JHMI
  - Joseph Katz, Rajat Mittal, Tak Igusa Whiting School
- Conrad Grant JHU APL
  - Management: Marty Devaney, Jacopo Biasetti


### **Tissue Engineered Peristaltic Muscle Pump**





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### **Cost of Ventricular Assist Devices**

by Leslie W. Miller, Maya Guglin, and Joseph Rogers

*Circulation Volume 127(6):743-748 February 12, 2013* 



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Left ventricular assist devices (LVAD) therapy: expenses and gains.



Leslie W. Miller et al. Circulation. 2013;127:743-748



Left ventricular assist devices (LVAD) early costs are comparable with other life-saving therapies.





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## 30% of the west's healthcare spend is in the last year of life

'Modern medicine has prolonged not only our lives but also our period of dying'



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### Tannsjo 2005





### Patient selections should be careful and limited to those 'who are likely to derive sustained benefit in terms of survival and quality of life'.

significantly in recent years and continues to do so'.





## NICE also notes that the 'technology for this procedure has evolved





- the scale of the problem
- · access
- cost:benefit
- legal and ethical
- the role of faith







## distributive justice

### access to expensive treatment

### TAH cost ≈ £100-200,000

### cash is limited

### who should get the TAH?



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### TAH care ≈ £100-200,000

### medical 'worth' social worth wealth lottery



## distributive justice

## treat the heart or treat cancer?



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### "Medical ethics, once a private ethic governing the intimate transactions between patient and physician, has become, by virtue of such devices as TAH, a public ethic".

Albert R Jonsen, 1973



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## The totally implantable artificial heart will continue pumping after a person is otherwise dead



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by ALBERT R. JONSEN





### I have a digatmare





### Rancho Los Amigos Hospital, California, 1953



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### Article 2 of the Human Rights Act (1998) states:

### Everyone's right to life shall be protected by law.

No one shall be deprived of his life intentionally save in the execution of a sentence of a court following his conviction of a crime for which this penalty is provided by law.





The **right to life** is a moral principle based on the belief that a human being has the right to live and, in particular, should not be killed by another human being.





## ethical principles guiding implantation

### "best interests"

- relief of suffering
- preservation or restoration of function
- extent and quality of life
- "goals of medicine"
  - prevention, cure and care of illness
- "futile interventions"
  - no expectation of therapeutic benefit
  - no cognitive awareness of benefit





## You can turn it on, but when should you turn it off?

### **CONTEMPLATING TOTAL ARTIFICIAL HEART INACTIVATION IN CASES OF FUTILITY**

### **KATRINA A. BRAMSTEDT**

Monash University, East Bentleigh, Victoria, Australia and Loma Linda University, Loma Linda, CA, USA Death Studies, 27: 295–304, 2003



Under current law, a healthcare professional's legal duty is to care for a patient and to take reasonable steps to prolong their life.



### it is generally accepted (both legally and morally) that adult patients with decision-making capacity can make informed choices to have life-sustaining therapies terminated





A person with capacity may decide either contemporaneously or by a valid and applicable advance decision that they have reached a stage where they no longer wish treatment to continue.

If a person lacks capacity, this decision must be taken in their best interests and in a way that reflects their wishes (if these are known).





## what if your advance directive demands that you be kept 'alive', come what may?



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### care that is medically futile is that which is unlikely to produce 'significant benefit' for the patient

### quantitative futility: a treatment is capable of producing desired result, but probably not in the case in hand

### qualitative futility: a treatment is likely to produce a result, but "is lacking in purpose"







support therapy."



"it is difficult to exclude TAH therapy as a form of aggressive care that could be ethically withdrawn.

### When beneficence cannot be facilitated, families and physicians must consider termination of this life

### Bramstedt 2003



this technology is not going to **COBMENDO** more heart failure, more patients wide public debate & engagement









## Thank You



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### "Trump can try again for the Republican nomination after 4 years waiting for an artificial soul"



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Professor Tom Karl



# our new ending?



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### less heart death, but more dementia?





Aortix<sup>™</sup> for the **ambulatory** treatment of chronic heart failure