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Acidic Medium Effect on the Natural Frequency of Bones

Ameen M Al Juboori* and Shaker Sakran Hassan

Department of Mechanical Engineering, Technology University, Baghdad, Iraq

Research Article

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***For Correspondence**

Ameen M Al Juboori, Department of Mechanical Engineering, Technology University, Baghdad, Iraq, Tel: +009647700016183, 07901544134.

E-mail: ameenketab@gmail.com

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ABSTRACT

This study focus on the simulation of calcium efflux and its effects on the natural frequency of the bone. The calcium was removed from the bone by the aid of diluted sulfuric acid (20-30% concentration and pH 1). Sulfuric acid will act as reducing agent. The reaction between the bone and the acid will results Calcium sulfate and hydrogen. Ten cows bone samples were collected from different animals. Those bones was submerged in the diluted acid formula for 24 hrs. CT Scan for the bones was performed before and after the treatment. Finite Element analysis was conducted based upon the DICOM imaged obtained from the CT Scan. The Finite element analysis results was compared with experimental results obtained by conducting impulse test for the bones before and after the treatment. There was good agreements between the results in both cases. The results shows that the natural frequency of the treated bone is higher than the fresh bone. This can be related to the mass lost due to the chemical reaction. This study can give us an information about the relationship between the loose of inorganic elements in the bone matrix and the natural frequency of the bone.

INTRODUCTION

Bones has complicated structure build by a matrix. This matrix consists of organic and inorganic materials. The composition and the arrangements of those materials gives the bone its mechanical properties. The disrupting of this matrix can lead to change in the health condition of the bone. The natural frequency analysis is promising field of study which can give an indication about the health condition of the bone [1-3]. Inorganic materials (Calcium and Phosphate) are responsible for the bone strength [4]. Bone disease and calcium regulation can affect the bone integrity due to the change in the bone mineral density. Sometimes the bone is surrounded by acidic medium due to the release of Lactic acid from the muscles in intensive exercise [5]. The acidic medium can also be generated due to the presence of metabolic acidosis which will influx the calcium from the bone. Patient who are suffering from osteoporosis take doses of calcium but in many cases there is no significant change in the calcium content in the bones. The acidic medium may prevent the calcium placing inside the bone matrix and instead it will be used to neutralize this medium [6]. Many studies were done focusing on the effect of acidic medium on the bone composition and showed that osteoporosis and Metabolic Acidosis are linked [7].

The bone can be considered as beam made of composite materials (organic and inorganic) and its mechanical properties depends on the on the nature of distribution of those materials. The disease and calcium regulation inside the body will affect directly the density of the bone. The mechanical properties of the bone has strong correlation with the apparent density. The structural dynamic properties of any structure depends on the mechanical as well as geometrical properties. If the bone is loosing calcium due to any reason this will reduce its mass and the structural dynamic properties of the bone will change. Frequency analysis is a technique can be used to verify the health condition of the bone [8]. All the standard test available to measure the bone integrity or to diagnose bone disease are radioactive. Therefore, developing a new diagnosis test without radiation hazard is highly important. To do so we need to understand how the natural frequency of a bone changes when the inorganic elements are disrupted.

Finite Element Analysis

A finite element model of the bone is difficult to be build due to its shape irregularity and density variation. In order to build a three dimensional model a CT-Scan test **(Figure 1)** was used. The images of the bones were collected and stored in DICOM format (Digital Imaging and Communications in Medicine). Those images has the size of 512 × 512 pixels. CT-scan device type GE Medical Systems\Discovery CT 750 HD was used and the images were taken with the same setting (KVP 120, slice thickness 2.5 mm, and tube current 120 mA). The test was conducted before and after submerging in diluted acid.

Figure 1. CT-Scan test for the bones.

The DICOM images are exported to MIMICS program to construct the three dimensional model. Program named 3-matic was used to generate the surface meshing. The quality of the meshing was tested by using height to base ratio. The volumetric meshing was generated by using elements type TET 4 (3-matic program has two option for the volumetric meshing TET 4 and TET 8). The meshed modal is exported to MIMICS program again for the material assignment. Based on the grayscale of each pixel in the region of interest the apparent density was calculated. The finite element modal is exported to ANSYS mechanical APDL for the modal analysis **(Figure 2)**. Modal analysis is used for the calculation of the natural frequency for different modes of vibration. **Figure 3** shows the process of construction the three dimensional finite element model.

