Thesis Project Portfolio

'MAP'PING MICROFLUIDIC DEVICES USED FOR MAP HYDROGEL FABRICATION WITH COMPUTATIONAL FLUID DYNAMICS SIMULATIONS

(Technical Report)

FROM BIAS TO INADEQUATE PATIENT CARE: IDENTIFYING CONFOUNDING AND MODIFYING VARIABLES IN PHYSICIAN IMPLICIT BIAS AND STRATEGIES TO LIMIT THEM

(STS Research Paper)

An Undergraduate Thesis

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Brooks David Pollard

Spring, 2023

Department of Biomedical Engineering

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Introduction

This paper focuses on the design of devices for microporous annealed particle (MAP) gels for tissue regeneration methods in the clinic as well as the specific variables that affect the relationship between implicit bias and patient care in clinical settings. The loose coupling between device development for clinically relevant hydrogels and the current progress being made by physicians to resist effects of implicit biases provides for an investigation of translational research from bench to bedside. It addresses the broad question, "How can translational research engineering designs be more efficacious to better the treatment and care of all patients without the harm of implicit bias from providers?" Through realizing the confounding and modifying factors that lead to poor patient care as a result of implicit bias and improving engineering designs, specific strategies can be implemented to directly combat bias and treatment efficacy of translational procedures can be improved.

Modeling Microfluidic Devices for MAP Hydrogels with Computational Simulation

Injectable biomaterials, such as hydrogels, are widely used to support tissue regeneration in volumetric muscle loss (VML) injuries. Microporous annealed particle (MAP) gel is a specific type of hydrogel that provides interconnected pores for cellular migration and integration with surrounding tissues (Griffin et al., 2015). MAP scaffolds have been shown to improve cell delivery and communication and could act as an alternative for grafting techniques (Koh et al., 2019). This property of MAP gel is made possible by the unique methodology for its synthesis, which uses microfluidic devices to achieve optimal particle sizes. The differentiation in particle size affects the stiffness and porosity of the gel; which is important for robust tissue regeneration (de Rutte et al., 2019). The current design for step emulsification devices with channels smaller than 10 microns results in nonuniform particle size and hinders high throughput fabrication due to issues with fluid dynamics and pressure. Certain hydrogel formulations present similar complications at even larger channel sizes due to their chemical properties. Without resolution of this issue, negative effects such as lack of control over porosity, cellular integration, and increased foreign body response could result in vivo or impede the use of bioactive formulations. The primary objective of the capstone study is to design a novel device that improves the uniformity of particle sizes and effectiveness of MAP gels by ensuring consistent physicochemical properties. Upon reaching an optimal design that resolves previous device flaws, the device will be created and used for further studies in treating VML with MAP gel.

Identifying Confounding and Modifying Variables in Physician Implicit Bias that Affect Patient Care and Proposed Strategies to Limit Them

The engineering design phase of hydrogel development is only truly effective if implemented to all patients that need them, which requires medical doctors to provide quality care to patients of different races, ethnicities, and socioeconomic backgrounds. Implicit bias refers to a nonconscious preference or positive association for certain groups or communities of people over others. These biases are inherent for almost everyone, despite explicit attitudes or behaviors. While they may not have a direct effect in many social situations, in the field of healthcare there is a researched and documented effect they have on minority communities when medical doctors/physicians exhibit them. Since this issue can have harmful and negative effects on the minorities affected, there has been a push for implicit bias awareness and training for upcoming physicians. Most of the current literature and research on implicit bias in healthcare points out a cause and effect relationship between implicit bias and the negative effects it has on minority patient communities. While these evaluations are necessary for identifying implicit bias' effects, there is a lack of identification in literature of the potential confounding and modifying factors that may detail the path from bias to lower quality care. These specific variables contribute to bias intensity and exacerbation, which leads to worse outcomes in patient care quality. Identifying these variables explicitly would provide critical information in mitigating the low quality care by providing specific strategies that can limit the effects of confounding factors. The primary goal of the paper was to identify specific confounding/modifying factors that strengthen the negative outcomes in patient care that are associated with implicit bias in healthcare and to suggest how these variables could be mitigated or removed to lessen their effects.

Conclusion

In regards to the technical project, I have successfully recreated the CAD versions of the original microfluidic devices that are actually used in the Griffin lab and ran three COMSOL simulations on the 19.7um, 10um, and 5.6um devices. From this, I was able to quantify the pressure and velocity differences of fluid flow through the channels and how the different sizes affect these parameters. I found that the pressure gradient is much higher on the 5.6um channel size and that the velocity increases as fluid moves through the channels. While I did not achieve the objective of creating a new microfluidic device, I have been able to provide information that can be used by the lab to possibly recreate the device. For future research, the simulation data could be used to better design a new device that improves upon the current.

As for the STS research topic, I believe I successfully achieved the specific objectives I set in that I used relevant literature sources to identify variables that affect the cause and effect relationship of implicit bias and patient care. Additionally, in a table format, I provided strategies I found would be beneficial in limiting the identified variables. I believe that I also personally gained a better understanding of the actual factors that lead to lower quality patient care, which sheds light on the gap between implicit bias and its effects. In future research, I think it would be interesting to experimentally test the strategies against these variables in medical settings to determine their effectiveness. Moreover, information like this could be expanded upon and used to educate physicians so they better understand the effects of implicit bias.

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor Dr. Don Griffin, Department of Biomedical Engineering

‘MAP’ping Microfluidic Devices for MAP Hydrogels with Computational Simulation

A. ABSTRACT

Microporous annealed particle (MAP) gel is a specific type of hydrogel with a capability to provide cellular channels for migration and integration with surrounding tissues[1]. The desirable functionality of MAP gel is made possible with microfluidic devices that produce particles of uniform size and shape. The differentiation in particle size affects the stiffness and porosity of the gel; components important for robust tissue regeneration[2]. The current design for step emulsification devices with channels smaller than 5um result in nonuniform particle size due to issues with fluid dynamics and pressure. The downstream negative effects of this are potentially a lack of biocompatibility and enhanced foreign body response in vivo. The primary objective of the capstone study is to identify issues associated with fluid movement with small channel size devices in order to propose design modifications for a novel device that improves the uniformity of particle sizes and effectiveness of MAP gels by ensuring consistent physicochemical properties. The study had two specific aims: (1) to identify fluid pressure issues that create non-uniform MAP gel particle sizes in the current design of microfluidic devices for MAP gel synthesis, and (2) to create a more effective novel microfluidic device design that improves device capability for optimal MAP gel production. The 19.7 and 5.6um versions of the device were recreated in CAD and simulated in COMSOL Multiphysics software to identify velocity and pressure profiles. The 5.6um channel device exhibited higher overall velocity compared to the 19.7um device, but experienced increased pressure in aqueous passages. Proposed device modifications included elongation of channels to decrease velocity and changes in geometry of the aqueous passages to decrease overall pressure. Future work includes further simulations to better understand the relationship these parameters have in MAP gel quality and later development of a novel device.

Keywords: Microporous annealed particle gel, microfluidic devices, particle size, simulation, physicochemical properties

B. INTRODUCTION

Volumetric muscle loss (VML) is a large-scale injury event to skeletal muscle that affects both civilian and military patients. This is characterized by a volume of tissue removed from traumatic injury or surgical ablation that is large enough to have loss of extracellular matricies (ECM's) and stem cells, thus rendering the tissue nonfunctional and incapable of regeneration without intervention[3]. In most cases, patients must undergo amputation of the area affected, making these incidences extremely debilitating. For military personel, VML injuries contribute most to long-term disability and can lead to signficant strength loss[3].

Current Treatments for Volumetric Muscle Loss

Most of the injuries that involve volumetric muscle loss are due to high-energy causes, like bullets or bomb blasts, where military patients are most affected. Civilian incidents usually involve high impact fractures that also result in VML[4]. The two most common outcomes from these injuries are limb salvage or amputation. Both of these surgical procedures are not ideal and can lead to life-long disability. In the case of limb salvage, muscle function is rarely recovered due to lack of regenerative capabilities[3], despite soft tissue reconstruction.

Another approach is a reconstructive method that uses acellular ECM's to create a microenvironment that facilitates regeneration. This procedure involves removal of scar tissue and implantation of decelluarlized ECM in affected areas. Previous studies with this technique are limited and show only a marginal improvement in strength ability and function[3]. Other similar approaches involve acellular biomaterials in combination with cells or growth factors as well as rehabilitation therapies (Table 1) although they are limited to rodent subjects[5].

