Minimally invasive bone cutting system for TKA/UKA

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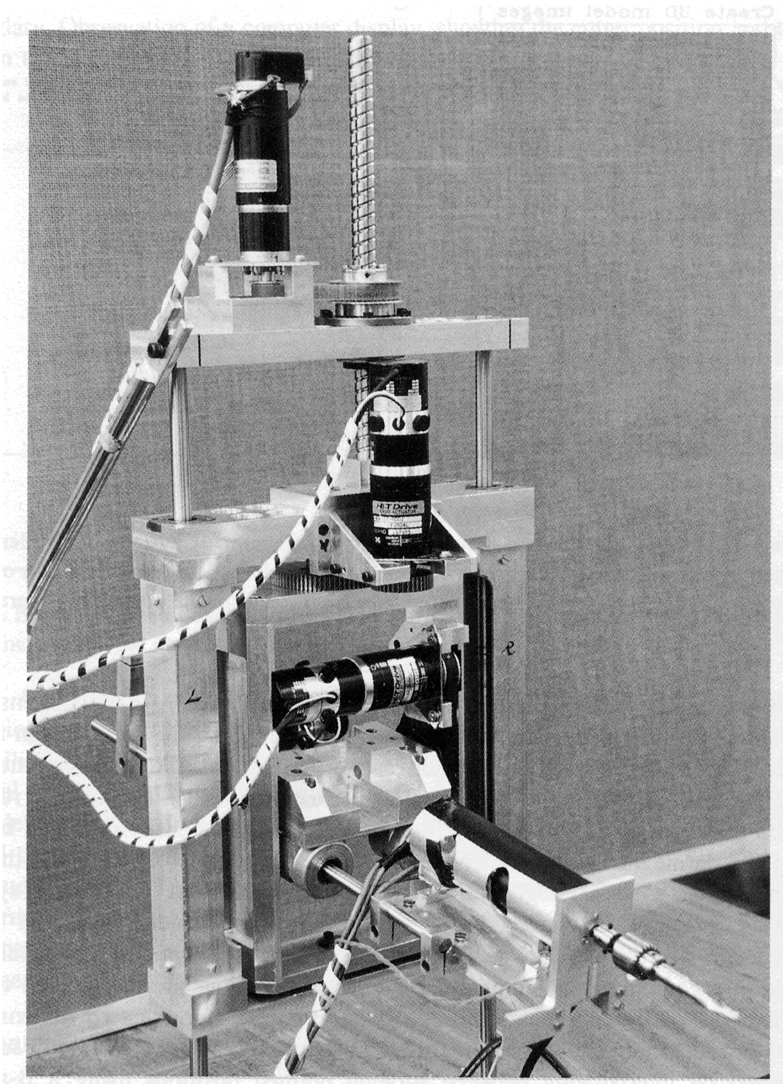
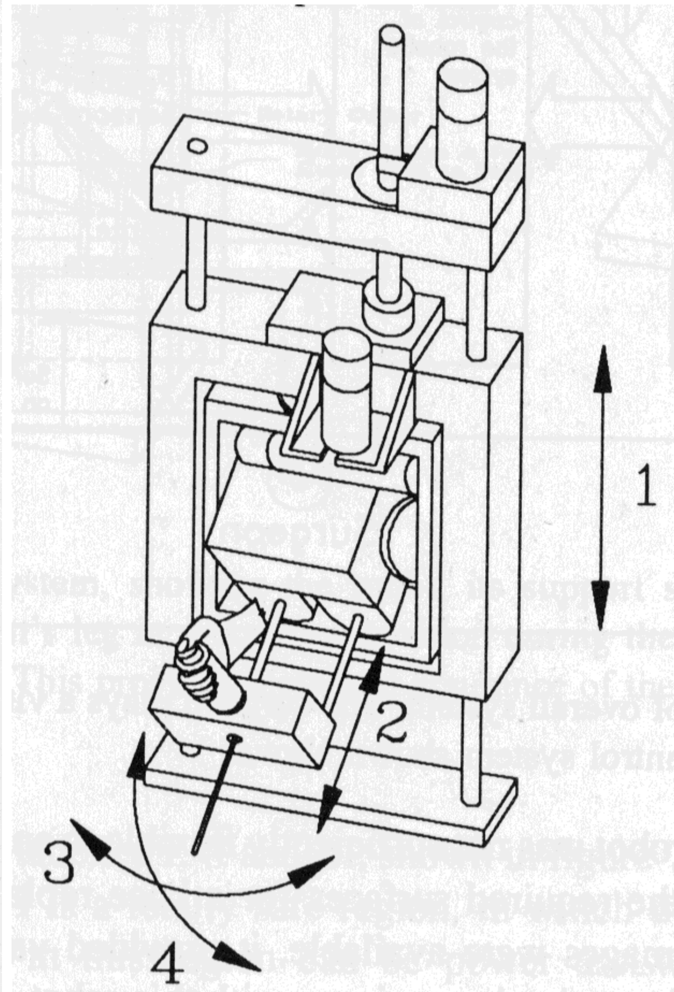
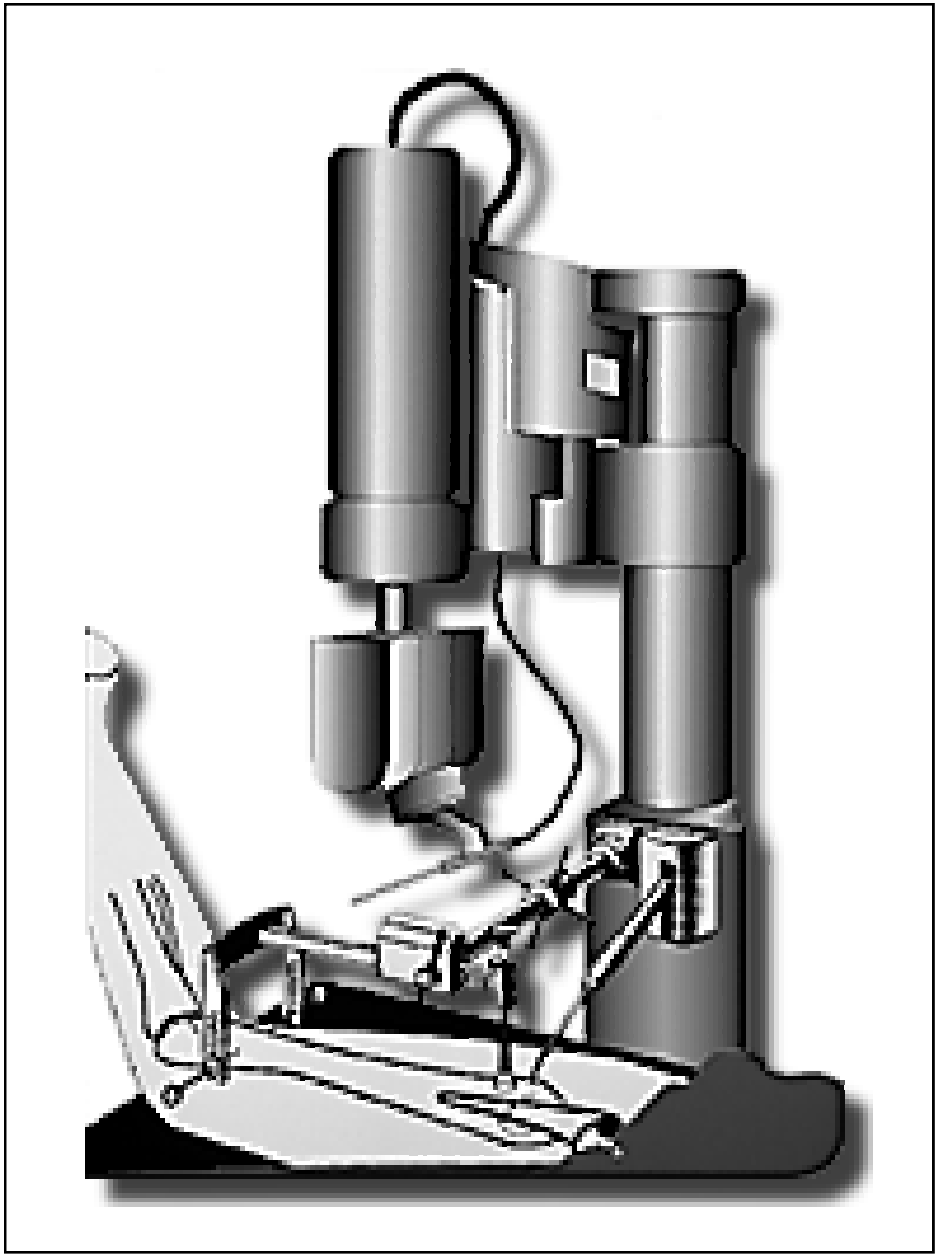
[4]Nakashima Propeller Co. Ltd., [5]CORETEC INC.

Imperial College of Science, Technology and Medicine, Prof. Davies,B.L.