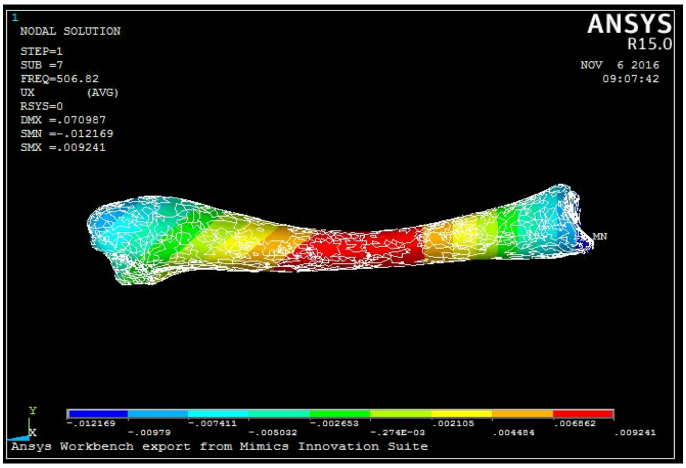

Figure 2. FEA in ANSYS.

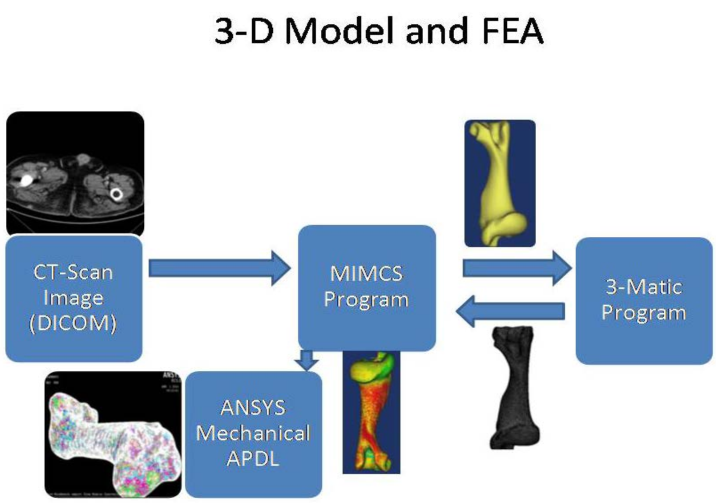

Figure 3. Three dimensional modal and FEA model.

Material an Experimental

The samples were collected from different cows (10 samples). Most soft tissue was removed carefully. The samples were stored in -20°C. Sulfuric acid is a very corrosive agent and to reduce its effect on the bone it was diluted (20-30% concentration and pH 1). The bone was submerged is acidosis medium for 24 hrs. The bone is taken out from the acidosis medium and washed with water. A white layer of Calcium sulfate was removed from the surface of the bone. The bone was left to dry.

Modal test was used to extract the natural frequency experimentally. The Modal test was conducted before and after acidosis treatment. The equipments used in the modal test are listed in the **Table 1** below.

Table 1. Modal test equipments.

No	Device	Company	Description
1	Impulse hammer type IH-1	YMC PIEZOTRONICS,INC	Sensitivity 25 mV/N
2	Dynamic signal Analyzer	YMC PIEZOTRONICS,INC	YMC 9004 IEPE
3	Miniature Accelerometer	YMC PIEZOTRONICS,INC	Sensitivity 100 mV/g

The modal test was done with free-free boundary conditions [9,10]. The free-free boundary condition was simulated by placing the bone on soft sponge. The bone was excited by hammering on different locations on the bone by using the impulse hammer. The load cell on the tip of the hammer record the striking force signal. The response is captured by using miniature accelerometer. The dynamic signal analyzer will plot the frequency response function (FRF) by using the two signals. Peaks were identified on the magnitude curve of the FRF. The natural frequency is extracted by the help of the phase angle diagram. The quality of the test was monitored by the coherence. Any FRF plot which has coherence lower than 1 is ignored [11]. Due to the free-free boundary condition the second strike was a challenging issue. A care must be applied when hitting the bone. **Figure 4** shows the experiment setup.

Figure 4. The modal test experiment setup.

RESULTS

The natural frequency for the bones before and after submerged in diluted sulfuric acid was extracted by using FEA and experimentally by impulse test. Five modes of vibrations were verified and extracted for each sample. Peaks were identified on the magnitude graph of the frequency response function. The natural frequencies were extracted by the help of the phase angle diagram. The extraction of the lower modes of vibration (natural frequency) is hard to be found and in many times we could not extract them. This happened because the soft rubber hammer tip did not provide enough energy to excite the lower modes. There were good agreements between the finite element and experimental results. The maximum error between the FEA and the experimental was less than 10%. **Table 2** below shows the natural frequency the bones before and after the treatment. Several frequencies were extracted for different modes of vibration.

