UNIVERSITY OF NEBRASKA AT OMAHA

UNIVERSITY *of* NEBRASKA–LINCOLN

College of Engineering

MECHANICAL & MATERIALS ENGINEERING

Development of 3D Printed Prostheses for Farmers and Veterans

Jorge Zuniga Ph.D.
Associate Professor of Biomechanics
Department of Biomechanics
3D Printed Prosthetic, Orthotic & Assistive Devices

Carl Nelson Ph.D.
Professor of Mechanical & Materials Engineering
Hergenrader Distinguished Scholar
College of Engineering

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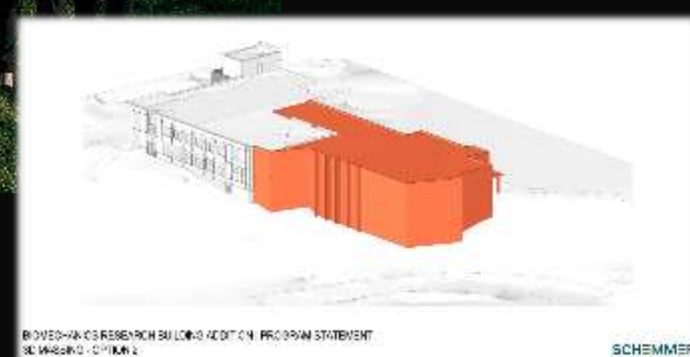
What is Biomechanics?

- 73 people employed
- Obtained the largest funding in UNO history

Dr. Nick Stergiou
Distinguished Community Research
Director of the Biomechanics
Research Building

CENTER FOR RESEARCH IN
HUMAN MOVEMENT VARIABILITY



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Graduate Assistants

DAVID SALAZAR, BS

Pursuing a Master's Degree in Exercise Science

KEATON YOUNG, BS

Faculty Advisor: Dr. Zuniga

Pursuing a Master's Degree in Exercise Science

Christopher Copeland – ccopeland@unomaha.edu
Student Worker
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Master of Science in Biomechanics
Department of Biomechanics, Team Zuniga
Read profile

Professional Collaborators

Rakesh Srivastava CPO and
CEO of Innovative Prosthetics & Orthotics

INNOVATIVE

Jean Peck OTL, Certified Hand Therapist
CHI Health

CHI Health

Gabe Linke
Cardiac CT/MR Imaging & 3D Printing Coordinator

Children's
HOSPITAL & MEDICAL CENTER

Dr. Scott Fletcher M.D.
Director, Cardiovascular Magnetic Resonance Imaging

UNMC

Dr. Justin Cramer M.D.
Assistant Professor of Radiology

COPPER 3D

Andrés Acuña

Daniel Martinez

Dr. Claudio Soto

NASA Nebraska Space Office

Director

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MECHANICAL & MATERIALS ENGINEERING

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THE PROBLEM

Upper-limb Prosthesis for Adults

- Many Veterans with upper-limb amputations **are not fitted** with a functional prosthesis due to cost of repairs, weight, and lack of adaptation to the new prosthesis.
- In the fiscal year 2016, **22%** (n = 20,158) of the U.S. veterans who received amputation care at Veterans Affairs (VA) medical facilities had experienced an upper-limb amputation.
- For those patients that have access to an upper-limb prosthesis, **35% to 52% rejected or abandoned the device.**
- The term "**transitional prosthesis**" has been used to classify devices that are designed to introduce the patient to a prosthesis for restoring and preserving strength and range-of-motion.
- Transitional devices are often made by hand, requiring long construction time and highly skilled technicians to manufacture them taking **4 to 8 weeks.**
- In the adult population, fitting a patient with a prosthesis **within 4 weeks after amputation** will increase the likelihood of acceptance of the device.
- This time is known as the '**golden period**' of upper extremity prosthetic rehabilitation and may be the most vital factor in the patients' acceptance of the prosthesis.

U.S. DEPARTMENT OF DEFENSE

U.S. Department of Veterans Affairs

Upper-limb Prosthesis for Adults

- During the "Golden Period", **infections**, contractures and muscle atrophy are common risk factors that can affect prosthesis use and overall function

Bacterial Complications

Dermatoses

Folliculitis

Fungic Infection

Dehiscence

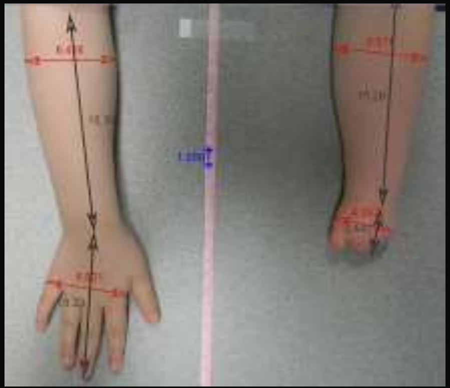
Mucormycosis

Estimated Cost: 28,2 Billion USD (only US)

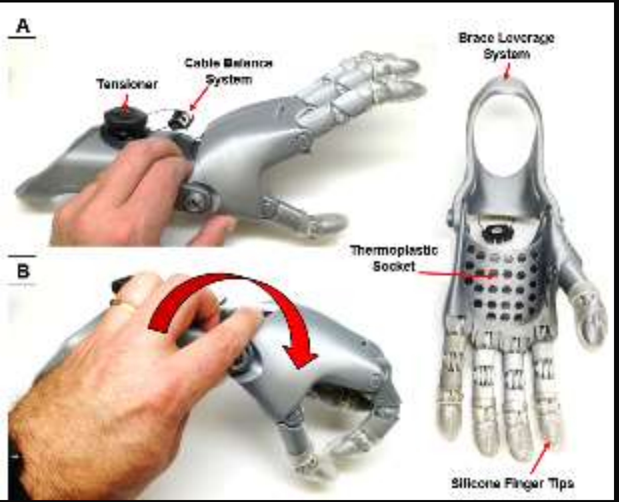
Adams, P. et al, Current Estimates from the National Health Interview Survey, Vital and Health Statistics

