



## Abstract

Arthritis is the leading cause of disability in the United States as it affects over 54 million adults and is caused by unsupported joints due to their inflammation. It is usually treated through using cartilage implants, but recently, researchers have turned to 3D-printing. At the University of Wollongong in Melbourne, Australia, scientists created the Biopen, a handheld device which outputs a fluid-like substance, bioink. This paper will examine the usage of Biopen as a means of treating arthritis patients, specifically by replicating the natural form and texture of the cartilage in a manner quicker than traditional methods. Biopen functions by adding the formulated Bioink directly onto the patient's bone layer-by-layer, with each layer being exposed to ultraviolet light to help replicate the rubber-like texture of cartilage. The bioink contains stem cells of hyaline cartilage extracted from the affected patients, a feature lacking in older cartilage implants. This treatment is beneficial because cartilage takes a long time to heal when damaged or inflamed and cannot regenerate. Through the eventual successful use of the Biopen on humans, it can more efficiently treat common joint problems specific to the patient's need with a shorter recovery rate and significantly reduce the number of arthritis surgeries. We will evaluate the sustainability of the Biopen and Bioink in regards to the cost, recovery time, and the materials they are composed of. It is an important innovation for all engineers to recognize because it represents a convergence of engineering and medicine producing a comprehensive solution, as well as having the potential to revolutionize the recovery track of an arthritis patient.



Normal knee joint



Knee joint with arthritis

## Arthritis

- Arthritis contributes twenty-seven billion dollars in health care expenditures annually.
- Arthritis of the knee is inflammation and stiffness of the joint characterized by breakdown of the cartilage, bony changes of the joints, deterioration of tendons and ligaments, and various degrees of inflammation of the synovium surrounding the joint.
- Current treatments to treat arthritis, such as arthroplasty and Autologous Chondrocyte implantation have many possible complications, including graft failure, tissue hypertrophy, and a loss of ability to produce reparative tissue.
- Biopen provides the benefits of knee surgery without the complications

## 3D Printing

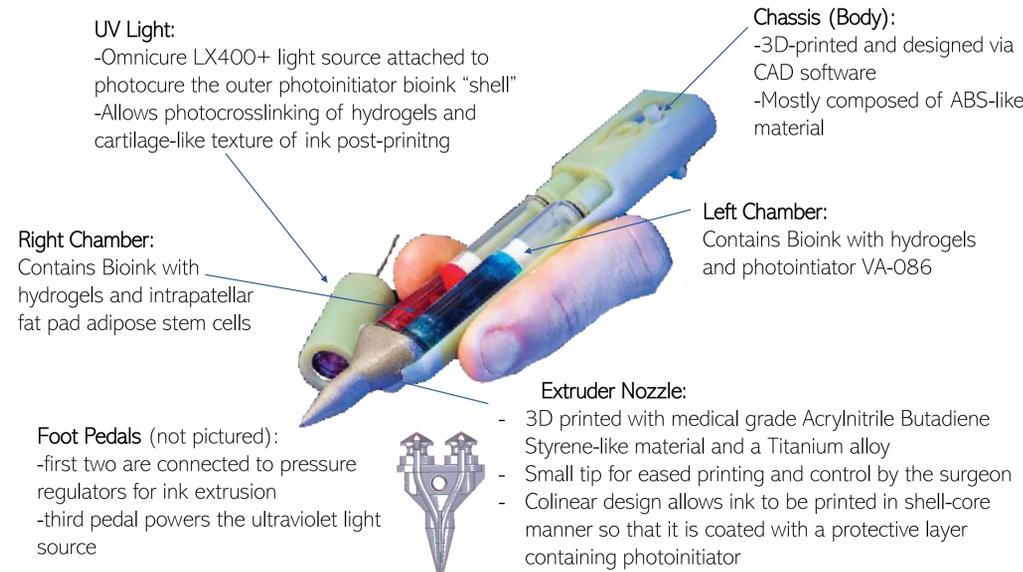
-3D Printing is also referred to as additive manufacturing, and creates structures layer-by-layer.  
-The Biopen prints scaffolds, which are "biocompatible and biodegradable materials that serve to provide...mechanical support, physical, and biochemical stimuli for optimal cell growth and function" directly onto the patient's knee.

	Types of 3D Printing		
	Ink-Jet Based	Extrusion Based	Laser Based
<b>Pros:</b>	-Cost Effective -Compatible with biological components	-Fast Printing Speeds -High amount of control -Precise	-Uses Viscous Materials -Most Precise
<b>Cons:</b>	-Requires low viscosity materials	-Requires low shear stress	-Large production of excess heat

-The Biopen uses an extrusion based printing method because it allows surgeons the most control, prints quickly, and produces little heat.