Microporous Annealed Particle Gel in Volumetric Muscle Loss

Injectable biomaterials, such as hydrogels, are widely used in regenerative medicine to provide aid to redevelop tissue from events of volumetric muscle loss (VML). Microporous annealed particle (MAP) gel is a specific type of hydrogel with a capability to provide cellular channels for migration and integration with surrounding tissues[1]. MAP scaffolds have been shown to improve cell delivery and communication and could act as an alternative for grafting techniques[2]. The impressive and desirable functionality of MAP gel is made possible by the unique methodology for its synthesis using microfluidic devices to achieve optimal particle sizes. The differentiation in particle size affects the stiffness and porosity of the gel; components important for robust tissue regeneration[3].

gure 1: Artistic interpretation of MAP gel facilitating tissue healing[12].

MAP gel has shown to rapidly improve muscle function from VML with 80% recovery from baseline, the maximum that is considered possible[6]. This is made possible by a vascular network formation from MAP that allows for robust cell integration and subsequent force generation from skeletal muscle. Cells from surrounding tissue move

Table 1: Previous Treatment Methods Involving Biomaterials

Method	Number of Rodents	Percentage of VML	Rehabilitation	Outcome in Fiber Regeneration
Acellular biomaterial + cells				
Corona et al.[7]	6	20%	Yes	Low-moderate fiber regeneration
Garg et al.[8]	8	20%	No	No fiber regeneration, protective effect
Machingal et al.[9]	5	50%	No	Significantly increased strength
Acellular biomaterial				
Greising et al.[10]	3-6	20%	Yes	Moderate, strength increased by 33%
Marcinczyk et al.[11]	8-11	15%	No	Hydrogel - Significant improved muscle weight and infiltration of satellite cells

into the gel and the VML created gap is bridged by cells themselves, as seen in Figure 1. This creates functional muscle tissue even after degradation of the MAP scaffold, effectively treating volumetric muscle loss in the affected area.

Microfluidic Devices for MAP Gel Synthesis

Considering the overwhelming positive benefits of MAP gel for injury involving VML, there is a signficance for creating MAP gel in an efficient and efficacious manner. Microfluidic, or parallelized step emulsification devices, were developed to synthesize MAP gels with scalable high throughput and pH controlled crosslinking for highly modular microporous environments[2]. Microfluidic devices are riddled with micro-channels with two inputs: one for oil and one for the MAP gel solution. MAP gel solution is pushed through the channels by fluid pressure from syringe vessels and particles are moved along by oil movement (Figure 2). Proton acceptors, dissolved in the oil phase, are able to initiate crosslinking to create uniform physicochemical properties of particles. In an ideal scenario, this method provides for scalable high throughput and continous production of MAP gel that outperforms other low throughput procedures[2]. It aims to increase uniformity of particle diameter by using channels with gradual expansion, compared to sharp expansion. Additionally, there is an ability to modulate the stiffness, or robustness of crosslinking, to control the rate of degradation in tissues, based on the regenerative goals. However, the current design for step emulsification devices lacks this ability for small particle sizes and results in nonuniform particle size and loss of robust tissue redevelopment due to issues with fluid dynamics and pressure.

Principles of Proposed Device

The current device design does not account for the fluid dynamics associated with channel sizes that are 5 microns or smaller. Within the current channels, pressure is created from fluid movement and builds up with no escape, resulting in particles pushed through that are too large and nonuniform. This has direct negative effects in vivo, such as lack of biocompatibility, loss of cellular integration, and enhanced foreign body response[7]. The novelty in the proposed device design relies on a device that consistently performs with high throughput while maintaining uniform particle diameter. The creation of such a device would allow for experimentation with smaller sized particle gels for downstream applications in tissue regeneration.

The primary objective of the capstone study is to design a novel device that improves the uniformity of particle sizes and effectiveness of MAP gels by ensuring consistent physicochemical properties. In achieving the objectives of the lab, thorough understanding of the current state of the device and the problems associated with it is necessary. Then device designs can be created and tested via software

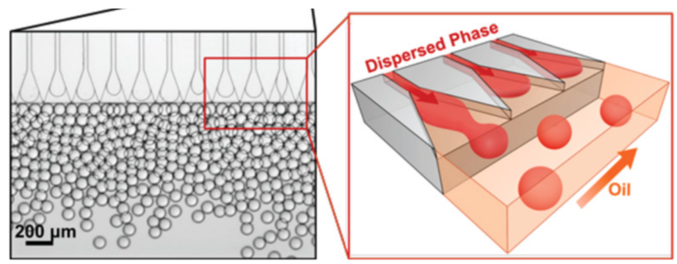

Figure 2: Microfluidic device channels dispersing particles in oil phase[3].

simulations to determine their effectiveness. Upon reaching an optimal design that resolves previous device flaws, the device will be created and used for further studies in treating VML with MAP gel. This procedure is achieveable through the following specific aims:

Aim 1: To identify fluid pressure issues that create non-uniform MAP gel particle sizes in the current design of microfluidic devices for MAP gel synthesis.

- Pressure build up within the microchannels in step emulsification can inhibit MAP gel solution passage through channels or force fluid through the channels too quickly. These effects limit throughput and create gels that have non uniform particle size, which has downstream effects in tissue regeneration.
- Using engineering and physics software, a simulation of the fluid flow and dynamics will be modeled and observed. Pressure, velocity, and shear fluid forces can be determined as well as areas of interest for pressure build up.

Aim 2: To create a more effective novel microfluidic device design that improves device capability for optimal MAP gel production.

- The positive characteristics of the current design include the high throughput, efficiency, and initiation of crosslinking in the oil phase, among others. The resolution of negative aspects includes manipulation of pressure, pumping velocity, and shearing forces (among others) to have uniform physicochemical properties of particles.
- Using AutoCAD and AutoDesk Fusion360, new device designs will be developed with measurable dimensions similar to the current design. Simulation software will allow for testing of completed designs to ensure resolution of current issues. This will be accomplished in the form of a measurable reduction in excess pressurization or shearing forces within channels that produce particles. Additionally, a change in the way the MAP aqueous solution is pumped will be modified to better reduce pressure build up.

If the primary objective of the capstone study is achieved, a novel device design that improves the uniformity of particle sizes and effectiveness of MAP gels by ensuring consistent physicochemical properties will be fabricated. Upon reaching an optimal design that resolves previous device flaws, the device will be created and used for further studies in treating volumetric muscle loss with MAP gel.

C. RESULTS

Microfluidic Device Recreation in CAD

The current step emulsification devices were designed in CAD using Autodesk Fusion360 to be compatible for use in computational fluid dynamics simulations. With the template provided by de Rutte et al.[2], the aqueous and oil passages were cut 0.25mm into a solid that represents PDMS, which was extruded to 6.35mm. Then, based on the channel height, the bottom template was cut into the PDMS solid. The height of the channel refers to how extruded the channels are from the PDMS solid (Figure 3). The following channel heights that are used in the Griffin lab for MAP gel fabrication were designed: 52um, 41.2um, 26.1um, 19.7um, 10um, and 5.6um.

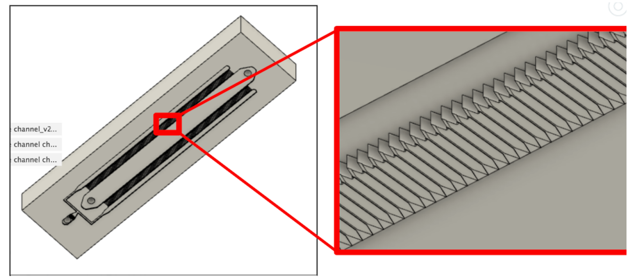

Figure 3: CAD version of the original microfluidic device

To complete the device, a solid rectangular prism (75x26x1mm) was added to cover the bottom of the device. This mimics the glass slide used in the lab that adheres to the PDMS so that fluid flow is constrained to the microfluidic channels. The finished 19.7um device (Figure 4) was used as a model void of pressure issues associated with channel height. As such, it served as a baseline control to compare fluid dynamic properties to that of the smaller channel height device, the 5.6um. Finished renderings of the 19.7 and 5.6um devices were then uploaded onto COMSOL Multiphysics software.

