Creating a Better way to locate Vasculature for Intravenous Therapy

774,144

IV's placed per day in EMS

Identified Needs Statement:

Paramedics need a way to quickly locate vasculature for IV placement.

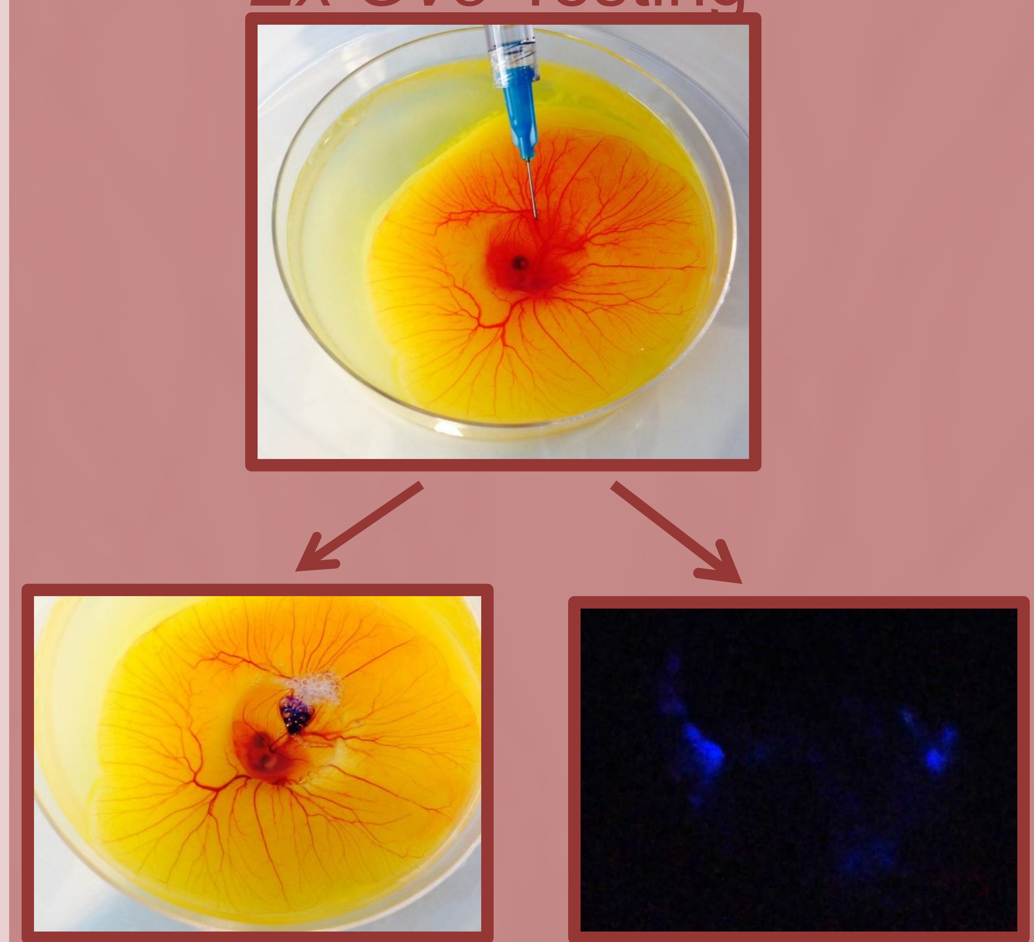
Description:

Over 300 million IVs are placed by paramedics in the EMS setting each year. Of these IVs, an average of 28% are placed incorrectly, causing multiple needle sticks, patient discomfort, an increased risk of infection, and delays in medical treatment. To help paramedics locate veins for IV puncture, we have developed a novel topical ointment that increases visibility of veins suitable for IV therapy, making drug delivery more efficient and beneficial to patient health. Testing showed that our product safely changes the color of blood and enlarges the veins, making veins more visible to the paramedic. This addresses a $4.9B market and has the ability to be successfully integrated into the EMS setting. Feedback from paramedics and other collaborators has been extremely positive both for our final product and the professional level of our process as a whole.

