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Article

Near-infrared activation of environmentally-friendly gold and silver nanoparticles for unclogging arteries

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SUMMARY

Coronary artery disease, the number one cause of death throughout the world, is the most prevalent form of heart disease. It occurs when there is unhealthy cholesterol build-up in the coronary arteries, which impairs their ability to provide blood and oxygen to the heart, leading to a heart attack or stroke. Although many conventional medications and approaches (e.g., stents) can re-establish blood flow in clogged arteries, medications do not target specific pathological areas (such as thrombosis), affecting nearby healthy blood vessels, and surgical procedures can be highly invasive. We hypothesized that certain nanoparticles (gold and silver coated with aspirin) activated by near-infrared (NIR) would improve blood flow in clogged arteries because they exhibit special thermal responsive properties. Both nanoparticles used in this study were obtained from environmentally friendly materials and are safe to help minimize toxicity during metabolism in important parts of the body, such as the lungs and brain. After the green synthesis of these nanoparticles, we characterized them using dynamic light scattering (DLS) to determine their average size. After adding these nanoparticles to a clogged artery model system and activating them by NIR, the simulated blood flow rate increased from 3.6 to 10.2 mL/min with aspirin-coated gold nanoparticles and increased from 3.9 to 8.3 mL/min with aspirin-coated silver nanoparticles. In summary, this study demonstrated that gold and silver nanoparticles improved the flow rate in a fluid model of a clogged artery and should, thus, be further studied for cardiovascular disease applications.

INTRODUCTION

Coronary artery disease (CAD) develops when cholesterol deposits build up in the coronary arteries, causing them to narrow and limit the supply of blood, oxygen, and essential nutrients to the heart (1). Some of the symptoms most commonly associated with CAD are chest pain, fatigue, breath shortness, and heart failure (1). Around 371,506 Americans died from CAD in the year 2022, and adults aged 20 years or older have a 5% chance of being diagnosed with CAD (2). Atherosclerosis, a process where harmful cholesterol and fatty deposits accumulate in the coronary artery walls and create plaques, is the most common cause of coronary artery disease (1). Over time, cholesterol plaques can thicken and harden, narrowing the arteries and restricting blood flow to the heart, leading to a heart attack if the plaque ruptures and obstructs blood flow downstream (1). Current treatment options include medications such as statins, which lower cholesterol levels and stabilize plaques through the inhibition of the HMG-CoA enzyme, blood thinners and antiplatelet medications such as aspirin, which reduce blood clotting, and surgical procedures such as invasive stent placement to open up the clogged artery and coronary artery bypass surgery (1,3).

While these approaches are invaluable in the management of CAD, they nonetheless each have disadvantages that limit their use. The major disadvantage of conventional heart medications is their inability to target specific areas of inflammation, blood clots, or extensive cell growth within the heart or blood vessels, which results in unintended effects on nearby healthy tissues (4). To improve their targeting ability, cardiovascular nanomedicine uses nanomaterials to enhance CAD prevention, diagnosis, and treatment (4). For example, researchers have placed encapsulated enzymes such as urokinase and streptokinase that prevent blood clotting or substances inhibiting thrombin inside liposomes, iron oxide, and perfluorocarbons to reduce the size of the clots while minimizing side effects to other parts of the body (4, 5). Nanoparticles can be modified in terms of size, shape, and surface properties for better cardiovascular treatment (6). While none of these nanomaterials used for CAD have received regulatory approval in the United States, they are showing great promise in the laboratory setting. Nanomedicine has the potential to treat specific diseases at their sight of occurrence effectively without having any major negative side effects from conventional cardiovascular medicine (4).

Although promising, the aforementioned nanoparticle approaches still require precious time someone having a heart attack may not have. We hypothesize that proactive near-infrared (NIR) activated nanoparticles can quickly re-establish blood flow in CAD patients by heating up on-demand. NIR-activated gold and silver nanoparticles have been used widely for anti-cancer and anti-infective therapies, in which external NIR activation can increase nanoparticle temperature by 3–4 °C to selectively kill cancer cells or bacteria (7). Qian et al. found that silver particles irradiated at 0.5 W/cm² of 808 nm NIR irradiation can kill pathogens in infected wounds in rats and cleave bacterial biofilms in vitro (3). Such small changes in temperature do not affect healthy cell functions and may unclog clogged arteries to re-establish blood flow.