THE POTENTIAL SOLUTION

3D PRINTING PROCESS



3D PRINTED PROSTHESIS



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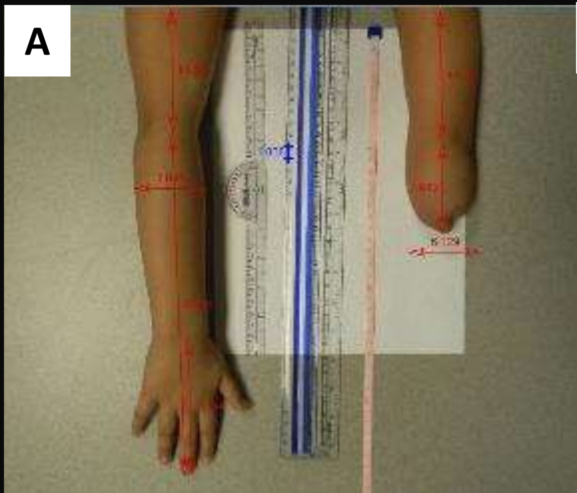
3D PRINTED ARM PROSTHESIS



CHILD FRIENDLY DESIGN

Jean Peck
OT, CHT

Rakesh
Srivastava
MS, CPO

It was great meet you and some of our team. I look forward to working with you all. As for my 6 year old. His name is [redacted] his mother name is [redacted] the cost of getting him a prosthesis with the help from a upper extremity specialist from the manufacture of the arm part, [redacted] is **$38,956.70.** Then there changes as he grow and additional cost. This is why it's so hard to get kids something that I hope they will use and not let it sit on a shelf. Cost, Cost, Cost! Here is a picture of the young man. I have a list of componentry and there cost. I will show that to you at our next get together if that's alright, or if you need it sooner just let me know. This young man really needs something.

Tom Kalina,C.P., President
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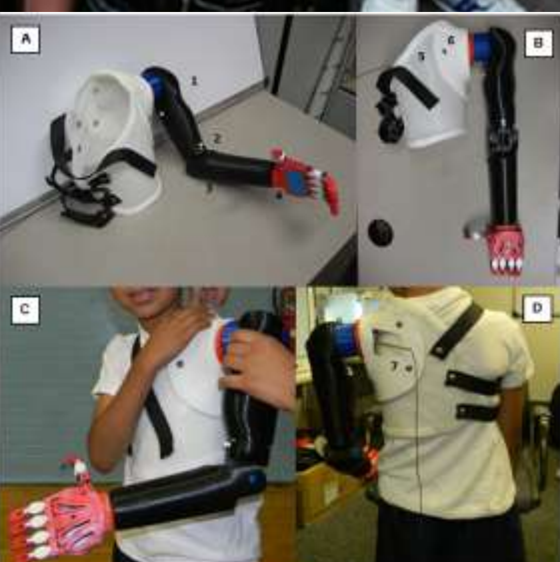

[redacted]

Material cost $200

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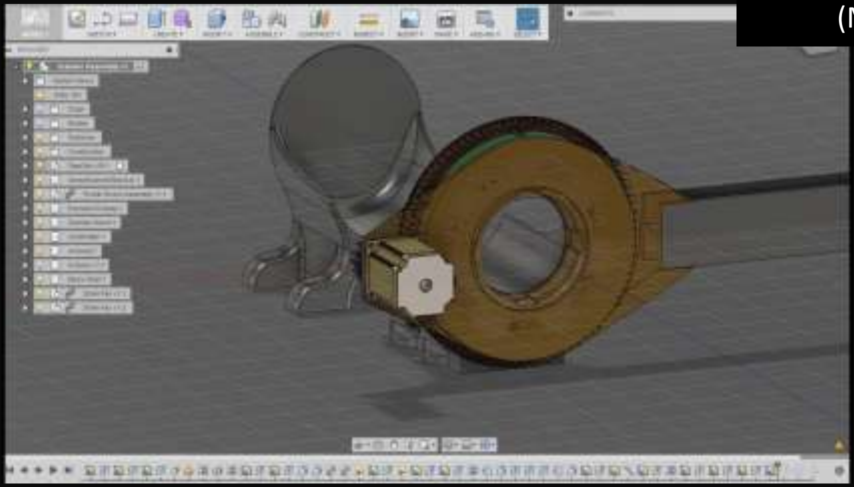
James Pierce
(Master's)

Hand Exoskeleton

Hand scanning device



Research Findings

-Remote Fitting

-Bench Testing

-Trans-radial Prosthesis

-Function

Taylor & Francis
Taylor & Francis Group

Expert Review of Medical Devices

ISSN: 1743-4440 (Print) 1745-2422 (Online) Journal homepage: https://www.tandfonline.com/loi/ierd20

Remote fitting procedures for upper limb 3d printed prostheses

Jorge M. Zuniga, Keaton J. Young, Jean L. Peck, Rakesh Srivastava, James E. Pierce, Drew R. Dudley, David A. Salazar & Jeroen Bergmann

To cite this article: Jorge M. Zuniga, Keaton J. Young, Jean L. Peck, Rakesh Srivastava, James E. Pierce, Drew R. Dudley, David A. Salazar & Jeroen Bergmann (2019): Remote fitting procedures for upper limb 3d printed prostheses, Expert Review of Medical Devices, DOI: 10.1080/17434440.2019.1572506

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Lecturer at Christ Church
Senior Research Fellow in Engineering & Entrepreneurship

