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# Surgical Microdrilling for Osteoarthritis Treatment

A Finite Element Study of Bone and Cartilage

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## Sammanfattning

Mikrofrakturering är i många fall en väl fungerande behandling av artros, (eng. Osteoarthritis). Mikrofrakturering innebär att man perforerar benet under det skadade brosket och på så sätt skapar blödningar. Blodet som genom blödningarna når leden innehåller stamceller som hjälper till vid återuppbyggnaden av det skadade brosket. Det är känt att mikrofrakturering påverkar ledens struktur, både mekaniskt och biologiskt, men i vilken omfattning leden påverkas är ännu inte fastställt.

Utifrån en litteraturstudie gjord på tidigare forskning inom ämnet mikrofrakturering och andra intilliggande områden kunde viktiga influerande parametrar fastställas. Efter litteraturstudien utfördes flera simuleringar med finita elementmetoden på ben- och broskstrukturer genom att utföra faktorförsök. Variansanalys (ANOVA) användes för att utvärdera resultaten och fastställa vilken påverkan de olika ingående parametrarna har. De olika parametrarna är; benstyvhet, bentjocklek, brosktjocklek och mikrofrakturering.

Resultaten visade att brosktjockleken är den parameter som har störst påverkan på ledens mekaniska beteende. Efter brosktjocklek kom bentjocklek och mikrofrakturering. Påfrestningarna i benet kan mer än fördubblas jämfört mot genomsnittet. Utifrån dessa iakttagelser kan slutsatsen dras att minskad broskmängd kraftigt påverkar det mekaniska beteendet hos en led. Det kan även påvisas att mikrofrakturering har en stor påverkan på benets struktur och att variationer i bentjocklek på grund av artros inte går att försumma.

En experimentell testrigg för att studera mikrofrakturering i ben hos möss togs fram. Målet med denna testrigg vara att kunna utföra mer användarvänliga försök med god repeterbarhet. Ett x-y bord designades och integrerades med ett lämpligt reglersystem bestående av stegmotorer och en Raspberry Pi reglerenhet.

Nyckelord: artros, benmärgsstimulering, FEM, mikrofrakturering, subkondral borrning

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## Abstract

Surgical microdrilling is a potential treatment method for many patients suffering from osteoarthritis (OA). During microdrilling, the bone underneath the damaged cartilage is perforated to induce bleeding. The blood that enters the joint contains stem cells which help to restore the damaged cartilage. Microdrilling is known to affect the joint structure both biologically and mechanically, but knowledge regarding its structural effects is still limited.

Based on literature review of previous research in microdrilling and adjacent areas, important influencing parameters were identified. Thereafter, a finite element study was performed simulating the bone and cartilage structures using a factorial design approach. Analysis of variance (ANOVA) was used to evaluate the results and to identify the relevance of the parameters: bone stiffness, bone thickness, cartilage thickness and microdrilling.

The results revealed that the cartilage thickness is the most relevant factor regarding its influence on the mechanical properties of the joint, followed by bone thickness and microdrilling. Stresses in the bone can increase more than two times the value from the baseline. Based on the findings, the conclusion can be drawn that loss of cartilage has a significant influence on the contact mechanics of a joint. Furthermore, microdrilling affects the bone structure significantly, and alterations in bone thickness due to OA are not negligible.

As a third element, an experimental test rig for studying microdrilling in mice was developed. The objectives of the development were to increase the user-friendliness and to enhance reproducibility. An actuated x-y table was designed including the corresponding control system using stepper motors and a Raspberry Pi.

**Keywords**: surgical microdrilling, FEM, subchondral drilling, osteoarthritis, marrow stimulation

To Nicole and my family.

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## Nomenclature

#### **Roman Symbols**

Α	Contact area
Ε	Young's modulus or Elastic modulus
$p_0$	Hertzian contact pressure
r	Radius
Greek Symbols	
δ	Deformation
v	Possion's ratio

au Shear stress

### Acronyms / Abbreviations

- ANOVA Analysis of Variance
- *BMP* Bone morphogenetic protein
- CAD Computer Aided Design
- *CDF* Cumulative Distribution Function
- CEBC Centre for Engineering Better Care
- CU University of Cambridge

CUED	CU Engineering Department
ЕСМ	Extra Cellular Matrix
ESC	Embryonic stem cells
FEM	Finite Element Method
FGF	Fibroblast growth factor
GUI	Graphical User Interface
IGF	Insulin-like growth factor
iPSC	Induced pluripotent stem cell
MD	Microdrilling
MSC	Mesenchymal Stem Cell
OA	Osteoarthritis
PBSC	Peripheral Blood Stem Cell

 $TGF - \beta$  Transforming growth factor- $\beta$