Multidiscipline Participation:

Our student team has worked with paramedics, EMTs, veterinarians, biologists, chemists, attorneys, and entrepreneurs. Although rooted in biomedical engineering, this project spans chemical engineering and materials science principles. We shadowed paramedics and EMTs in our local EMS system to identify unmet medical needs and product requirements for successful implementation into the EMS market. Once our team decided to pursue a solution in the form of an ointment, we began collaborating with professors at our local college of veterinary medicine who specialized in skin permeability and chemistry. These professors helped us develop testing protocols and gave us advice to optimize skin permeation. Due to the innovation of our product, it has been important for our team to protect our intellectual property by working with a patent attorney and entrepreneur.

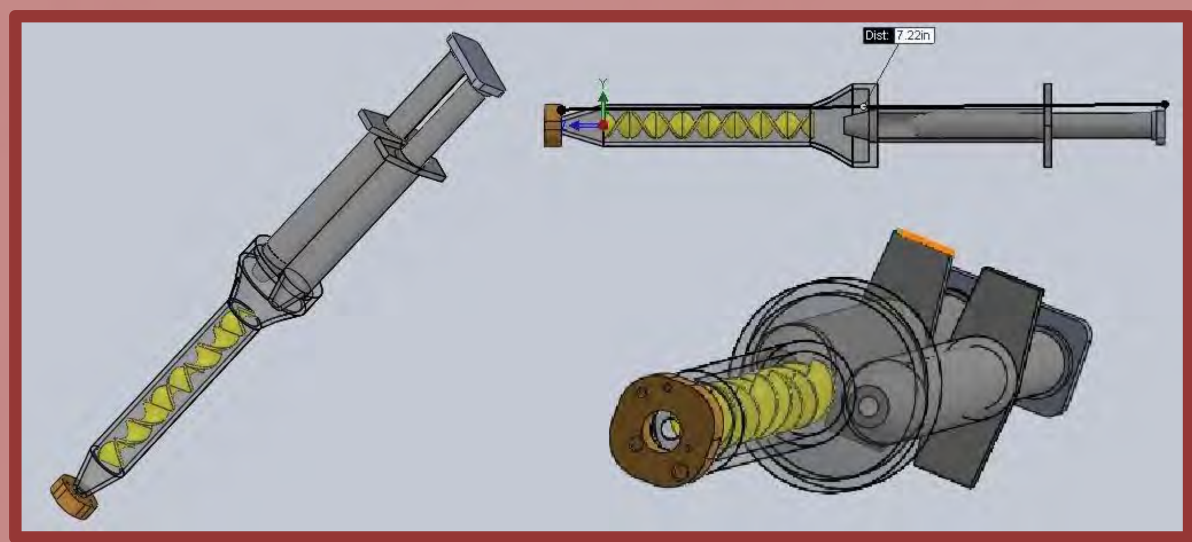
Ex Ovo Testing



When tested on chicken embryos outside of the egg (*Ex Ovo*) our product resulted in the blood changing to a deep violet color and simultaneously glowing with no external light source.

Collaboration:

The student design team has been working with faculty in Biomedical Engineering during the development and solution brainstorming phase of our project. A collaboration with the Veterinary school was established in order to gain further insight on our solution and perform skin permeation testing along with the possibility of in vivo testing at a later date. A partnership with a paramedic employed by the local EMS branch was also crucial as we gained vital solution parameters from a future end-user. To ensure our solution was manufacturable, a licensed PE gave incredible insight and advice from an industry perspective on how our solution would be implemented and manufactured. The Vascular Visionaries are currently in the process of drafting a provisional patent for our ointment. This process has involved collaboration with a local patent attorney in conjunction with the university's Office of Technology Transfer.