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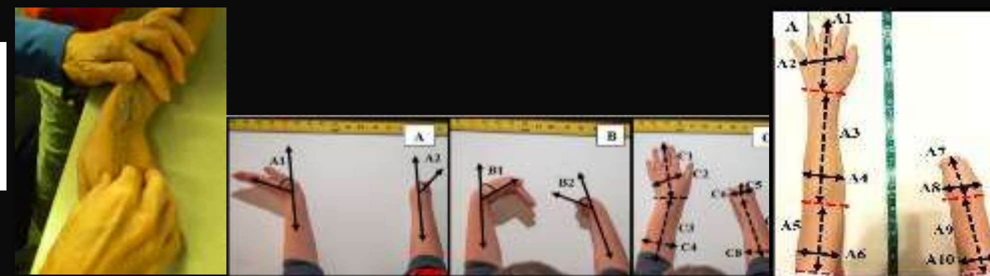
General Procedures

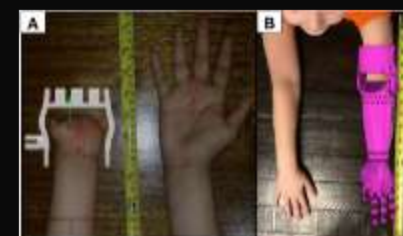
Direct and Remote Measurements

- Anthropometric Measurements: Several anthropometric and ROM measures are extracted using a CAD or image editing software.



3D Modeling and Scaling

- The main aspects of our digital fitting procedures consisted of properly scale the digital design of the prosthesis to the dimensions of: 1) the patient's residual limb for generating an appropriately sized socket, and 2) the non-affected limb to approximate limbs length and overall symmetry.



3D Printing and Assembling

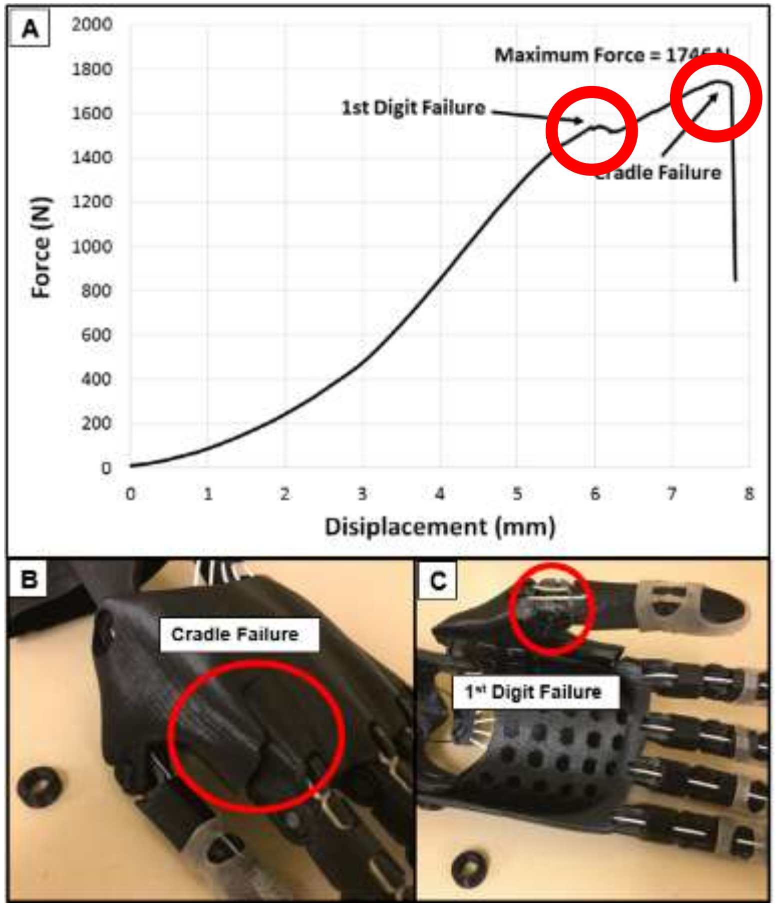
- The 3D printed prostheses can be manufactured using desktop or industrial 3D printers.
- The materials used for printing the prosthetic hand were Raptor polylactic acid.
- All parts were printed at 40% infill (hexagon pattern for desktop, crosshatch for industrial), 60-100 mm/s print speed, 150-200 mm/s travel speed, 70° C heated chamber for acrylonitrile butadiene styrene (50° C heated bed for plolylactic acid), 0.15-.25 mm layer height, and 1mm shell thickness.

BIOMECHANICS RESEARCH BUILDING

Bench Testing of a 3D Printed Partial Hand Prostheses

Compression Failure Test

1. The 1st digit failed at the joint housing allowing for separation of the digit from the hand at 1550 N (348.5 lbf)
2. The prosthetic hand ultimately failed at 1746 N (392.5 lbf)
3. The palm failed by shattering on the dorsal side.