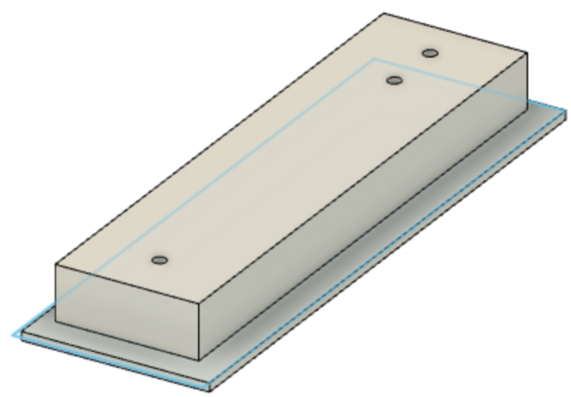

Figure 4: 19.7um finished CAD design in Autodesk Fusion360

COMSOL Multiphysics Computational Fluid Dynamics Simulations

The 19.7um and 5.6um device simulations were run using the physics modules of creeping flow (spf) and transport of diluted species. The creeping flow (or Stokes flow) physics model is commonly used in microfluidics because it describes the flow of viscous fluids at low Reynolds numbers, where the inertial forces are negligible compared to the viscous forces. The SPF interface allowed for the simulation of laminar flow in microfluidic channels and could be used to accurately predict flow velocities, pressure drops, and shear stresses. Additionally, to simulate the transport of solutes in microfluidic devices, the Transport of Diluted Species physics interface was used. This interface accounted for the advection and diffusion of solutes in the fluid and allowed for the simulation of phenomena such as diffusion-driven reactions, electroosmotic flow, and ion migration.

To simulate the flow of fluid through a microfluidic device, the device geometry had to be accurately represented as a mesh. The COMSOL software generated a mesh by discretizing the geometry of the device into small elements or nodes. This process was necessary for numerical simulations as it allowed the equations governing the fluid flow to be solved on a finite set of discrete points. COMSOL used an automated mesh generation algorithm to create a mesh based on the device's CAD rendering. The software took into account the geometry, dimensions, and complexity of the device when generating the mesh. The resulting mesh (Figure 5) could be refined and adjusted as necessary to achieve an appropriate balance between accuracy and computational efficiency. Once the mesh had been generated, the fluid flow simulations could be carried out using the appropriate physics models and boundary conditions.

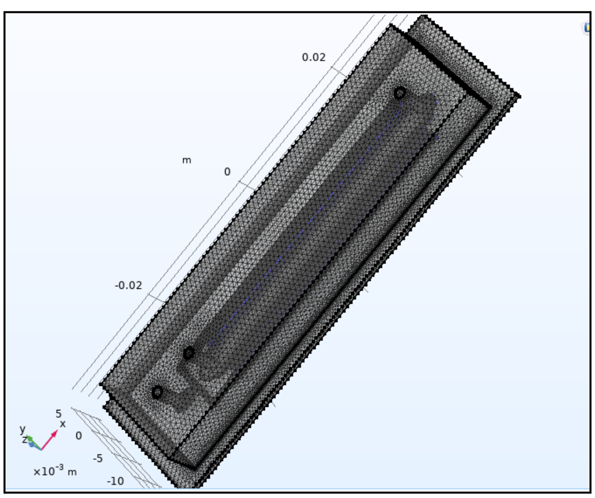

Figure 5: 19.7um mesh build

With a completed mesh build of both devices, the stationary 1 study using the creeping flow (SPF) and transport of diluted species physics in COMSOL could be conducted. The boundary conditions, including inlets and outlets were appropriately determined. The aqueous and oil flow rates were set to 6ml/hr and 10ml/hr, respectively, as those rates are conventionally used in the lab for MAP gel fabrication. Once the physics settings and boundary conditions had been specified, the simulation could be run using the stationary 1 study type.

The completed stationary study results for the full devices principally included the velocity profiles for the 5.6um and 19.7um devices (Figures 6 & 7).

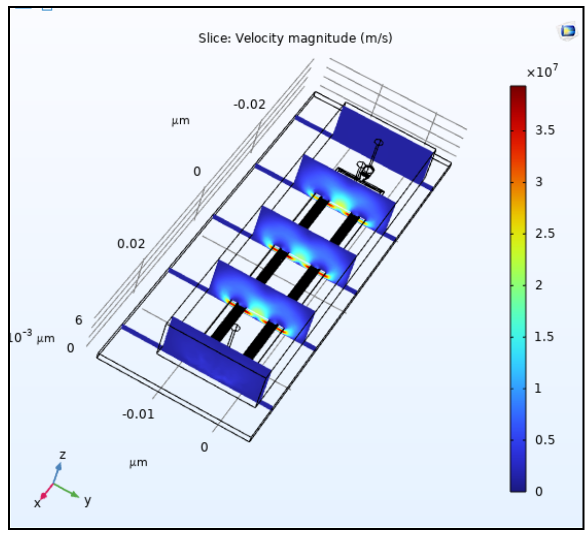

Figure 6: Full (5.6um) device velocity profile for stationary study

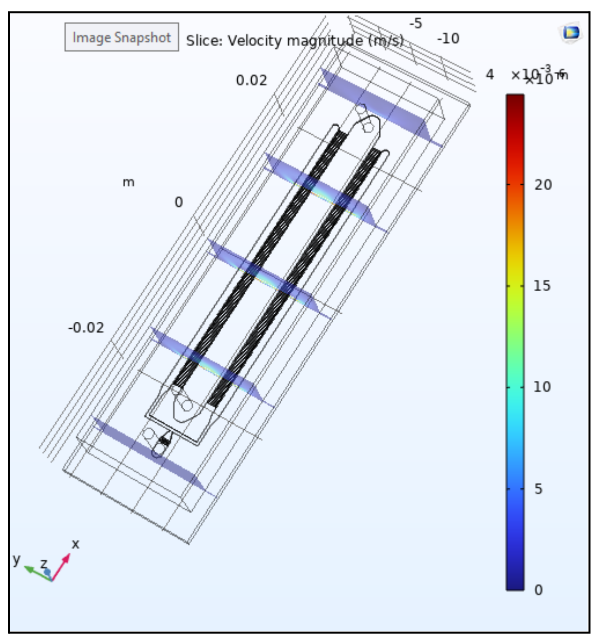

Figure 7: Full (19.7um) device velocity profile for stationary study

Figure 8 shows the velocity profile of the fluid as it flows through the device channels of the 19.7um. The velocity is highest at the outlet of the channel, where the fabricated gel particles exit. The velocity of the aqueous fluid as it enters the channel and throughout the channel maintains a constant, slower speed than the exit. As such, the velocity profile is asymmetric, with a higher velocity on the exit side of the channels than on the other.

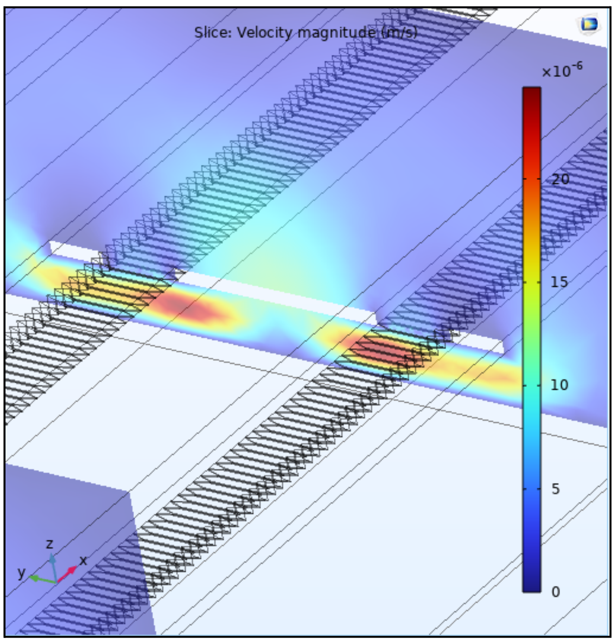

Figure 8: 19.7um device close up of velocity profile

Figure 9 exhibits the close up of the 5.6um device's velocity profile, where there is increased velocity of the fluid before entering the channel, throughout the channel, and exiting the channel. This shows a symmetric pattern of high velocity throughout aqueous solution moving through the channel.