This single-use applicator consists of two chambers which store our ointment as two separate solutions. This application system stores, mixes, and applies our product to the arm of a patient.

Knowledge Gained:

This project allowed us to develop technical and professional skills beyond that of typical undergraduate students. Through this project, we have learned the importance of networking; this allowed us to obtain over $1,000 in donated supplies. The regulatory pathways of the FDA are very complicated, and we now have the skillset to navigate these regulations. We learned the importance of ethnographic research and catering to the need of an end-user. Testing allowed us to develop our own protocols and gain skills in the laboratory. We learned to give professional presentations to investors and collaborators to allow the growth of our project.

Benefit to Public Health, Safety, and Welfare:

The goal of our project was first and foremost to improve the health of patients. By developing an ointment that allows paramedics to place IVs correctly, we directly improve the health and well-being of any individual needing IV therapy. We also directly improve the safety of patients, as the number of IV sticks required significantly decreases therefore decreasing the risk of contracting infection at the puncture site. Increased precision in IV placement also reduces the use of potentially harmful methods of performing IV which is extremely painful for the patient, namely intraosseous infusion (injecting drugs directly into the bone). With over 1 billion IVs being placed worldwide, this solution has the ability to improve the health of 280 million patients each year.

The Vascular Visionaries' project has been a yearlong design process completed by a team of five undergraduate Biomedical Engineering students. We were tasked with identifying an unmet medical need and developing an innovative solution for it. We identified hundreds of needs and through a feasibility process decided on a need to help paramedics initiate IV (intravenous) therapy by assisting them in locating the patient's vasculature. Our goal is to make IV therapy more efficient, cost effective, and beneficial for the roughly 774,000 patients affected each day. Throughout this year, our team has learned the process of gaining FDA approval for medical devices and has worked in multidisciplinary collaboration with professionals across different industries to create an effective solution for this problem.

Our solution is a topical ointment that both increases blood vessel size and augments color contrast such that first responders can easily visualize vasculature and gain needle access. The augmented color contrast is accomplished by temporarily changing the color of the blood while simultaneously causing it to luminesce (glow) in a locally targeted area. A strong relationship with local emergency medicine personnel was established to develop product requirements and ensure the clinical effectiveness of our final solution. This relationship was developed over many ambulance ride-alongs, iterations of needs, current solution landscape, and brainstorming. Initial testing, business models, and different risk analyses were completed with help from professors in Biomedical Engineering and Bio-manufacturing with focuses in entrepreneurial ideation. An attorney from a local law firm and the office of technology transfer at the team's university were consulted to help with drafting a provisional patent to protect the team's innovative ointment that will allow paramedics to more easily visualize patient vasculature. Animal testing and further development of the ointment was done through a partnership with faculty at the local College of Veterinary Medicine. A professional engineer with decades of experience in the design and manufacturing of plastics was collaborated with to create an effective device that properly stored, mixed, and dispensed the components of our ointment to the patient. The final product, which consists of both the device and ointment, is estimated to have a cost of goods sold of $4 per dose. At this cost, a price point can be established that will enable EMS divisions to effectively employ the team's solution.

Applying ethical engineering practices to real world needs in the medical field with the help of a multi-disciplinary team of industry professionals has given the team experiences will be extremely useful for both the continued success of the project and each individual's personal professional success. Some of these experiences include navigating a design control process that emulates the FDA's Quality System Regulation, Business and Product Risk Assessments, Intellectual Property Landscape, Identifying Needs and translating them in to Engineering Specifications, Design for Manufacturing and Detailed Manufacturing Specifications, Proof of Concept Prototyping, Experimental Design and Qualification Testing. Criteria for successful projects included factors such as originality and patentability, technical feasibility, clinical utility, economic feasibility, and market potential.

