



## ***Cultured Meat – a realistic proposition?***

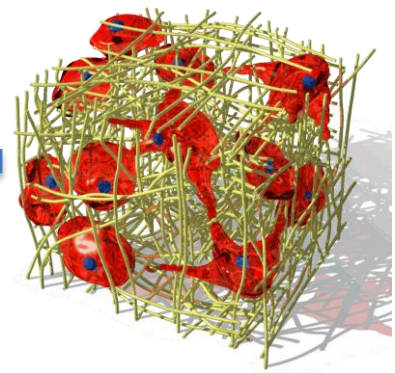
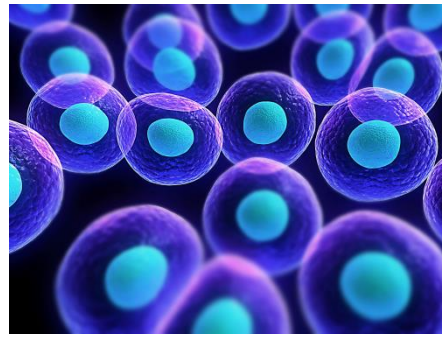
Dr Marianne Ellis PhD, CEng, MChemE  
Senior Lecturer in Biochemical Engineering  
Department of Chemical Engineering  
The University of Bath, UK  
[M.J.Ellis@bath.ac.uk](mailto:M.J.Ellis@bath.ac.uk)



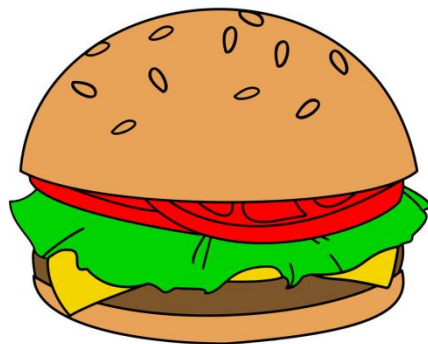
# Overview

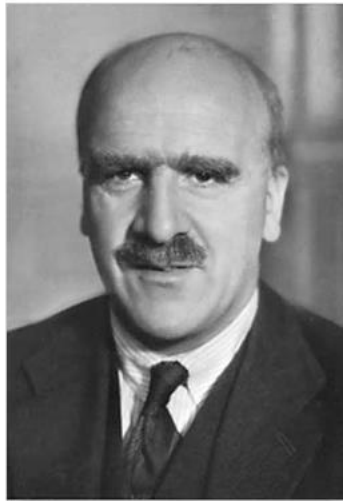
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- What is cultured meat?
  - A brief history
- Why bother?
  - Motivations for cultured meat
- Yuck!
  - 'Consumer' research
- How to produce cultured meat
  - The scientific challenge
  - The engineering challenge



Cultured meat is meat produced *in vitro*, in a cell culture, rather than from an animal  
– New Harvest





1927

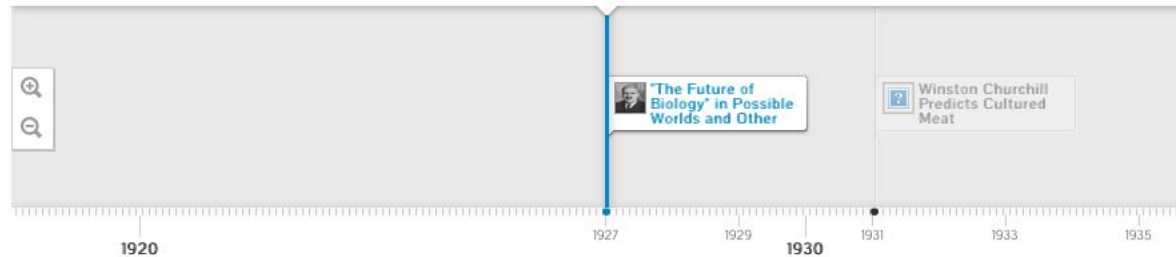
## "The Future of Biology" in Possible Worlds and Other Essays

In the collection, JBS Haldane wrote, "We can now kill an animal and produce a fluid from inorganic constituents that will keep its heart or liver alive for a day or more... We could cut our beefsteak from a tissue culture of muscle with no nervous system to make it waste food in doing work, and a supply of hormones to make it grow as fast as that of an embryo calf."



1931

Winston Churchill  
Predicts Cultured  
Meat



“Fifty years hence, we shall escape the absurdity of growing a whole chicken in order to eat the breast or wing by growing these parts separately under a suitable medium.” - Winston Churchill in 1931





MAY 1, 2005  
The Dutch In-Vitro Meat Project Begins



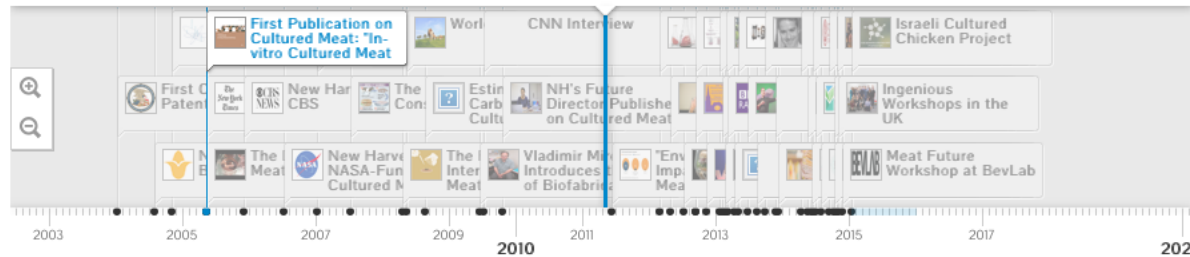
12:00 AM  
May 3, 2005

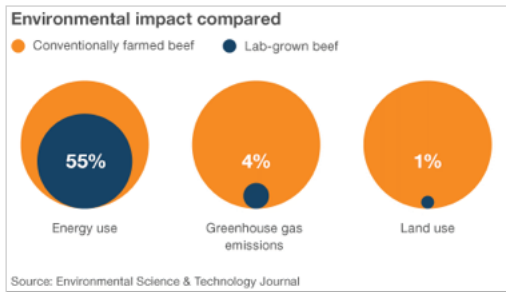
## First Publication on Cultured Meat: "In-vitro Cultured Meat Production"