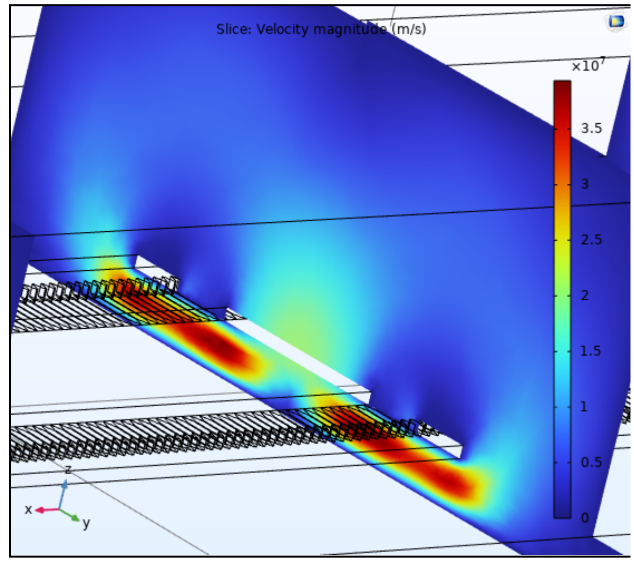

Figure 9: 5.6um device close up of velocity profile

In Figure 10, close view snapshots of the pressure profiles of the fluid through the devices are shown, as pressure is another important characteristic that affects the performance of the device. The pressure profile of the fluid as it flows through the 5.6um aqueous passages is higher than that of the 19.7um device, as indicated by the lighter blue color key. For both devices, the pressure is highest at the oil passage, where particles are exiting the microfluidic channels.

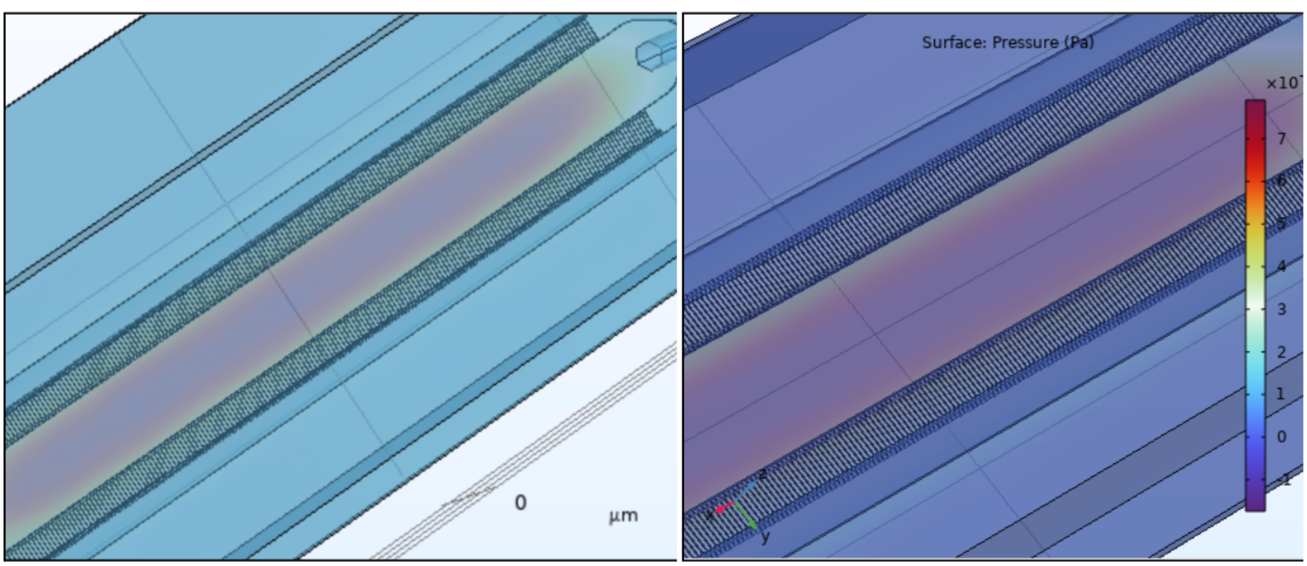

Figure 10: Pressure profile close ups for 5.6um (left) and 19.7um (right) devices

D. DISCUSSION

The results presented in this study provide insights into the issues associated with small 5.6um channel devices and potential modifications to improve the quality of the MAP gels that use this size. The velocity profile analysis in Figure 8 and Figure 9 indicates that the fluid velocity is highest at the outlet of the channel where the fabricated gel particles exit. This suggests that the gel particles experience a higher shear force at the exit, which can potentially lead to deformation or damage of the gel particles. Additionally, the symmetric velocity profile observed in the 5.6um device implies that the gel particles experience a higher shear force throughout the channel length. This could result in non-uniform deformation or damage to the gel particles and thus impact the quality of the MAP gel. Therefore, it is important to carefully balance the fluid flow rate to avoid excessive shear forces on the gel particles.

The pressure profile analysis presented in Figure 10 shows that the pressure is highest at the oil passage, where particles are exiting the microfluidic channels, for both devices. However, the pressure profile of the fluid through the 5.6um aqueous passages is higher than that of the 19.7um device. This indicates that the 5.6um device may experience a higher flow resistance, which could lead to flow instability or clogging. To mitigate this issue, modifications such as optimizing the channel geometry or adjusting the fluid viscosity could be explored.

The simulation results show that the velocity and pressure profiles through the microfluidic device are affected by the presence of narrow channels, as well as by the presence of channels that divert some of the fluid flow to one side of the device. Understanding these profiles can help in the design and optimization of microfluidic devices for channel sizes that are smaller than 10 microns.

Future Work

There are several areas of future research that can be investigated based on the results of this study. One potential suggestion would be to include simulations with more variations in channel height. This study only focused on the 19.7 and 5.6um sizes so including more sizes could provide a more comprehensive analysis of height's effects on velocity and pressure profiles in the devices.

Another suggestion for future research would be to utilize the simulation results to redesign the current devices to create higher quality MAP gels. Device modifications, like manipulating the aqueous and oil passage geometry, could reduce pressure build up and decrease velocity through the channels. Additionally, application of channel coatings could reduce the shear forces associated with the smaller channel heights and lead to improved quality of MAP gels.

Challenges and Limitations

There was a significant amount of time spent attempting to operate the Autodesk Computational Fluid Software (CFD). There were multiple problems related to the storage and loading capacity of the computer as well as the file size of the microfluidic device CAD. Upon pivoting to Comsol's version of the software on a different computer, there were limitations in how long the software could be used. Moreover, one simulation study took 13 hours or more to completely finish running. Even small steps, like mesh building or boundary inputs, consumed time due to the file size and low RAM on the computer being used.

Another challenge was the learning curve associated with both Autodesk CFD and Comsol Multiphysics software. Given there was no previous experience in the software from advisors and teaching assistants related to this study, the software had to be learned independently, which was very time consuming.

E. MATERIALS & METHODS

<u>Modeling Current Device in CAD</u>
Using Autodesk Fusion360 software, the current device design that was proposed by de Rutte et al.[2] was modeled in 3D orientation. Six versions of the device were created that varied in the following channel sizes: 52um, 41.2um, 26.1um, 19.7um, 10um, and 5.6um.

<u>COMSOL Fluid Simulation</u>
The designs were uploaded into COMSOL Multiphysics software, where a simulation of the

fluid movement was conducted. Using the simulation, areas within the device of fluid pressure build up were analyzed and tabulated. The parameters that were most attended to was the excess pressure in channels, shear fluid forces through channels, and fluid velocity.

F. END MATTER

Team and Experience

I have worked as a volunteer assistant researcher for over a year in the Griffin Lab under the supervision of Areli Rodriguez. Throughout my time, I have been able to produce MAP gel using microfluidics, purify MAP gels, observe animal mechanical/fluid testing, run chemical modification assays, biomaterial mechanical testing, etc. Before the Griffin Lab, I was involved in mice studies that investigated how genetic variation in mice populations affected bone and muscle loss from mechanical unloading at Virginia Commonwealth University. I have become familiar with the lab goals of the Griffin Lab and have taken on this research effort to better the methods used for synthesizing MAP gels.

Acknowledgements

This work was achieved with the advising and aid of Areli Rodriguez, a Ph.D. candidate in the Department of Biomedical Engineering, and Dr. Don Griffin, a professor in the Department of Biomedical Engineering; both affiliates of the University of Virginia. Additionally, Zehra Demir, a graduate student teaching assistant for the Capstone course helped troubleshoot technical problems.