DEVELOPING AN OINTMENT TO BETTER LOCATE VASCULATURE FOR INTRAVENOUS THERAPY

I. Project Description

IV (intravenous) and catheter equipment make up over 20% of the medical device industry. Each year, 300 million IVs are placed by EMS personnel in the United States. 28% and 54% of these IV lines fail to be placed in adults and children respectively simply due to a lack of visualization of patient vasculature. This failure rate illustrates the inability to quickly and efficiently deliver life-saving drugs to stabilize patients in an emergency setting. Our team, the Vascular Visionaries, is made up of five undergraduate biomedical engineering students dedicated to helping paramedics and other medical personnel locate vasculature suitable for IV placement, making IV delivery more efficient and beneficial to patient health. To meet this goal, **we have developed a novel ointment that makes a patient's veins more visible by temporarily increasing blood vessel diameter and safely changing blood color to improve contrast between blood and surrounding tissues.**

The process for developing this ointment has been a yearlong project for our team. Our design process has been divided into five formal phases. In Phase 1 of our project, our student team was given the task of identifying an unmet medical need. We began this process with a single contact in a local hospital and were given the opportunity to shadow in the operating room. From this contact, we developed connections in other areas of the hospital to widen our range of observations. These areas included intensive care units, rehabilitation/physical therapy centers, EMS ambulances, and patient care rooms. Doctors, nurses, surgeons, and other medical professionals were interviewed to determine the extent of our identified needs. Two-hundred hours were spent shadowing medical professionals, during which we identified 70 unmet medical needs. The need we pursued was witnessed in an ambulance ride-along. During the ride-along, a severely dehydrated patient needed fluids through an IV to stabilize her condition. The paramedic tried for 30 minutes to locate a vein suitable for IV placement but could not successfully place an IV catheter and start administering fluids. As a result, the woman was unsuccessfully stuck at least 10 times across her body, causing her to bleed excessively and eventually go into shock from dehydration. The paramedic eventually gave up trying to locate her veins, and she was transported to the hospital with no form of treatment. From this experience, our team observed that **paramedics need to find a way to quickly access vasculature suitable for IV placement, making drug delivery more efficient and beneficial to patient health**. Our solution has the ability to impact the approximately **774,000 patients given IV therapy each day** in the US.

Phase 2 of the design process was the time during which our team explored different product concepts for locating vasculature in the EMS setting. This began by researching current products on the market used to identify vasculature. Initially, it seemed that the market was saturated with an array of devices that use near-IR light to create a real-time image of veins. However, upon further investigation, we discovered that these devices were not being used by paramedics. We used feedback from paramedics in conjunction with literary research to create a list of product requirements. To be successfully integrated into the EMS market, a device must increase visibility of veins, be usable by a single paramedic, be cost-efficient, and be durable. Table 1 shows current devices and their shortcomings as stated by our product requirements.

Product	Durable	Cost Efficient	Can be used by 1 Paramedic	Increase Visualization
	✓	✗	✓	✗
	✓	✗	✓	✗
	✗	✗	✗	✓

Table 1. Current technologies include (from top to bottom) O2-Amp Glasses, VenoScope, and the AccuVein. None of these devices are able to meet all four product requirements that allow successful integration into the EMS market.

Our team used this product landscape analysis and voice of customer input to ensure that our own product was innovative, feasible to develop, and that it addressed the problems associated with competing medical devices on the market. The Vascular Visionaries also determined the prevalence of the problem our product solved at this time. The segmented addressable market of our product in the emergency medicine setting is conservatively $4.9B. The Vascular Visionaries decided to develop a transdermal ointment to increase visibility of veins because it has the ability to meet all four product requirements listed above.

Phase 3 of the design process was spent creating a manufacturing plan for the development of our transdermal ointment. This process involved detailing the manufacturing specifications for the ointment, identifying potential suppliers, and establishing a route to FDA approval according to ISO Standards. A testing protocol was developed during this time to ensure our ointment can penetrate the stratum corneum and epidermis (outer skin layers) to reach the underlying vasculature. Novel protocols were developed entirely by the team to ensure the ointment can cause a color change in blood and increase vein diameter.