Written by P.D. Edelman, D.C. MacFarland, V.A. Mironov and New Harvest's Jason Mathery, "In-vitro Cultured Meat Production" was published in the journal Tissue Engineering. This article was the first article to seriously look at cultured meat as a replacement for factory farmed meat considering modern



12:00 AM  
New Harvest on CBS





June 2, 2011

# "Environmental Impacts of Cultured Meat Production" Published

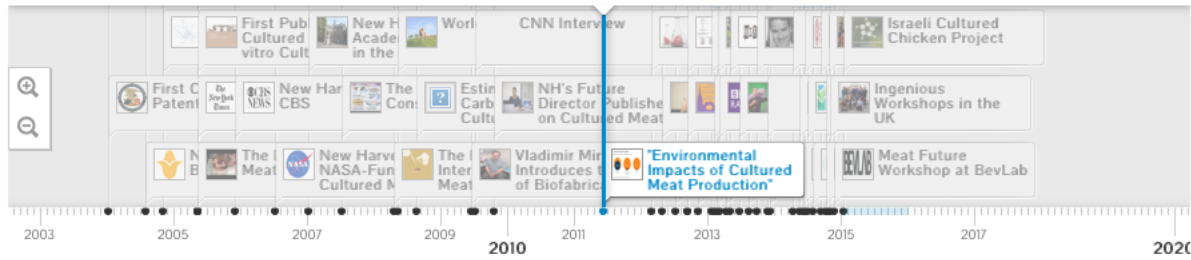
NH funded "Environmental Impacts of Cultured Meat Production," is accepted to the journal Environmental Science and Technology. This key environmental assessment paper has since been cited a countless number of times in quantifying the potential environmental benefit of cultured meat

←

**OCTOBER 11, 2009**  
 NH's Future Director Publishes on Cultured Meat

→

**12:00 AM**  
 The Next Agricultural Revolution: Emerging Production Methods for Meat Alternatives





JUNE 4,  
2014

New Harvest  
Awarded \$9,000  
Stanford Grant



June 18, 2014

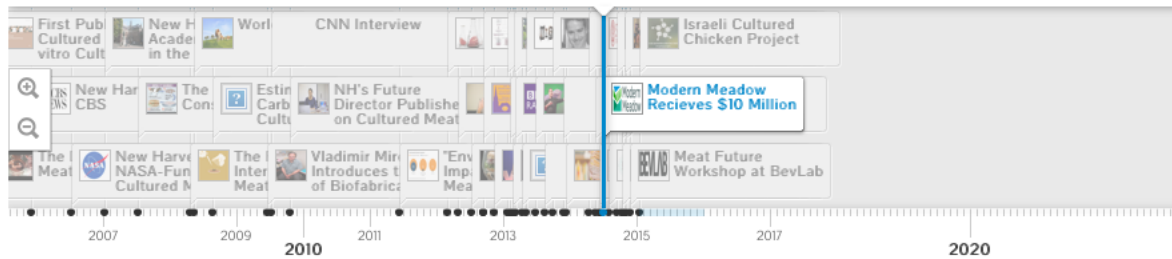
## Modern Meadow Receives \$10 Million

Modern Meadow [raises \\$10 million](#)  
from Horizons Ventures in order to  
3D print meat and leather products.



JULY 23,  
2014

10 Years Old!







SEPTEMBER 30, 2014

Multi Receives \$2M to Develop Animal-Free Milk!



October 2014

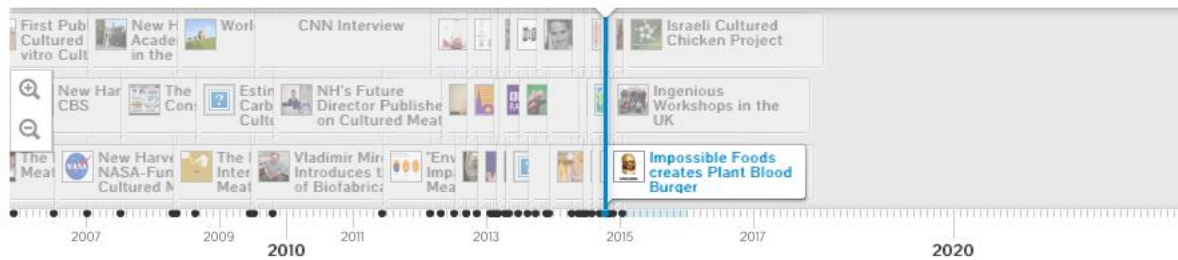
## Impossible Foods creates Plant Blood Burger

Impossible Foods creates the meatiest veggie burger to date - by adding a molecule derived from a plant analog of hemoglobin.



OCTOBER 16, 2014

MOFAD: The Future of Meat



The future?