Table 2. The natural frequencies (Hz) of the bone before and after the treatments for different modes of vibration.

NO	Sample	Fresh		Acidosis Treatment		Percentage Increase (%)
		Exp	FEA	Exp	FEA	
1	A1	5358	5555	5541	5349	3.30%
		6738	6732	7055	7066	4.50%
		7006	7207	7373	8077	5.00%
		7116	7261	7568	8407	6.00%
		7666	7666	8056	9018	4.80%

2	A2	5371	5180	5517	5465	2.60%
		6054	6152	6591	6773	8.10%
		7275	7320	7470	8268	2.60%
		7983	8209	8496	8614	6.00%
		8837	8410	9472	8868	6.70%
3	B1	6103	6289	6591	6119	7.40%
		7031	7134	7446	7069	5.60%
		7499	7470	7812	7558	4.00%
		7995	7564	8203	8148	2.50%
		8105	8308	8520	8858	4.90%
4	B2	3198	2669	3344	2938	4.40%
		3552	3851	3759	3757	5.50%
		5517	5767	5908	5558	6.60%
		6054	6057	6542	6224	7.50%
		7153	6913	7617	8267	6.10%
5	C1	6555	6784	6982	7131	6.10%
		6054	6355	6542	6729	7.50%
		6762	7188	7177	7187	5.80%
		7336	7310	7768	7776	5.60%
		7751	7643	8178	8167	5.20%
6	C2	5175	5271	5541	5292	6.60%
		6018	6168	6567	6164	8.40%
		6530	6684	6933	7036	5.80%
		6958	7019	7348	7260	5.30%
		7153	7233	7470	7359	4.20%
7	D1	5054	4932	5468	5218	7.60%
		5603	5066	5957	5438	5.90%
		6152	5874	6372	6009	3.50%
		7006	6900	7568	7668	7.40%
		7617	7350	7983	7974	4.60%
8	D2	6079	6280	6640	6137	8.40%
		7214	7246	7641	7582	5.60%
		7446	7598	7812	7728	4.70%
		8605	8745	9008	8690	4.50%
		9008	9291	9399	8997	4.20%
9	E1	6176	6075	6420	5945	3.80%
		6481	6422	6860	6456	5.50%
		6886	6707	7226	7063	4.70%
		7177	7208	7617	7389	5.80%
		8581	8435	8911	8344	3.70%
10	E2	5566	5455	5957	5429	7.20%
		6225	6123	6787	6348	8.90%
		6640	6492	7128	7777	6.30%
		7116	7714	7812	8087	8.60%
		7421	8074	7983	8471	6.60%

DISCUSSION

The bone mechanical properties has strong correlation to the bone mineral density. Disease or calcium regulation has strong impact on the bone density which will change the mechanical properties of the bone. The natural frequency depends on the mechanical and geometrical properties of the bone. Therefore, natural frequency changes with the changes affecting the bone. The later can used as indication about the health condition of the bone. As we stated before the acidosis medium inside the body can found due to the extensive exercise and due to the presence of the metabolic acids. The body will try to neutralize those acids by using the calcium from the bones (the bones are the reservoir of calcium for the body). This procedure will reduce the calcium content inside the bone. Eventually the bone density will be reduced.

There were good agreement between the FEA and experimental; results (less than 10%). The variation between the two results is due to the free-free boundary condition simulation because we can't achieve perfectly the free-free boundary condition experimentally.

The results shows that there is increase in the natural frequency after the treatment. This due to the mss lost in the chemical reaction (Calcium sulfate). The percentage of increase in the natural frequency vary from 2-9%. This variation can be related to variation in the sulfuric acid concentration (20-30%).

CONCLUSION

The Acidic medium simulate the effect of calcium efflux from the bone. Studies have proved that there is a link between the pH factor and the osteoporosis disease. This study give us better understanding about the effect of the acidic medium on the bone natural frequency. The results shows that the natural frequency of the bone is increased due to the loose of mss (chemical reaction). Although, the effect of bone disease does not affect the inorganic materials inside the bone matrix but we need to have better understanding about the influence of calcium efflux on the natural frequency of the bone. The aim of all the studies which are dealing with frequency analysis of the bone is to develop nonradioactive test to measure the bone health condition without exposing the patient to radiation hazard. This aim require the understanding the influence of each element inside the bone matrix on the natural frequency.

CONFLICT OF INTEREST

No outside funding or grants in support of our research for or preparation of the work is received. And no personal or institutional financial support is related to the study. Furthermore, we have had full control of all primary data and we agree to allow the journal to review the data if recommended. Therefore, we accompany this submission with Authorship Responsibility and Disclosure Regarding Commercial Interest form.

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