In Phase 4 of the design process we constructed a product prototype based on the Phase 3 prototype concept plan. The testing protocols drafted began with *ex ovo* testing (outside the egg) of our color-changing components on chicken embryo capillaries (testing on embryos outside the egg). As seen in figure 1, the testing was successful, meaning **administration of our product causes a color change in the blood in less than 30 seconds.** This has never been tested in a living system before, so these results alone show a novel development.

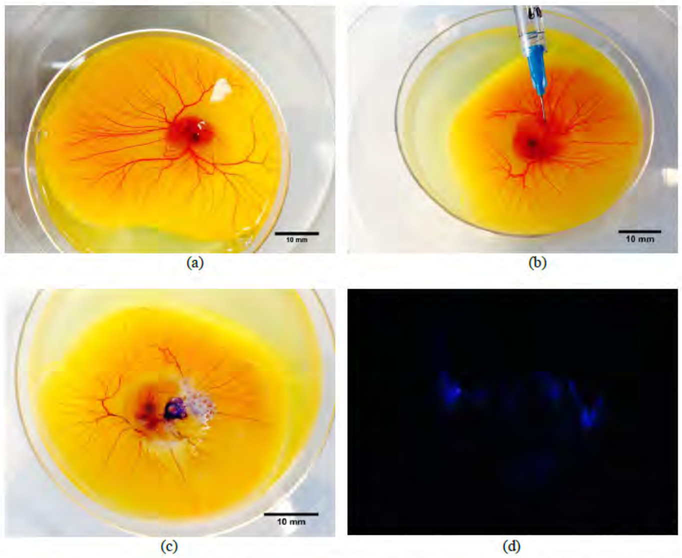


Figure 1. Chicken embryos are shown at each stage of testing. A 6-day-old embryo (a) is injected with our solution (b) through the CAM membrane. This results in a color change to a deep violet (c) while simultaneously glowing (d).

Our team also developed a two-chambered applicator that safely stores, mixes, and applies our ointment. This shows the thought process to translate this product into clinical use. **A professional engineer with experience in plastics and manufacturing was collaborated with extensively to develop this applicator.**

The team is currently in Phase 5 of the design process. In this phase, testing was completed on skin penetration and vessel dilation. For this testing, pig skin was used to assess our product's ability to permeate the skin and dilate vasculature. A swine model was used due to similarities between swine and human skin to ensure applicable results. The vessels were successfully dilated within 5 seconds of administration, showing a successful test. Several studies have previously shown successful permeation of our product components through the skin; analysis of our results is still being conducted

Current Status and Future Direction

The product we developed takes the form of a single-use ointment housed in a plastic applicator. It can be administered within seconds and is considerably less expensive than competing technologies with a **cost of goods sold at approximately $4 per dose**. Our product addresses each of the four product requirements illustrated in table 1. By using an ointment, the product can be used by a single paramedic, it helps visualize veins by changing blood color and enlarging blood vessels, it is cost-effective, and is durable enough to withstand the rough EMS setting. With a **$4.9 billion market**, this solution has the ability to compete with leading technologies currently on the market.

Our project is still undergoing testing to optimize delivery of the ointment through the skin. Several delivery systems are being considered. Once skin permeation is optimized, *in vivo* testing (inside a living system) will be performed on a swine model, setting the stage for human trials per FDA regulations. We are currently working with a patent attorney to file a provisional patent with the intent to file a full patent.