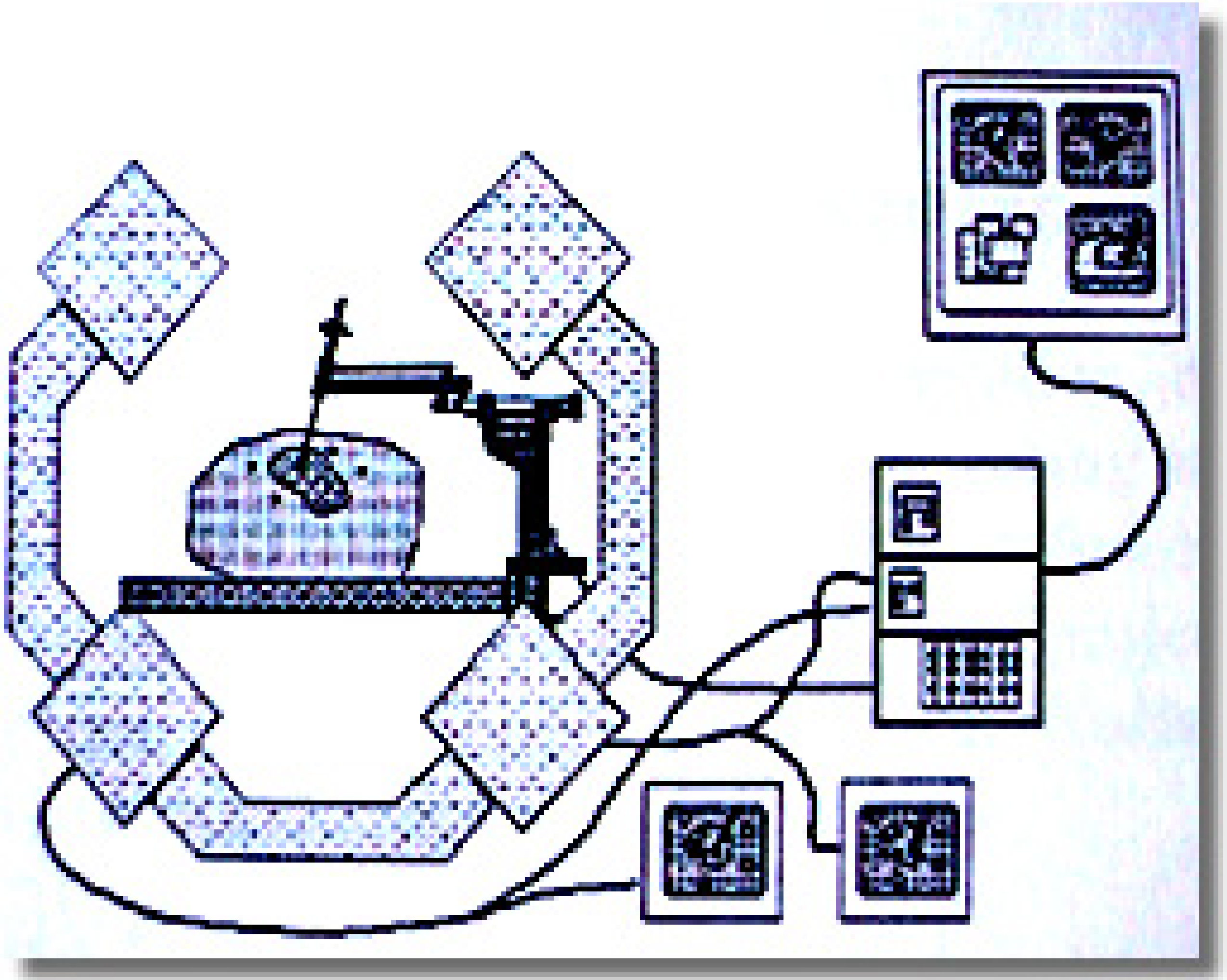




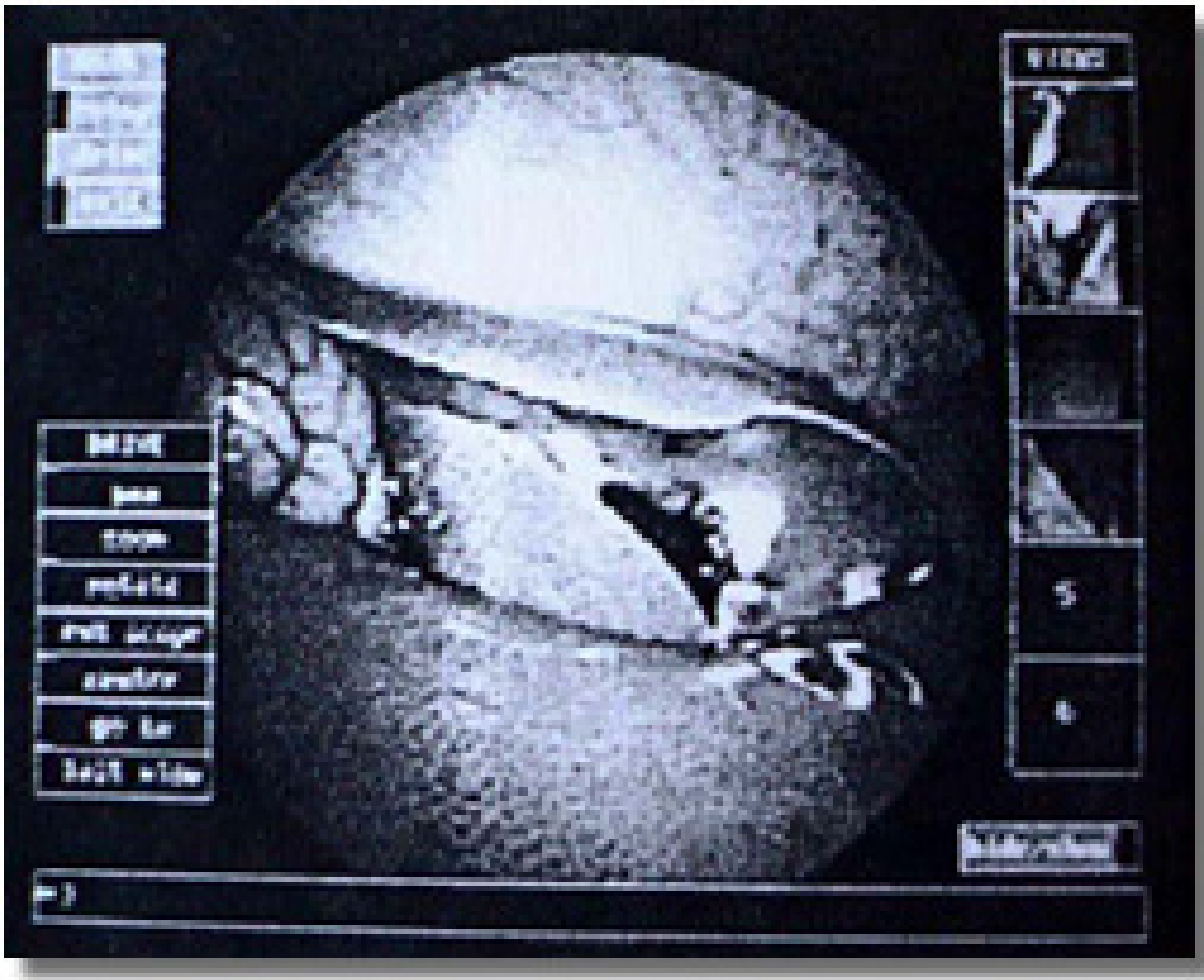
ROBODOC

The Johns Hopkins University

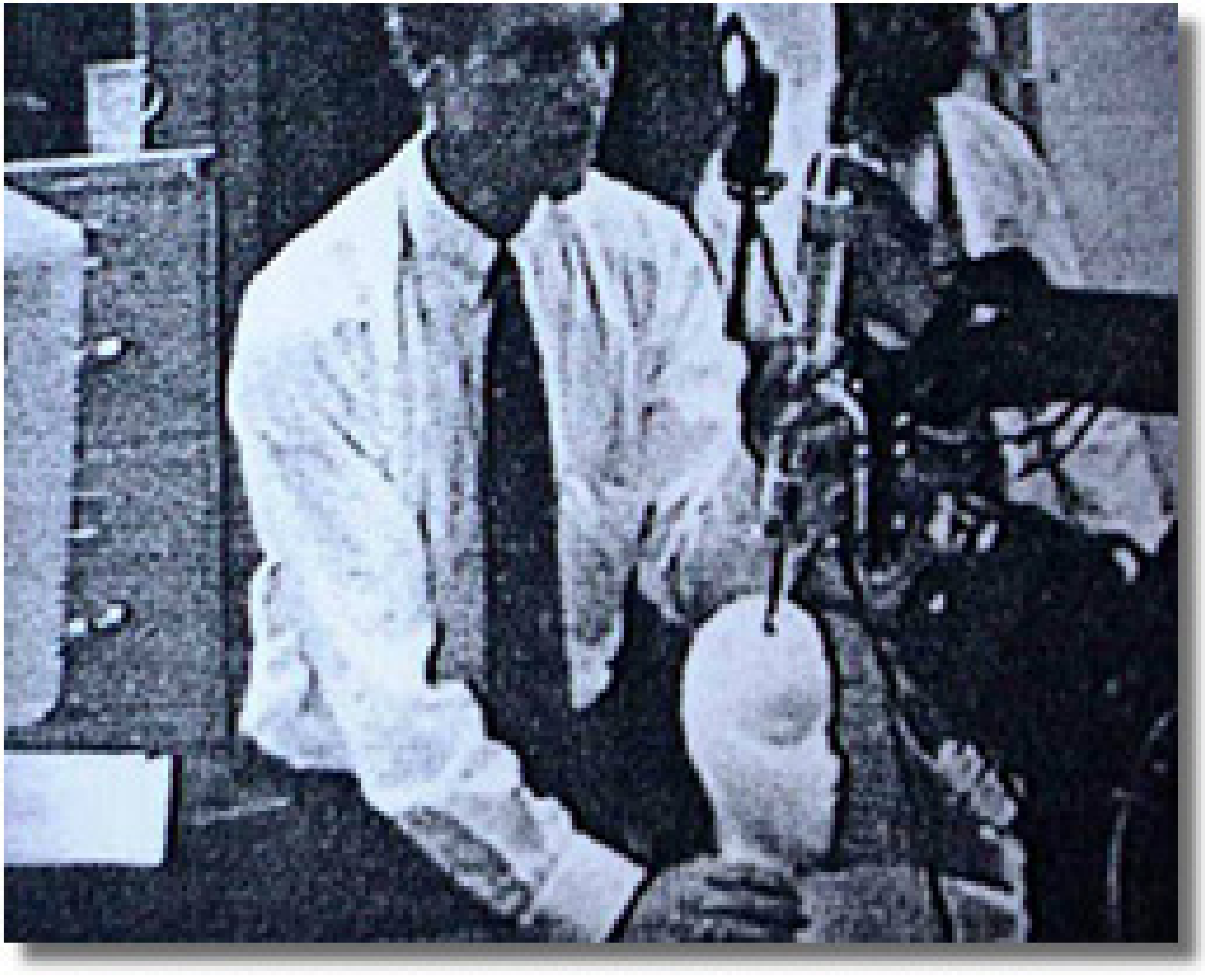
Robotic System for minimally invasive cancer therapy



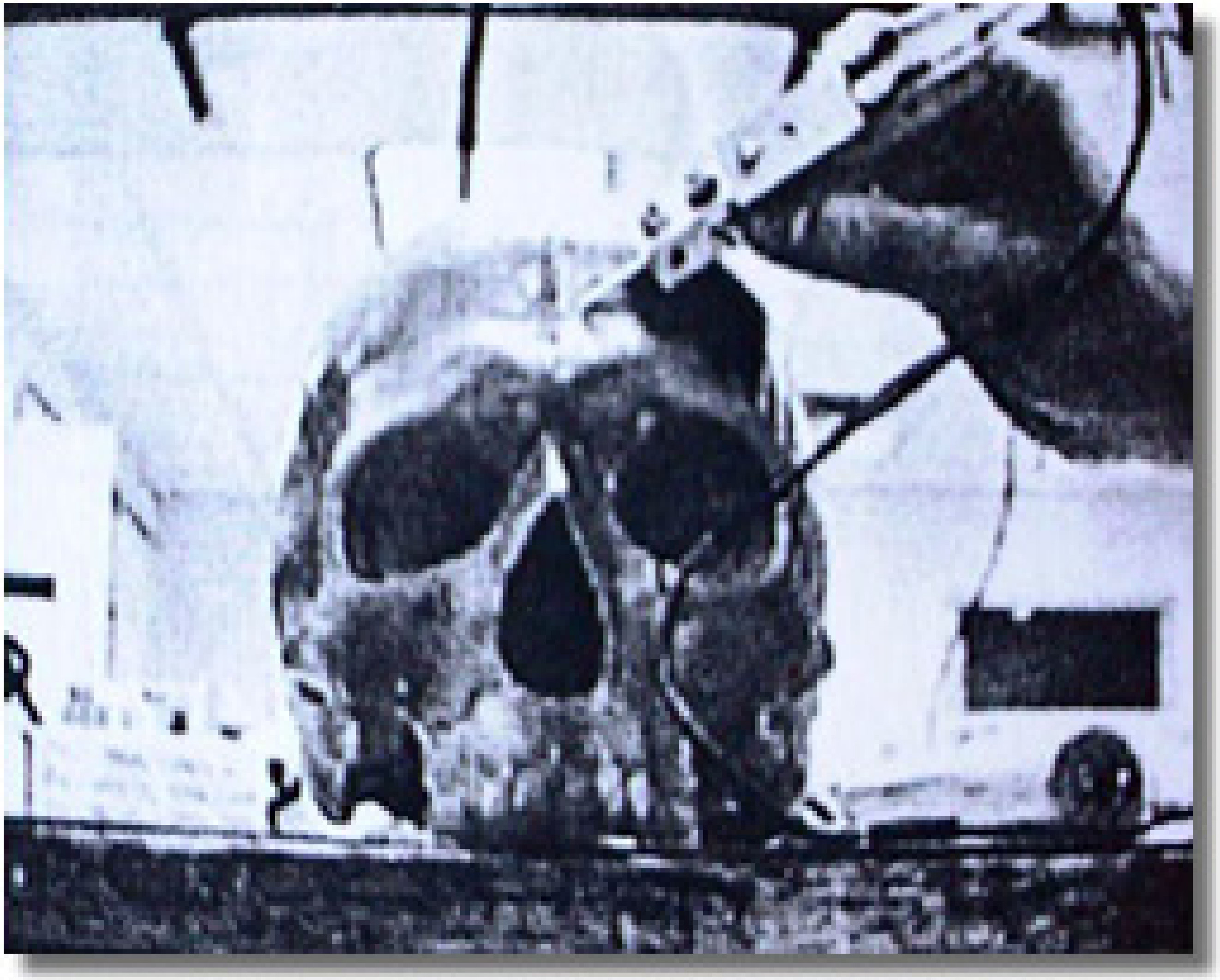
View through a robotically held camera during Laparoscopic Surgery



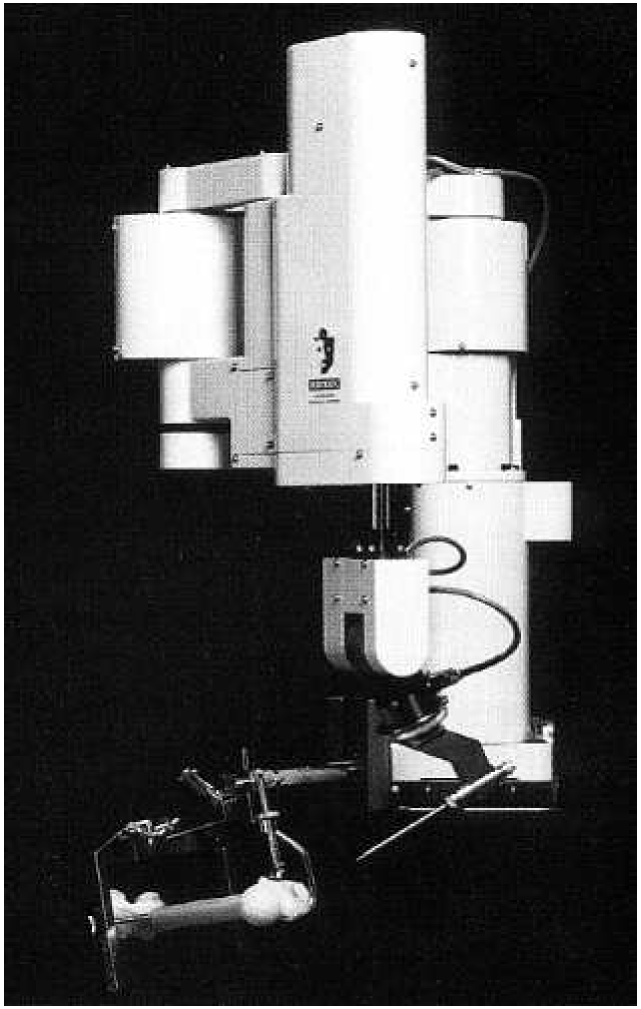
Using a robot for steady-hand assistance for neurosurgery