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In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Brooks Pollard

Spring, 2023

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor Kent Wayland, Department of Engineering and Society

Introduction

Implicit bias refers to a nonconscious preference or positive association for certain groups or communities of people over others. These biases are inherent for almost everyone, despite explicit attitudes or behaviors. While they may not have a direct effect in many social situations, in the field of healthcare there is a researched and documented effect they have on minority communities when medical doctors/physicians exhibit them. Since this issue can have harmful and negative effects on the minorities affected, there has been a push for implicit bias awareness and training for upcoming physicians. Most of the current literature and research on implicit bias in healthcare points out a cause-and-effect relationship between implicit bias and the negative effects it has on minority patient communities. While these evaluations are necessary for identifying implicit bias' effects, there is a lack of identification in literature of the potential confounding and modifying factors that may detail the path from bias to lower quality care. These specific variables contribute to bias intensity and exacerbation, which leads to worse outcomes in patient care quality. Identifying these variables explicitly would provide critical information in mitigating the low-quality care by providing specific strategies that can limit the effects of confounding factors. As such, the research question for this paper is "What specific confounding/modifying factors strengthen the negative outcomes in patient care that are associated with implicit bias in healthcare and how can each one be mitigated or removed to lessen their effects?"

Context on Implicit Bias in Healthcare

There is evidence to suggest that implicit bias exists in healthcare and disparages minority communities, like non-white, lower socioeconomic status, etc patients. Physicians experience low to moderate levels of implicit bias against people of color (Hall et al., 2015). While these levels of implicit bias are comparable to those of the general population, it must be known that especially in healthcare there are negative effects experienced by people of color. For example, pro-white bias physicians were less likely to recommend diagnosing thrombolysis in black patients when compared to white patients (Hall et al., 2015). In addition to unnoticed diagnoses, there is evidence to suggest that implicit biases led to “delay in seeking care, non-adherence, mistrust, reduced health status, and avoidance of the health care system” (Sabin et al., 2009). These factors taken together illustrate the harm that even low to moderate implicit bias can have on minority communities and the importance of combating bias in healthcare.

Context on Modifying/Confounding Variables

Confounding variables are a type of extraneous variable that are related to a study’s independent variable and causally related to the study’s dependent variable. As such, they are related to both exposure and outcome, but not on the causal pathway between the two (Nurmatov et al., 2012). Confounding factors serve to intensify a relationship between cause and effect without being directly tied to the cause itself. In the context of implicit bias in healthcare, implicit bias is the cause and lower quality patient care is the effect. The confounding factors could include behaviors, communications, treatment options, etc. that contribute to lower quality patient care, while maintaining a correlation with use of implicit bias. It is critical to investigate these factors further to define more narrowly what contributes to lower quality patient care and to more easily combat them at their sources.

Modifying factors, or effect modification, is a measure of association of a third-party variable on the effects of the factor that is being studied. In other words, it is a risk ratio that explains why some category may experience less or more of a given effect. These variables are not biases, but rather properties that may contribute or not contribute to the intensity that an effect has (Nurmatov et al., 2012). In the context of this paper's goals, these variables may be a specific race, socioeconomic status, gender of patients or even patient behaviors, like patients that ask more questions versus those that stay silent. These factors will help identify specific groups or types of patients that experience more negative effects so physicians can be more aware of intensified effects of bias.

Context on Previous Attempts to Mitigate Bias Effects

Most medical schools, hospitals, and healthcare industries are aware of the implicit bias presence and have implemented training and/or strategies to mitigate it. One particular strategy is patient activation, which refers to increased engagement of patients toward physicians. These patients will advocate for themselves more, ask frequent questions, or make their opinions or concerns known (Gainsburg et al., 2022). This type of strategy works to reduce the negative effects of bias rather than attempting to reduce the levels of bias itself. There was sufficient evidence to suggest that patients behaving in a more engaging and active manner reduced the negative effects of bias for black patients (Gainsburg et al., 2022). Despite these results, it is not ethically the patient's responsibility to reduce bias effects as healthcare professionals should provide high-quality unbiased care to everyone.

Another common method for reducing bias effects is to implement training courses or classes for medical school students to be aware of the bias and how to work against it. The method involved having medical school students take an Implicit Association Test (IAT) before and after a teaching session on health disparities and implicit biases. Additionally, students were expected to self-report on their own biases and if they believed they would unconsciously affect healthcare decisions. It was shown that students that denied the existence of unconscious bias affecting their decisions in medicine were dismissive of the implicit bias test (Gonzalez et al., 2014). The students that accepted the fact unconscious bias affects their decisions in medicine were assumed to be aware due to the course they took on the matter. It was suggested that implicit bias cannot be taught in a single course and should be focused on in a more robust way to eliminate health disparities that result from bias.

Significance of Research

Much of the previous literature investigating implicit bias is limited in that it does not account for effect modification and confounding variables (Maina et al., 2018). These variables have the potential to exacerbate or alter the impact of implicit bias on patient care, and therefore, must be taken into consideration. In a review by Maina et al., they detailed that only one or two studies out of the 14 they reviewed explored extraneous variables, like physcian gender, physician awareness of bias, and aversive racism (2018). This significant limitation in previous studies has made it difficult to identify the actual causes of negative effects and find solutions to improve patient care.

To address this issue, this paper focused on identifying these extraneous factors and their effects on patient care. By doing so, the study aimed to offer plausible solutions that could have a greater impact on patient outcomes than solely mitigating implicit bias. This approach provided an understanding of the factors that contributed to negative outcomes in patient care and provide strategies to address them effectively. The study contributed to the literature by providing more nuance to the understanding of the relationship between implicit bias and patient outcomes, in hopes of helping to improve the quality of care for minority patients.

Methodology

The primary objective of this study was to conduct a comprehensive analysis of the relationship between implicit bias and its impact on patient care, with the ultimate goal of developing strategies to mitigate negative effects on minority patients. In answering the principle research question, the following two specific aims had to be achieved: 1) identification of effect modification and confounding variables that related to implicit bias' effects in patient care and 2) offering specific solutions or strategies to overcome the variables and in turn limit the effects of implicit bias.

The first method of the study involved conducting a review of the current literature, with a focus on identifying extraneous factors that may have contributed to the cause and effect relationship between implicit bias and patient outcomes. This review built upon the work of Maina et al., who had conducted a systematic review of studies on this topic over the past decade. The discussion and results sections of each paper were closely examined, and any mentions of relevant factors were compiled into a chart. The chart was organized to clearly reflect the influence of each factor on the relationship between implicit bias and patient outcomes, with each factor identified as either effect modification or confounding. An intensity score based on the outcome of patient care was assigned to each variable for a qualitative analysis, based on prominence seen in the literature.

Once the variables that contributed to the negative effects of implicit bias on patient care had been identified, the second aim was to develop strategies to limit or eliminate these factors. For each variable, a unique approach or solution was proposed, with the goal of improving patient conditions. Additionally, a proposed outcome of the strategy was provided to demonstrate how it could potentially benefit patients. To ensure a holistic understanding of the strategy, at least one limitation or potential pitfall was determined that may have needed to be addressed.

These specific aims, once achieved, provided a deeper understanding of the relationship between implicit bias and patient care outcomes through identification of factors that affected it.

Moreover, targeted strategies to improve care for minority patients were also provided. By identifying and addressing the factors that contributed to negative outcomes, there was an overall goal to improve the quality of care for all patients, regardless of their race or ethnicity.

Relevant Terminology

The following terms are discussed and mentioned in subsequent sections of the paper. Here, these terms are defined and given context for a better understanding of the presented results and discussion.

- Aversive Racism: Aversive racism is characterized by a combination of high levels of implicit bias and low levels of explicit bias, or racism. This means that the explicit bias is known and exhibited while there is denial that one's behaviors or motives are racist. As such, this is not the same as implicit bias itself, but can contribute to increased levels of implicit bias in an individual (Chen et al., 2021).
- Cognitive Stressors: Cognitive stressors are factors that can cause cognitive overload or stress for individuals. In the context of healthcare, cognitive stressors can include factors such as high workload, time pressure, ambiguity, and uncertainty. These stressors can have negative effects on healthcare providers' decision-making processes, increasing the likelihood of cognitive biases and errors.
- Stereotype Activation: Stereotype activation refers to the process by which individuals unconsciously activate and apply stereotypes about certain groups of people. In the context of healthcare, stereotype activation may lead to differential treatment of patients based on their race, ethnicity, or other characteristics.
- Clinical Ambiguity and Algorithmic Situations: Clinical ambiguity refers to situations in which healthcare providers have incomplete or uncertain information about a patient's

condition, diagnosis, or treatment. Algorithmic situations, on the other hand, refer to situations in which healthcare providers rely on decision-support tools, such as clinical algorithms, to make decisions.