Here, we heated gold and silver nanoparticles under NIR, used an infrared device to observe their temperature differences, and determined if there were any thermodynamic property changes useful for cardiovascular applications. The nanoparticles were further coated with aspirin to eventually

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	Size (before aspirin coating, nm)	Amount of aspirin added (mg)	Size (after aspirin coating, nm)
Gold nanoparticles	79.74 ± 20.03	324	793.5 ± 112.4
Silver nanoparticles	648.9 ± 159.5	243	1612 ± 266.6

Table 1: Dynamic light scattering (DLS) size characterization of silver and gold nanoparticles before and after coating with aspirin. The average nanoparticle size increased for silver and gold nanoparticles when coated with aspirin to 963 nm and 713.76 nm, respectively. The table shows the standard deviation of each particle size to account for the variability among three separate trials.

restore blood flow to clogged arteries due to the blood thinning properties of aspirin. The nanoparticles were added to a clogged artery system and activated by NIR, and the return of model blood flow was measured. In this case, vegetable shortening in a glass tube was used to emulate the clogging of arteries.

The objective of this study was to build a nanoparticle system that can help deliver drugs and be activated by NIR to more efficiently and effectively decompose plaque in patients with CAD to prevent heart attacks or cardiac arrest. Such a treatment may be effective for those wanting less expensive pharmaceutical treatment options while avoiding invasive procedures like cardiac catheterization or cardiac bypass surgery, which can take several months to recover from. We hypothesized that due to their unique photothermal activation properties, these gold and silver nanoparticles coated with aspirin and heated under NIR would ultimately help increase the blood flow rate in a clogged artery model system. Our nanoparticles were able to achieve a flow rate increase from 3.6 to 10.2 mL/min with aspirin-coated gold nanoparticles heated under NIR and a flow rate increase from 3.9 to 8.3 mL/min with aspirin-coated silver nanoparticles heated under NIR, suggesting a potential role for nanoparticles in resolving clogged arteries.

RESULTS

The synthesized gold and silver nanoparticles were measured to have radii of 79.74 nm and 649 nm, respectively. These nanoparticles were added to dissolved (in ethanol) aspirin pills to determine if a nano-coating of aspirin formed around the gold and silver nanoparticles. It was hypothesized that an increase in size would result from coating the nanoparticles with aspirin. Results of the present study showed that the nanoparticles increased in size when coated with aspirin, as expected (**Table 1**). Specifically, dynamic light scattering (DLS) showed that the gold nanoparticles increased from 79.74 nm to 793.5 nm, while the silver nanoparticles increased from 649 nm to 1,612 nm, representing 713.76 nm and 963 nm for gold and silver nanoparticles, respectively.

Moreover, a photothermal responsive property was hypothesized to be present for both gold and silver nanoparticles to be useful for unclogging arteries when heated by NIR. A temperature probe was used to measure the temperature of the nanoparticles over a 5-minute period when placed in water after being heated by an NIR device. The results of the present study confirmed that both silver and gold nanoparticles can be activated remotely by NIR to heat up (**Table 2**). Specifically, the results of this study showed that after NIR exposure, the silver nanoparticles had an average temperature increase of 1.4 °C, while the gold nanoparticles had an average temperature increase of 1.9 °C, compared to water, which only had a 0.4 °C temperature increase. This temperature change provides promising evidence for their use in the coronary arteries, where the nanoparticles can be heated up to decompose cholesterol deposits.

	Silver nanoparticles	Gold nanoparticles	Water (without nanoparticles; control)
Initial temperature of nanoparticles (°C)	21.0 ± 0.26	20.3 ± 1.15	20.6 ± 0.35
Temperature after heating with NIR for 5 min (°C)	22.4 ± 0.85	22.2 ± 2.03	21.1 ± 0.36
Change in temperature (°C)	1.4 ± 0.7	1.9 ± 1.9	0.5 ± 0.25

Table 2: Near infrared (NIR) activation increased the water temperature when using silver and gold nanoparticles. Silver and gold nanoparticles increased by 1.4 °C and 1.9 °C, respectively, compared to water controls, which only had a 0.4 °C temperature increase. The standard deviation was calculated to test variability among all three separate trials for gold and silver nanoparticle NIR activation. All changes in temperature between the nanoparticles and the water without nanoparticles are statistically significant ($p<0.05$).