# Motivations for cultured meat

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- Meat consumption predicted to double in the next 40 years
- Health problems due to over-consumption of meat
- Animal welfare due to farming intensification
- Currently 30% of (ice-free) land is used for raising livestock for meat
- ~18% of greenhouse gases from the livestock (~39% of methane, ~65% nitrous oxide)
- Beliefs and ethical standpoints versus choice and desires
- Defined intake
- Diversification is resilience

Post 2012; Tuomisto & de Mattos 2011

New Harvest



“Intensive farming produces such a large number of animals at such a fast pace that livestock farming is no longer part of a holistic approach to farming”

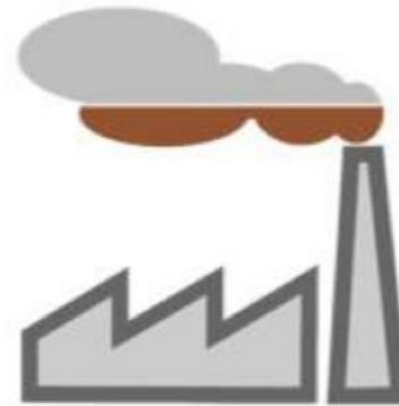
*From 'How meat contributes to global warming' in Scientific American (2009)*



**One third** of all  
(ice-free) land



**8%** of global  
water supply



**18%** of all  
greenhouse  
gases

# The Telegraph

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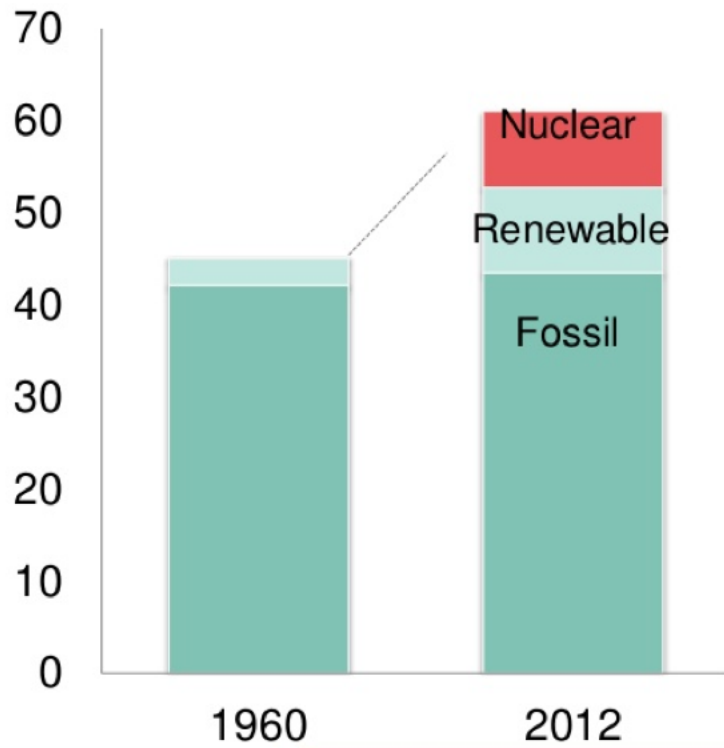
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## London 2012 Olympics: China bans athletes from eating meat for fear of ingesting banned substance clenbuterol

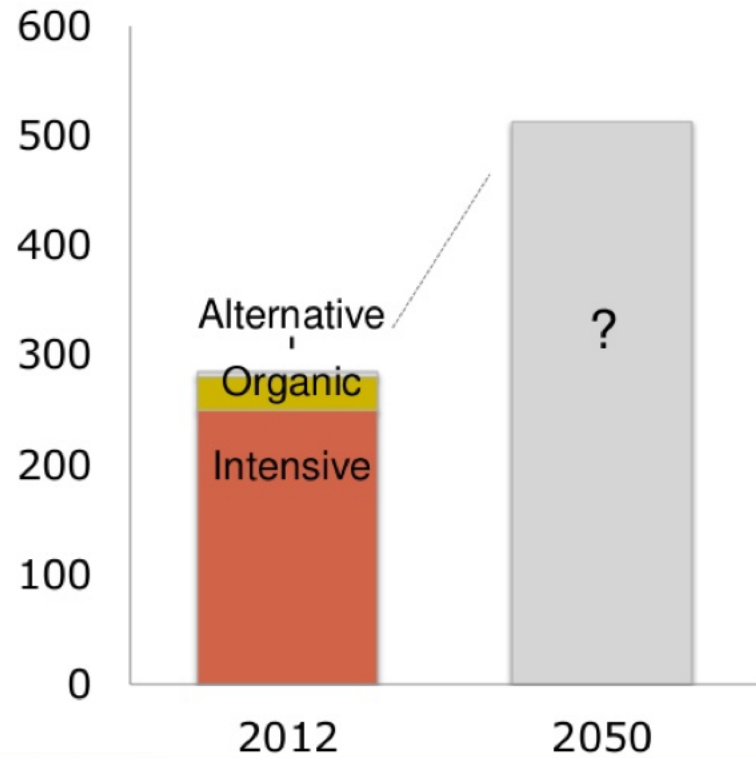
China's national team athletes headed for the London Games have been ordered to stop eating many forms of meat, due to fears that they could consume the banned substance clenbuterol.

"It's a disaster for athletes as the prohibited substance in over 52 per cent of the meat products in Beijing has exceeded the drug test standard."