- Circular Intervention: Circular intervention is a technique used to address biases that involves recognizing that biases can become self-reinforcing and thus taking proactive steps to break the cycle of bias. In the context of investigating physician implicit bias, circular intervention may involve implementing policies, procedures, or training programs to promote diversity and encourage inclusive practices (Johnson et al., 2016). The goal is to interrupt the feedback loop of bias and prevent it from perpetuating itself.

Results

Table 1: Potential Confounding and Modifying Variables Throughout the Literature

Variable	Classification	Intensity Score	Outcome in Patient Care	Author, Year
Aversive racism - Low explicit bias levels w/ high implicit bias	Confounding	4	Black patients responded negatively and reported lowest satisfaction	Penner et al., 2010
Patient percieved discrimination	Confounding	4	Greater physician verbal dominance and less patient involvement in treatment decisions. Also possible avoidance of healthcare	Hagiwara et al., 2016 Gonzalez et al., 2018
Negative role modeling from faculty in medical school	Confounding	2	Negative comments about Black patients and unfavorable interactions with African American faculty were associated with increased racial bias.	(van Ryn et al., 2015)
Physician/provider gender	Effect Modification	2	There was weaker bias in female versus male physicians	(Cooper et al., 2012)
Cognitive stressors such as patient load and overcrowding	Confounding	4	Associated with increased bias in emergency department, but actual patient care effects are unknown	(Johnson et al., 2016)
Stereotype activation	Confounding	4	Providers spending less time with patients they have bias against or assume they are engaging in unhealthy behaviors which can lead to missed diagnoses	(Sabin & Greenwald, 2012)
Clinically ambiguous versus algorithmic situations	Confounding	2	There is an association between increased implicit bias in clinically ambiguous situations, like pain management, not seen in more algorithmic situations.	(Dovidio & Gaertner, 2000)

Increases discrimination in treatment decisions and diagnoses for patients

Table 2: Potential Strategies for Overcoming or Removing Confounding/Modifying Variables

Variable	Proposed Strategy/Methodology	Proposed Outcome in Patient Care	Limitations
Aversive racism - Low explicit bias levels w/ high implicit bias	Elimination of explicit bias through robust counseling and intervention	The negative outcome associated with the interaction between implicit and explicit bias would be diminished	Does not address the high implicit bias levels - should be used in combination with a implicit bias limiting strategy
Patient percieved discrimination	- Patients ask more questions, communicate more, and be more engaged, despite perception of discrimination - Physician acknowledgement of bias with circular intervention	- This would potentially prevent verbal domination by physicians as well as keep them involved in treatment options/decisions - Increases trust and engagement between physician and patient	- Asking too much of patients as they should not have to advocate for themselves to avoid discrimination - Has potential to confirm/strengthen previous perceptions in future visits
Negative role modeling from faculty in medical school	Since medical school experiences were associated with changes in student implicit racial bias, there is potential for medical education to reduce physician contribution to racial disparities in health care by increasing number of African American faculty	Students that reported highly favorable contact with African American faculty had decreased racial bias so this could be expected with positive African American role models in medical school	May not have a profound effect on all medical students Requires African American faculty to knowingly be more "positive"
Physician/provider gender	Should encourage males to be even more aware of implicit bias and its effects	Should at least bring implicit bias levels comparable to that of women.	Difficult to target males on a more intense scale when it comes to training/strategies.
Cognitive stressors such as patient load and overcrowding	Improve staffing to prevent overcrowding and using evidence based decision tools can decrease cognitive overload	Would potentially decrease cognitive stress and in turn implicit bias levels	May not be feasible for certain hospitals with limited funding
Stereotype activation	Implicit bias training to become aware of their own biases as well as diverse hiring practices/cultural competency training	This could allow providers to become more aware of their associations and the harm they can cause to improve treatment decisions	It is impossible to eliminate implicit bias, so this may only reduce the levels
Clinically ambiguous versus algorithmic situations	Support tools to assist clinicians in making more objective and consistent decisions. Using decision trees or algorithms to guide treatment decisions based on clinical data	Help to eliminate the implicit bias increases that are associated with ambiguous decision making could lead to better treatment decisions for patients	A limitation may be trying to apply a one size fits all solution to a variety of different patient circumstances -> decreased nuance

Discussion

The results of this paper provided insights into the complex relationship between implicit bias and patient outcomes, and the potential impact that extraneous variables can have on this relationship. The review of current literature highlights the importance of considering effect modification and confounding variables when investigating the relationship between implicit bias and patient care. The proposed strategies to mitigate the impact of extraneous variables on the relationship between implicit bias and patient outcomes offer a practical approach to addressing this complex issue. Each solution is unique to the specific variable it addresses, and the proposed outcome of each strategy demonstrates the potential benefits for patients. However, it is important to note that there may be limitations or potential pitfalls associated with implementing each strategy, and further research may be needed to address these challenges. The following subsections further explain and elaborate on the most compelling variables that were identified:

Aversive Racism

The presence of aversive racism, classified as a confounding variable with an intensity score of 1, has been identified as a significant challenge in patient care, particularly for Black patients who report lower satisfaction levels (Penner et al., 2010). Aversive racism is characterized by low levels of explicit bias but high levels of implicit bias.

The proposed strategy for overcoming aversive racism was the elimination of explicit bias through counseling and intervention. While this may diminish negative outcomes associated with the interaction between implicit and explicit bias, it does not address the high levels of implicit bias that are characteristic of aversive racism. Therefore, it is important to consider a combination of strategies to address both implicit and explicit bias in patient care.

Stereotype Activation

Physicians have been shown to unconsciously associate minority patients with stereotypes that can have harmful effects on their care or treatment quality. Associations with stereotypes like non-compliance and reduced cooperativeness for minority patients can potentially lead to different treatment options (Maina et al., 2018). This stereotype activation was considered a confounding factor in the implicit bias and patient care relationship with an intensity score of 4 due to its harmful effects. For example, a healthcare provider may unconsciously assume that a patient of a particular race is more likely to engage in unhealthy behaviors, leading to lower quality care or providers spending less time with patients they perceive as having low social status.

The proposed strategy healthcare providers can undergo to overcome this factor was implicit bias training to become aware of their own biases and develop strategies for avoiding stereotype activation. Healthcare organizations can also implement policies and practices that promote diversity and inclusion, such as diverse hiring practices and cultural competency training.

Cognitive Stressors

Cognitive stressors, such as patient load and overcrowding, have been identified as a confounding variable in patient care with an intensity score of 4. These stressors have been associated with increased bias in the emergency department, although the actual effects on patient care are unknown.

The proposed strategy for overcoming cognitive stressors is to improve staffing levels to prevent overcrowding and reduce cognitive overload. Additionally, evidence-based decision tools can be used to decrease cognitive stress among healthcare providers, which in turn may decrease implicit bias levels (Johnson et al., 2016). Evidence-based decision tools are developed using a robust collection of data on previous decisions made by physicians in regard to patient treatment options. An analysis of previous outcomes from given treatment options based on the symptoms or situations patients are going through can provide objective information that physicians can use to aid their decision making and reduce cognitive stress. This can enable providers to focus more closely on patient care and make unbiased decisions.

A possible limitation to consider could be some hospitals having limited funding or resources to implement changes in staffing levels or to adopt evidence-based decision tools. Additionally, the effectiveness of these strategies may vary depending on the specific context and patient population. It is also important to note that while reducing cognitive stress may help decrease implicit bias, it may not completely eliminate it. Other strategies, such as implicit bias training and organizational policies promoting diversity and inclusion, should be considered in combination with addressing cognitive stressors to fully address the impact of implicit bias on patient care.

Patient Perceived Discrimination

Patient perceived discrimination was classified as a confounding variable with an intensity score of 4, meaning it can have a significant impact on the outcome in patient care. It has been found that patients who perceive discrimination from healthcare providers are more likely to experience greater physician verbal dominance and less involvement in treatment decisions, which can lead to a negative impact on their health outcomes (Hagiwara et al., 2016). Moreover, patients may avoid healthcare altogether due to their perceived discrimination, which can further exacerbate their health conditions (Gonzalez et al., 2018).

