Bone Fracture Repair: Analysis of Mechanical Strength and Porosity Properties of Biocompatible Collagen Cements

Owen Vincent, Walker Pedinotti, Milo Miller
Dr. Barnabas Gikonyo
Chemistry Department, SUNY Geneseo, Geneseo, NY 14454

Introduction

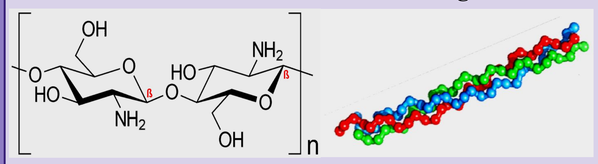
Calcium Phosphate Cements (CPCs) are under study as a method of replacing autografting.[1] Hydroxyapatite (HA) is a calcium phosphate mineral and the primary mineral component of bone, and can help to facilitate osteoconduction in vivo. HA cements alone however lack mechanical strength and porosity required for cell attachment and durability. The addition of dental cement has shown promise in improving mechanical strength, and naturally occurring polymers have shown promise in helping to improve porosity and the degradation of the cement as new bone is formed.[2]

In this project we examine the mechanical strength and porosity of HA CPCs with the addition of the protein polymer collagen. We examine compressive strength and shear strength, and examine the pore structure of the CPC with respect to naturally occurring bone.

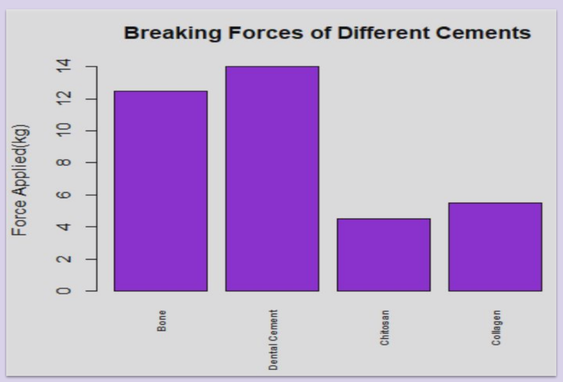
Previous Results

Last semester, we synthesized CPC samples with the addition of two naturally occurring polymers, collagen and chitosan. Collagen is a protein polymer found in connective tissue, and chitosan is a polysaccharide polymer derived from crustacean shells.

Chitosan **Collagen**



We found that collagen was a much more effective additive to our cements. It increased the mechanical strength and formed a pore structure comparable to that of natural bone. Despite the increase in mechanical strength, the addition of collagen did not result in a cement with strength comparable to natural bone. The collagen-CPC could withstand only ~5 kg when tested for shear strength, while natural bone withstood more than 12 kg.



Current Focuses

Since the addition of collagen succeeded in matching the pore structure of bone, our focus now shifts to increasing the mechanical strength of the cement and more rigorous testing of strength.

In addition to shear strength, we are also examining compressive strength. Compression is a much more common force placed on a load-bearing bone, so high compressive strengths are of interest when designing a CPC.

This project is ongoing, and data is currently being collected and analyzed. This poster will discuss methodology and expected findings.

Methodology

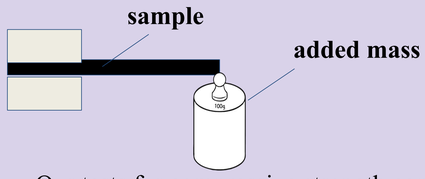
Cement Synthesis and Preparation

Our cement is synthesized by mixing a dry powder and a liquid component. The dry powder is composed of: 5g of dental cement, 3g of hydroxyapatite, and 2g of sodium bicarbonate. The liquid component is composed of 7mL of dental solvent and 3mL of 10% hydrochloric acid.. These are mixed in a beaker and placed in silicone molds for setting. This procedure can be modified to produce cements with 2.5%, 5%, or 10% collagen by mass.

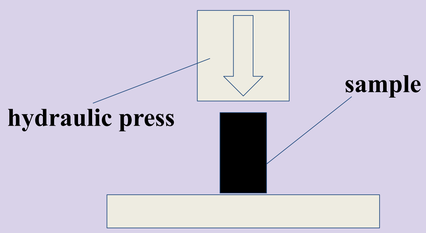
Mechanical Testing

Mechanical testing will comprise of shear strength and compressive strength.

Our tests for shear strength consist of a two-point bending device in which weight is gradually added until the sample snaps.



Our tests for compressive strength consist of a hydraulic press that will compress our sample to various points of structural failure so we can observe the breakage pattern.