Quadrillion  
BTUs



Million  
Tons



Source: U.S. Energy Information Administration Annual Energy Review 2011, UN FAO





# 'Consumer' research

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"Barrier perception has double the effect compared to motive perception" Wim Verbeke - U. Ghent

- Not real
- No trust
- Not natural





# 'Consumer' research

"Barrier perception has double the effect compared to motive perception" Wim Verbeke - U. Ghent

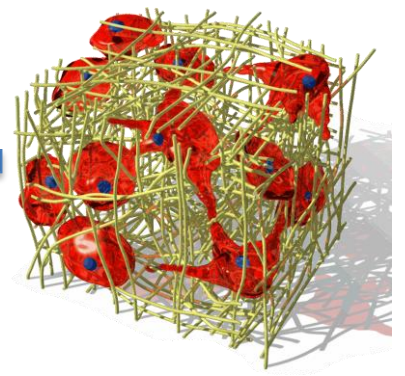
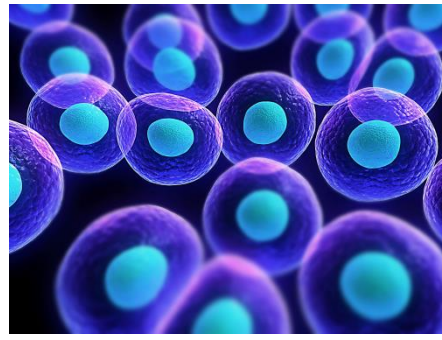
- Not real
- No trust
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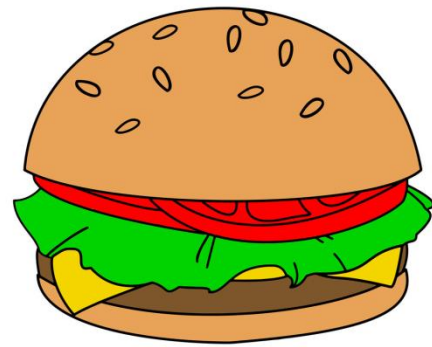
*Versus*