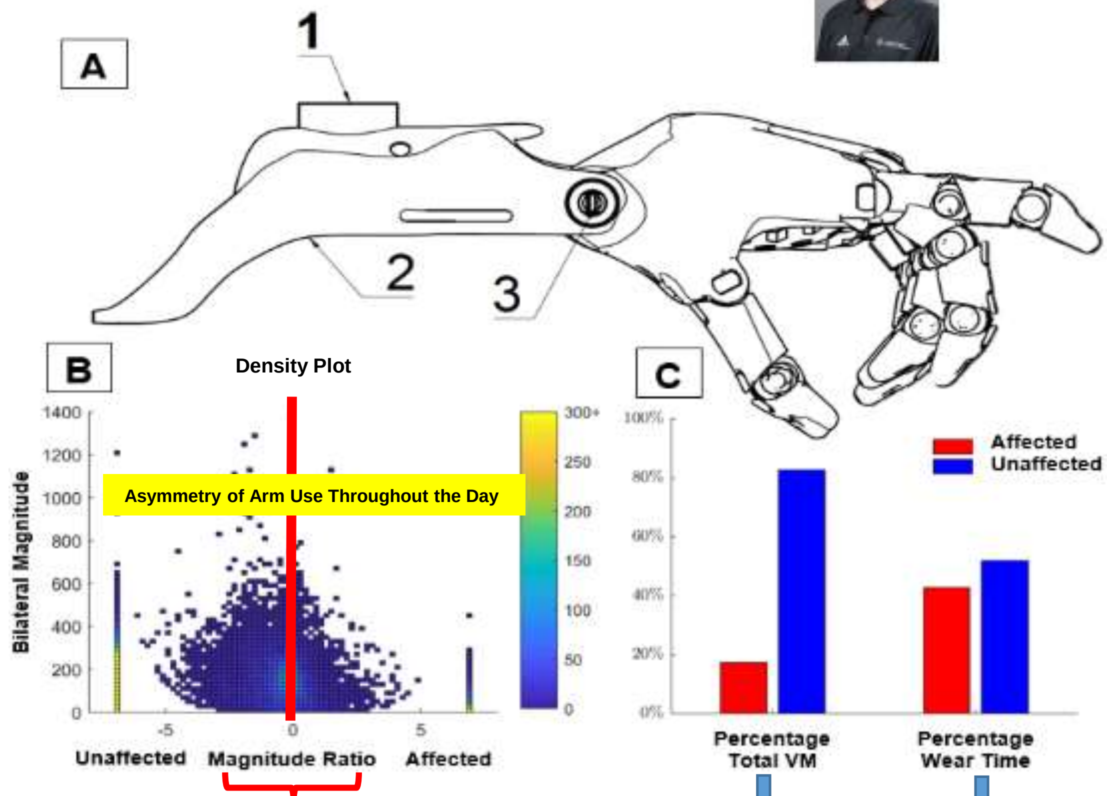
We would like to thank **Jennifer Murphy** from the Department of Physical Medicine and Rehabilitation, Northwestern University Feinberg School of Medicine for her help with designing and preparing the bench test setup.

Brian Knarr, PhD

Assistant Professor
Email: [illegible]

QUANTITATIVE ASSESSMENT OF UPPER-LIMB PERFORMANCE

Figure 1. A) Wireframe drawing showing the integration of sensors into the 3D printed prosthesis. (1) Inertial measurement unit (IMU) and data processing module (2) Thermistor embedded into the gauntlet of the prosthesis (2) Potentiometer embedded into the wrist actuation interface. B) Density plot analysis proposed by Lang et al.,[49] showing asymmetry of arm use favoring the unaffected arm during a 2 day-period of prosthetic use. C) Percentage of wear time and vector magnitude during a 2 day-period. *Data from a 12-year-old research subject with a right partial hand reduction using a 3D printed partial hand prosthesis.



The Bilateral Magnitude quantifies the intensity of activity across both upper limbs

The Magnitude Ratio quantifies the contribution of each upper limb to activity

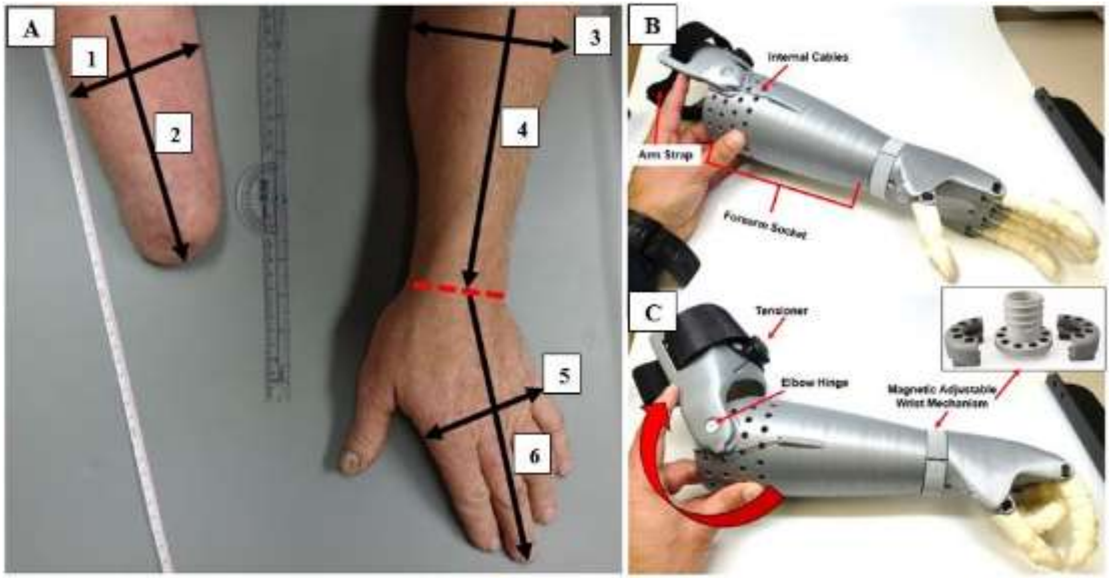
Relative movement

Prosthesis use

Functional Performance and Patient Satisfaction Comparison between a 3D Printed and a Standard Arm Prostheses