Lastly, both aspirin-coated silver and gold nanoparticles were added to the model clogged artery system (a glass tube served as the model artery, and Crisco shortening served as cholesterol) to test their effect on flow rate. We also included a control using no nanoparticles. This experiment was performed to determine if the nanoparticles increased the water flow rate in the tube (replicating a clogged artery) when heated using NIR. Results of the present study confirmed that NIR-activated silver and gold nanoparticles increased the flow rate in the clogged artery model system (**Table 3**). Specifically, during NIR exposure, the aspirin-coated gold nanoparticles resulted in a statistically significant increase in water flow rate ($p=3.1\times10^{-5}$) from 3.6 to 10.2 mL/min, and aspirin-coated silver resulted in a statistically significant increase in flow rate ($p=4.2\times10^{-5}$) from 3.9 to 8.3 mL/min (**Figure 1**).

Test Tube Model with Nanoparticles and NIR	
Average flow rate without nanoparticles (control, mL/min)	3.76 ± 0.15
Average flow rate with aspirin-coated gold (mL/min)	10.2 ± 1.53
Average flow rate with aspirin-coated silver (mL/min)	8.3 ± 0.98

Table 3: NIR-activated silver and gold nanoparticles restored flow in model clogged arteries. Gold nanoparticles coated with aspirin increased the water flow rate from 3.6 to 10.2 mL/min compared to silver nanoparticles coated with aspirin, which increased the water flow rate from 3.9 to 8.3 mL/min. All nanoparticle values are statistically different ($p<0.05$) than water controls.

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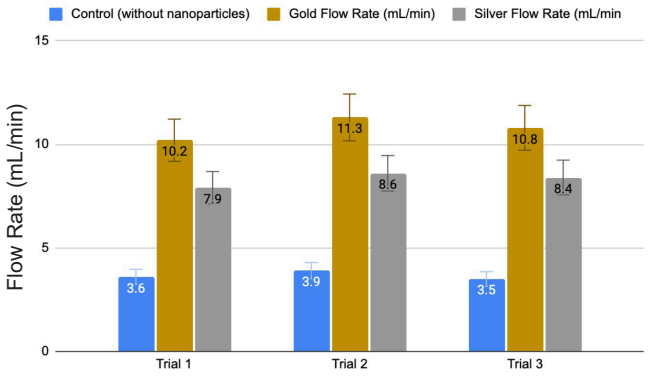

Figure 1: Gold and silver nanoparticles coated with aspirin increased flow rate in a clogged artery system, producing final flow rates of 10.2–11.3 mL/min and 7.9–8.6 mL/min, respectively. The p-value was 3.1×10^{-5} for the gold nanoparticle flow rate and 4.2×10^{-5} for the silver nanoparticle flow rate compared to the non-nanoparticle controls.

DISCUSSION

We found that gold was the better nanomaterial for cardiovascular applications as it heated up more and faster when remotely exposed to NIR compared to silver nanoparticles. Specifically, the gold nanoparticles had a higher average temperature increase of 1.9°C in comparison to the silver nanoparticles, which had an average temperature increase of 1.4 °C over a 5-minute period when activated by NIR. In addition, when testing the water flow rate of the model clogged glass test tube with aspirin-coated gold and silver nanoparticles and NIR, the aspirin-coated gold and silver nanoparticles resulted in a statistically significant increase in the water flow rate. The greater increase in flow rate for gold is likely because gold nanoparticles can heat up more easily than silver in the presence of NIR, as it has been reported that gold nanoparticles are more photothermally efficient in comparison to silver nanoparticles (8). This suggests that gold nanoparticles may be more effective in helping re-establish flow compared to silver nanomaterials.