- Welfare
- Security
- Environment

'Willingness to accept' decreases by 30% per 10 years of age increase



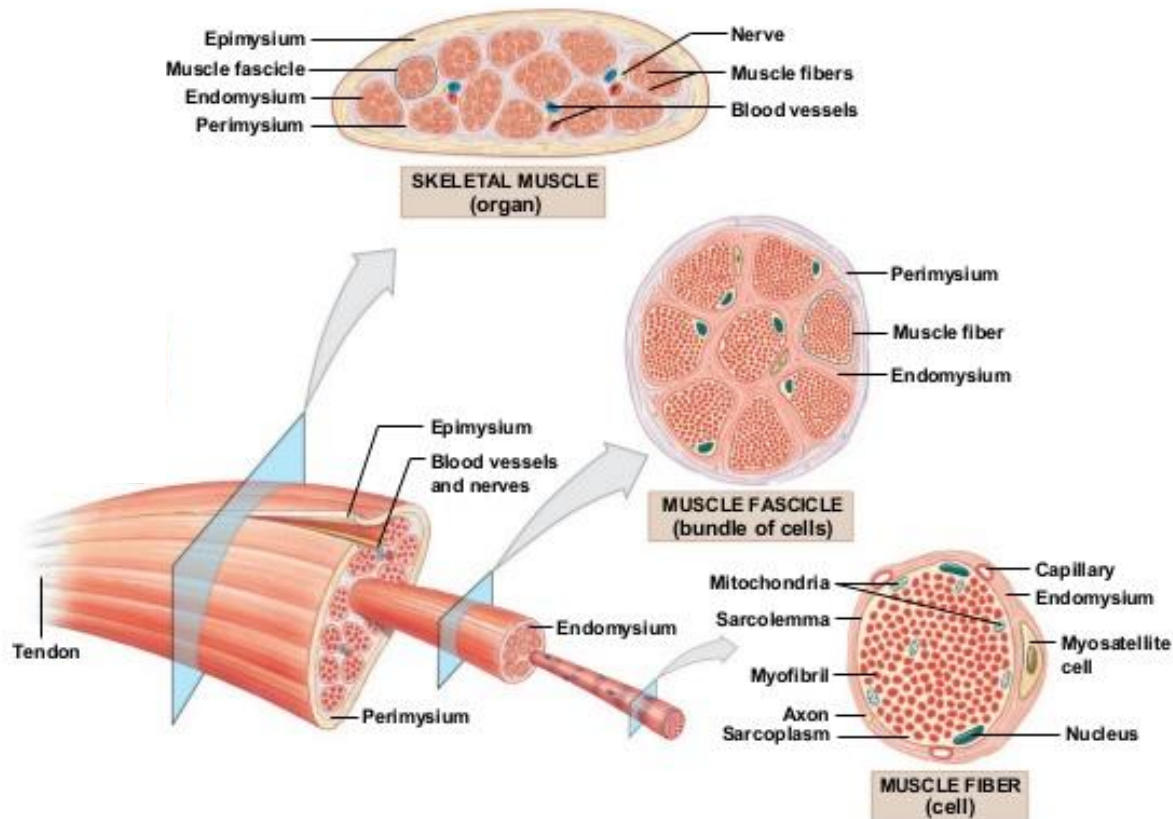
Producing cultured meat



# The scientific challenge

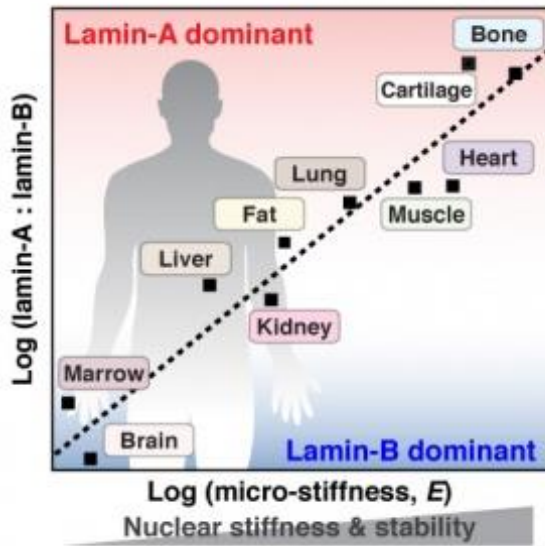
## (i) blood supply

Figure 9.1 Structural Organization of Skeletal Muscle

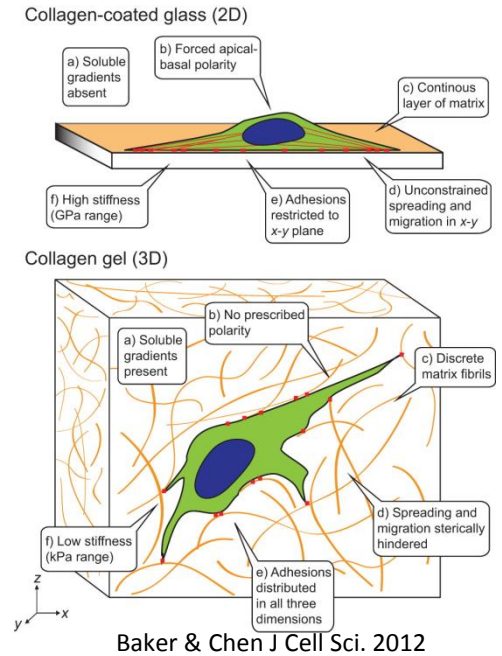
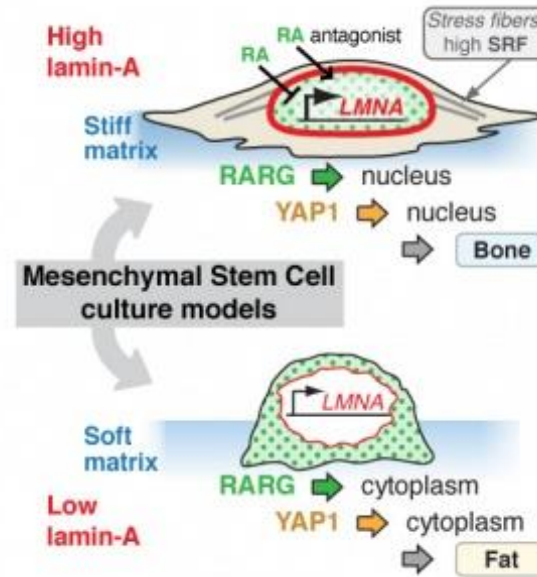


# The scientific challenge

## (ii) stem cells to muscle cells



Swift et al. Science, 2013



Baker & Chen J Cell Sci. 2012

AICHE

### Can Shear Stress Direct Stem Cell Fate?

**Sarah Stolberg**

Graduate Program in Quantitative and Systems Biology, University of California, Merced, CA

**Kara E. McCloskey**

Graduate Program in Quantitative and Systems Biology, University of California, Merced, CA  
School of Engineering, University of California, Merced, CA

DOI 10.1021/bp.124

Published online February 3, 2009 in Wiley InterScience (www.interscience.wiley.com).

*Mechanical forces are important signals in the development and function of the heart and lung, growth of skin and muscle, and maintenance of cartilage and bone. The specific mechanical force “shear stress” has been implicated as playing a critical role in the physiological responses of blood vessels through endothelial cell signaling. More recently, studies have shown that shear stress can induce differentiation of stem cells toward both endothelial and bone-producing cell phenotypes. This review will highlight current data supporting the role of shear stress in stem cell fate, and will propose potential mechanisms and signaling*

# The Solution

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“After years of stem-cell cookery, University of Maastricht researcher Mark Post [served] up a \$320,000 hamburger made from meat grown in a culture dish. The tasting [was] conducted in front of an invited audience in London on Aug. 5”, Ogilvy Public Relations on NewHarvest.org (2013)

problem with the



# The Solution => The engineering challenge



“After years of stem-cell cookery, University of Maastricht researcher Mark Post [served] up a **\$320,000** hamburger made from meat grown in a culture dish. The tasting [was] conducted in front of an invited audience in London on Aug. 5”, Ogilvy Public Relations on NewHarvest.org (2013)



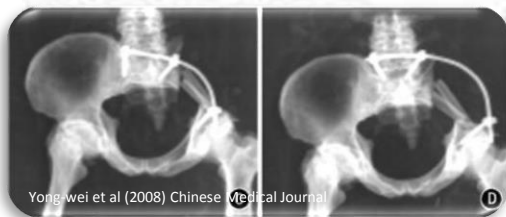
# Biochemical Engineering Solutions





**Warning**

Cost & Regulation



Yong-wei et al (2008) Chinese Medical Journal



[www.010.upp.ac.cn/ne.jp/r-ogawa/](http://www.010.upp.ac.cn/ne.jp/r-ogawa/)