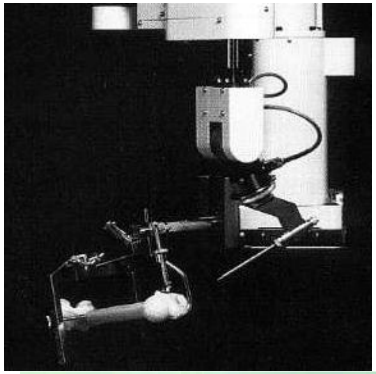


Digitizing skull model for simulated craniofacial surgery



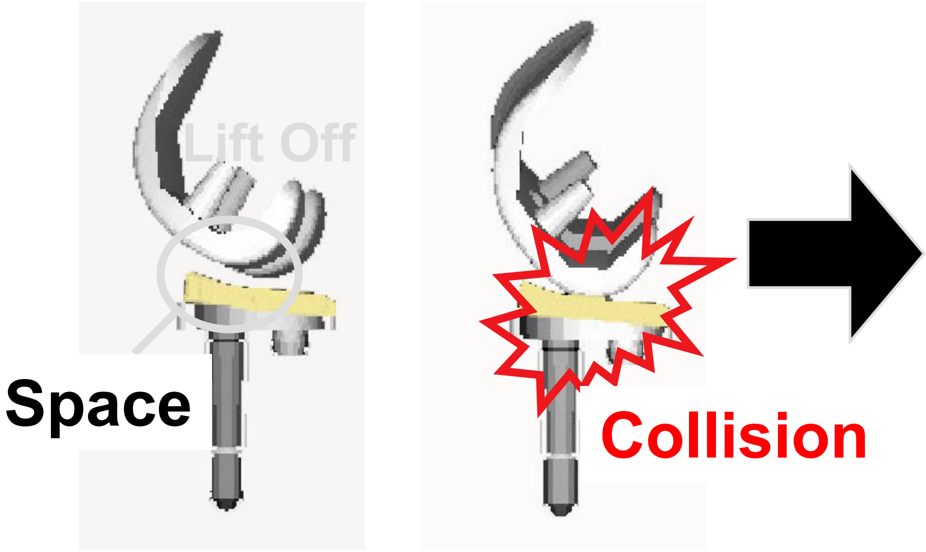
ROBODOC: Integrated Surgical Systems

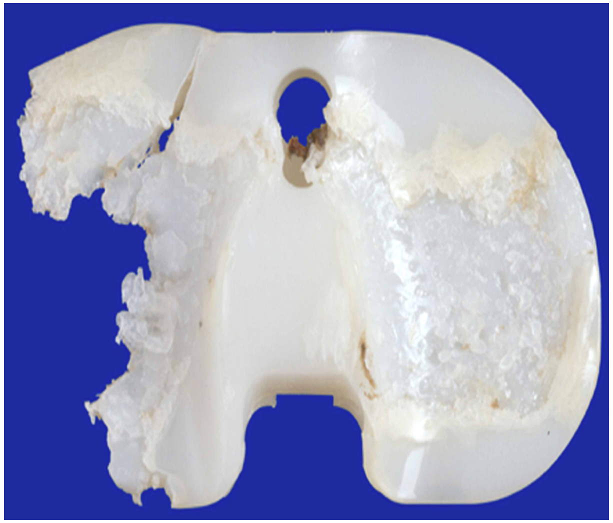




Artificial knee joint replacement

Importance of ligament balance

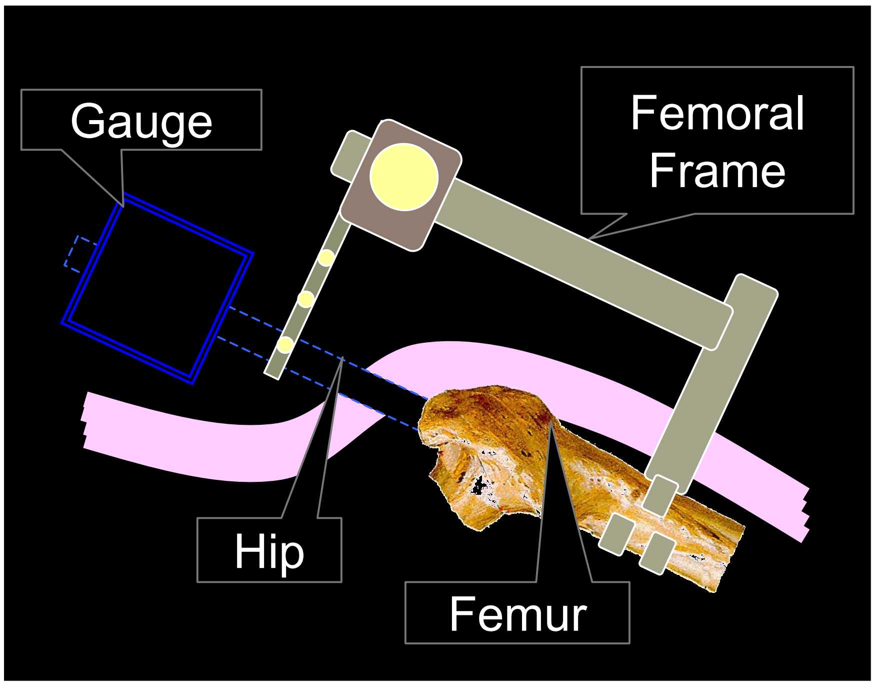


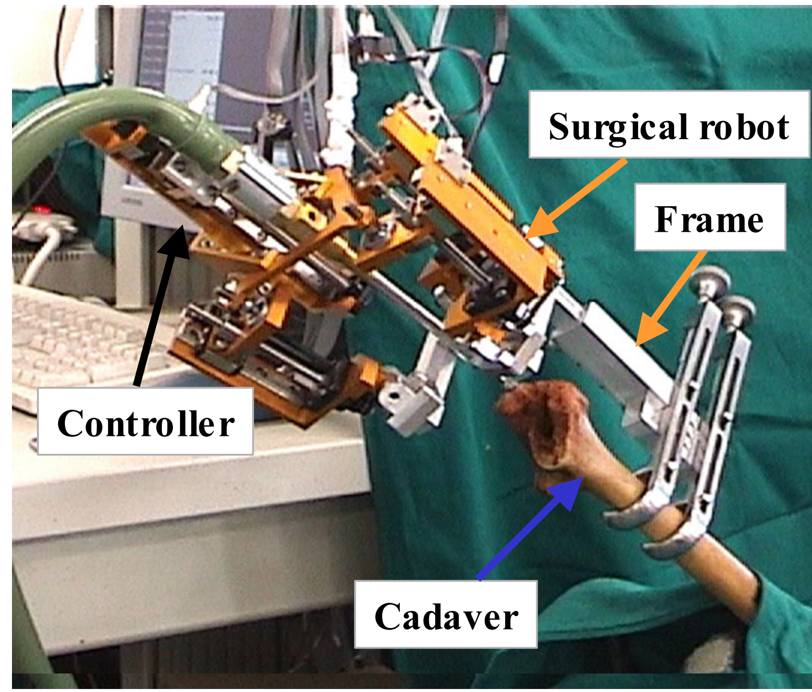


One part of the plastic wears.

Life time of the artificial knee joint becomes long by considering the balance of the ligaments.

ARTHROBOT, Bone-Mountable D.S.Kwon, KAIST, Korea





- Size : 190 X 150 X 200 mm^3
- Weight : 1.4 kg without pneumatic actuator
- Workspace : greater than cylinder with R50mm and H110mm

MIS-ARTHROBOT

Previous ARTHROBOT

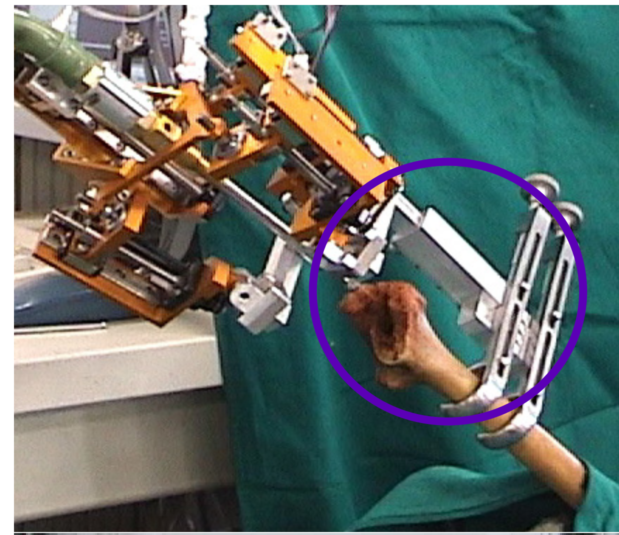
Arthrobot & ROBODoc® shows improved results than manual surgery.

Large incision in robot surgery : dislocation

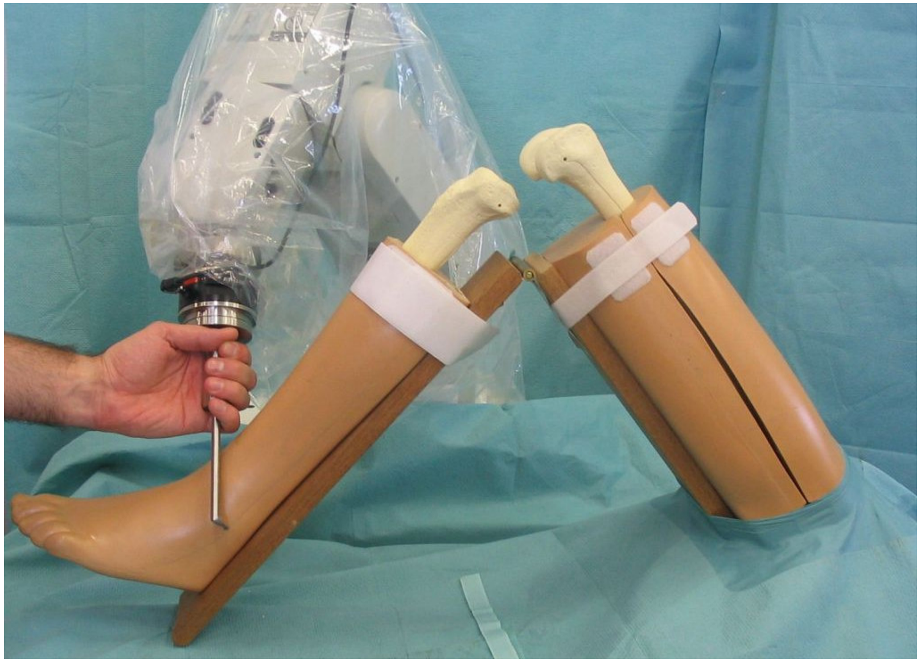
MIS ARTHROBOT

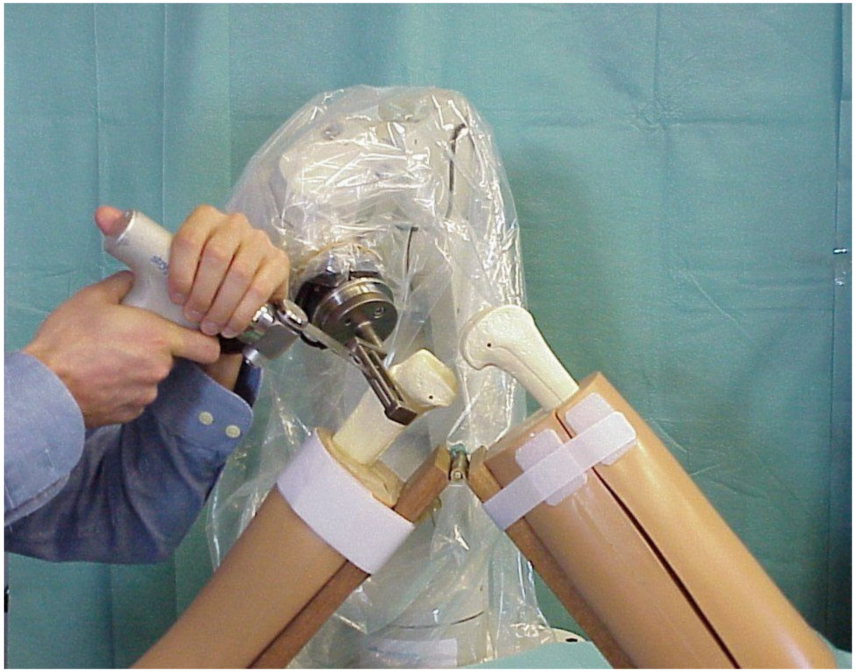
Robot is fixed in femoral canal

Less incision

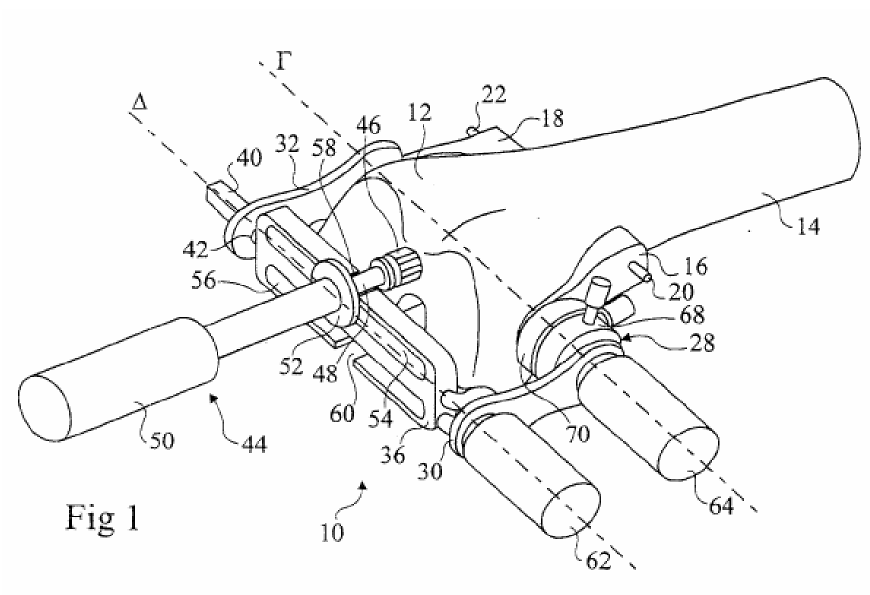


BRIGHT, Robotic Cutting Guide
Medtech SA, France

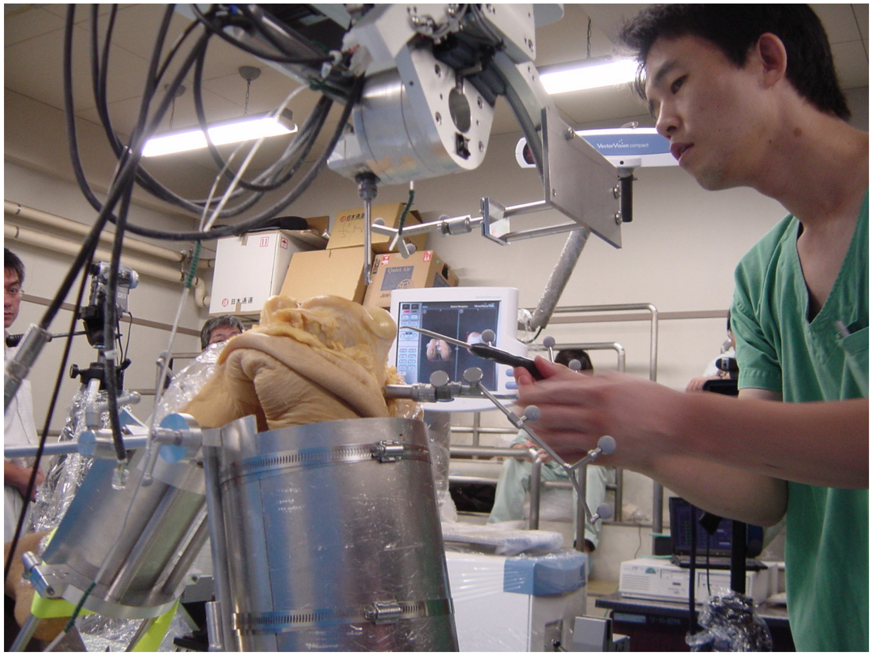


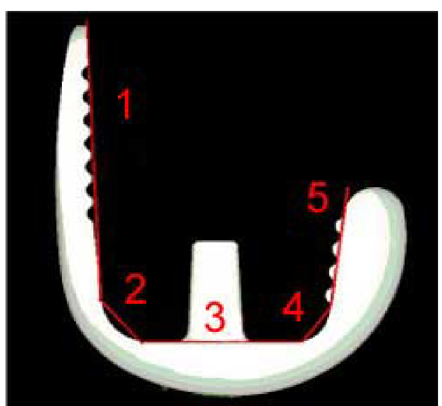


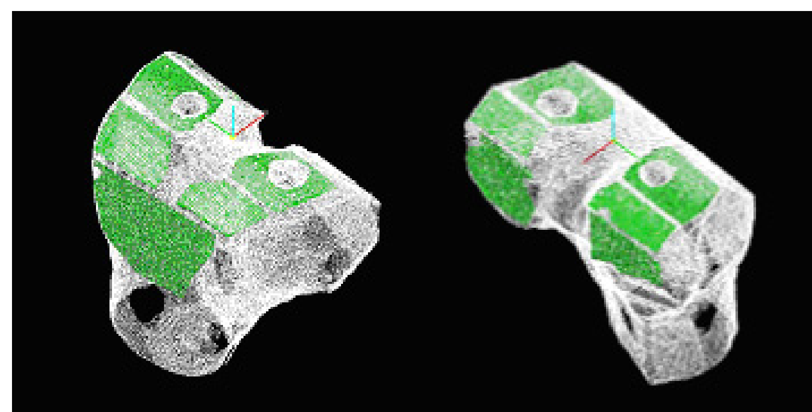
Sterilizable Robot for Orthopaedics
C.Plaskos, Univ. JosephFourier,Fr



