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Faculty of Medicine
Biomedical Engineering

Master of Science Thesis

Title: Thesis Template

by

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of (Heimatort or country of origin)

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Abstract

The abstract should provide a concise (300-400 word) summary of the motivation, methodology, main results and conclusions. For example:

Osteoporosis is a disease in which the density and quality of bone are reduced. As the bones become more porous and fragile, the risk of fracture is greatly increased. The loss of bone occurs progressively, often there are no symptoms until the first fracture occurs. Nowadays as many women are dying from osteoporosis as from breast cancer. Moreover it has been estimated that yearly costs arising from osteoporotic fractures alone in Europe worth 30 billion Euros.

Percutaneous vertebroplasty is the injection of bone cement into the vertebral body in order to relieve pain and stabilize fractured and/or osteoporotic vertebrae with immediate improvement of the symptoms. Treatment risks and complications include those related to needle placement, infection, bleeding and cement extravazation. The cement can leak into extraosseous tissues, including the epidural or paravertebral venous system eventually ending in pulmonary embolism and death.

The aim of this project was to develop a computational model to simulate the flow of two immiscible fluids through porous trabecular bone in order to predict the three-dimensional spreading patterns developing from the cement injection and minimize the risk of cement extravazation while maximizing the mechanical effect. The computational model estimates region specific porosity and anisotropic permeability from Hounsfield unit values obtained from patient-specific clinical computer tomography data sets. The creeping flow through the porous matrix is governed by a modified version of Darcy's Law, an empirical relation of the pressure gradient to the flow velocity with consideration of the complex rheological properties of bone cement.

To simulate the immiscible two phase fluid flow, i.e. the displacement of a biofluid by a biomaterial, a fluid interface tracking algorithm with mixed boundary representation has been developed. The nonlinear partial differential equation arising from the problem was numerically implemented into the open-source Finite Element framework *libMesh*. The algorithm design allows the incorporation of the developed methods into a larger simulation of vertebral bone augmentation for pre-surgical planning.

First simulation trials showed close agreement with the findings from relevant literature. The computational model demonstrated efficiency and numerical stability. The future model development may incorporate the morphology of the region specific trabecular bone structure improving the models' accuracy or the prediction of the orientation and alignment of fiber-reinforced bone cements in order to increase fracture-resistance.

Acknowledgements

Here you may include acknowledgements.

Ich erkläre hiermit, dass ich diese Arbeit selbständig verfasst und keine anderen als die angegebenen Hilfsmittel benutzt habe. Alle Stellen, die wörtlich oder sinngemäss aus Quellen entnommen wurden, habe ich als solche kenntlich gemacht. Mir ist bekannt, dass andernfalls der Senat gemäss dem Gesetz über die Universität zum Entzug des auf Grund dieser Arbeit verliehenen Titels berechtigt ist.

Bern, October 31$^{\text{th}}$ 2009

René P. Widmer

Contents

Chapter 1

Introduction

The introduction provides a thorough review of the background, including relevant literature, the motivation, the aims of the thesis and the hypotheses. Literature references for the thesis should be collected in one common bibliography at the end of the thesis.

With the population aging, medicine is recognizing the major impact of osteoporosis on health and function. The chief manifestation of osteoporosis is the pathologic fracture. Osteoporotic patients sustain fractures when minimal force is applied to weakened, discontinuous bone. Traditionally, most attention has been given to osteoporotic fractures of the hip. However, the 700'000 osteoporotic vertebral compression fractures per year in the United States easily outnumber fractures of the hip and ankle combined.

It is estimated that more than 200 million people worldwide are currently affected by osteoporosis, and 100 million are at risk of suffering from related complications. It is a proven fact that solely in Europe about 3.8 million osteoporotic fractures were treated in the year 2000. The prevalence of the disease is expected to rise significantly with the aging population: In the US, the number of annual osteoporosis-attributable fractures is expected to double by the year 2025, and the growth predictions for Switzerland are of comparable magnitude. The total cost of osteoporotic fractures in the US was estimated at 7 - 10 billion dollars in 1995 for a population of 250 million, and expenditures for the treatment of vertebral fractures alone were estimated at 377 million Euros in 2003 in the European Union.

Vertebral compression fractures have previously received limited attention from the spine care community. This oversight may be a result of the perception that vertebral compression fractures are benign, self-limited problems or that treatment options are limited. However, it has become clear that vertebral compression fractures are associated with significant physiologic and functional impairment, even in patients not presenting for medical evaluation at the time of fracture.