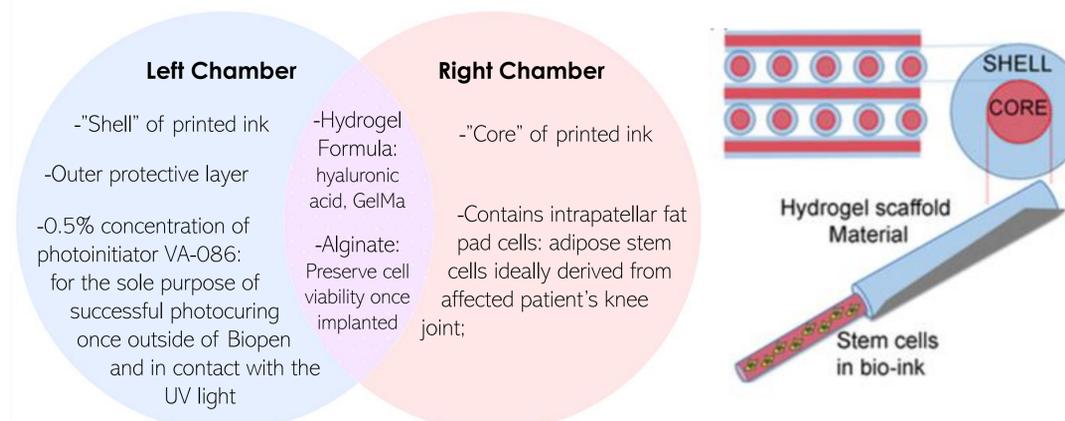
## What is the Biopen?

- Engineering device that prints, in real-time, live, differentiable, adipose stem cells in the form of Bioink
- Designed by engineers at the University of Wollongong in Australia, who prioritized ergonomics and sterisability
- Made primarily for surgeons to use on the defective knee joints of patients with arthritis, as a permanent replacement for their inflamed cartilage
- The Biopen is composed of six main parts (shown below):



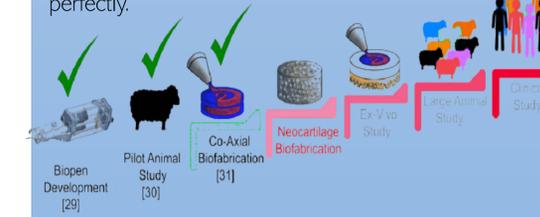
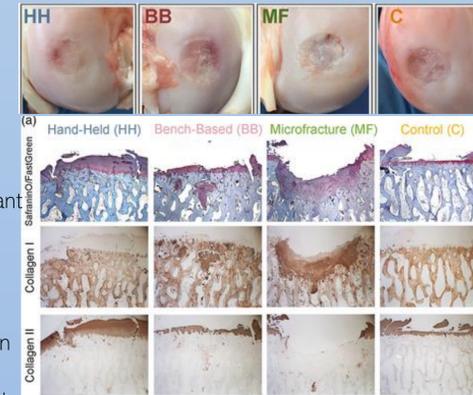
## What is Bioink?

Bioink is a fluid-like substance composed of biomaterials that is used as the ink in 3D printing medical or surgical devices. The Biopen utilizes two fairly similar types of Bioink, one in each chamber of the body, that the researchers behind the device formulated themselves, in order to obtain a gel like substance that would be able to properly withstand extrusion, properly settle post-extrusion, and have low shear stress. The two types and their shell-core orientation are shown in the figures below:



## Progress & Improvements

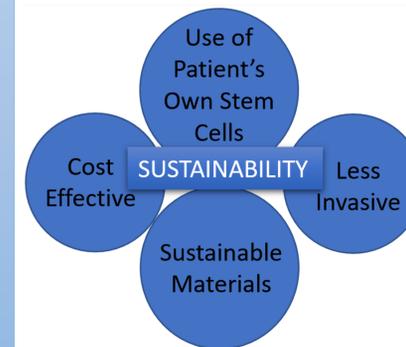
- Clinical trials of the Biopen have been successfully carried out on sheep
- Each defective joint was treated with a different surgical procedure:  
HH Biopen  
BB Traditional bioscaffold implant  
MF Microfracture procedure  
C Control group (no surgery)
- Researchers found that HH group joints provided the most promising results, since Bioink from the Biopen allowed for the most cartilage regeneration, along with the highest score in repair assessment.
- Surgeons found the Biopen to be a practical surgical device that was easy to use and fit the defect almost perfectly.



Engineers behind the Biopen are continuing to improve its design and performance:  
-Implementing a coaxial design for the extruder nozzle  
-Accounting more accurately for temperature affecting the Bioink's texture once printed  
-Looking towards performing human clinical trials, following the timeline on the left.

## Sustainability

- It has become of paramount for companies' products to be sustainable. Biopen and Bioink can improve the quality of life for millions of arthritis patients.
- ABS plastic used to make chassis is more sustainable than 70% of all plastics
  - Parts of the Biopen are printed via 3D printing, reducing manufacturing costs
  - Stem cells are the patients, not taken from baby's or other donors
  - Less pain, speedy recover, shorter hospital stay, and fewer complications than traditional models



## Ethics

Recently, the importance of having ethically sound products is essential for companies to be able to market their products. As the Biopen creators aim to manufacture cartilage to mimic the properties of real cartilage, pluripotent stem cells are used in the Bioink to create the extracellular components. Due to these cells having a limited life cycle, they are controversial to use since the risks currently can not be calculated. The creators of Biopen have addressed this issue by using the patients own stem cells rather than baby's or donor's stem cells. Additionally, they had previously obtained approval for this process by the Human Research Ethics Committee at St. Vincent's Hospital.