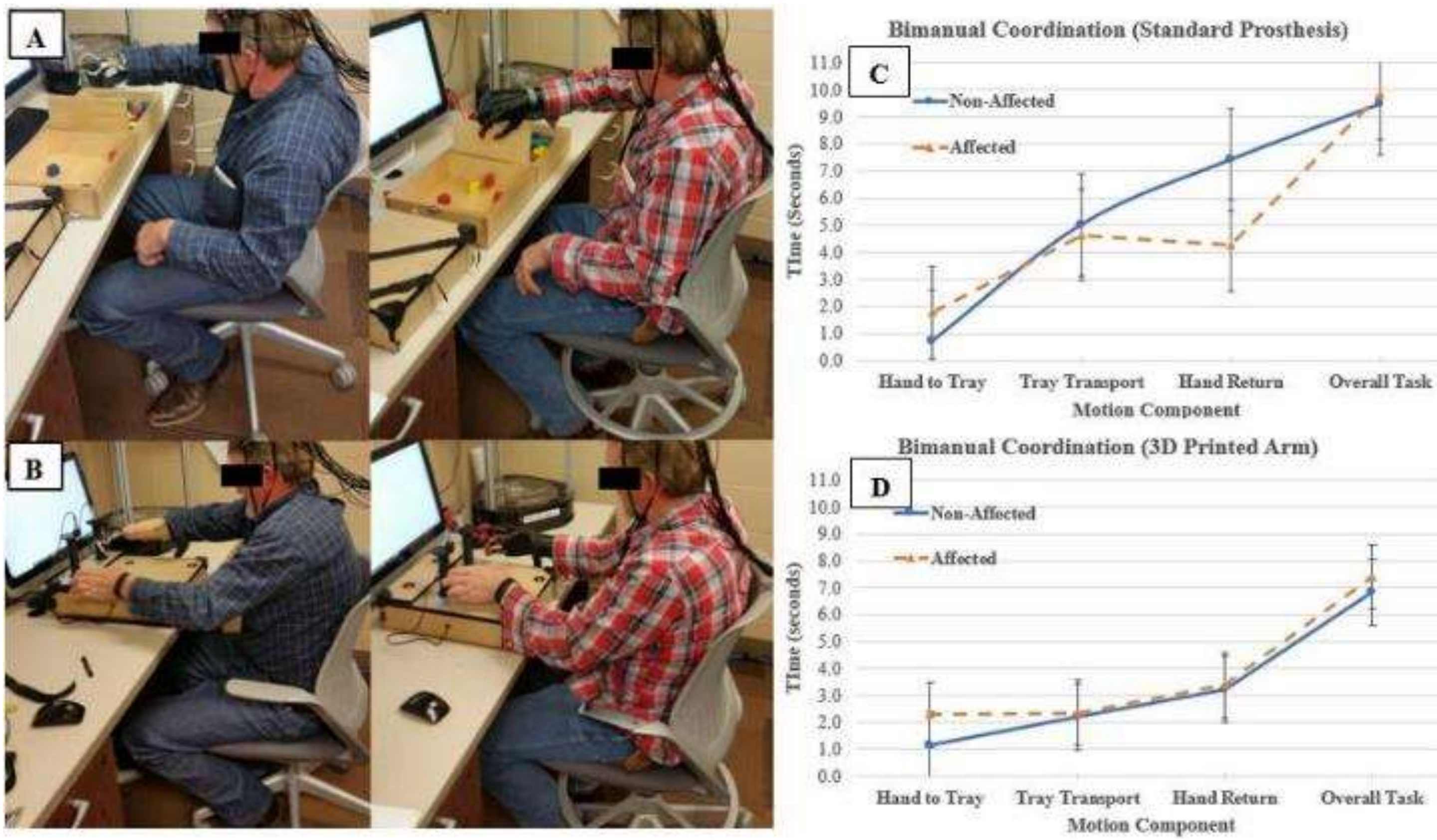
Purpose: The purpose of the current investigation is to compare functional outcomes and patient satisfaction between a standard arm prosthesis fitted in a clinic with a 3D printed arm prosthesis fitted remotely.

Methods: The patient was a 59-year-old male with a traumatic trans-radial amputation of the dominant arm. This case report describes the functional and patient satisfaction outcomes of a 3D printed arm prosthesis fitted remotely versus a standard arm prosthesis after 4 weeks of use.



Functional Performance and Patient Satisfaction Comparison between a 3D Printed and a Standard Arm Prostheses

Results: The main finding of this case study was that the use of a 3D printed arm prosthesis fitted remotely resulted in a better functional performance, but lower overall patient satisfaction than the standard arm prosthesis.



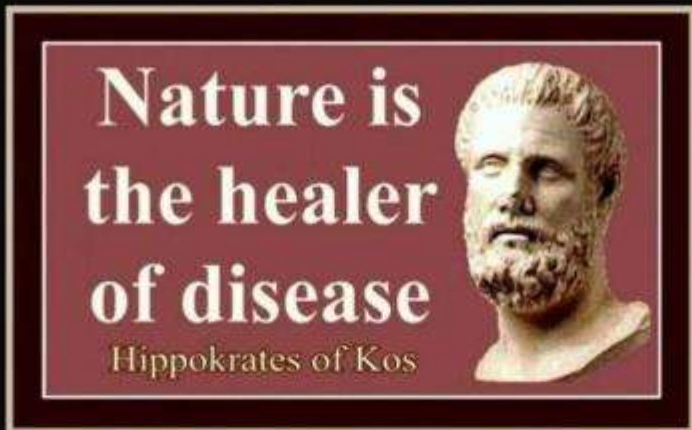
Advance Materials

-Copper Nanocomposites (Mechanism of Action)

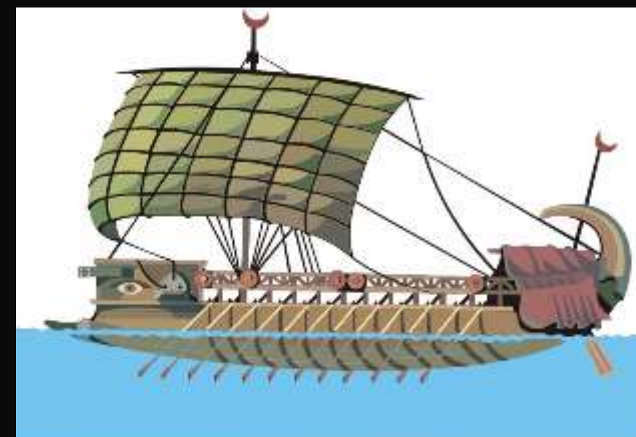
-Development of Antimicrobial 3D Printing Filaments

-Research Findings

Copper as a Biocidal Tool



- The ancient Greeks in the time of Hypocrates (400 BC) were the first to discover the sanitizing power of copper.



