Setting Chemistry in Motion: Medical Aspects of Bones and Movement in Chemistry Education

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Abstract

Every small movement of the human body requires a complex interaction of an ensemble of muscles, bones, and joints. Questions about how our body functions have occupied researchers for hundreds of years. Nowadays we know a lot about our body, its composition and chemical reactions which make it function the way we are used to. Understanding our body is not only a naturally aspired goal and motivating learning context but it is the key to networked scientific thinking, linking various scientific fields and it is an investment in our own health and future. With society in the 21st century facing new health problems like sitting too much, spending free time in front of screens, moving less, or avoiding animal products for nourishment come consequences for the human body, especially regarding the musculoskeletal system, e.g., because of bad posture or protein and mineral balance. Not only can muscle atrophy, osteoporosis, or gout cause health damage over years but balanced nutrients provide for muscle growth, strengthened bones and overall being healthy. Especially children and adolescents, who in majority miss the daily aim of 60 minutes of physical activity recommended by the WHO [1], therefore need to be better informed about their own physical needs and healthy lifestyles. One the one hand, this represents an interesting learning context with great importance for and relations to everyday life. On the other hand, scientific details in this complex offer great learning opportunities on the interface of health care, medicine, pharmaceutical science and organic as well as inorganic chemistry. Discussing calcium phosphate and other mineral salts provides a connection to classical curricular contents of chemistry education even for younger students while other important aspects of the musculoskeletal system like collagen, proteins, vitamins or nervous stimulation transfer and energy resources are interesting topics for advanced level students. It is proven that medical aspects have motivating effects particularly on young women and provide the opportunity to get an insight into possible careers in natural sciences besides in any case popular medical professions [2].

In this article, we present an experimental approach on how basic principles concerning the musculoskeletal system can be made accessible for different levels of chemistry education and school laboratories through didactic reconstruction. Based on a simple set of experiments concerning bone structure [3], hydroxyapatite and gelatin are tested for creating an artificial bone-like structure. The resulting composites are examined regarding their characteristics.

Keywords: *chemistry education, medicine, bones, gelatine, apatite, calcium phosphate, musculoskeletal system*

1. Introduction

Walking, jumping, raising an arm - moving our body is one of the most normal things to us. Every movement requires a complex interaction of muscles, bones, and joints. Even if we do not realize how many protagonists our body uses daily, we learn to value normal body functions after experiencing restrictions due to injuries like broken bones. After breaking a bone, the body needs time to heal - but how exactly are fractures repaired? Our body is capable of building new bone from collagen and biological hydroxyapatite [4], but sometimes, bone defects are too grave to be filled out naturally. Especially with society in the 21st century facing new health problems like sitting too much, spending free time in front of screens, not doing enough sports, or having problems with protein and mineral balance, health problems and diseases of the musculoskeletal system become rather common problems [1]. Thanks to modern medicine and decades of research, doctors know how to mimic human bone and what bone substitute materials to use to make it easier for our body to heal defects [4-6]. In this paper, we present a series of basic experiments to deduce the composition of (chicken) bones [3], develop gelatin and hydroxyapatite into an artificial bone-like structure, and compare the characteristics of the resulting composite to real bones.

2. Human Bones and Bone Substitute Materials

Bones consist of 30-40 % organic bone matrix and 60-70 % inorganic minerals. Main components are type-1-collagen and carbonated hydroxyapatite. This makes proteins, calcium and phosphate dominating chemical structures in bones. [4] Composition and decomposition of bones in our body is carried out by osteoblasts and osteoclasts as specialized cells and administered by hormones like estrogen and vitamins like vitamin D [4, 7]. Macroscopically, bones are divided in their outer cortex and their inner trabecular bone ("spongy bone"). Outer bone consists of concentrically closed layers with blood vessels coating a duct and bone marrow. [8] Although bones do not consist of extraordinary chemical components, it is difficult to mimic because of its microstructure and different layers (Fig. 1). Most substitute materials are designed to stimulate bone building and to replace real bone only for a time [8]. Bone defects can temporarily be filled out with cements [9], bioglass [10], or collagen-hydroxyapatite-composites [11]. Using metal implants is possible but means no stimulation of bone formation [4]. Despite resemblance in chemical composition, bone substitute materials often do not show the same characteristics as real bone because of differing macro- or microstructures.