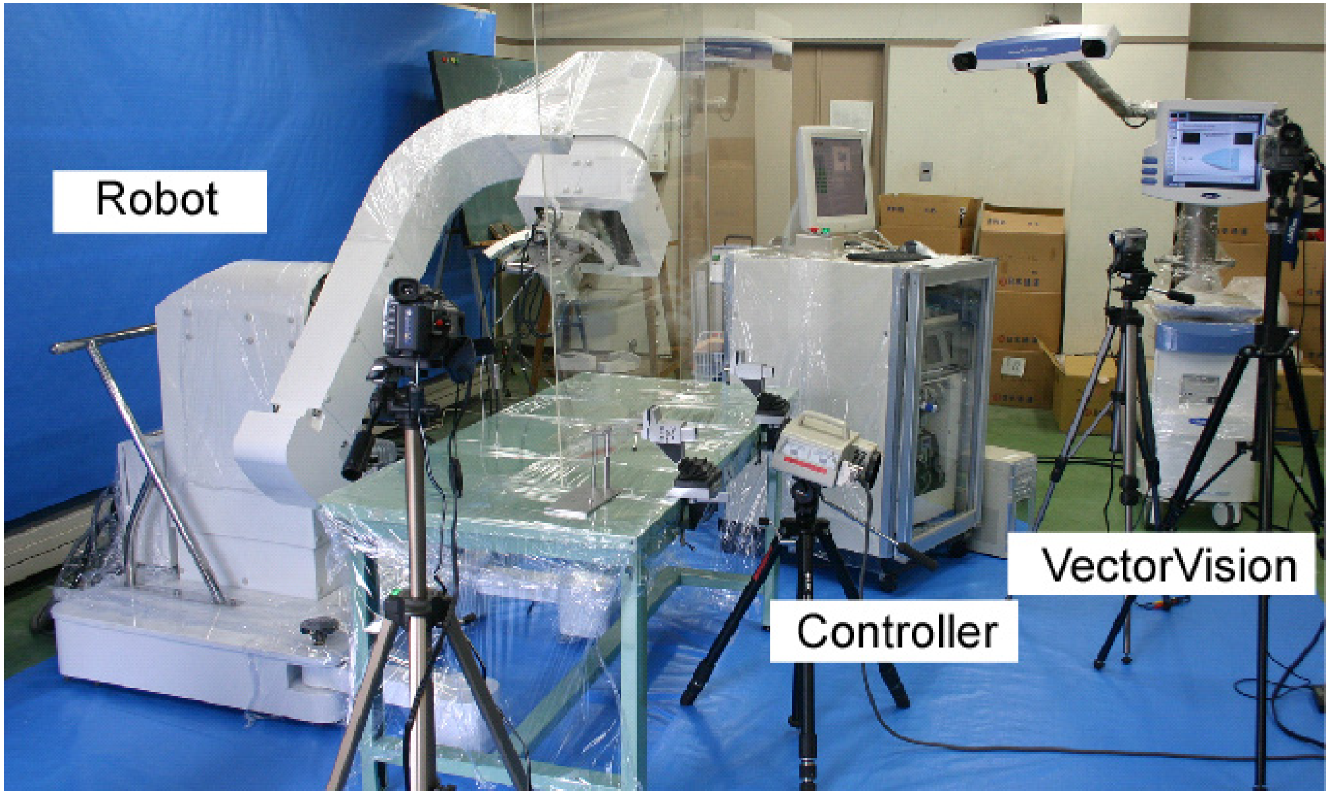
Knee joint replacement

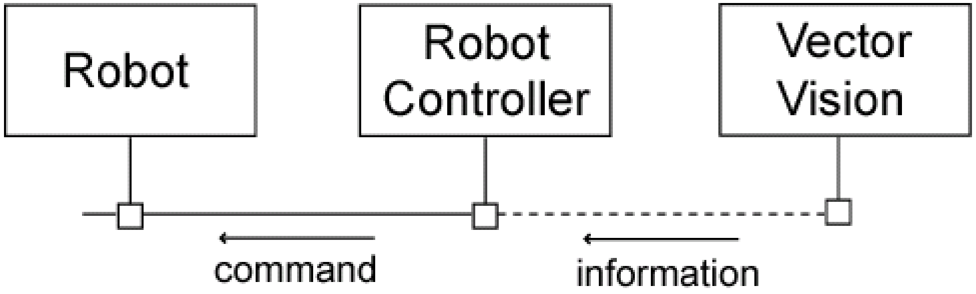




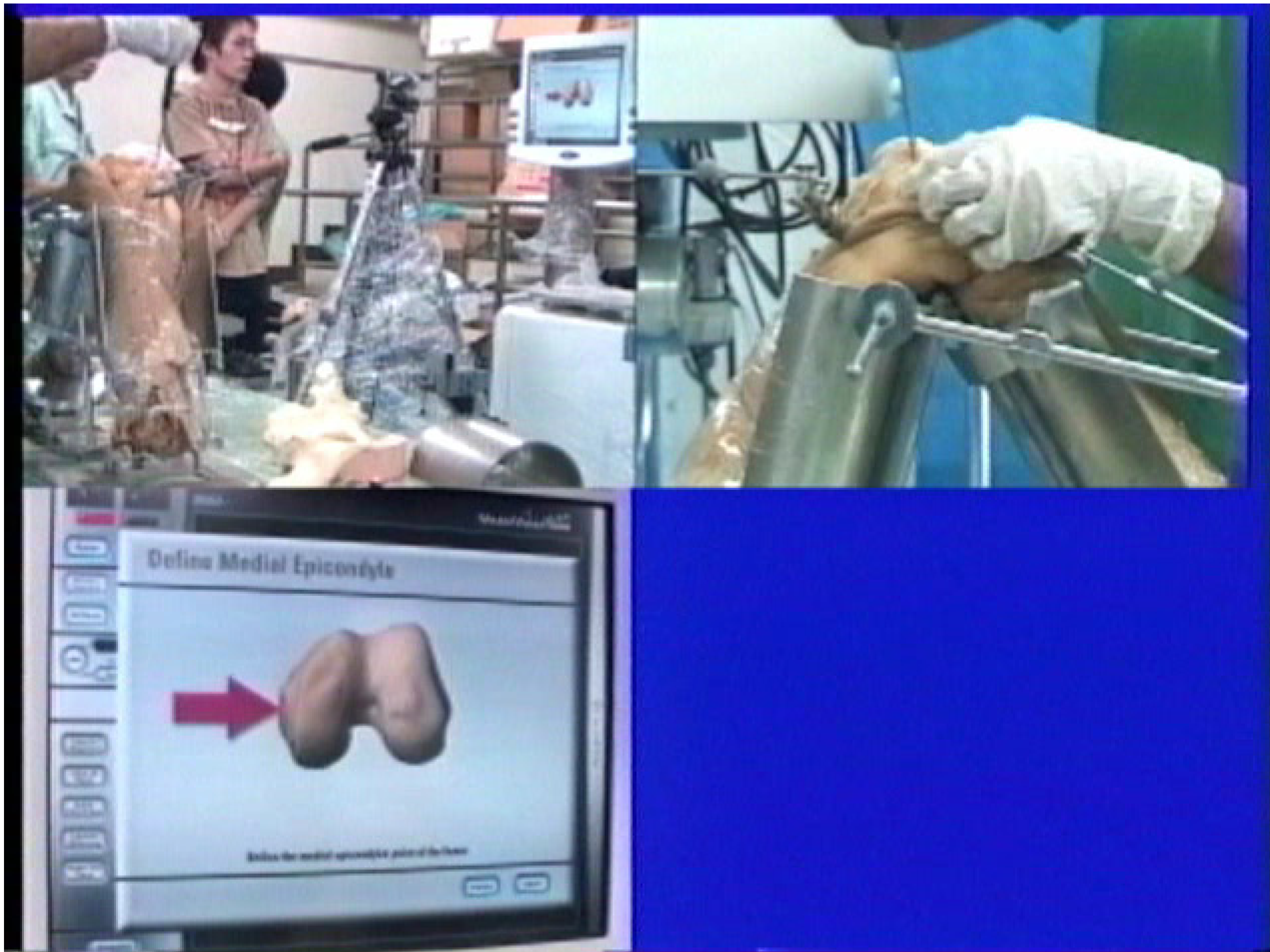


System overview



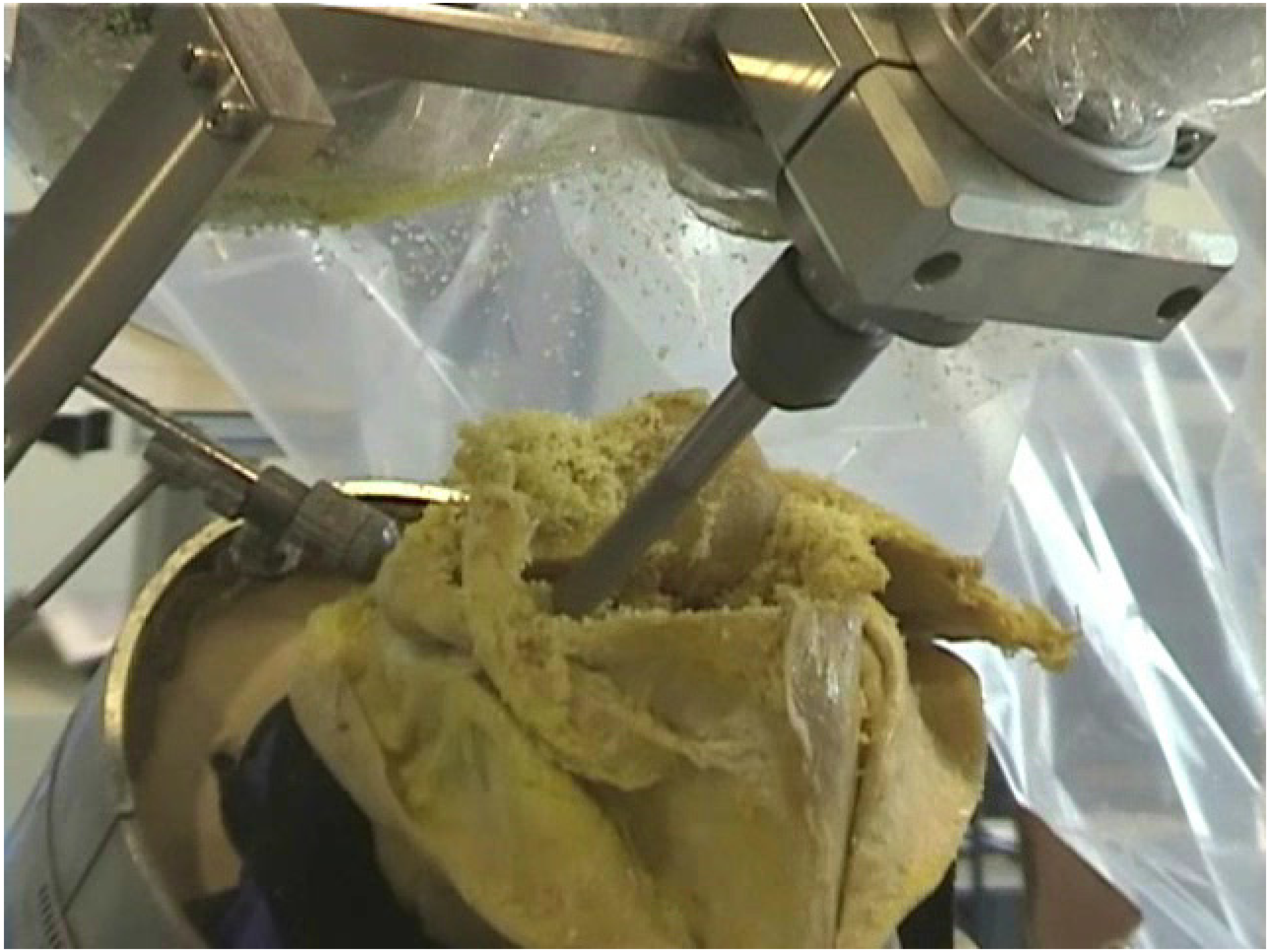


Cadaver experiment



In the video, anterior surface of the femur was cut.

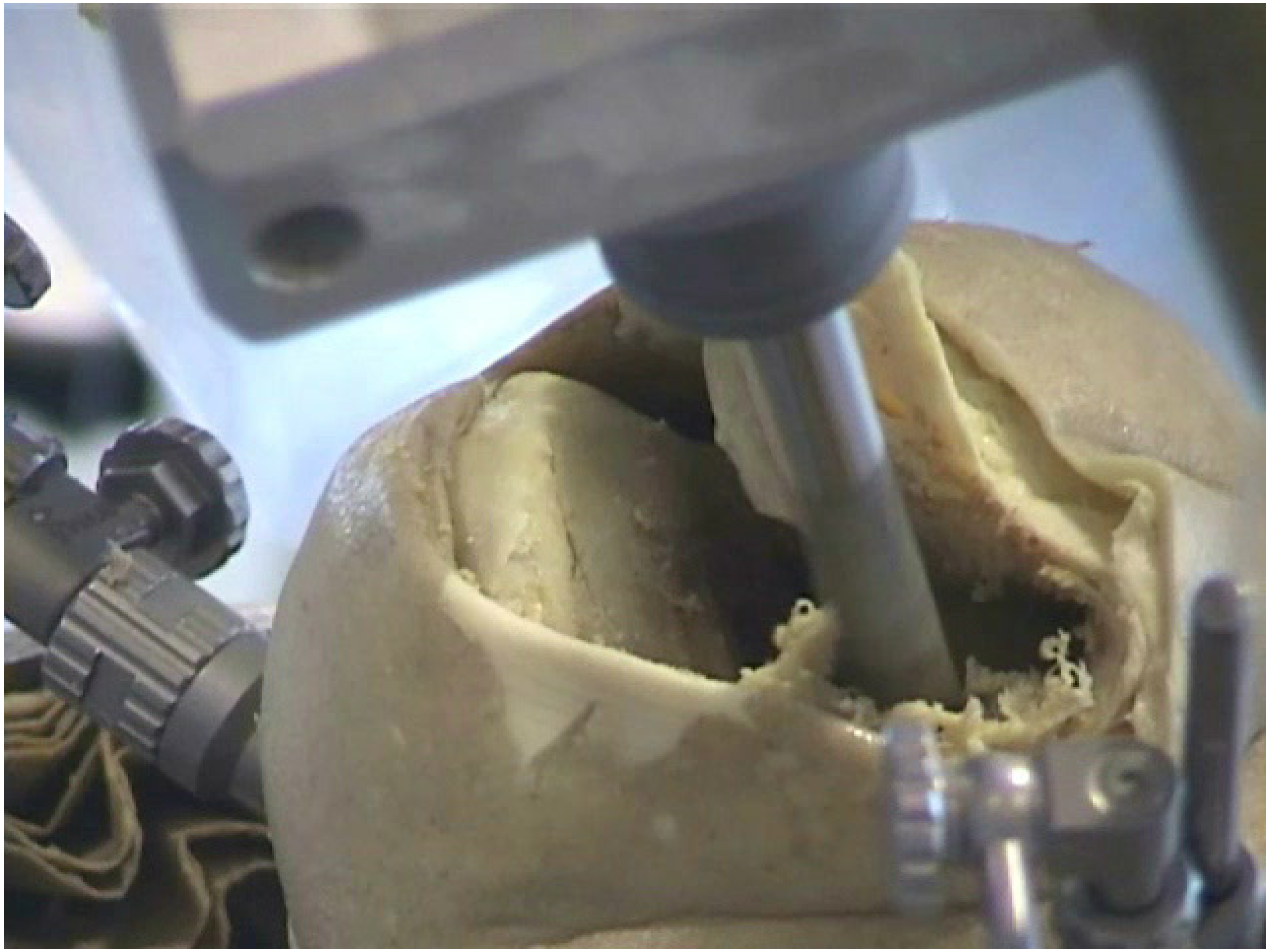
Minimally invasive bone cutting (TKA: total knee arthroplasty)