- The early Phoenicians nailed copper strips to the body of their ships to inhibit microorganisms, plants, and algae, since cleaner vessels are faster and more maneuverable.

Gadi, B.; Jeffrey, G. Copper as a Biocidal Tool. Curr. Med. Chem. 2005, 12, 2163–2175, doi:10.2174/0929867054637617.

Mechanism of Action

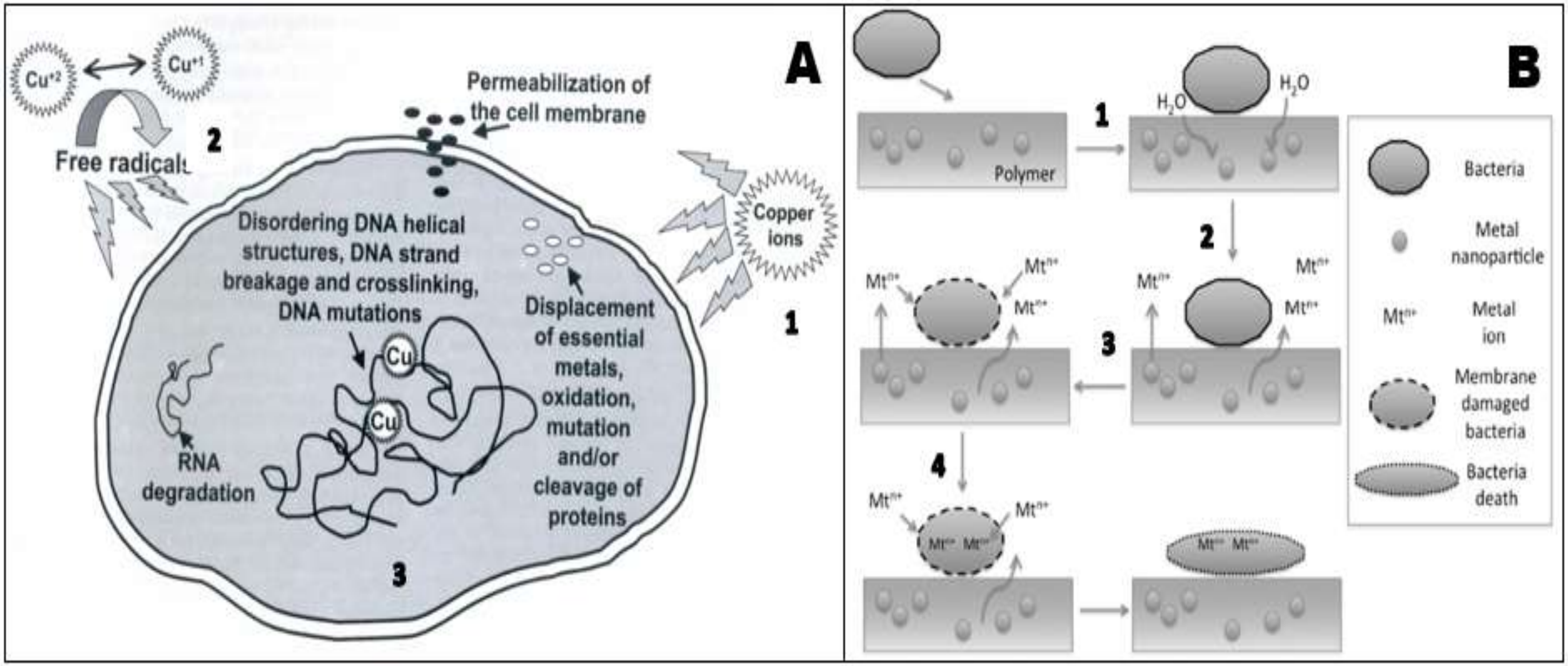


Figure 1. Copper is an essential element for optimal human body function, but toxic to microorganisms. **A.** The main antimicrobial mechanisms of copper consist in producing cell membrane damage via copper ions that damage polyunsaturated fatty acid compromising the structure of the cell membrane and producing leakage of mobile cellular solutes (i.e., potassium ions) resulting in cell death **(A1)**. The redox cycling between Cu^{2+} and Cu^{1+} can catalyze the production of highly reactive hydroxyl radicals (part of reactive oxygen species or ROS), which can subsequently damage cell membrane lipids, proteins, DNA, RNA, and other biomolecules **(A2)**. Once copper and associated hydroxyl radicals are inside of the cell, it produces DNA denaturalization damaging helical structures. Copper also damage and alter proteins acting as a protein inactivator via RNA, useful to deactivate virus such as herpes, HIV-1, and West Nile **(A3)**. **B.** Mechanisms for the enhanced antimicrobial behavior of copper nanocomposites on thermoplastic matrices. Copper nanoparticles on a polymer structure present a stronger antimicrobial effect than microparticles or metal surfaces and facilitate the following process: adsorption of bacteria on the polymer surface triggering the diffusion of water through the polymer matrix due to the medium surrounded the bacteria **(B1)**; water with dissolved oxygen reaches the surface of embedded metal nanoparticles allowing dissolution or corrosion processes and in this way metal ions are realized **(B2)**; metal ions reach the composite surface damaging the bacteria membrane **(B3)**; Afterward, metal ions can diffuse into the bacteria **(B4)**.