II. Collaboration of faculty, students, and licensed professional engineers

The success of our novel ointment is due largely to the collaborative nature of our project and team. A **licensed P.E.** has been monitoring our progress since the start of this project and has become a crucial member in the past few months. As an expert in manufacturing, his input was essential in determining the feasibility of our product's production in an industrial setting. Aspects such as packaging, application, and logistics were developed with his insight. Our faculty mentor and the P.E. we collaborated with have been colleagues for years, so interaction between them was natural and beneficial to the team. While the P.E. dealt largely with the manufacturing process, students also collaborated intensely with faculty from the College of Veterinary Medicine. This collaboration was used primarily to develop and use a testing protocol to assess the effectiveness of our ointment. The students were also able to interact with several paramedics in order to keep the voice of the customer the main concern during the development and testing of our product. The intense collaborative environment of this project provided opportunities students never would have had otherwise. Students were able to establish contact with professionals such as professors, paramedics, attorneys, doctors, and P.E.s and use this network of contacts to develop a very marketable and effective product. Working with professionals in many fields has prepared us for our future careers and has been an integral part of the design process.

III. Benefit to public health, safety, and welfare

The health, safety, and welfare of the public is the **sole focus and core foundation** of our design team. Our mission statement reads: "a team dedicated to improving patient well-being through exceptionally innovative solutions." We have embraced this mission statement throughout the length of our project and use it as a basis for our decisions as a team. Currently 28% of IV sticks in adults and 54% of IV sticks in children are unsuccessful. Each unsuccessful attempt causes patient discomfort, increases the risk of patient infection, and causes delays in treatment. Allowing paramedics to visually locate veins suitable for IV placement with our novel ointment will lower the number of sticks required to successfully start IV therapy. Keeping patient health in mind, almost all the components of our solution have previously been approved for use by the FDA. This should not only speed the regulatory approval process but also prevent unwanted side effects when used on a patient. Paramedic safety was also a main concern, so the application system of our product prevents unnecessary contact between the paramedic and the ointment during administration.

Many of the critical engineering decisions made over the course of our product's development were relating safety to efficacy. We found many products currently available that can increase vein diameter within seconds of application; however, these products are so potent that it lowers the patient's overall blood pressure, which can be dangerous to the patient. There are also several natural products available to enlarge veins, but the time-scale and efficacy of these products are not suitable for our application. As a team, we were forced to agree on a way to enlarge veins to a suitable extent without becoming hazardous to the patient. Our decisions were also based on FDA regulations in order to speed the approval process of our ointment and get our ointment to market quickly. The team is now aware of the impact an engineering decision can have; a single decision has the ability to affect the effectiveness of the product, the patient's safety, manufacturability, and even the regulatory approval process. Therefore the impact of engineering decisions was considered a cornerstone when initially developing the product.

Our project has the ability to positively influence healthcare on all levels. With a worldwide rate of incorrect IV placement hovering around 28% and over 1 billion IVs being placed each year worldwide, our product has the ability to improve the health of approximately 280 million people each year. These figures highlight the ability of engineering to solve problems nationally and worldwide.

The project and design process fostered self-reliance, cooperation among the team and with outside mentors, and responsibility. This project was started with a single mentor in a local hospital. From there, our team took responsibility of our project and cooperated with at least 10 additional professionals over the entire length of the project in addition to countless professionals we reached out to over the course of a year. We alone were responsible for identifying unmet medical needs in a variety of fields, developing a novel solution, and documenting our process in a 5-phase design process suitable for FDA approval. Team members were forced to be self-reliant, going beyond the minimal standards to reach out to company representatives, develop our own testing protocols, and ensuring the product would fulfill all our requirements. Extensive cooperation was seen throughout the process; we cooperated with companies in order to obtain donated supplies, a patent attorney to draft a provisional patent, and of course with a licensed P.E. to ensure our product is feasible on a manufacturing scale.

IV. Multidiscipline and/or allied profession participation

The main appointment of the Vascular Visionaries' team members is biomedical engineering. Although the prominence of biomedical engineering is seen in our design process, aspects of our ointment involve materials science and engineering along with chemical engineering. A short list of other professions included in this project includes: emergency medicine (EMS), veterinary medicine, biology, chemistry, patent law, business, and biochemistry. Veterinarians were able to help us develop our ointment in a way that it would penetrate the skin, and a chemist ensured the compatibility of our materials. Paramedic input allowed us to form a set of product requirements in order to produce an ointment that could be successfully integrated into the emergency medicine market. Since our product is novel in several respects, we are working with a patent attorney and an entrepreneur to protect our intellectual property. Within our own team, fields of biomaterials, biomechanics, and bioinstrumentation were present within the biomedical engineering discipline.