Howard Sochurek/CORBIS

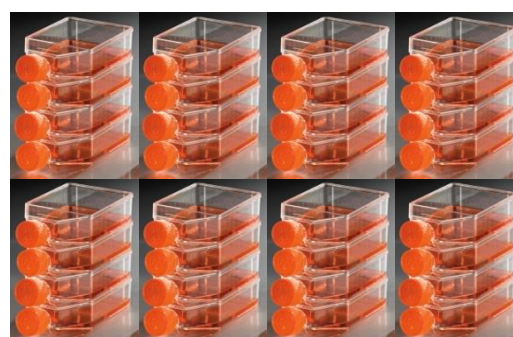
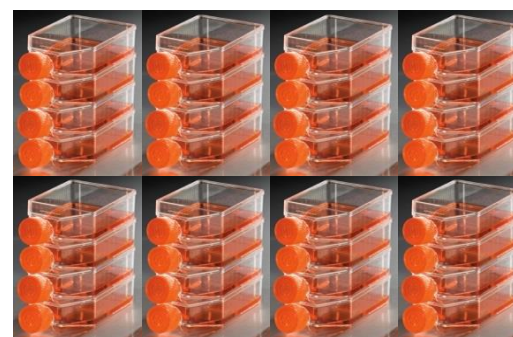
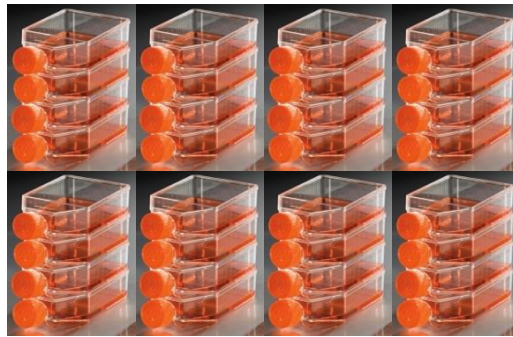
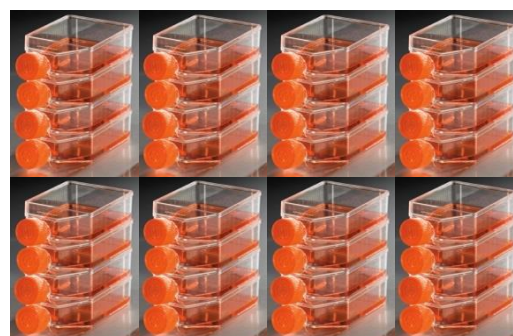
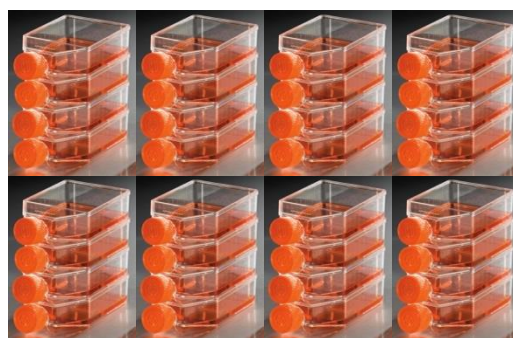
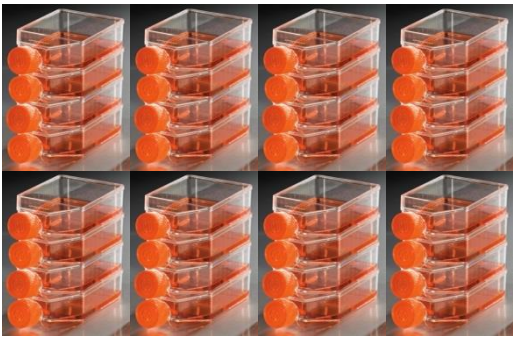


[www.toyima.gr](http://www.toyima.gr)



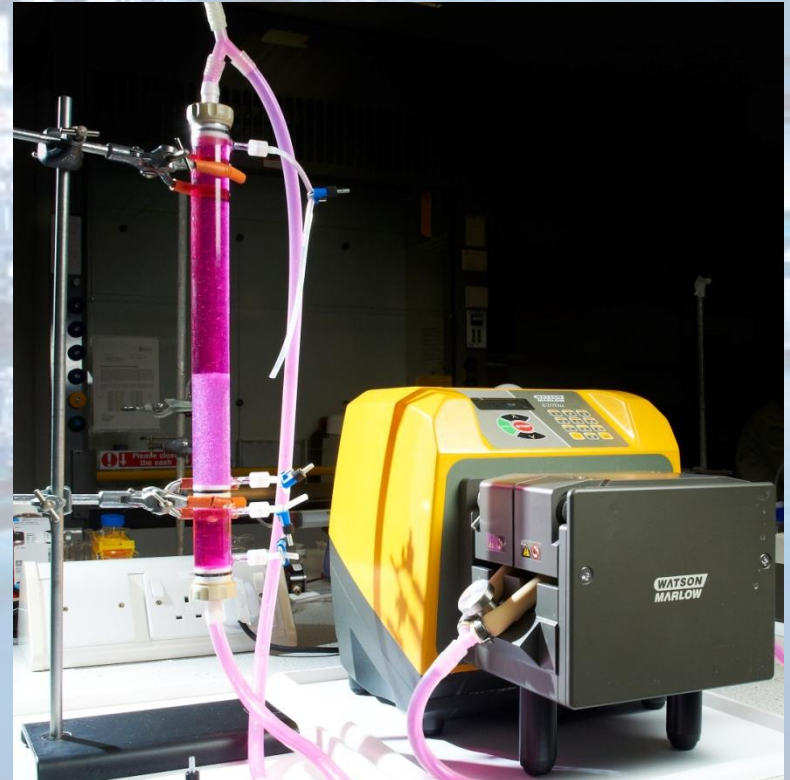
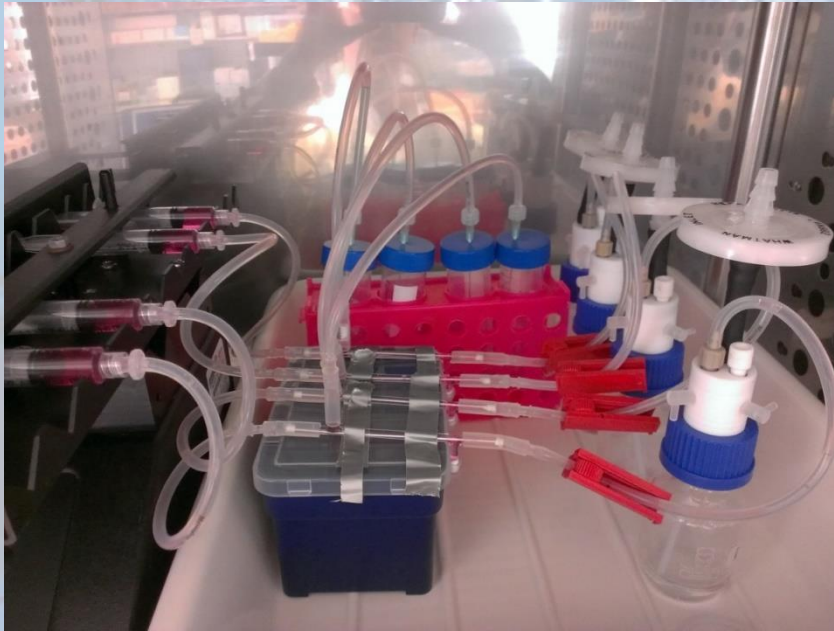
[www.newharvest.org](http://www.newharvest.org)