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applied sciences

MDPI

Brief Report

3D Printed Antibacterial Prostheses

Jorge M. Zuniga [1,2]

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Received: 21 July 2018; Accepted: 12 September 2018; Published: 14 September 2018

check for updates

Featured Application: **The use of antibacterial 3D printed filaments has promising potential applications in the development of medical devices associated with bacterial development, such as postoperative prostheses, wound dressings, and surgical equipment.**

INTRODUCTION

Bacterial Complications

Dermatoses

Folliculitis

Fungic Infection

Dehiscence

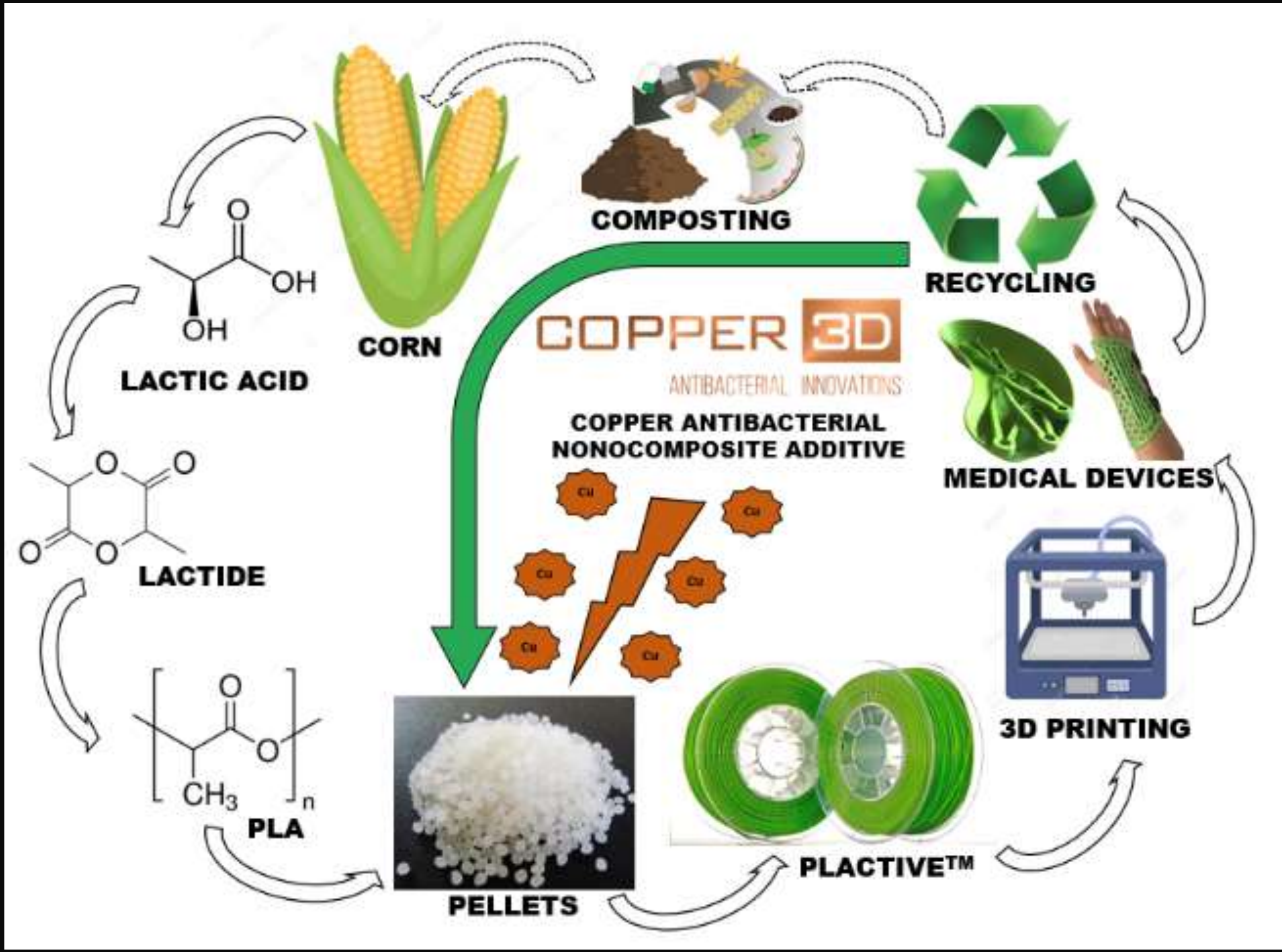
Mucormycosis

Estimated Cost: 28,2 Billion USD (only US)

Adams, P. et al, Current Estimates from the National Health Interview Survey, Vital and Health Statistics