Further, this research was successful in that gold and silver nanoparticles were shown to be coated with aspirin using an easy process, as proven by the increased particle size from the DLS data. For example, silver nanoparticles went from 649 nm to 1,612 nm when coated with 243 mg of aspirin. Through the experiments, it was observed that the aspirin was completely dissolved in ethanol and, thus, assumed to be completely coated on the nanoparticles; however, future experiments will have to verify this. In addition, gold (MesoGold) nanoparticles increased from 79.7 nm to 793.5 nm when coated with 324 mg of aspirin. Since both the gold and silver nanoparticles placed in dissolved aspirin increased in size according to DLS measurements, an aspirin coating was presumed.

Of course, there are some assumptions to the present study. For example, the glass test tube model did not perfectly model clogged blood flow as the glass was used to model the arterial wall, there were no blood cells present, and the tube was not as clogged as an obstructed coronary artery which has been reported to have a flow rate of 2.54 mL/s (9). The glass is beneficial in modeling the arterial wall as it has adhesive (hydrophilic) properties when the water is being poured (10). However, it may not necessarily be the best model as it lacks the elasticity and flexibility properties typically found in coronary arteries.

In addition, expressing results on raw flow rates (units volume/time) may not be the most reproducible way to analyze the results because the baseline flow rate observed is highly dependent on the details of the experimental setup. For example, if a different size test tube, or slightly more or less Crisco or a different pressure head was used, the results would vary. The diameter of the test tube (2 in) was larger than a coronary artery, which has a diameter of only 2 to 4 mm, which doesn't accurately measure flow dynamics as flow can be more turbulent. In addition, the typical healthy blood pressure of a human coronary artery is around 120/80 mmHg, which has less pressure compared to the glass test tube, causing it to be rigid and unable to stretch as a coronary artery would normally (11). A more generalizable way to express these results in future experiments would be the percent change in flow rate (flow rate after nanoparticles were added – flow rate before nanoparticles were added / flow rate before nanoparticles were added; units %). For instance, the percent change in flow rate for gold nanoparticles would be 183.3% from 3.6 to 10.2 mL/min, and the percent change in flow rate for silver nanoparticles would be 112.8% from 3.9 to 8.3 mL/min. This could help account for small changes in the baseline conditions and help understand how the nanoparticles might affect arteries of different sizes, flow rates, or occlusion severity. Nonetheless, this study provides significant data that gold nanoparticles can be heated to a temperature using an external NIR device to potentially unclog arteries for CAD patients.

Gold nanoparticles have many advantages that should be considered for further cardiovascular nanomedicine applications. They can be directed to specific diseased tissues in the artery (such as the intima, tunica media, and adventitia) while preventing damage to other nearby healthy blood vessel tissue (12,13). These gold nanoparticles are essentially conjugated to ligands such as monoclonal antibodies, which are peptides that bind to specific receptors and help facilitate drug delivery to tumor cells, which can allow for selective drug accumulation in targeted locations, such as diseased areas of the heart (12). One can also theoretically control drug release to either clog or flow by modifying the surface properties of gold nanoparticles, and drug release kinetics can be controlled (14). This could enable a sustained or triggered release of thrombolytic drugs, ensuring a prolonged and effective therapeutic effect at the site of a plaque (14). In addition, by adding stimuli-responsive coatings, like pH-responsive polymers, the gold nanoparticles can be used to encapsulate drugs, controlling drug release through remote NIR excitation to the arteries (15). These pH-responsive polymers essentially work by altering the hydrophilicity or solubility of the nano-drug carriers, which changes the drug carrier structure and release dynamics (15). However, there are some disadvantages of gold nanoparticles, which include the potential to damage blood cells in the coronary artery and in the bloodstream, for example (16). Gold nanoparticles are also limited in size as they range from 1–100 nm, which sometimes makes it harder for them to be effective in drug delivery to heart vessels, as they exhibit higher surface energy.

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Furthermore, based on the results of the current study, silver nanoparticles should also be highly considered for numerous medical applications as they have a high surface area-to-volume ratio, which enables efficient drug loading and enhanced drug release kinetics (17). The nanoparticles can also be surface modified or coated with biocompatible materials to minimize potential toxicity or adverse effects when interacting with the coronary artery to unclog areas with high plaque (cholesterol) formation (18). They can also be modified by targeting ligands that specifically bind to receptors in the cells of the coronary artery (19). However, silver nanoparticles can also be cytotoxic to various cell types, including cardiac cells, at high concentrations (20). These nanoparticles thus need more testing, but are safe when used in the right circumstances.