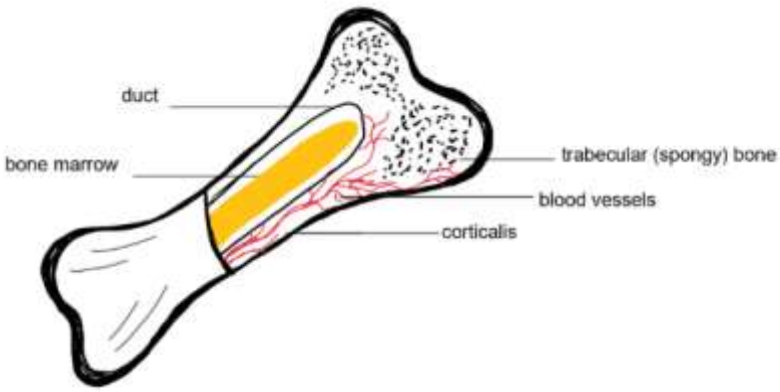

Fig. 1. Bone structure.

3. Didactic opportunities

Medical topics at the interface of different natural sciences offer great possibilities to provoke students' interest in otherwise less popular subjects like chemistry [12]. Because especially girls tend to find sciences as a school subject less likeable while taking significantly more interest in medicine as a field of knowledge and their later career [2, 13], connecting chemistry and medicine is an obvious chance for creating effective learning opportunities. Research shows that students suggest more experiments and connections to real-life contexts to make chemistry education more interesting [13]. Inevitably, didactic reconstruction of chemical topics embedded in medical contexts students can relate to will provide for creating a promising way of teaching chemistry. Using the musculoskeletal system as a topic and specializing on bones offers linkage to elements of the curriculum such as proteins and macromolecules, minerals and ionic substances, structure-relationship-properties, or chemical analysis.

4. Experimental: Chemical analysis of bones and bone substitute materials

To deduce the main different bone components - protein/organic matrix and minerals with calcium and phosphate - two approaches have been made to differ between organic and inorganic components, and to analyze exact substances. Based on these findings, a gelatin-hydroxyapatite-composite has been made. Didactic reconstruction provides an opportunity for contextualized learning and learning through discovery.

4.1 Chemical analysis of chicken bones

First, two simple experiments [3] were conducted to identify organic and inorganic material as components of bones. Therefore, cleaned chicken bones were 1) placed in 2 M HCl for 48 hours and 2) burned out with a Bunsen burner. Placing bone in acid results in dissolving inorganic minerals, leaving the bone rubbery and elastic (Fig. 2).

Fig. 2. Partially (left) and fully burned (center, right) chicken bone with visible spongy structure.

Burning away proteins and organic material to (essentially) carbon dioxide and water leaves a white crystalline, crumbly, and disintegrated mineral substance (Fig. 3). There is spongy bone at the ends and a now white coated duct in the middle of the bone visible. Additionally, a Biuret test to detect proteins was carried out positively before and negatively after 2) (Fig. 4).

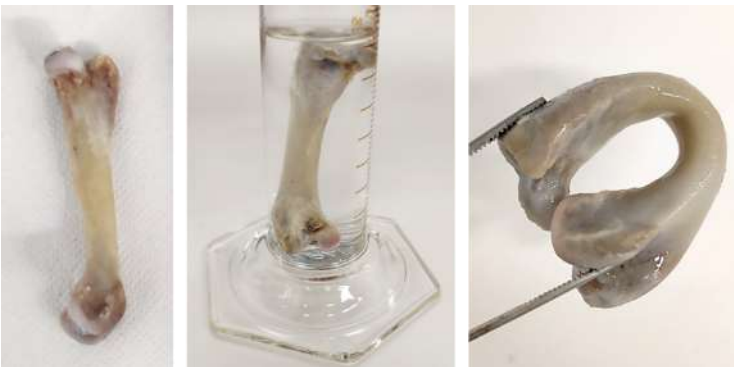

Fig. 3. Bone before (left), during (center), and after (right) incubation in 2 M HCl.

Fig. 4. Biuret test before (left) and after burning.