V. Knowledge or Skills Gained

The 5-phase design process used to develop this product fostered the creation of new knowledge for the student team. The process spanned the entire realm of device development from observation and ideation to creation and testing of a device to meet an identified need. Acting under the process, the team documented all items necessary for an FDA submission. The regulatory pathways required us to gain knowledge in the process for FDA approval, medical device classification, and document control. These skills were also honed when learning about patent law. Since we are working with a local attorney to draft a provisional patent with the intent of filing a full patent, extensive research was also done to ensure our intellectual property would be protected within the US and internationally.

When identifying unmet medical needs, several skills were gained, such as the importance of ethnographic research. When conducting interviews, surgeons and doctors were unable to state many problems they currently experienced in the medical field. However, observing them during their shifts allowed us to assemble a list of 70 needs that have not been effectively met in the medical field. Ethnographic research allows us as outsiders to see medical professionals working in their natural environment, which is more revealing and effective than literary research or even interviews. Networking is another skill gained throughout this process. Our team started with one clinical mentor, and through networking, we gained an extensive list of professionals to help us throughout the process. At first, our networking was limited to medical professionals as we tried to find unmet medical needs. As the project progressed, however, our networking efforts increased to include company representatives, a law firm, a P.E. mentor, veterinarians, a chemist, and countless other professionals who have helped us along the way. Through this network, **over $1,000 of equipment has been donated to our project**, over twice that of our original budget. A veterinarian contact recently told us that "**our project and professionalism has given me hope for the next generation of researchers.**" This proves that we have not only learned networking but also professional practices that will serve us well in the future.

During our initial needs assessment, we searched the current landscape to identify technologies on the market that claim to help paramedics visualize vasculature. We found several devices that utilized near-IR light to create a real-time image of veins. This was the first real set-back we had encountered and almost gave up on the idea until we realized that none of these devices were actually being implemented into the EMS market as they intended. Professors at prestigious universities told us that "the problem had already been solved," citing the same patents we had found. However, we learned how to **analyze the current market, question what we were told, and discover why the devices on the market were not adopted into the EMS setting**. There is often a gap between research and market, and this was a classic example. Learning from others' mistakes, we used feedback from paramedics to create our product requirements, giving a product that is a **purely translational** project. Based on the feedback we have received from medical fields, our product should **easily be adopted into the EMS field, a feat not seen in devices currently on the market**. This whole experience gave us skills to analyze the facts we are given and the skillset to translate a project from bench-top to bedside.

The above skills encompass a fraction of the professional skills we gained throughout this experience. We also gained knowledge on an academic level through development, testing, and analyzing the effectiveness of our product. Biochemistry was learned in order to develop our ointment, which relies on biological factors within the body to visualize the veins. It was vital to study to anatomy and physiology of the skin and vasculature to ensure our product will cross the skin barrier and act upon veins. After the product was developed, bench-top testing was required to ensure the efficacy of the product on a non-living system. This required students to gain knowledge in current research methods and **develop protocols from scratch** to ensure (1) the color-changing component was successful on systemic blood while in circulation, (2) veins will increase in diameter upon administration, and (3) the product will cross the skin barrier. These testing protocols were all successfully developed and utilized.

The professional and practical skills learned through this process has allowed the team to grow both together and individually into engineers ready to enter the field and make a real impact on the world. The obstacles we met only made us more resilient and allowed us to become critical thinkers, which cannot be taught in an ordinary classroom. We believe this project has prepared us to observe a problem, create a feasible solution, and then implement our design into the existing market with success.