# Bioreactor culture

- Less Space
- Less Time
- Less Manual processing
- More *in vivo*-like environment



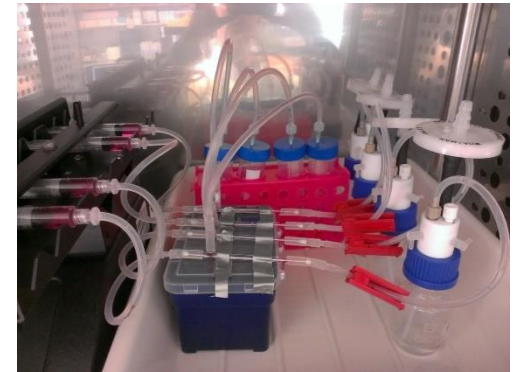
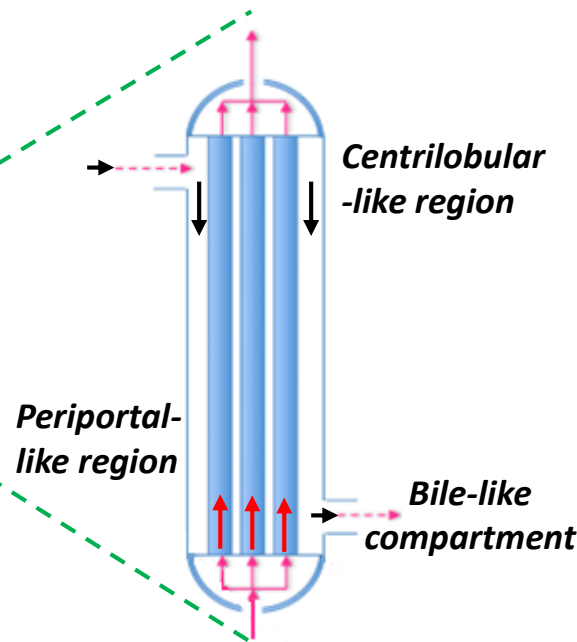
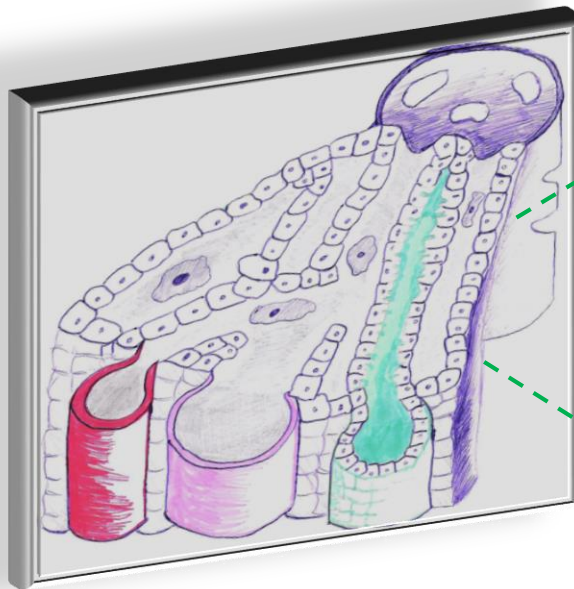
# Replicating an hepatic sinusoid