Calcium was precipitated as calcium oxalate and phosphate was detected with ammonium molybdate from the acidic solution after 1) (Fig. 5). Biuret test stays negative with the acidic solution (Fig. 7). Working with basic school laboratory equipment and with non-hazardous chemicals makes the analysis of bone structure and composition accessible for lower-level education.

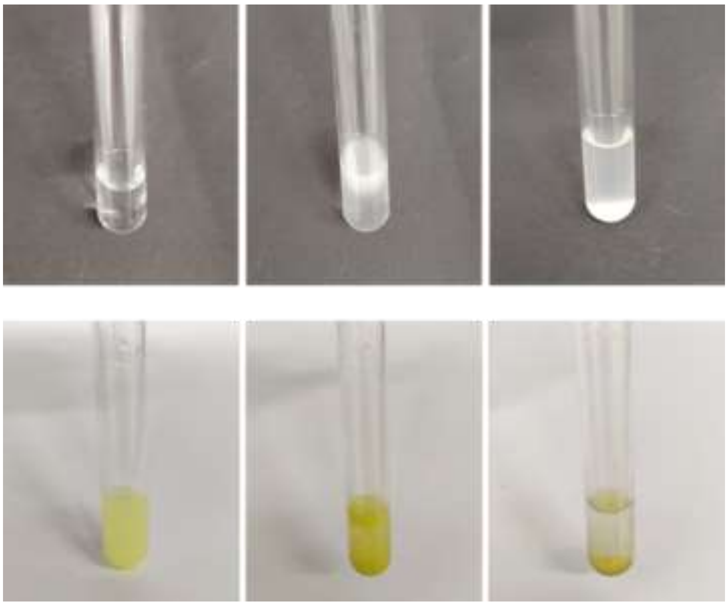

Fig. 5. Precipitation of calcium oxalate (top) and ammonium molybdophosphate (bottom).

4.2 Creating an artificial bone-like structure

Based on the findings in 4.1 and medical background knowledge, we conducted the fabrication of an artificial bone-like composite with a gelatin-hydroxyapatite-ratio from 1:2 and a hydroxyapatite-calcium carbonate-ratio from 3:1. Gelatin (ω = 15 %) was dissolved in water at 60 °C and treated with a milk frother to create fibrils [11]. After mixing in the minerals, the composite was poured in different forms and let harden. The composite is breaking easily and with a straight edge whilst bone breaking requires greater force and the bone tends to splinter. Burning the composite leaves only crystalline mineral rests with no macro- or microstructure like different layers, ducts, or spongy tissue (Fig. 6). Placing the composite in acid produces foam and leaves a gelatinous solution (Fig. 6). Biuret test can be carried out positively on the composite as well as in that solution (Fig. 7).

Fig. 6. Composit (left), after burning (center) and during incubation in 2 M HCl (right).

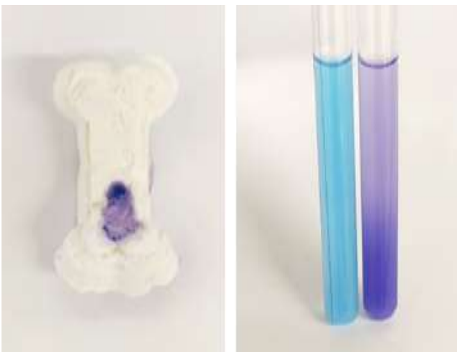

Fig. 7. Biuret test on the composite (left), in the acidic "bone solution" (right, left glass), and in the acidic "composite" solution (right, right glass).

Comparing bone and our composite, it is revealed that even though they have a resembling chemical composition, simple methods as ours cannot equal structures generated by alive organisms. There are notable differences between collagen as the protein present in bones and gelatin as re-arranged collagen. Evaluating this comparison can show important structure-property-relationships as well as help students appreciating life and nature.

5. Outlook

The experiments will be embedded in learning arrangements for chemistry lessons concerning ionic substances and macromolecules (proteins) for different levels of school education. Other biochemical aspects like nutrient requirements for healthy bones, other bone substitute materials, and chemical aspects of the interaction of muscles and bones will be integrated into the arrangement as well. The experiments will be piloted, evaluated, and optimized. They could as well be a part of interdisciplinary projects in connection with biology and physics.

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