In this study, we used inexpensive, environmentally friendly ways to synthesize silver and gold nanoparticles. Importantly, these methods do not involve using the toxic chemicals often employed in nanoparticle synthesis, which can be harmful to important parts of the body, such as the lungs and heart (21). Using natural materials such as tea to make silver nanoparticles and a MesoGold drink supplement to obtain gold nanoparticles represents environmentally friendly processes, limiting their toxic effects on parts of the body. The silver nanoparticles were made using a tea-based extraction method, in which a commercially available FDA-approved wound gel containing silver nitrate was heated and mixed with boiling chamomile tea. Then, the solution was placed outside under direct sunlight, which led particles to form on the bottom of the beaker. Chamomile tea contains organic compounds, such as flavonoids and terpenoids, that act as reducing agents and are therefore capable of reducing silver ions (Ag^{+}) to elemental silver (Ag^{0}), which is the metallic form needed to form nanoparticles (22,23). Sunlight accelerates the reduction process by exciting the electrons (29). The exact size and shape of the nanoparticles can be influenced by the concentration of silver nitrate, the composition of the chamomile tea, and the duration of sunlight exposure. This bottom-up approach using natural plant extracts like chamomile tea and sunlight for the synthesis process is ultimately more sustainable and environmentally friendly than traditional ways of making silver nanoparticles as chemical reduction is involved. Similarly, the gold nanoparticles obtained for the present study were obtained from a commercially available gold drink supplement called MesoGold, which is readily available and safe to consume.

Green synthesis approaches use readily available biological materials as reducing and stabilizing agents, which can reduce the overall cost of nanoparticle production. These methods may also produce fewer toxic byproducts that are harmful to human health and the environment (24). In certain applications, such as medicine or electronics, these strategies could potentially reduce waste or improve energy efficiency, leading to a net positive environmental impact (24). Essentially, when scaled correctly, the green synthesis of nanoparticles is beneficial for the environment. It is important to have safeguards in place during the synthesis of such nanoparticles to avoid environmental damage if the present silver or gold nanoparticles were to be used for future applications. Further, such nanoparticles can be coated with aspirin to further aid in cardiovascular applications. Gold nanoparticles can thus potentially be delivered to clogged coronary arteries (and attach to unhealthy cholesterol, for example) to open up high-cholesterol vessels for patients with coronary artery disease. These nanoparticles can also be surface-modified or coated with biocompatible materials to minimize potential toxicity or adverse effects when interacting with the coronary artery to unclog areas with high plaque (cholesterol) formation (25).

In the future, these gold and silver nanoparticles can be further studied by altering particle geometries and sizes (which impact their photothermal properties) and testing their effect on flow rate in real clogged coronary arteries. Spherical, cubical, and hexagonal shapes can be tested in future studies, and different sizes ranging from 50 nm to 2000 nm can be tested to determine if geometry or size has an effect on the ability of these particles to unclog arteries. A scanning electron microscope can be used to determine the geometry and size of nanoparticles which can be the focus of future studies. Although not directly related to this Crisco simulation, aspirin can be useful when testing the particles in real coronary arteries in future experiments due to its role as a blood thinner. Additionally, a 1˚C increase in temperature would not necessarily be enough to release the aspirin coating from the particles for the context of this study, so a greater temperature change may be needed.

Additionally, the study was limited due to the lack of a few controls. DLS controls can be used in future experiments to measure the size of particles after dissolving the aspirin coating, ethanol only as a negative control, and nanoparticles of a known size (if available). This is significant because, according to the MesoGold product information, the gold nanoparticle size should be between 2–4 nm, but the measured size here was 80 nm, which is a significant difference.

Further, it is unclear if water is the best control for the simulated vessel test. Both the gold and silver nanoparticle solutions were suspended in different liquids and solutions, which have different temperature retention behaviors, which could have affected the results. Finally, test tube model controls can be implemented in the future as it is unclear how the particles interacted with the model vessel. To support conclusions from this test, aspirin-only and nanoparticles-only (no aspirin) controls can be included, as well as samples that do not undergo NIR activation. This will test if aspirin itself has any effect on flow in the model. The nanoparticles-only control would test whether the presence of the nanoparticles themselves or the release of something such as aspirin increases flow. Finally, the effect of NIR could also be tested because since all the samples had NIR exposure, it cannot be confirmed whether the NIR alone actually had any effect.