METHODS

Antimicrobial Filament Development

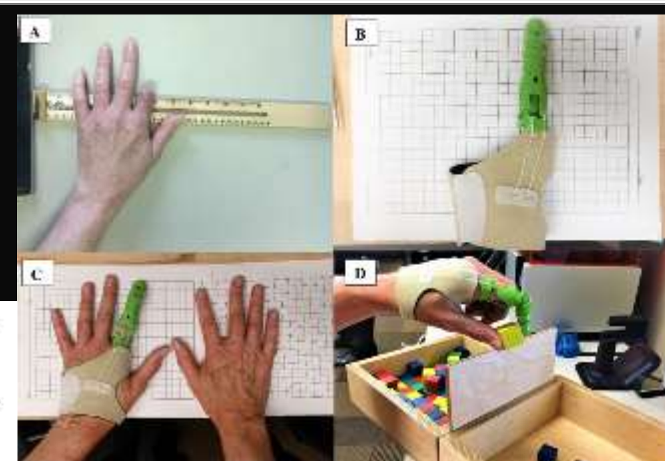


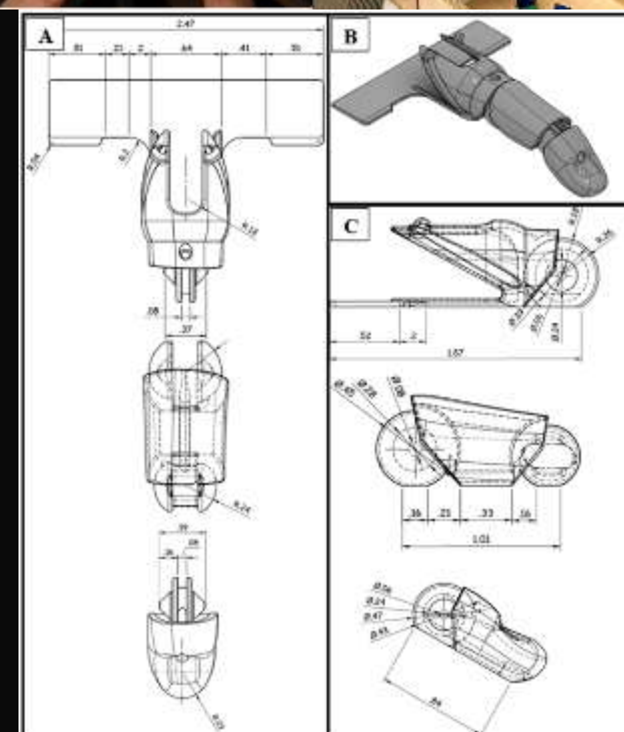
RESULTS

Table 2. Quebec User Evaluation of Satisfaction with assistive Technology (QUEST) Ratings and Box and Block Test.

Items How Satisfied Are You with *:	Subject 1	Subject 2
Dimensions (size, height, length, width)	5.0	4.2
Weight	4.7	4.7
Adjustments (fixing, fastening)	4.3	4.3
Safety (secure)	5.0	5.0
Durability (endurance, resistance to wear)	4.5	4.5
Ease of use	5.0	4.5
Comfort	5.0	5.0
Effectiveness (the degree to which your device meets your needs)	4.6	4.5
Device satisfaction	4.76 ± 0.28	4.59 ± 0.29
Box and Block Test (Blocks per Minute)		
Without prosthesis (3 trials)	17.7 ± 0.6	21.0 ± 1.0
With prosthesis (3 trials)	22.3 ± 1.5	32.3 ± 2.5

* 1 = not satisfied at all, 2 = not very satisfied, 3 = more or less satisfied, 4 = quite satisfied, 5 = very satisfied.



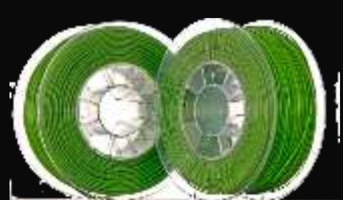


RESULTS

Table 1. Bacterial Analysis Summary

Laboratory	Inoculum (initial load, CFU/ml)	Log_{10} Reduction at 24 hours	Reduction (%)
1	Methicillin-resistant Staphylococcus aureus (7.10E+9)	1.65	98.95
	Escherichia coli (3.33E+9)	1.32	95.03
2	Staphylococcus aureus (6.3E+5)	5.7	99.99
	Escherichia coli (9.3E+5)	4.6	99.99

*CFU: colony forming unit.



DISCUSSION

- **The main findings of the current investigation were that the antibacterial 3D printed filament, PLACTIVE™, can be effectively used for the development of functional 3D printed finger prostheses.**

- **Furthermore, the antibacterial properties of the 3D printing filament after extrusion were not affected.**

- **The thermoforming properties of polylactic acid were not affected by the addition of copper nanoparticles and allowed for necessary post-processing modifications for the final fitting of the 3D printed antibacterial finger prosthesis.**

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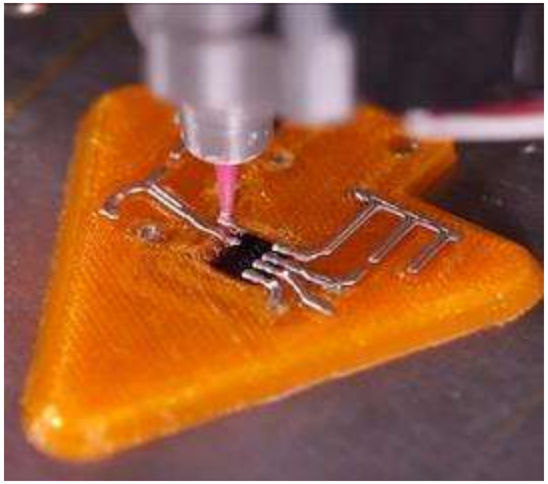
Body-driven (passive mechanical) prosthetics

Active (motorized) prosthetics

Enabling tech: multi-material 3D printing

- Specify different material properties (stiffness, hardness, color)
- Commercial systems (high quality)
  - 3D Systems: ProJet
  - Stratasys: Polyjet
- Desktop or DIY
  - Multi-extruder 3D printers
  - Accessories to add extruders to 1-extruder machines
  - Manually stop/start printing (exchange filaments)



Enabling tech: laser scanning

- Low-cost way to digitize an individual's body shape
- Example: Sense scanner (~$500)
- Easily convert to CAD formats for 3D printing

Enabling tech: microcontrollers

- "Brains" of a powered prosthesis
- Have become extremely affordable over the past 5 years
- Example: Arduino
  - Huge user community and open programming resources
  - Digital and analog input/output
  - Kits for ~$50 include lots of extras (buttons, switches, wire, sensors…)

Enabling tech: EMG

- Electromyography (picking up electrical signals from muscle)
- Allows prosthetic to act based on wearer's intent
- Simple "sticker" sensors
- Requires some signal conditioning (noisy otherwise)
- Myo Band is a popular new product making this more accessible

3D modeling and libraries

- NIH 3D Print Exchange (e-NABLE)
  - https://3dprint.nih.gov/collections/prosthetics
- Thingiverse
  - UnLimbited Arm
- Free CAD software (build/customize models)
  - SketchUp
  - FreeCAD
- No need to reinvent the wheel!

University of Nebraska Omaha

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