To overcome this confounding variable, one proposed strategy is for patients to ask more questions, communicate more, and be more engaged in their healthcare despite their perception of discrimination. By doing so, patients can potentially prevent verbal domination by physicians and keep themselves involved in treatment options/decisions. However, this proposed strategy may have limitations as it places an undue burden on patients to advocate for themselves in situations where they are already vulnerable due to their health conditions. Patients should not have to bear the responsibility of avoiding discrimination by healthcare providers.

Another approach that may be useful and not require patients to advocate for themselves is physician acknowledgement of bias with circular intervention. Circular intervention is a technique used in addressing biases that involves recognizing that biases can become self-reinforcing and thus taking proactive steps to break the cycle of bias. If effective, this would increase trust and engagement between physicians and patients. These interventions can take many forms, such as training, education, diversity and inclusion programs, or policy changes. For example, a company may identify a pattern of hiring only people who fit a certain profile and by circular intervention, the company may implement new policies and procedures that aim to widen the pool of applicants, promote diversity, and encourage inclusive practices. A potential limitation is that there is a possibility of previous perceptions of discrimination being confirmed/strengthened in future visits due to the outward acknowledgement by physicians.

Conclusion

This paper contributes to a growing body of literature that seeks to understand and address the impact of implicit bias on patient care. The variables identified in this study, including aversive racism, stereotype activation, cognitive stressors, and patient perceived discrimination, all have significant impacts on patient outcomes. Healthcare providers must be aware of these variables and take proactive steps to address them to provide high-quality care for all patients. The proposed strategies, such as implicit bias training, organizational policies promoting diversity and inclusion, and improving staffing levels, can potentially help reduce the impact of implicit bias on patient care. However, it is important to recognize that no single solution may be sufficient, and a combination of strategies may be necessary to fully address the impact of implicit bias on patient care. Further research is needed to validate the effectiveness of the proposed strategies and identify additional variables that may be impacting patient care. By taking a comprehensive approach to addressing implicit bias, healthcare providers can improve patient outcomes and promote equity in healthcare.

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Prospectus

INTRODUCTION

Hydrogels are an emerging biomaterial that help facilitate tissue regeneration and infiltration of satellite cells to areas of injury. This type of biomaterial is very modifiable in terms of porosity, degradation profile, and mechanics (Carnes & Pins, 2020), making it desirable for volumetric muscle regeneration. Microporous annealed particle (MAP) gel uniquely has microporous channels for cellular integration and accelerated wound healing (Griffin et al., 2015). MAP gel has shown to rapidly promote the formation of new muscle fibers (Ginn et al., 2021). This is made possible by a vascular network formation from MAP that allows for robust cell integration and subsequent myoblast fusion.

Considering the overwhelming positive benefits of MAP gel for injuries, like volumetric muscle loss, there is a signficance for creating MAP gel in an efficient and efficacious manner. Microfluidic, or parallelized step emulsification devices, were developed to synthesize MAP gels with scalable high throughput and pH controlled crosslinking for highly modular microporous environments (de Rutte et al., 2019). The devices aim to increase uniformity of particle diameter by using channels with gradual expansion to increase biocompatibility and cellular integration. However, the current design for step emulsification devices lacks this ability for small particle sizes and results in nonuniform particle sizes due to issues with fluid dynamics and pressure. As such, an engineering design that mimics the positive aspects of the previous device and mitigates the negative aspects would improve the uniformity of particle sizes in MAP gel synthesis.

The engineering design phase of hydrogel development is only truly effective if implemented to all patients that need them, which requires medical doctors to provide quality care to patients of different races, ethnicities, and socioeconomic backgrounds. There is evidence to suggest that medical doctors unknowingly exhibit low to moderate implicit bias in their practice and interactions with patients (Hall et al., 2015), which limits the quality of care for minority patient groups. Strategies for mitigation of the negative effects of implicit bias have been practiced and used in hospitals and medical schools to combat these inherent biases, but the outlook, review, and/or perspective of medical schools on these programs' successes have not been reported. Analyzing the physcian perspective on implicit bias mitigation strategies and their effectiveness would provide insight into social training program's role in altering inherent biases and how the mitigation of bias changes patient care.

The loose coupling between device development for clinically used hydrogels and the current progress being made by physicians to resist effects of implicit biases provides for an investigation of translational research from bench to bedside. Through realizing the medical doctor's perspective on current implicit bias training, the role of the individual physician in combating bias and the accessibility of translational procedures can be discovered.

TECHNICAL CAPSTONE RESEARCH

Volumetric muscle loss (VML) is a large-scale injury event to skeletal muscle that affects both civilian and military patients. This is characterized by a volume of tissue removed from traumatic injury or surgical ablation that is large enough to have loss of the extracellular matricies (ECM) and stem cells, thus rendering the tissue nonfunctional and incapable of regeneration without intervention (Testa et al., 2021). In many cases, patients must undergo amputation of the area affected, making these incidences extremely debilitating.

Injectable biomaterials, such as hydrogels, are widely used to support tissue regeneration in volumetric muscle loss (VML) injuries. Microporous annealed particle (MAP) gel is a specific type of hydrogel that provides interconnected pores for cellular migration and integration with surrounding tissues(Griffin et al., 2015). MAP scaffolds have been shown to improve cell delivery and communication and could act as an alternative for grafting techniques(Koh et al., 2019). This property of MAP gel is made possible by the unique methodology for its synthesis, which uses microfluidic devices to achieve optimal particle sizes.

The differentiation in particle size affects the stiffness and porosity of the gel; which is important for robust tissue regeneration(de Rutte et al., 2019). The current design for step emulsification devices with channels smaller than 10 microns results in nonuniform particle size and hinders high throughput fabrication due to issues with fluid dynamics and pressure. Certain hydrogel formulations present similar complications at even larger channel sizes due to their chemical properties. Without resolution of this issue, negative effects such as lack of control over porosity, cellular integration, and increased foreign body response could result in vivo or impede the use of bioactive formulations.

The primary objective of the capstone study is to design a novel device that improves the uniformity of particle sizes and effectiveness of MAP gels by ensuring consistent physicochemical properties. In achieving the objectives of the lab, thorough understanding of the current state of the device and the problems associated with it is necessary. Then device designs can be created and tested via software simulations to determine their effectiveness. Upon reaching an optimal design that resolves previous device flaws, the device will be created and used for further studies in treating VML with MAP gel. This procedure is achieveable through the following specific aims 1) to identify fluid pressure issues that create non-uniform MAP gel particle sizes in the current design of microfluidic devices for MAP gel synthesis and 2) to create a more effective novel microfluidic device design that improves device capability for optimal MAP gel production.

The current device, while impressive in efficient throughput, does not account for smaller particle sizes or alternate formulations of MAP gel that are desirable for applications in volumetric muscle loss in the Griffin Lab. Although this is evident in real-time MAP gel synthesis, it is unclear which fluid dynamic properties are responsible for the issues regarding non uniform particle sizes and inconsistent physiochemical properties. As such, there is a requirement for diagnoses of the geometrical aspects of the device that cause excess pressurization. Using engineering and physics software, a simulation of the fluid flow and dynamics can be modeled and observed. Pressure, velocity, and shear fluid forces can be determined as well as areas of interest for pressure build up.

Given both the positive and negative aspects of the current device, the novel, engineered microfluidic device design will maintain the benefits while improving upon the pitfalls. The positive characteristics of the current design that include the high throughput, use of the oil phase will be preserved. The resolution of negative aspects like pressure build up, pumping velocity, shearing forces, and porosity will be mitigated through the improvement of the device structure and geometry. This will ensure small particle MAP gel is synthesized efficiently with proper uniform physicochemical properties of particles.