Minimally invasive bone cutting (UKA: unicondylar knee arthroplasty)

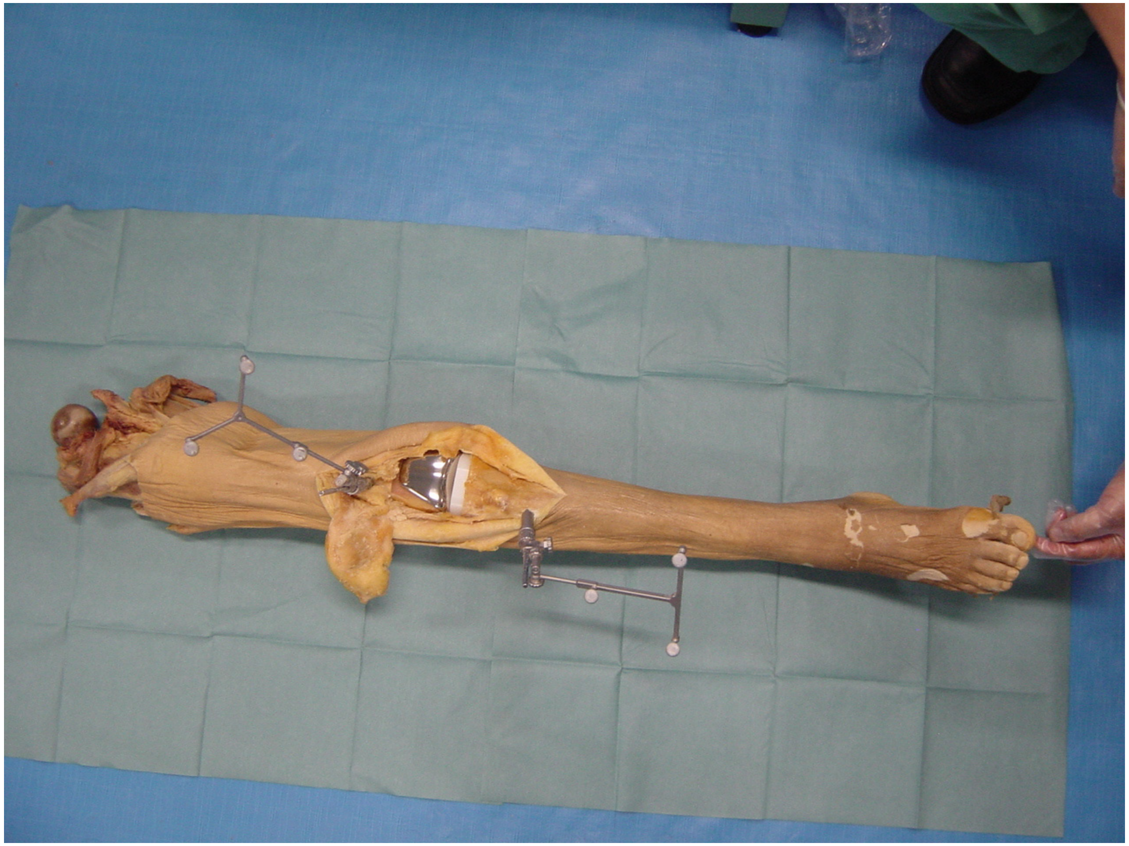
Bone cutting machine tool #3

Minimally invasive bone cutting (UKA: unicondylar knee arthroplasty)

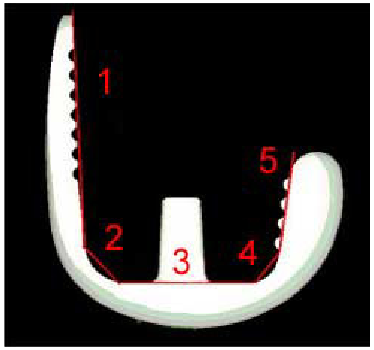


Bone cutting machine tool #4

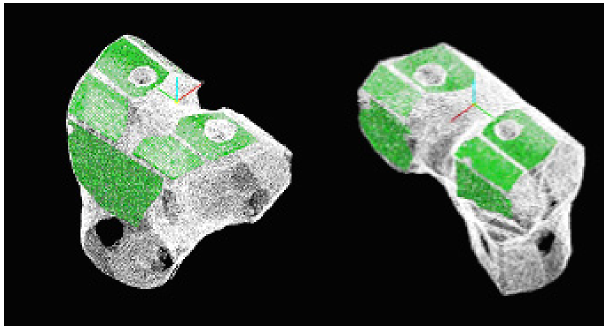
Accuracy



Plane No.	Standard Deviation [mm]
1	0.08
2	0.06
3	0.03
4	0.06
5	0.13



Plane No.	Planned angle (deg.)	Measured angle (deg.)	Error (deg.)
1-3	95.0	95.7	0.7
2-3	135.0	135.1	0.1
3-4	135.0	135.1	0.1
3-5	90.0	91.4	1.4



Objectives

1) Recently, a bone cutting robot for assisting a surgeon to replace the joint for an artificial one has been developed and it is introduced for the clinical use.

2) One of the crucial problems is to increase the quality of the bone cutting based on the individual skill, including the experience of the surgeon.

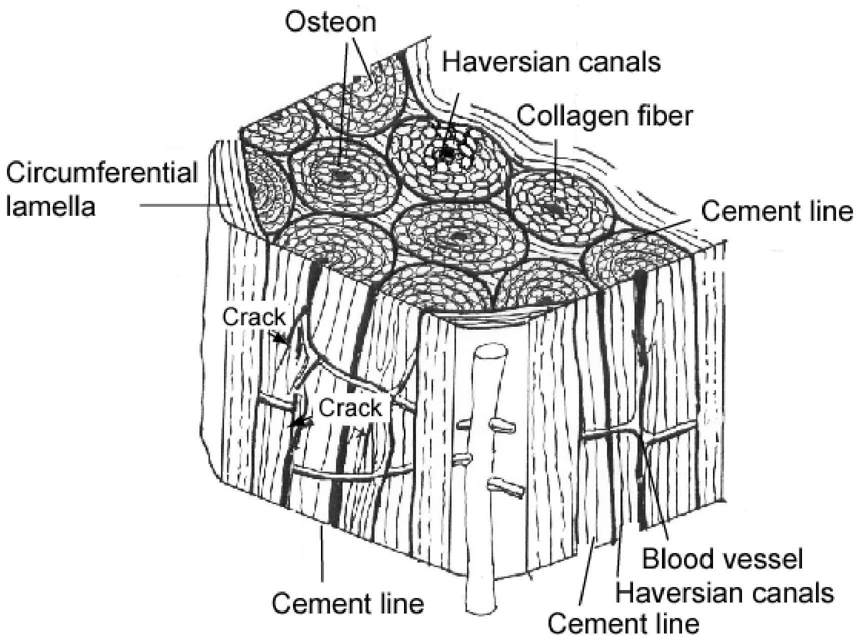
3) Development of a high performance bone cutting system and providing an appropriate bone cutting information based on the engineering research to the clinical field are essential.

4) It is reported that the tissue will be died if the temperature is increased more than 50 degrees centigrade. It is desired to reduce the cutting force and temperature.

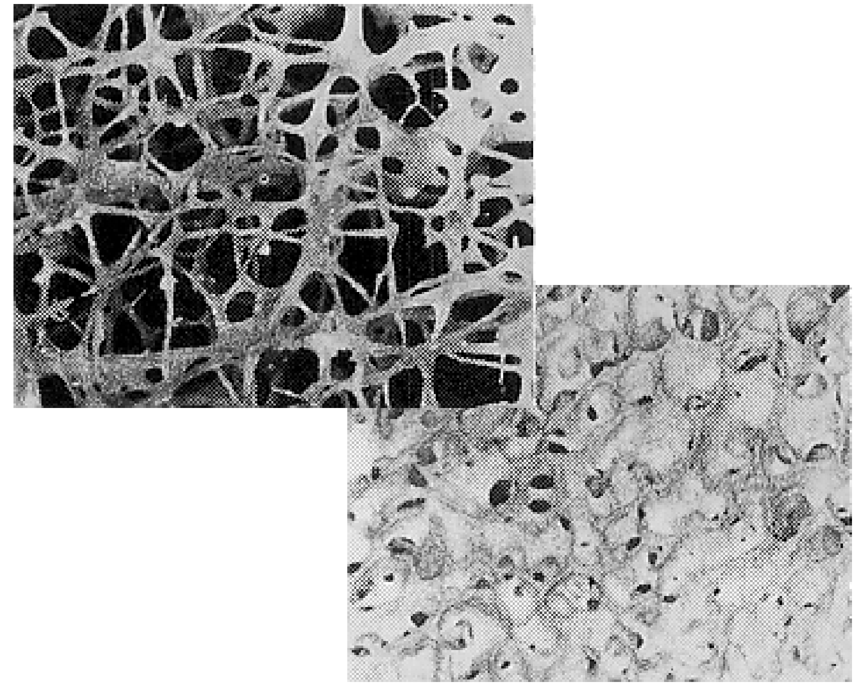
Observation of bone cutting processes

Structural characteristics of bone

Cortical bone



Cancellous bone



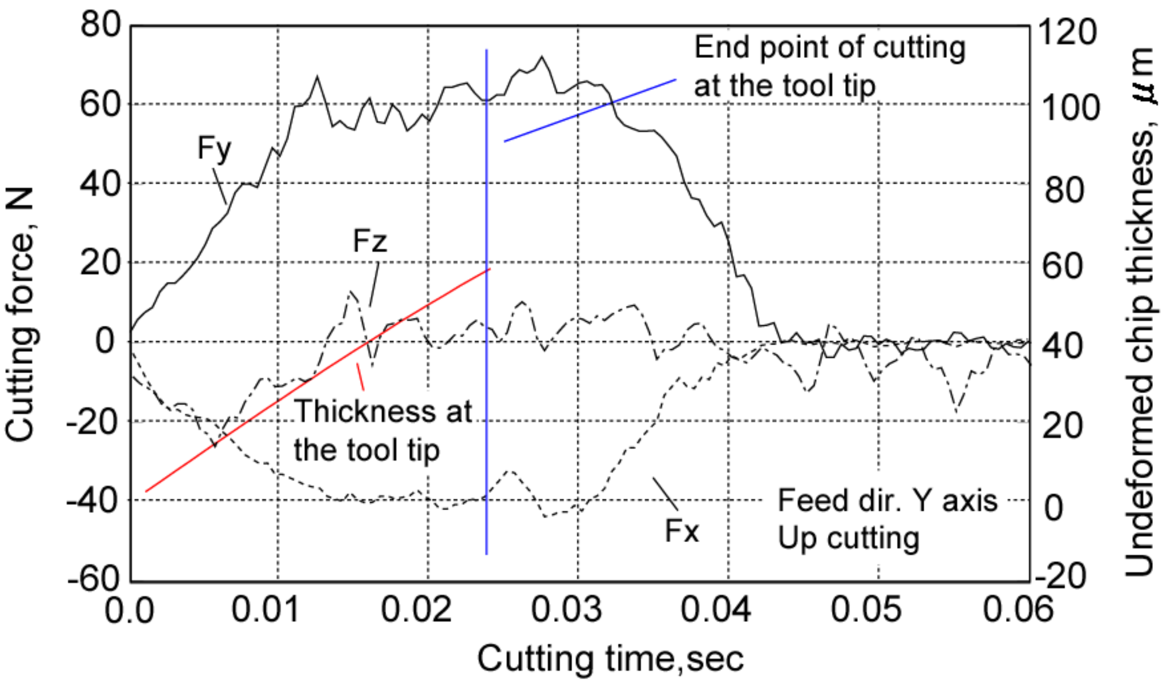
From " the Bone"

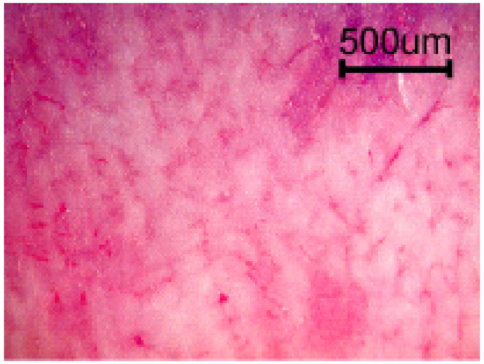
The cortical bone can be considered as a one directional continuous fiber reinforced type compound material.

The cancellous bone can be considered as a spongy material. Structures called trabecula are stretched around the calcellous bone.