*A hollow fibre bioreactor*

*Liver Sinusoid*

*Plasma-like compartment*

$\sim 1 \times 10^6$  cells



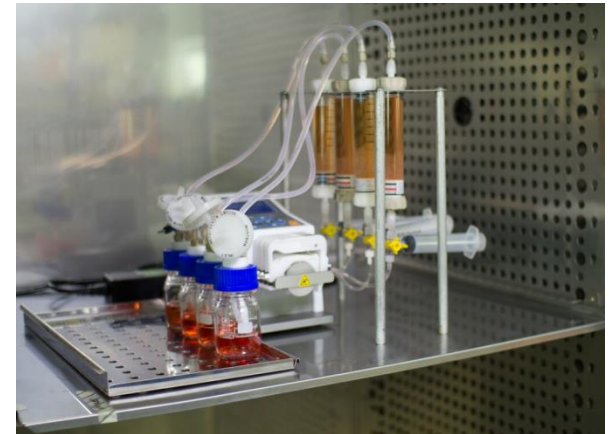
# Bone Regeneration



Copyright Bone Clones® 2004

Long-term aim  
~500ml  
~ 1 x 10<sup>9</sup> cells

Pilot-scale project  
~50ml



# Treg Cell Therapy



010641 [RM] © www.visualphotos.com



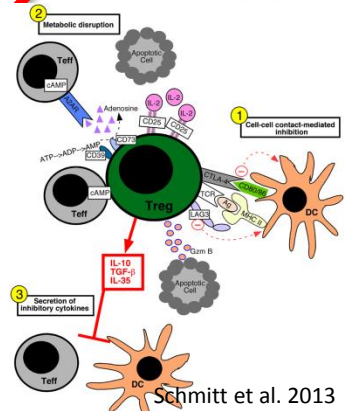
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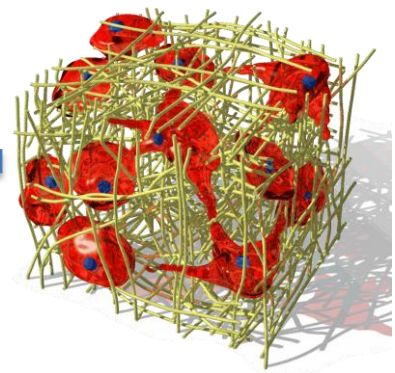
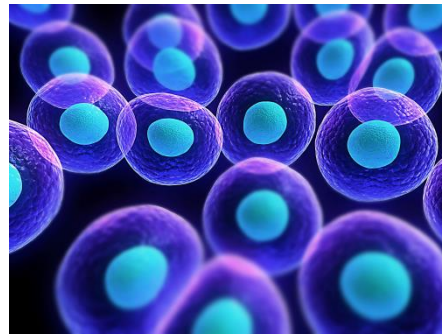


Per patient:  
 $2.5 \times 10^9$  cells  
 Two weeks of culture



Schmitt et al. 2013





Average global meat consumption is 39kg

UNFAO Published by [Daily charts from The Economist](#) (2012)

Say this was a 100g burger

If we only ate burgers:

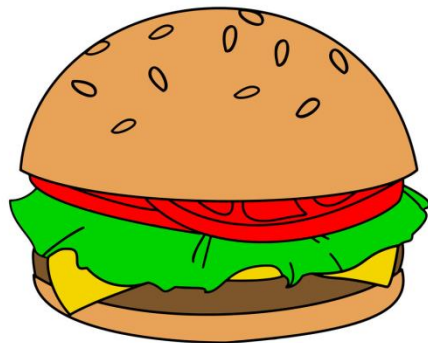
$5.6 \times 10^{12}$  cells

Five weeks

Per burger:

$1.5 \times 10^{10}$  cells

Three weeks of culture



## For 12kg of protein from cultured meat

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- Based on the following
  - 31% dry weight of the muscle cells are protein
  - Cells double in number every two days
  - 80% to 95% viability
  - starting population of 1 million cells
- This would require  $2 \times 10^{13}$  cells
- And would take 44 or 27 days

# The Bioreactor

|                                | Media change                | Mixing /shear                                      | Tissue development | Culture dimensions  | Reactor size needed to grow a functional unit* | Reactor size needed to grow an organ** |
|--------------------------------|-----------------------------|--|--------------------|---|--|--|
| <b>Tissue culture flask</b>    | Batch                       | Poorly mixed<br>No shear<br>Diffusion              | 2D sheet           | $\wedge 290 \text{ cm}^2/\text{L}$<br>$\wedge 1 \times 10^5 \text{ cell/ml}$      | 1-10 ml  | 10-1000 L                              |
| <b>Agitated vessels (CSTR)</b> | Batch or continuous         | Well mixed<br>Shear<br>Convection                  | 2D or 3D           | $\wedge 2,800 \text{ cm}^2/\text{L}$<br>$\wedge 5 \times 10^5 \text{ cell/ml}$    | 0.2-2 ml                                       | 2-200 L                                |
| <b>Packed beds</b>             | Continuous feed (perfusion) | Well mixed<br>Shear<br>Convection                  | 3D                 | $\wedge 18,000 \text{ cm}^2/\text{L}$<br>$\wedge 2.5 \times 10^6 \text{ cell/ml}$ | 40-400 $\mu\text{l}$                           | 0.4-40 L                               |
| <b>Fluidised bed</b>           | Continuous feed (perfusion) | Well mixed<br>Shear<br>Convection                  | 3D                 | 25,000-70,000 $\text{cm}^2/\text{L}$<br>$\wedge 5-6 \times 10^6 \text{ cell/ml}$  | 20-200 $\mu\text{l}$                           | 0.2-20 L                               |
| <b>Membrane bioreactors</b>    | Continuous feed             | Well mixed<br>Shear<br>convection<br>and diffusion | 3D                 | 100,000-200,000 $\text{cm}^2/\text{L}$<br>$\wedge 2 \times 10^8 \text{ cell/ml}$  | 0. 5-5 $\mu\text{l}$                           | 0.005-0.5 L                            |

<sup>1</sup>Brunstein, C.G. et al. *Blood* 117.(2011)

Adapted from: Ellis M, Jarman-Smith M, Chaudhuri JB. 2005. In: Chaudhuri JB, Al-Rubeai M, editors. *Bioreactors for tissue engineering*. Amsterdam: Kluwer Academic Publishers. p 1-18.

$\wedge$ Scragg 1991

\*A typical functional subunit contains  $10^2$ - $10^3$  cells (Palsson 2001)

\*\*A typical organ contains a few hundred million subunits or  $10^9$ - $10^{11}$  cells (Palsson 2001)



# Conclusions

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- Cultured meat will become an alternative food source
- There are challenges with
  - reproducing the meat structure
  - making an affordable product
  - consumer, and potential producer, perception
- Production has begun in the USA and the Netherlands
- There is an opportunity to
  - help meet global environmental and health needs
  - become world leaders in a new food product

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Thank you for listening!

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[isha@new-harvest.org](mailto:isha@new-harvest.org)

dreamstime.com



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## **Closing remarks**

**Jon Duffy**

*AIC Chairman*





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