A miniature robot for bone milling in total knee replacement

**Objectives**
- Versatile tool for milling and sawing in image-free computer assisted TKA
- Open TKA with medial and lateral fixation

**Previous prototype** [Stindel et al. CAOS 2004]
- Open TKA with medial and lateral fixation

**System Components:**
- Positioning unit
- Passive mill guide
- Fixation and adjustment system

**Praxiteles Mini-Robot**
- Hybrid Passive / Motorized Architecture
- Fixed entry point milling tool guide

**Calibration and Positioning**
- Two step kinematic calibration phases:
  - Passive
  - Active
Side Milling Technique

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

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

Model Formulation

Effect of feed rate on feed force

Slow feed = opposing force
Fast feed = 'pulling' force

Effect of radial cutting depth on feed forces

Incorporate a bone-milling force model to optimize cutting conditions on-line
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 ($F_x, F_y, t_c$) are key parameters for predicting forces.
- A novel mini robotic platform for manual bone-milling has been developed for knee surgery.