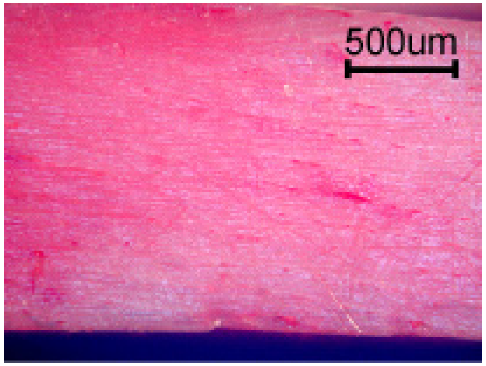
Relationship between cutting force variation and cortical bone structure

Cutting force of compact bone (cortical bone)





Parallel to the bone axis



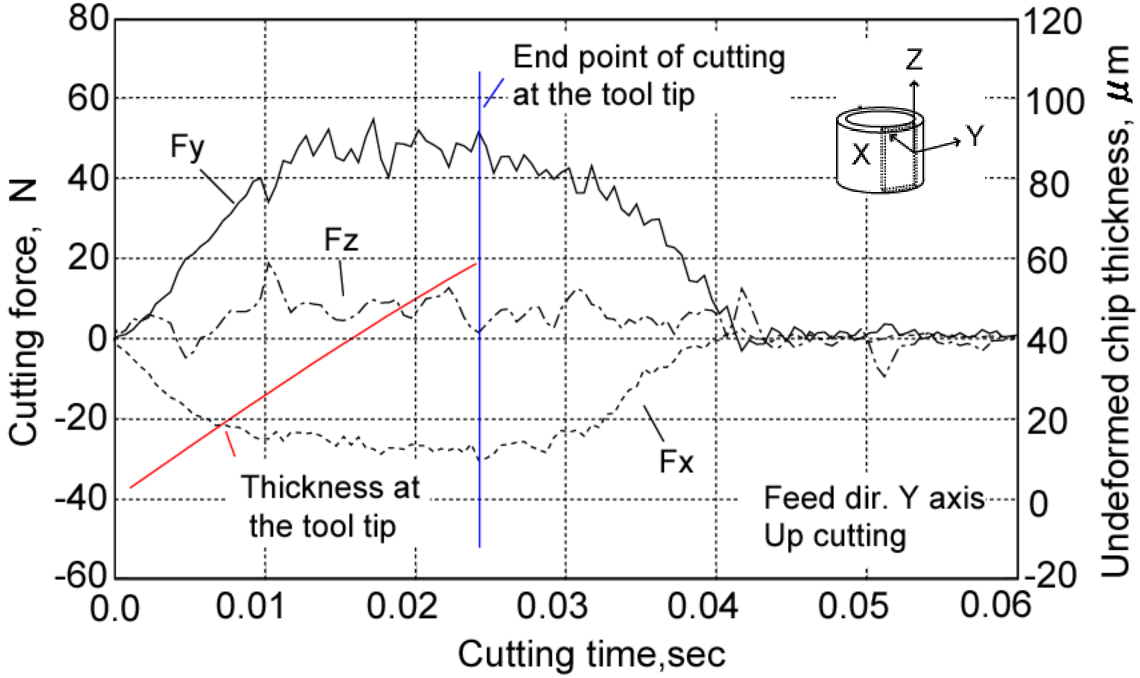
Perpendicular to the bone axis

Density: 1.96 g/cm^3

(a) Force while one flute is cutting

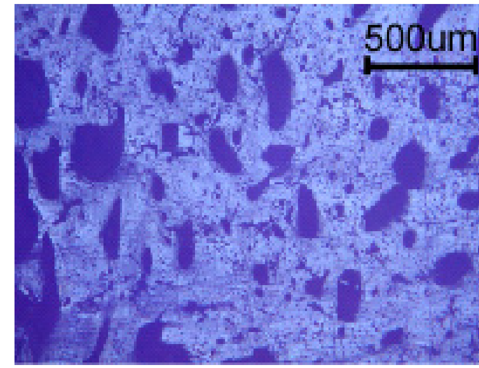
(b) Micrograph of the bone surface

Cutting force of porous bone (cortical bone)

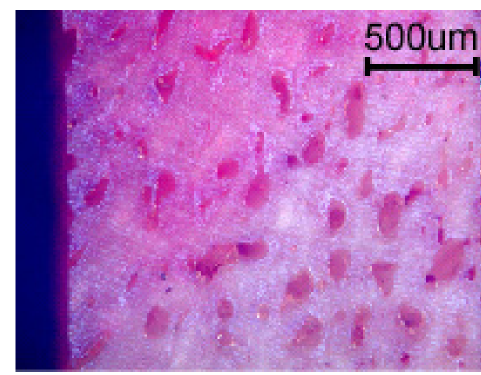


Density : 1.78 g/cm^3

(a) Force while one flute is cutting



Parallel to the bone axis



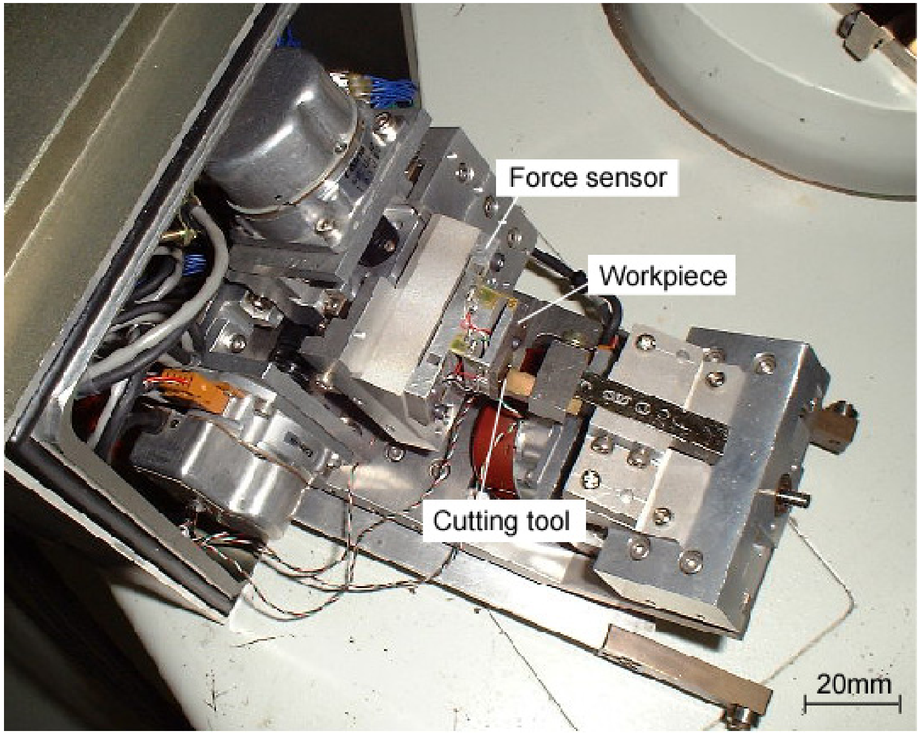
Perpendicular to the bone axis

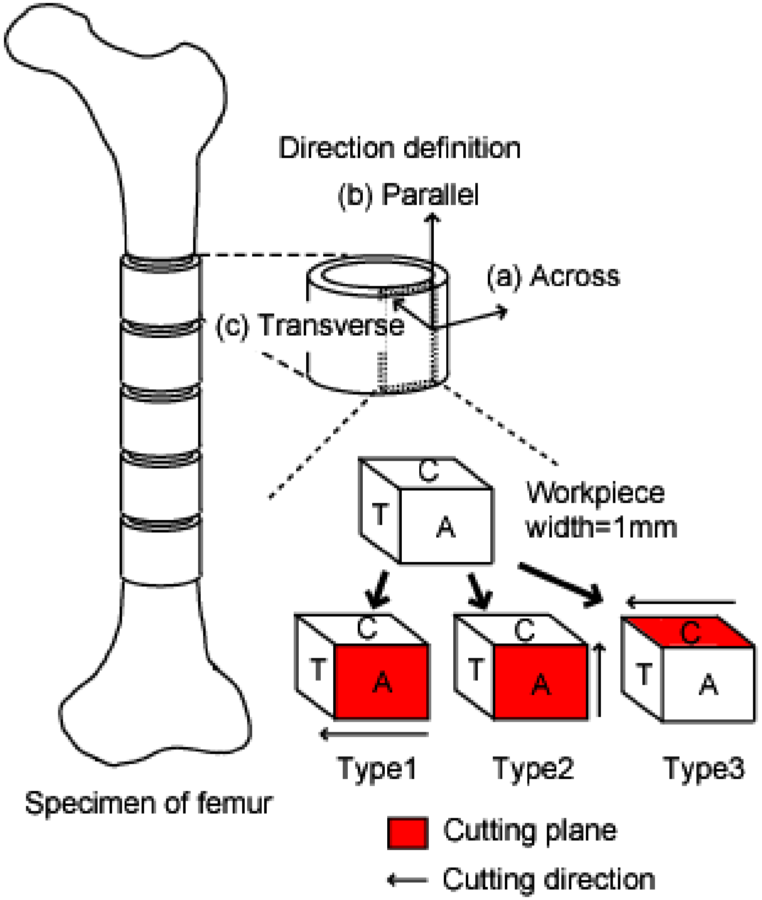
(b) Micrograph of the bone surface

Visualization of micro cutting under SEM

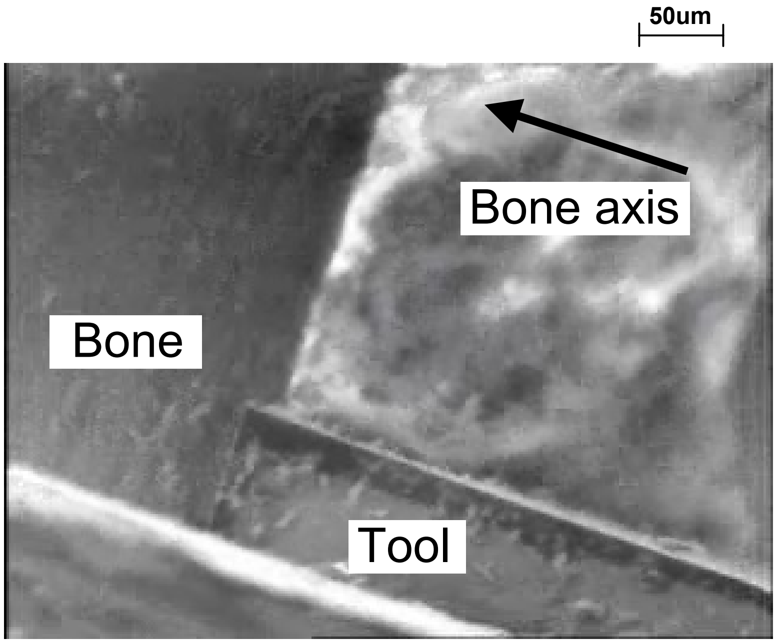
2-dimensional cutting system under SEM

Cortical bone of pig femur (Dried)

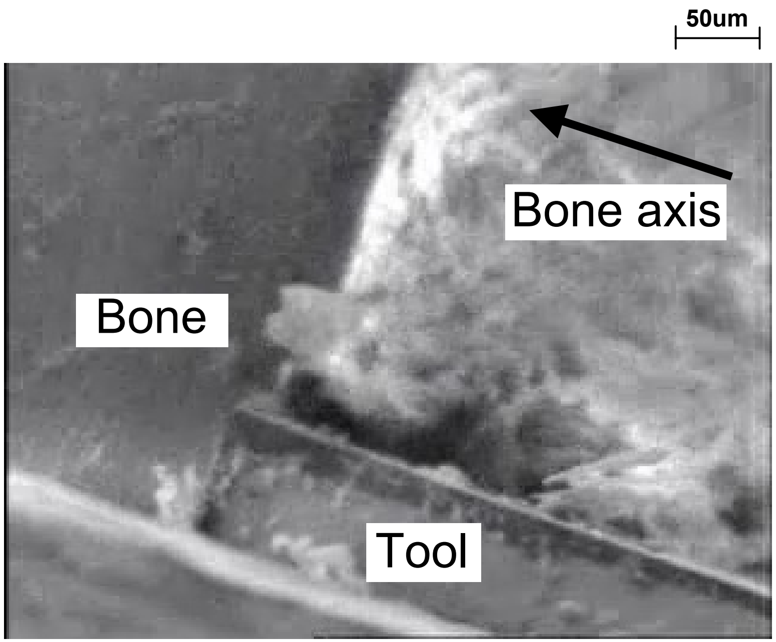




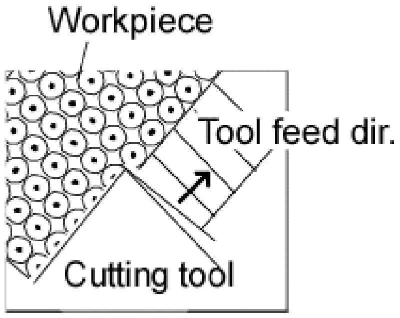
Observation of micro cutting under SEM



(a) Continuous cutting chips are generated.

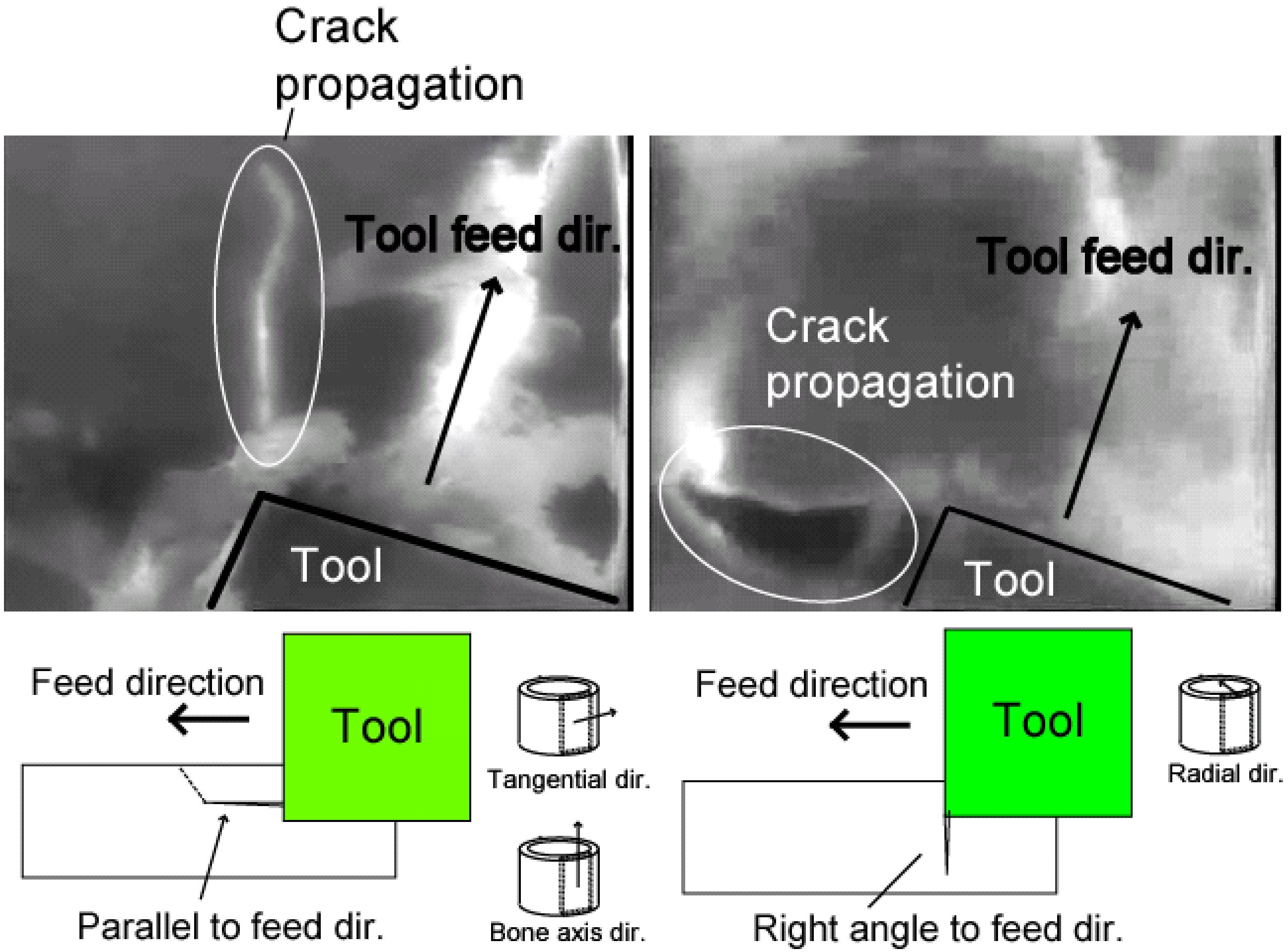


(b) Block destruction occurs



Cutting conditions:
Feed direction: Tangential to bone axis
Cutting speed V=200um/sec
Axial depth of cut: (a) d= 6 micrometer
(b) d=10 micrometer
Width of cut: B=1mm, Cutting tool: diamond cutting tool,
Rake angle: 5deg., Clearance angle: 5deg.