AutoDesk Fusion360 will be used to develop a new device design with measurable dimensions similar to the current design, like the number of channels. Simulation software will allow for testing of completed designs to ensure resolution of current design issues. This will be accomplished in the form of a measurable reduction in excess pressurization or shearing forces within channels that produce particles. If the issue is efficiency, a possible approach may be to add more channels or create more areas for fluid to move through to facilitate robust particle synthesis. An issue with the velocity of the fluid being pumped in will be modulated to move at a slower velocity to reduce pressure. If the issues cannot be resolved with changing pumping velocity, optimizing the geometric layout of the channels may improve the issues of pressure build up and shearing forces. Using Autodesk CFD simulation software, variations of the device will be produced as CAD designs and tested for the aforementioned possibilities. After each simulation, the metrics for pressure build up, pumping velocity, shearing forces, and throughput will be tabulated and analyzed. For verification of successful modulation of these properties, the polydispersity index physicochemical properties of particles, like particle diameter, will be compared to controls. This process will be repeated until mitigation of negative factors is achieved and uniform physicochemical properties of particles is achieved.

If the primary objective of the capstone study is achieved, a novel device design that improves the uniformity of particle sizes by ensuring consistent physicochemical properties will be fabricated. Upon reaching an optimal design that resolves previous device flaws, the device will be created and used for further studies in treating volumetric muscle loss with MAP gel.

SCIENCE, TECHNOLOGY, AND SOCIETY (STS) RESEARCH

Implicit bias refers to a nonconscious preference or positive association for certain groups or communities of people over others. These biases are inherent for almost everyone, despite explicit attitudes or behaviors. While they may not have a direct effect in many social situations, there is a researched and documented effect they have on minority communities when medical doctors/physicians exhibit them. Since this issue can have harmful and negative effects on the minorities affected, there has been a push for implicit bias awareness and training for upcoming physicians. It is critical to examine the current implicit bias training methodology to determine its effectiveness in patient treatment and care. This will allow for a robust evaluation of the progress that has been made in mitigating physician implicit and proposal for other solutions given a lack of progress.

According to Hall et al., physicians experience low to moderate levels of implicit bias against people of color (2015). While these levels of implicit bias are comparable to those of the general population, it must be known that especially in healthcare there are negative effects experienced by people of color. For example, pro-white bias physicians were less likely to recommend diagnosing thrombolysis in black patients when compared to white patients (Hall et al., 2015). In addition to unnoticed diagnoses, there is evidence to suggest that implicit biases led to "delay in seeking care, non-adherence, mistrust, reduced health status, and avoidance of the health care system" (Sabin et al., 2009). These factors taken together illustrate the harm that even low to moderate implicit bias can have on minority communities and the importance of combating bias in healthcare.

Most medical schools, hospitals, and healthcare industries are aware of the implicit bias presence and have implemented training and/or strategies to mitigate it. One particular strategy is patient activation, which refers to increased engagement of patients toward physicians. These patients will advocate for themselves more, ask frequent questions, or make their opinions or concerns known (Gainsburg et al., 2022). This type of strategy works to reduce the negative effects of bias rather than attempting to reduce the levels of bias itself. There was sufficient evidence to suggest that patients behaving in a more engaging and active manner reduced the negative effects of bias for black patients (Gainsburg et al., 2022). Despite these results, it is not ethically the patient’s responsibility to reduce bias effects as healthcare professionals should provide high-quality unbiased care to everyone.

Another common method for reducing bias effects is to implement training courses or classes for medical school students to be aware of the bias and how to work against it. The method involved having medical school students take an Implicit Association Test (IAT) before and after a teaching session on health disparities and implicit biases. Additionally, students were expected to self-report on their own biases and if they believed they would unconsciously affect healthcare decisions. It was shown that students that denied the existence of unconscious bias affecting their decisions in medicine were dismissive of the implicit bias test (Gonzalez, et al, 2014). The students that accepted the fact unconscious bias affects their decisions in medicine were assumed to be aware due to the course they took on the matter. It was suggested that implicit bias cannot be taught in a single course and should be focused on in a more robust way to eliminate health disparities that result from bias.

There is a clear sociotechnical system that involves the tools for implicit bias training, the group receiving the training (the medical school students), as well as the institutions that implement the training. Given the current methods and approaches to combat implicit bias in clinical settings and in medical schools, this sociotechnical system can differ greatly and range in scope as it relates to effectiveness. However, there is not any feasible way to determine effectiveness through survey of medical doctors without robust evaluation of minority community’s experiences. As such, this system could be examined by analzying the perspectives and outlooks of medical students at the University of Virginia medical school to gain insight into the social training program's role in altering inherent biases and the degree of student and institutional responsibility that is required to mitigate the negative effects of bias. Achieving this objective will require the following specific aims to be met: 1) to determine the current state of implicit bias mitigation methods and training programs (web modules, etc) and the claims of their efficacy provided to medical students by the University of Virginia and further 2) to evaluate the roles of the student, institutions, and technology of these programs and the student perspective on the progress the training makes in mitigation of bias in patient care.

In order to determine the current state of mitigation methods, a case study on the University of Virginia medical school will involve determining/recording the current training programs, the type of media/technology used to implement them, whether or not they are mandatory for students, and courses that directly relate to implicit bias in medicine. This will provide the information that is relevant to the technology that is used as well as the institutional role in their implementation. The approach for collecting this information will be from reviewing the medical school's courses and training programs/modules that all students are required to particpate in. Optional courses and/or training will not be reviewed since the school's responsibility only accounts for what they ultimately require of their student body. This may also involve communicating with faculty members of the UVA medical school to identify the scope of the training offered and whether or not this is commonplace among medical schools. With the compilation of information regarding the current implicit bias training methods and technology, there will be evidence to suggest or outline the claims of the medical school in regards to their training's efficacy and progress.

In meeting the goals of specific aim 2, the student's perspective on the degree of achievement in implicit bias training goals, as it relates to the medical school's claims about the training, will be evaluated. A series of interviews with medical students will focus on the student perspective of and opinion of the current training programs offered by their respective institution. This will provide information on the student view of how effective these programs are and, more importantly, narrow in on the social/cultural factors that may contribute to whether or not the training meets the standards the school outlines. The medical school's role in training students on implicit bias, as it relates to their technology, will be compared to that of their suggestions and claims about the role they wish to operate in.

The approach for collecting the student perspective will be a set of questions on current training technologies at the UVA medical school and their view on whether or not the training meets the efficacy the institution proposes. Additionally, questions about the technology's role in mitigation will be discussed to determine if mitigation is correlated with the technology or the student's own disposition. This will provide insight into the actual role of the technology and the institution that is implementing it as it compares to the role they claim to play.

By evaluating the relationship between institutions, technology, and users, the shared responsibility of bias mitigation will be clear. From this perspective, persistent negative impacts of implicit bias can be easily associated with a given party, leading to early diagnosis of issues. Further, solutions that relate to student responsiblity, the technolgy itself, or the schools could be proposed and implemented to enhance the current training programs.

CONCLUSION

The expected outcome of the capstone technical study will be the successful diagnosis of the fluid dynamic parameters responsible for nonuniform particle diameter and inconsistent physicochemical properties in current microfluidic devices for MAP gel synthesis. More specifically, it is expected that a combination of excess pressure build-up caused by fast pumping velocity will be identified as responsible for nonuniform particle sizes in MAP gel. Additionally, there is an expectation for the development of a novel microfluidic device design that maintains the benefits (high throughput, crosslinking in the oil phase) of the current device while improving upon its pitfalls (excess pressurization of channels, excess shearing forces, harsh fluid velocity, insufficient channels, etc). This will be measurable through parameters diagnosed as problematic from Aim 1 in terms of uniform particle size.

Upon achieving the aforementioned results, the new optimal step emulsification devices would allow future labs to use and benefit from the more efficient method of MAP gel synthesis. This would eventually lead to more effective MAP gel for use in the Griffin Lab to enhance biocompatibility and functionality in treating volumetric muscle loss and other tissue injuries.

The advancement of translational research has led to new treatments that can reach patients more quickly and effectively by increasing access (Colloca & Miller, 2011). However, implicit bias in healthcare can have an effect on this access for people of color or lower socioeconomic status. Additionally, translational research has even shown to not include diverse peoples in practices (Rotsides et al., 2022). Given this, it is important to not only focus on the design of translational research practices, but also the healthcare environment these devices are being used in. An evaluation of the sociotechnical system that is implicit bias training programs in medical school institutions would provide knowledge of the role of the technology, students, and schools that require the training. Through the student perspective, the level of progress, responsibility, and efficacy of the implicit bias training can be reviewed. Furthermore, knowing the relationship between these parties in a shared responsibility for mitigation of implicit bias could lead to proper diagnoses of pitfalls and proposal of alternate solutions.

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