Expected Results

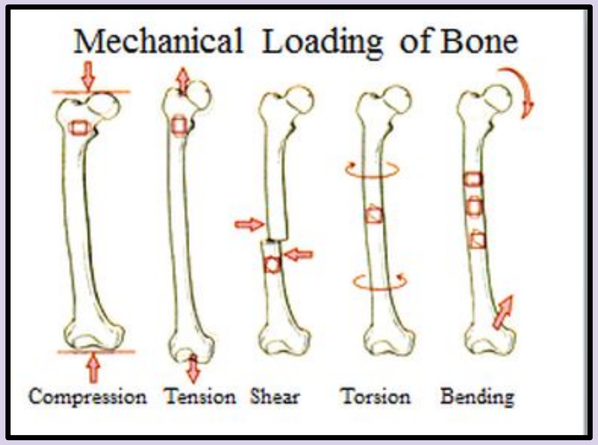
Mechanical Testing

The addition of collagen monomers should form polymers that span the whole cement mold. These collagen polymers would improve mechanical strength due to the organization of the polymer on a molecular level.

Under a shear force, the mechanical strength would theoretically increase as a result of the presence of the collagen polymers. Polymers spanning the entire length of the cement would act like rebar in cement, increasing the shear strength. Possessing a high resistance to shearing will be beneficial for medicinal application of this cement polymer.

Under a compressive force, a lack of shearing, buckling, or crumbling from our cement will indicate the presence of collagen polymers. Theoretically, under a compressive force the cement should decrease in height and increase in width. This would validate that the collagen polymers are providing structural, compressive support. A high resistance to compression is crucial for the medical application of the cement since compressive forces are the most common forces on most bones in the body.

Increasing the mechanical strength of our CPCs to the level of natural bone would increase the amount of use possible while healing from a bone fracture, as well as decrease total recovery time as the bone would shift less and be able to heal faster.[1]



Porosity

In increasing the mechanical strength of our CPCs, we need to make sure we do not sacrifice pore structure. The previous addition of collagen monomers resulted in a pore structure comparable to that of natural bone (20um - 260 um), so any additive we use to increase mechanical strength would ideally not change this range.

Future Directions

Immediate future direction will consist of discovering an adequate solvent. Our current solvent, a proprietary "dental solvent," helps set our cements quickly and effective;y, but its makeup is unknown to us. In order to properly understand why it is working and find a new solvent, using techniques such as IR and NMR spectroscopy may give us insight into what it is and what could be used as a viable alternative. Since the solvent is proprietary and expensive, finding a more widely available alternative with a known structure is of interest.

Along with the current focus of testing compressive strength and obtaining electron microscope images, using techniques such as Raman imaging may give us new insights into the cement's structure. Raman imaging would allow us to highlight specific functional groups or structures in order to elucidate more about the structure of the cements.

Next semester our research will focus on using silk fibroin, a protein in spider silk that may be more successful compared to collagen in forming a strong structure, while still maintaining porosity.[4] We believe that a combination of fibroin and collagen may be able to maintain the successful pore structure of our previous collagen CPCs and match the mechanical properties of natural bone.

Taking more steps to set the cements in physiological conditions is an important next step to allow for far in the future *in vivo* testing. Currently, our cements are not set under *in vivo* conditions, and observing the cement's behavior under physical conditions is of interest.

References

[1]Roberts, Rosenbaum, *et al.* Bone grafts, bone substitutes and orthobiologics. Organogenesis: 8 (2012): 114-124.
[2]Ishikawa, K. Takagi, S. et al. (1995) Properties and mechanisms of fast setting calcium phosphate cements. J. Mater Med. 6:528. Print.
[3]Moreau, J. L., Weir, M. D., Xu, H.K.X., Self-setting collagen-calcium phosphate bone cement: Mechanical and cellular properties. J. Biomed Mater Res A., 2009, 91(2): 605-613.
[4]Sun W, Gregory DA, Tomeh MA, Zhao X. Silk Fibroin as a Functional Biomaterial for Tissue Engineering. Int J Mol Sci. 2021 Feb 2;22(3):1499. doi: 10.3390/ijms22031499. PMID: 33540895; PMCID: PMC7867316.

Acknowledgements

We would like to thank Dr. Barnabas Gikonyo for his unending support and guidance; the SUNY Geneseo Chemistry Department for funding and material; and Dr. Sarah Gaudio for imaging support and guidance. We would also like to thank Dr. Anne Baldwin and the TRAC Grant program for helping us present our research at the ACS national conference this semester.