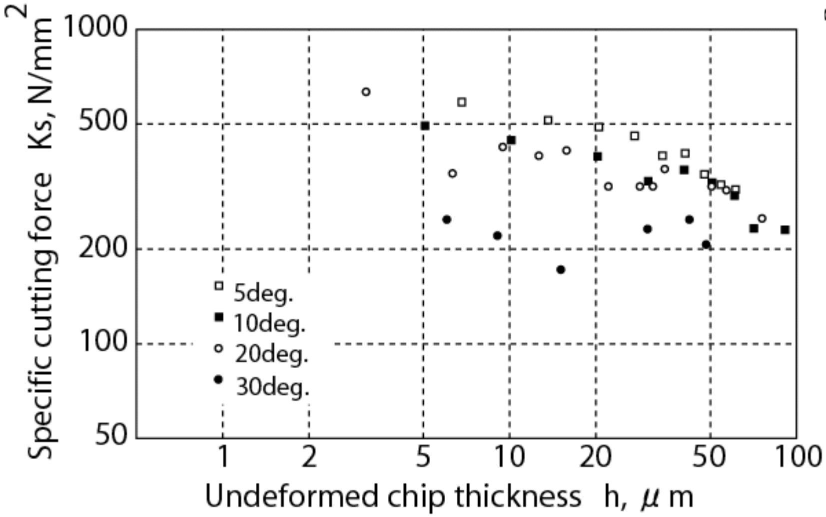
Cutting direction dependency for the crack generation



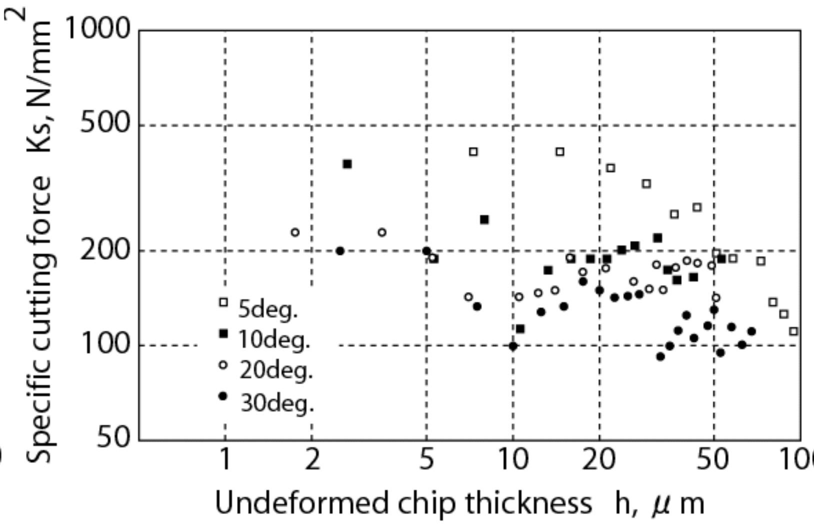
(a) Tangential and Bone axis dir. (b) Radial dir.

Relationship between specific cutting force and cutting parameters considering the bone tissue structure

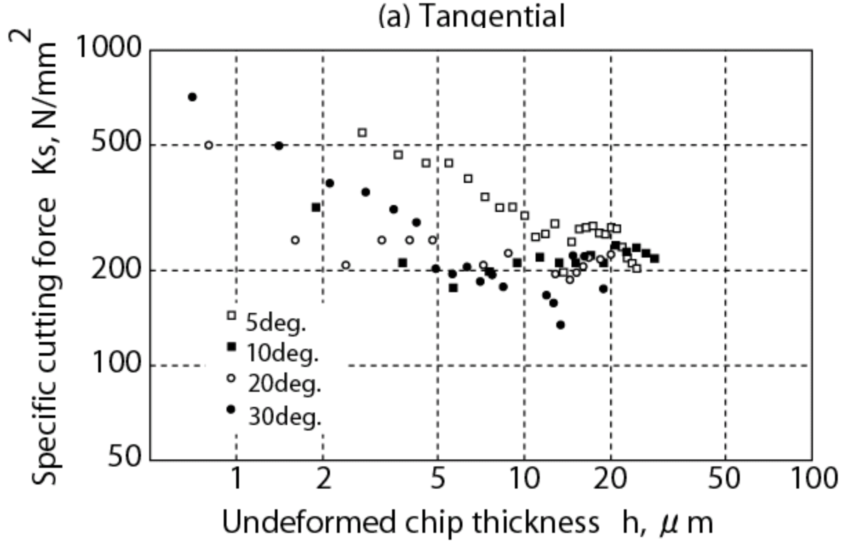
Relationship between the specific cutting force and the undeformed chip thickness



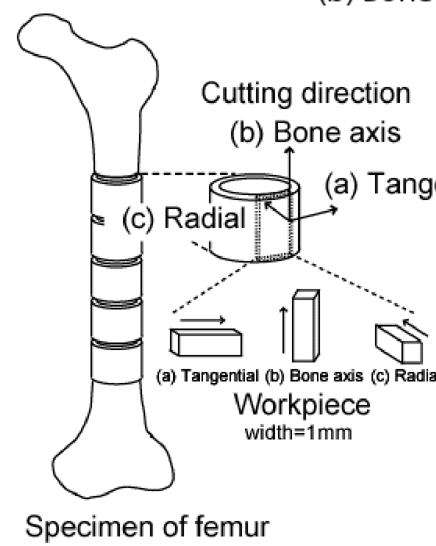
(a) Tangential



(b) Bone axis



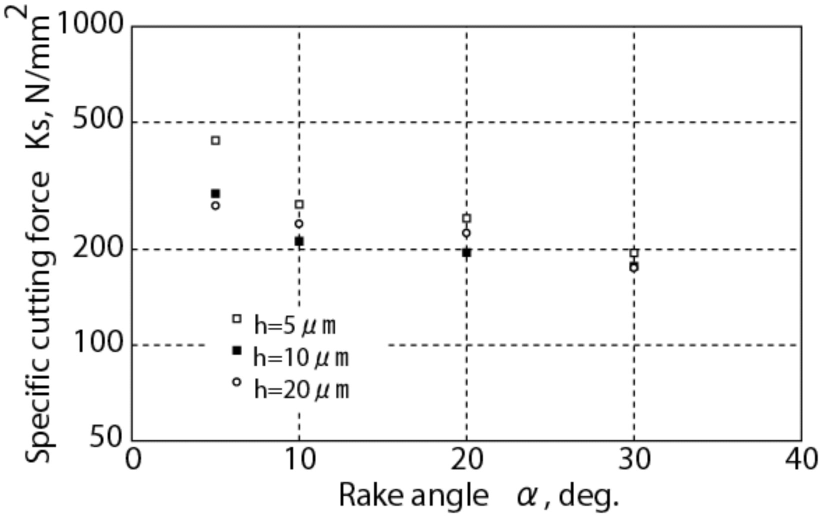
(c) Radial dir.



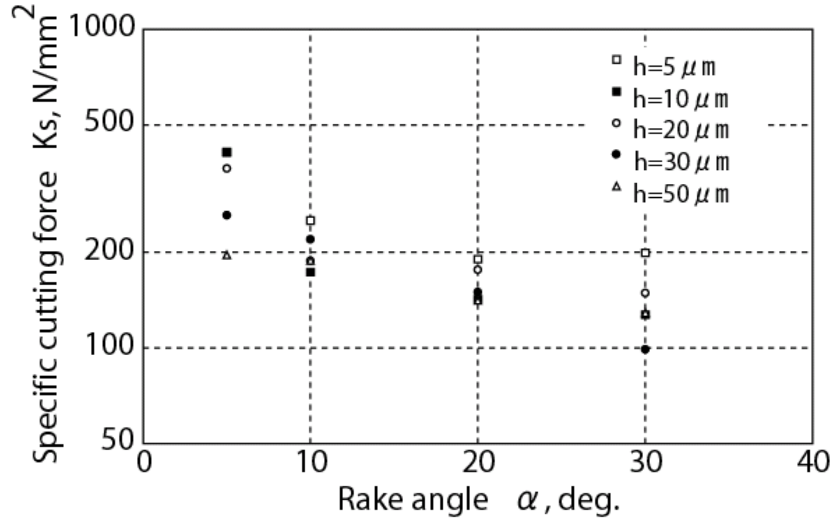
< Cutting condition >

Cutting speed,V=200 μ m/sec,
Width of cut : B=1mm
Cutting tool : diamond tool,
Rake angle 5-30deg.
Clearance angle 5deg.

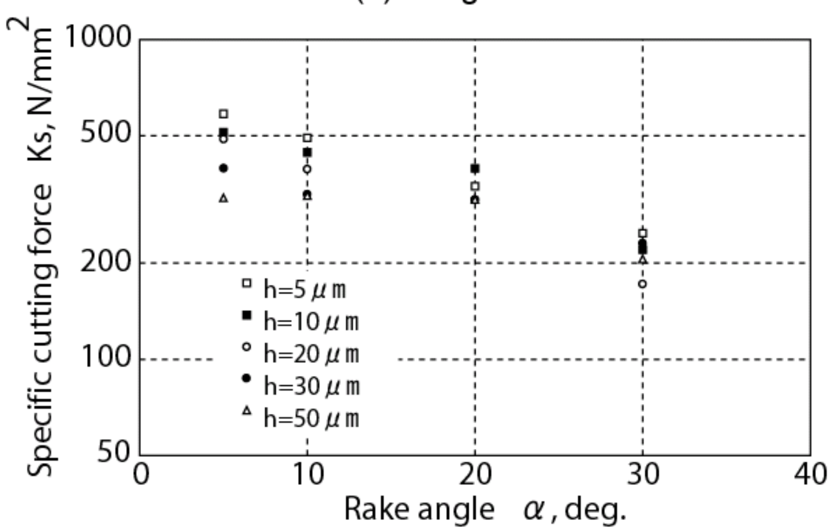
Relationship between the specific cutting force and the tool rake angle



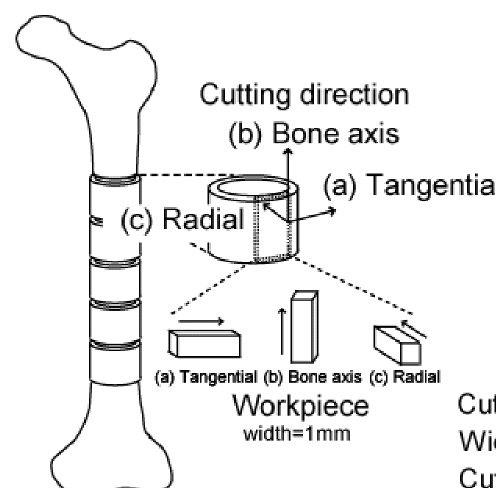
(a) Tangential dir.



(b) Bone axis dir.



(c) Radial dir.

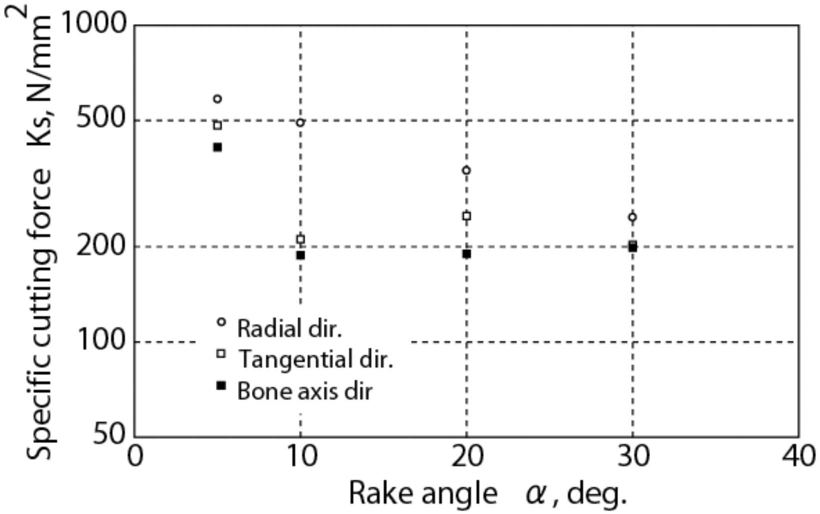


Specimen of femur

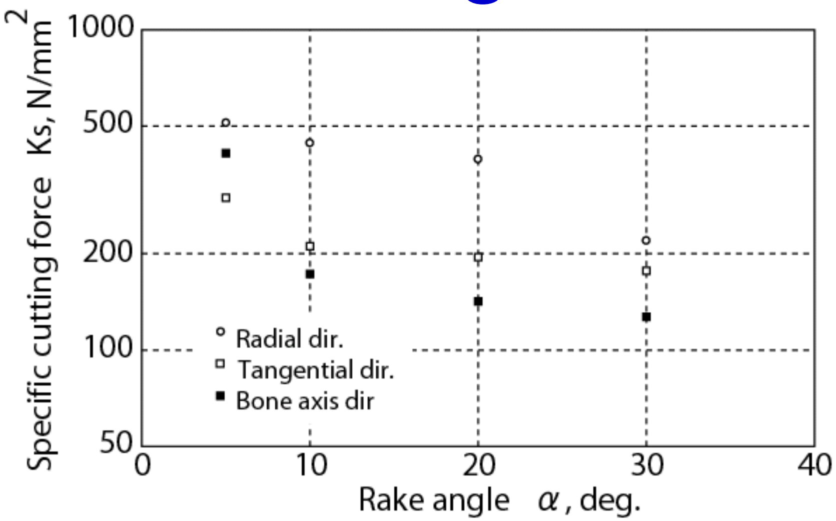
< Cutting condition >

Cutting speed,V=200 μ m/sec,
Width of cut : B=1mm
Cutting tool : diamond tool,
Rake angle 5-30deg.
Clearance angle 5deg.