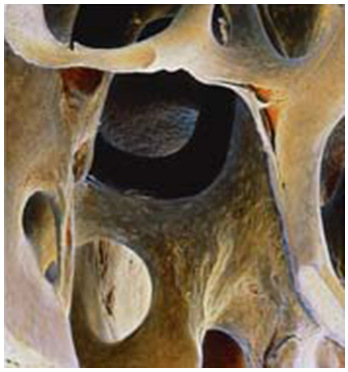
Open surgery is fraught with morbidity and implant failure in this frail patient population. Therefore, nonoperative management, including medications and bracing, has been recommended for the vast majority of patients. Unfortunately, large numbers of patients report intractable pain and inability to return to activities. The limitations of nonoperative management have encouraged increasing interest in new, percutaneous methods of fracture stabilization that allow early return to activity and do not require fixation in weak bone.

Percutaneous vertebroplasty was first performed in France in the mid 1980s, and there is extensive experience with the technique in continental Europe. Originally used to treat

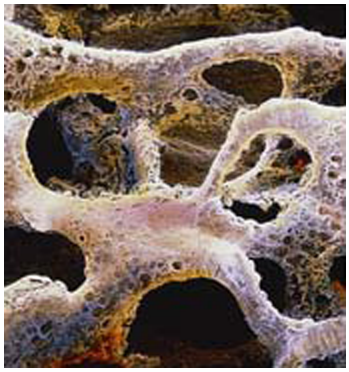
the painful, aggressive variant of vertebral haemangioma[1], percutaneous vertebroplasty has been applied to painful vertebral lesions caused by metastatic disease and painful osteoporotic fractures.

Osteoporosis is a skeletal disorder which is characterized by loss of bone mass and degradation of trabecular structure, which results in an increased fracture risk. Osteoporotic fractures most frequently occur in structures subjected to large strains, such as the spine or the hip, or bones commonly affected by falls, such as the distal forearm. Thoracic and lumbar vertebral collapses are recognized as the most frequent complication resulting from the loss of bony substance.

etc.



(a) Normal



(b) Osteoporotic

Figure 1.1. Normal and osteoporotic spongy microscale bone structure at 25x magnification. Image source: `http://facstaff.unca.edu/cnicolay/BIO223-F08/L06-bone.pdf`.

Please document your image sources.

[1] A haemangioma describes a benign overgrowth of blood vessels.

Chapter 2

A Sample Chapter

2.1 A Sample Section with a Table

2.1.1 Porosity Estimation

To parametrize the computational model the porosity of each foam type needs to be estimated from representative μCT data. Remember the definition of porosity as the ratio of the void volume and the total volume. μCT data is present in the form of binary data, i.e.

$$v_{m,n,p} \in \{0,1\} \qquad \forall m,n,p\,. \tag{2.1}$$

$v_{m,n,p}$ refers to the voxel value at instant position (m,n,p) in the three-dimensional μCT data array $\mathbf{V}$. Hence the porosity can be estimated as the ratio of voxels with an associated value of 0 and the overall number of voxels. Let

$$\begin{aligned} V &= \{v_{m,n,p}\} & &\forall v_{m,n,p} \in \mathbf{V} \\ V_0 &= \{v_{m,n,p}\} & &\forall v_{m,n,p} \in \mathbf{V} \wedge v_{m,n,p} = 0 \\ V_1 &= \{v_{m,n,p}\} & &\forall v_{m,n,p} \in \mathbf{V} \wedge v_{m,n,p} = 1 \\ & & & V_0 \subseteq V\,, \quad V_1 \subseteq V\,. \end{aligned}$$

V is the set of all voxels, V_0 the set of voxels with an associated value of 0 and V_1 the set of voxels with an associated value of 1 in the binary data array $\mathbf{V}$. Therefore $V = V_0 \cup V_1$. The porosity measure is then given by

$$\overline{\beta} = \frac{|V_0|}{|V|} = 1 - \frac{|V_1|}{|V|}\,. \tag{2.2}$$

$|S|$ is the *cardinality*, i.e. the size or number of members of the set S. Notice that $|V| = M \cdot N \cdot P$, meaning the size of the set V is equal to the number of voxels stored in the array $\mathbf{V}$.

The different porosity levels for the foams with {20, 30, 40} PPI pore density are presented in Tab. 2.1.

Table 2.1. *All numbers are dimensionless* – Aluminum foam porosity levels estimated from representative μCT data.

	20 PPI	30 PPI	40 PPI
$\|V\|$:		78094368	
$\|V_0\|$:	73224007	68342720	59401544
$\|V_1\|$:	4870361	9751648	18692824
Porosity $\overline{\beta}$:	0.938	0.875	0.761

Chapter 3

Discussion and Conclusions

3.1 Discussion

Interpret your results in the context of past and current studies and literature on the same topic. Attempt to explain inconsistencies or contrasting opinion. Highlight the novelty of your work. Objectively discuss the limitations.

3.2 Conclusions

Formulate clear conclusions which are supported by your research results.

Chapter 4

Outlook

Provide a vision of possible future work to continue and extend your thesis research.

etc.

Appendices

Appendix A

Vector and Tensor Mathematics

A.1 Introduction

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A.2 Variable Types

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Appendix B

Another Appendix

B.1 Section 1

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B.2 Section 2

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