A miniature robot for bone milling in total knee replacement

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PRAXITELES
Safe, accurate milling system for TKA

1. Modeling the Milling Process

2. Design of the Milling Guide

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Praxiteles Mini-Robot

System Components:

1) Fixation and adjustment system

2) Positioning unit

3) Passive mill guide

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Universal Cutting Guide

Objectives

- Versatile tool for milling and sawing in image-free computer assisted TKA

Previous prototype [Stindel et al. CAOS 2004]

- Open TKA with medial and lateral fixation

BEFORE AFTER

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Praxiteles Mini-Robot

- Hybrid Passive / Motorized Architecture
- Fixed entry point milling tool guide

Sagittal Rotation
AP Positioning
PD Positioning

5 cutting planes

Varus/Valgus Rotation

Internal/External Rotation

2 DoF Planar Milling Guide

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MIS Challenge

Design a robot with the constraints of Minimal Access TKA:

- 5 DoF + any implant shape/size
- medial attachment (approaches: mini-TKA, sub-vastus)
- permit access of all 5 cuts through small incision

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Calibration and Positioning

- Two step kinematic calibration phase:

1 Passive

2 Active

Brake release button

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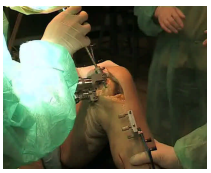
Side Milling Technique

- 5 cuts
- Computer controlled milling tool
- Integrated irrigation system



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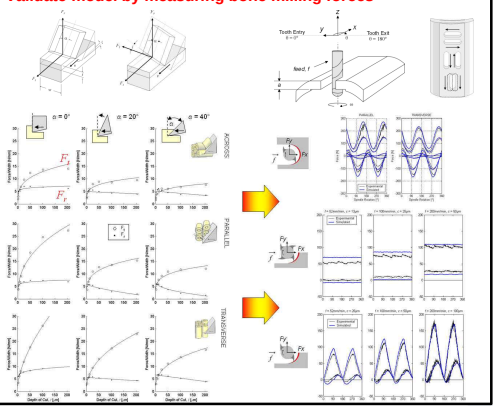
Validate model by measuring bone milling forces



2 MODELING OF HIGH SPEED BONE MILLING FORCES

Why model Bone milling forces?

- Accuracy
  - forces can reach high values
  - causes deflection of the tool
  - reduced surface accuracy
  - vibrations
- Safety
  - milling forces can be '*unpredictable*'
  - bur tends to '*slip*' from the intended trajectory

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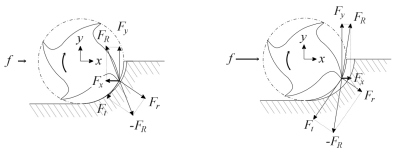
Effect of feed rate on feed force



Slow feed = opposing force

Fast feed = 'pulling' force

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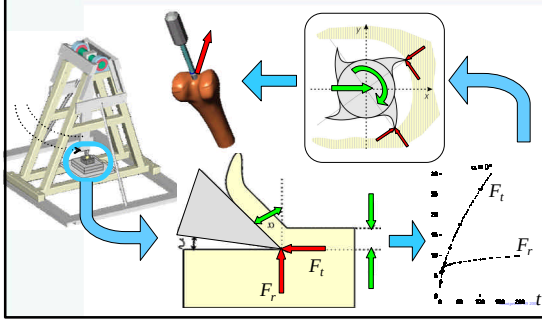
Model Formulation



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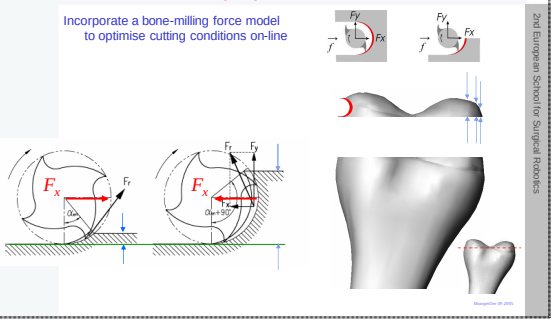
Effect of radial cutting depth on feed forces

Incorporate a bone-milling force model to optimise cutting conditions on-line



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Conclusions

- Bone milling forces are strongly non-linear and dependent on several parameters (cutting speed, tool geometry, radial cutting depth, feed rate and feed per tooth...)
- Orthogonal force components and chip thickness (t, F_r , F_t) are key parameters for predicting forces
- A novel mini-robotic platform for manual bone-milling has been developed for knee surgery