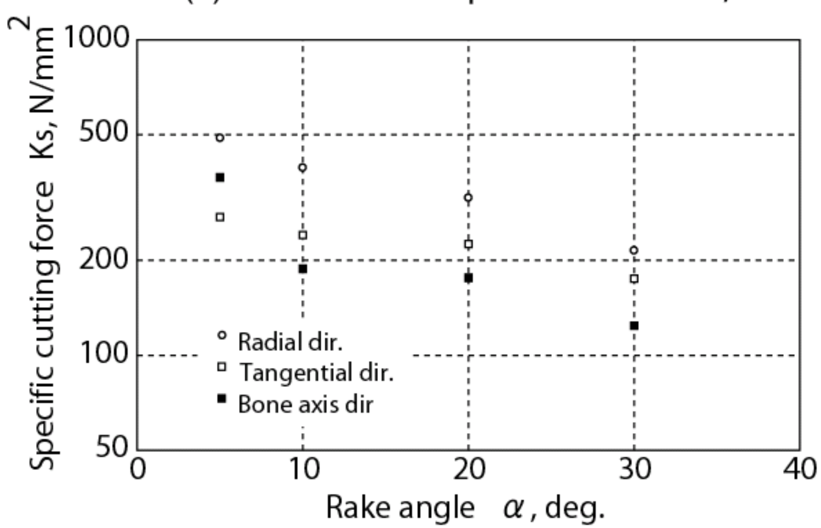
Relationship between the specific cutting force and the cutting direction



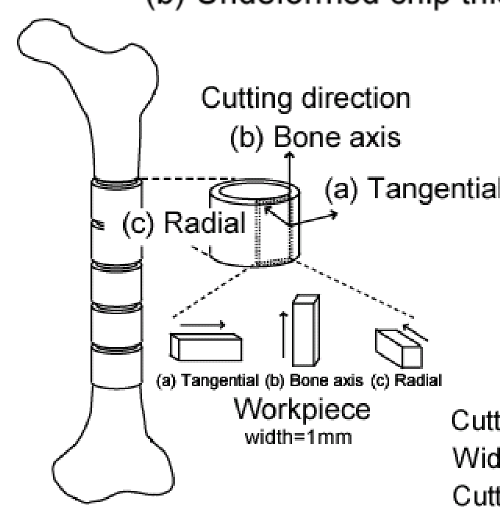
(a) Undeformed chip thickness h = 5 μm



(b) Undeformed chip thickness h = 10 μm



(c) Undeformed chip thickness h = 20 μm



Specimen of femur

< Cutting condition >

Cutting speed, V=200 μm/sec,
Width of cut : B=1mm
Cutting tool : diamond tool,
Rake angle 5-30deg.
Clearance angle 5deg.

Temperature measurement during bone cutting

Experimental method

1) The anterior plane of the cadaver femur was cut as a workpiece. The width of the cancellous bone is 50 mm. At the both ends, there exist cortical bones with width approximately 1 mm.

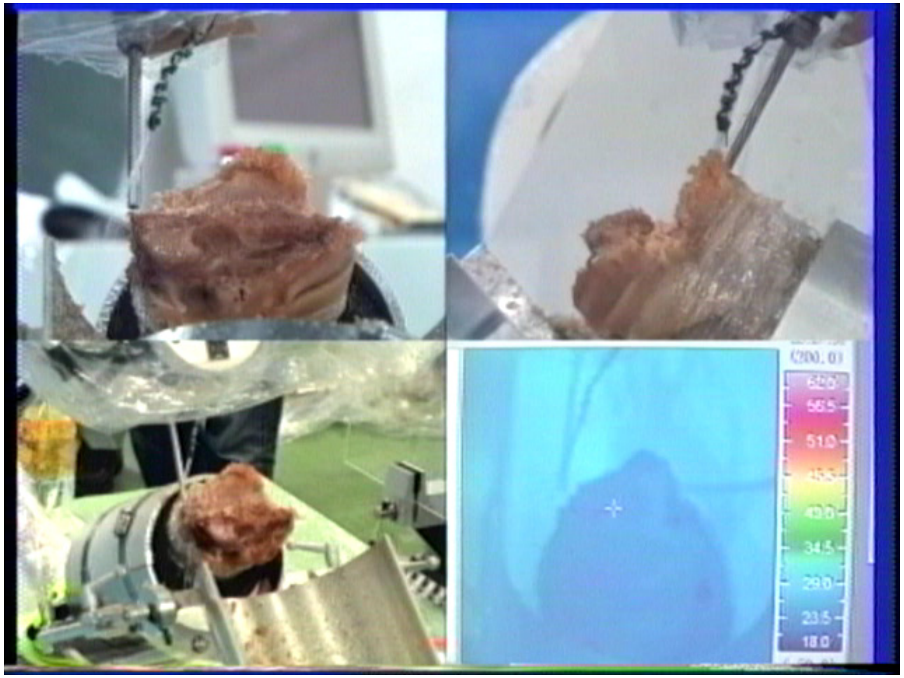
2) Cutting conditions were as follows: cutting type: side cut, cutting speed: 94.2 m/min, feed per tooth: 0.02 mm, width of cut: 2 mm, axial depth of cut: 5 mm.

3) Thermography was used to measure the temperature. Temperature variance at the cutting area was measured.

4) Physiologic saline, which was kept 4 deg. centigrade was used as a coolant.

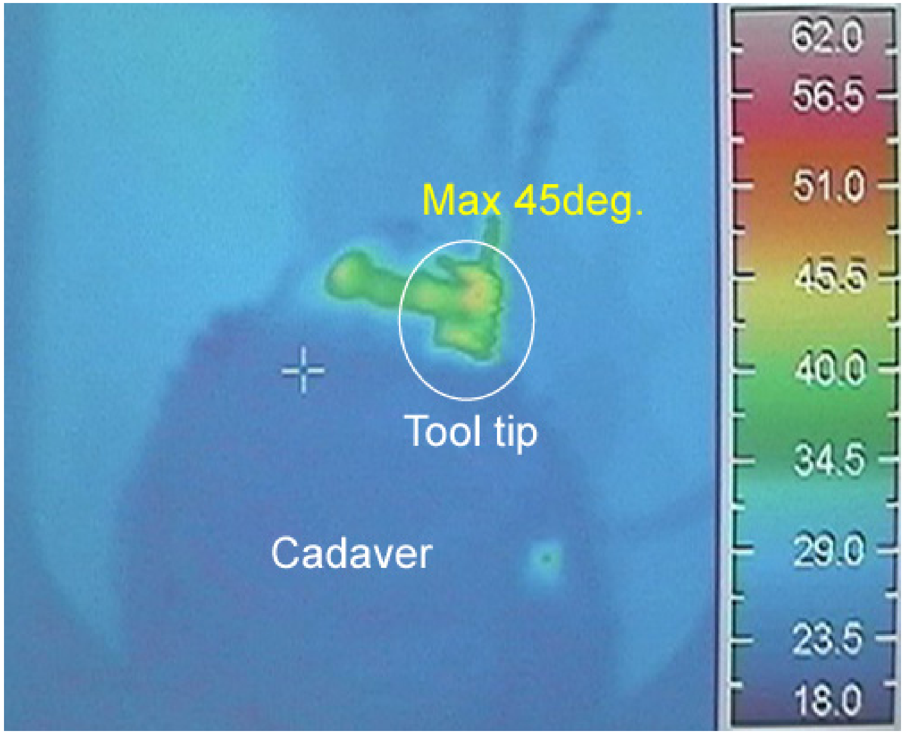
Measurement of cutting temperature

(a) Without coolant

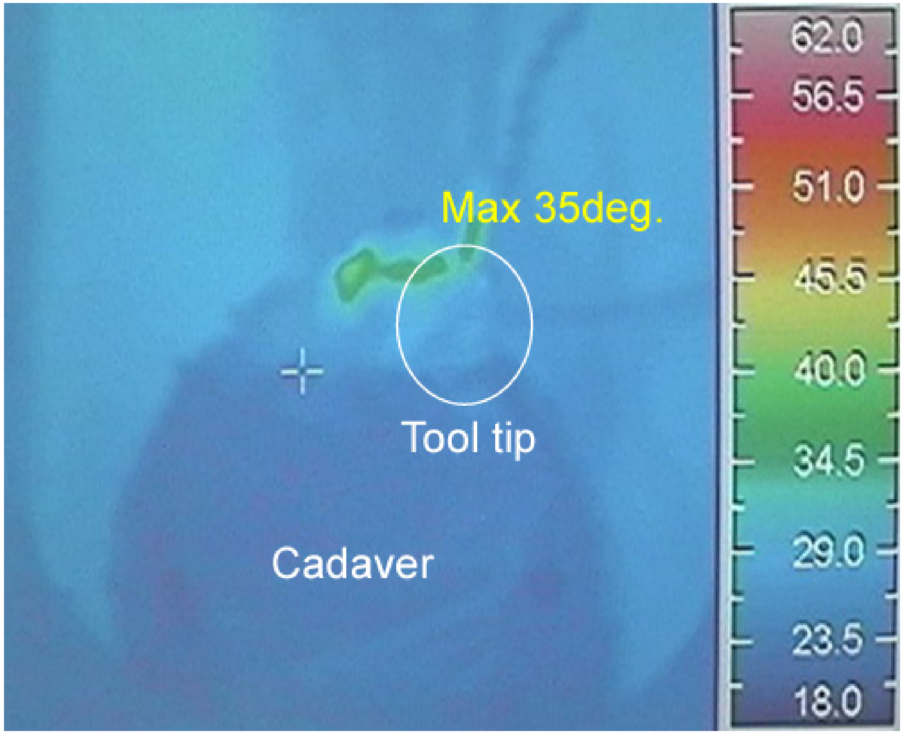


(b) With coolant

Effect of coolant



(a) Without coolant



(b) With coolant

Experimental result

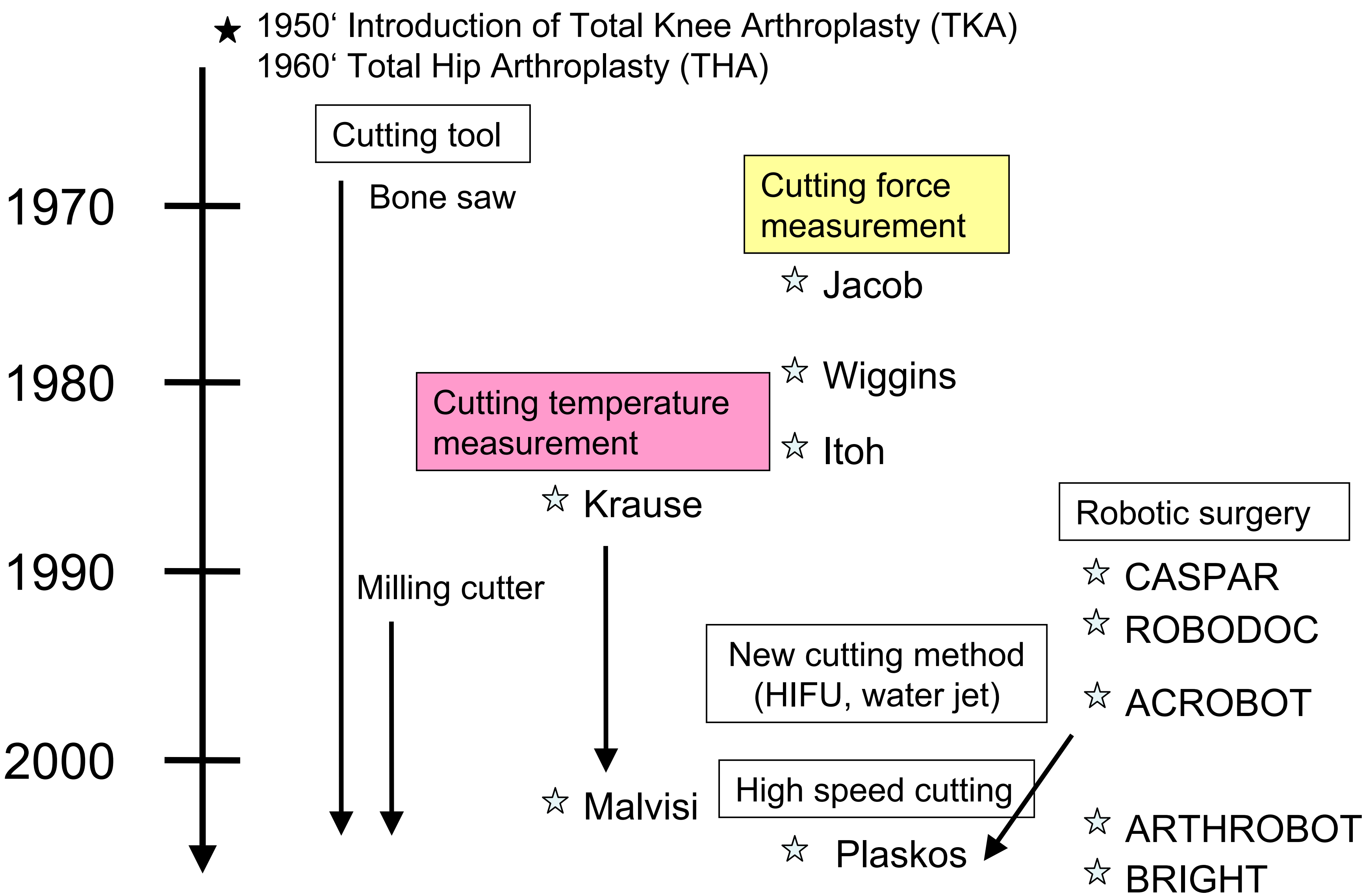
1) The cutting temperature at the tip of the cutting tool was maximum while cutting the cortical bone even though the influence of heat accumulation can be observed.

2) The maximum temperature was 45 and 35 deg. centigrade for without coolant and with coolant, respectively.

3) The cooling effect was approximately 10 deg. centigrade in the experiment.

4) Application to the surgical operation is expected because the cooling effect of the physiologic saline is large.

Related works



Related work

- Bone machining and measurement of cutting force
  - Jacob, et al., A study of Bone Machining, J. Biomechanics, 1974.
  - Wiggins, et al., Orthogonal Machining of Bone, ASME, 1978.
  - Plaskos, et al., Modelling and Optimization of Bone Cutting Forces in Orthopaedic Surgery, MICCAI, 2003.
  - In old researches, the depth of cut is more than 200 mm and, therefore, the cutting mode is crack-based.
  - No researches for analyzing the dynamic cutting mechanism in micro order.

Related work (cont.)

- Cutting temperature measurement
  - Krause, et al., Orthogonal bone cutting, ASME, 1987. (measurement of cutting temperature in 2 dimensional cutting)
  - Malvisi, et al., Milling versus Sawing, MICCAI, 2000. (comparison of the temperature between milling cutter and bone saw)
  - Few researches investigated the practical thermal damage avoidance.

Conclusions

1. A bone cutting machine tool which is suitable for minimally invasive surgery was newly developed.
2. The uniqueness of bone cutting and the need to determine the machining characteristics of each material from which bone is comprised were presented. Dependency of tissue structure of cortical bone for the cutting waveform was discussed.
3. The bone cutting processes were observed. Ductile mode cutting was observed in cortical bone when the undeformed chip thickness was small. Chip generation mode transits from ductile to brittle, depending on the undeformed chip thickness.

(cntd.)

Conclusions (cont.)

4. The specific cutting force depends on the chip thickness, rake angle of the cutting tool and the orientation of osteon. It shows an anisotropic feature.

5. The cutting temperature was measured in cadaver experiments to evaluate the likely damage to the tissue. The surface temperature of the bone was reduced from 45 to 35 deg. centigrade. It will be applied for the surgical operation.

6. The dependency of cutting conditions to the bone cutting temperature was investigated. The following cutting conditions were varied: up/down cutting, cutting speed, and feed per tooth.

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Conclusions (cont.)

7. Cutting temperature was reduced by cooling the cutting environment. The cooling method of a bone and a cutting tool is expected to be used in the surgical operation.