Overall, these results suggest that gold and silver nanoparticles could ultimately help reduce the risk of a heart attack or cardiac arrest, which would help save the lives of patients with coronary artery disease or high cholesterol.

MATERIALS AND METHODS

Gold and Silver Nanoparticle Synthesis

Gold nanoparticles can be most notably made using a chemical reduction method in which a reducing agent is used to reduce gold ions into metallic gold (26). Although this chemical reduction method is widely used, the gold nanoparticles used in this study were derived from MesoGold, a natural and safe drink supplement. These gold nanoparticles

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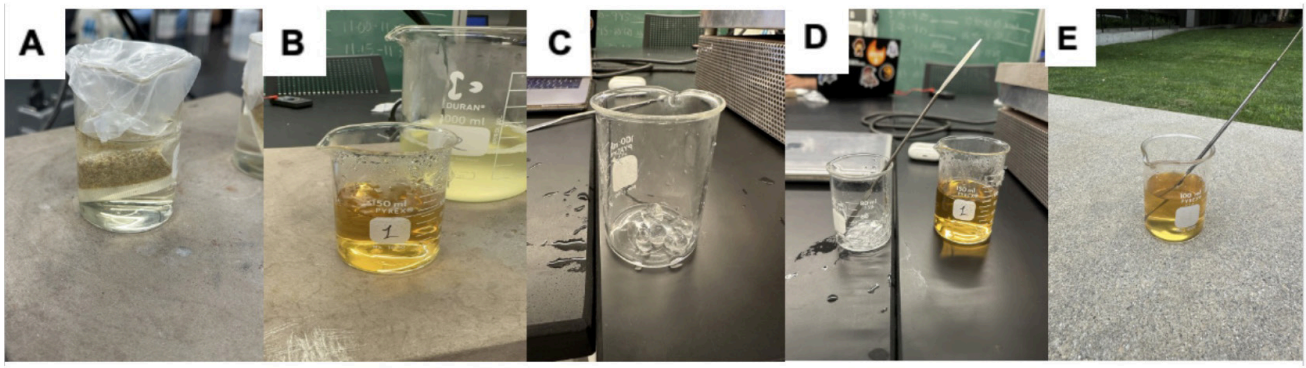

Figure 2: Steps for the environmentally friendly and inexpensive synthesis of silver nanoparticles. (A) Heating chamomile tea on a hot plate. (B) Chamomile tea turning yellow and starting to boil after 10 minutes. (C) Silver wound gel being added to a separate beaker. (D) Chamomile tea mixed with the silver wound gel. (E) Mixing both the tea solution and silver gel under sunlight.

were directly taken from the liquid in a MesoGold bottle using a pipette and were characterized with dynamic light scattering (DLS) both with and without an aspirin coating.

Silver nanoparticles have been widely used across all of medicine, including in FDA-approved wound healing gels, silver nanoparticle-impregnated catheters and endotracheal tubes, and commercially available band-aids due to their well-documented safety and anti-bacterial and anti-inflammatory properties (27). Silver nanoparticles can also be found in numerous household materials. To avoid the use of toxic catalysts frequently used in silver nanoparticle synthesis, we used an environmentally friendly method here (28). Specifically, a Celestial Seasonings chamomile herbal tea bag was heated in water on a hot plate to 260 °C for 10 minutes until it boiled. A commercially available silver wound gel (CVS Health Anti-Microbial Silver Wound Gel) was then heated for 3 minutes on a hotplate at 260 °C, and 3 mL of distilled water was added to aid in making a solution. The heated silver solution was placed under direct sunlight (for UV light energy) and mixed with 80 mL of the chamomile tea. The solution was vigorously mixed under direct sunlight for 5 minutes and left under direct sunlight for 10–20 minutes to allow the silver nanoparticles to form and settle on the bottom of the beaker (**Figure 2**).

Coating Aspirin on Nanoparticles

Gold and silver nanoparticles were coated with aspirin by dissolving 300 mg aspirin tablets (CVS pharmacy) in ethanol for 10 min and mixing the solution with the respective nanoparticle solution for 5 min using a magnetic stirrer. To confirm that a coating formed, the size of the nanoparticles before and after mixing with aspirin was observed to determine if the size of such nanoparticles increased. Since aspirin is not highly soluble in water, it was dissolved in ethanol. Once the gold and silver nanoparticles were added to the dissolved aspirin solution, the aspirin molecules were physically absorbed onto their surfaces due to van der Waals forces (29). In future experiments, the ethanol can be evaporated entirely before adding the aspirin-coated nanoparticles to the test tube to test the efficacy of the aspirin coating.

Dynamic Light Scattering (DLS)

A Nano-ZS DLS instrument was used to characterize the size of the nanoparticles in nanometers. Once the nanoparticles were synthesized, 12 µL of the respective nanoparticle solution were inserted in plastic tubes and measured by DLS for around 15 min. In this study, the DLS instrument was used to determine the size of the gold and silver nanoparticles before and after the aspirin coating. DLS works by analyzing fluctuations in the intensity of scattered light to find the hydrodynamic size of such particles or macromolecules in nanometers (30).

Near-Infrared (NIR) Activation of Nanoparticles

A NIR red light therapy device (Rotsha Infrared Red Light Therapy Device) was used to remotely heat up the silver and gold nanoparticles (both placed separately in 10 mL solutions) by inserting the device directly into the beaker of each nanoparticle respectively 1 in away from the surface of the solution. As cited in the manual, the specific NIR device used in this study had a wavelength of around 660–940 nm. A temperature probe was used to measure the temperature of the nanoparticle solution (and 10 mL water as a control) before and after a 5-minute interval of NIR light exposure.

Testing Blood Flow Rate of a Model Clogged Test Tube

A glass test tube was used as the artery to model a clogged human coronary artery, and Crisco shortening (30 grams) served as the cholesterol/fatty deposits and plaque. On average, the blood flow of a clogged human coronary artery is around 2.54 mL/s, and the blood flow of a healthy coronary artery is around 80–160 mL/s (9,31). The above-

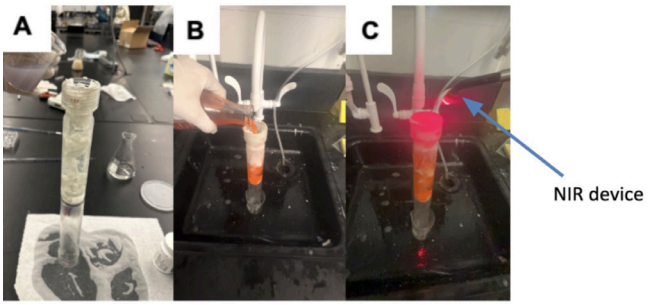

Figure 3: Steps for testing the flow rate of a modeled clogged artery using a test tube and aspirin-coated silver and gold nanoparticles. (A) Adding an aspirin-coated silver nanoparticle solution to the test tube. (B) Pouring water (with Kool-Aid red coloring) into the test tube to flow through the model clogged artery. (C) Using an NIR device to heat up the aspirin-coated nanoparticles to promote flow.10 minutes.

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mentioned silver and gold nanoparticles (between 53.9% and 100% intensity of light scattered of each particle per DLS) were coated with dissolved aspirin and were then separately added to the model clogged artery. The aspirin-coated silver and aspirin-coated gold nanoparticles had sizes of 1,612 nm and 793.5 nm, respectively, and were each in 10 mL solutions. Water was then poured from another beaker to flow through the model clogged artery, and the water flow rate was calculated by measuring the amount of water flowing past the filter down into a separate beaker over a 5-minute period (**Figure 3**) and the nanoparticles attached to the clogged artery and were heated using NIR for 5 min to test their ability to unclog the model artery. The Crisco tube was refilled and cleaned out for each gold and silver nanoparticle trial, as well as the control. The test tube artery model was 14 in long and 2 in wide, compared to an average human coronary artery diameter and length of 4.21 and 83.4 mm, respectively (32).

Statistics

All experiments were performed in triplicate and repeated across at least three different trials. Statistical differences between means were determined using student t-tests with $p<0.05$ considered statistically significant.

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