Computer-Integrated Femoral Head Fracture Reduction System

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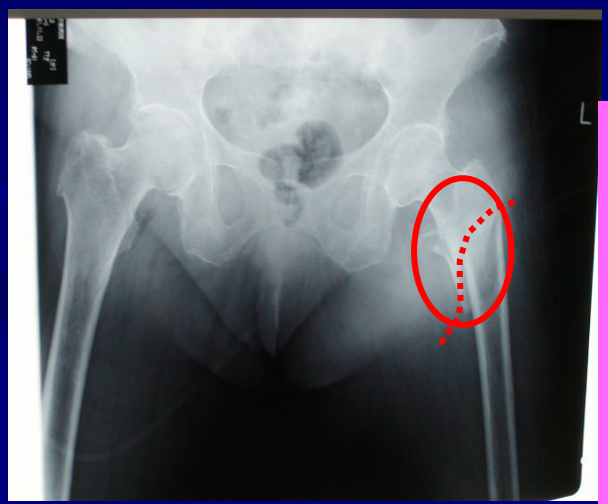
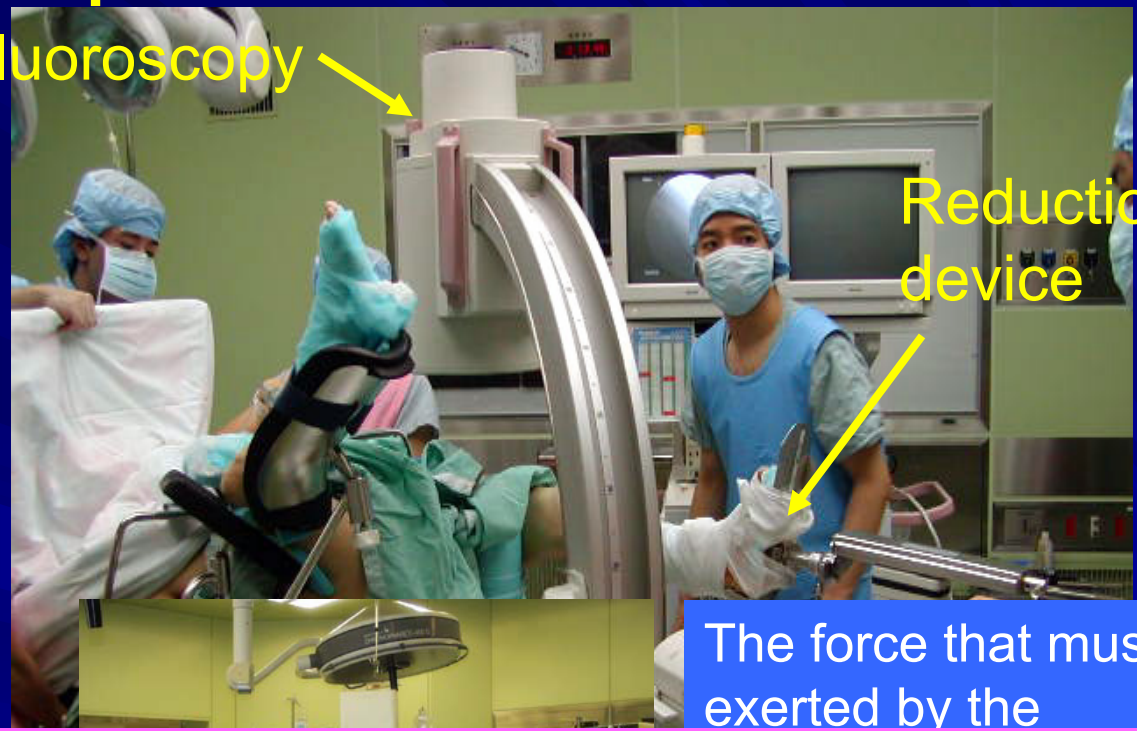
Background

Conventional method and its problems

Surgeons, medical staffs and patients are exposed to radiation during the operation.

Reduction accuracy depends on the ability of the surgeon.





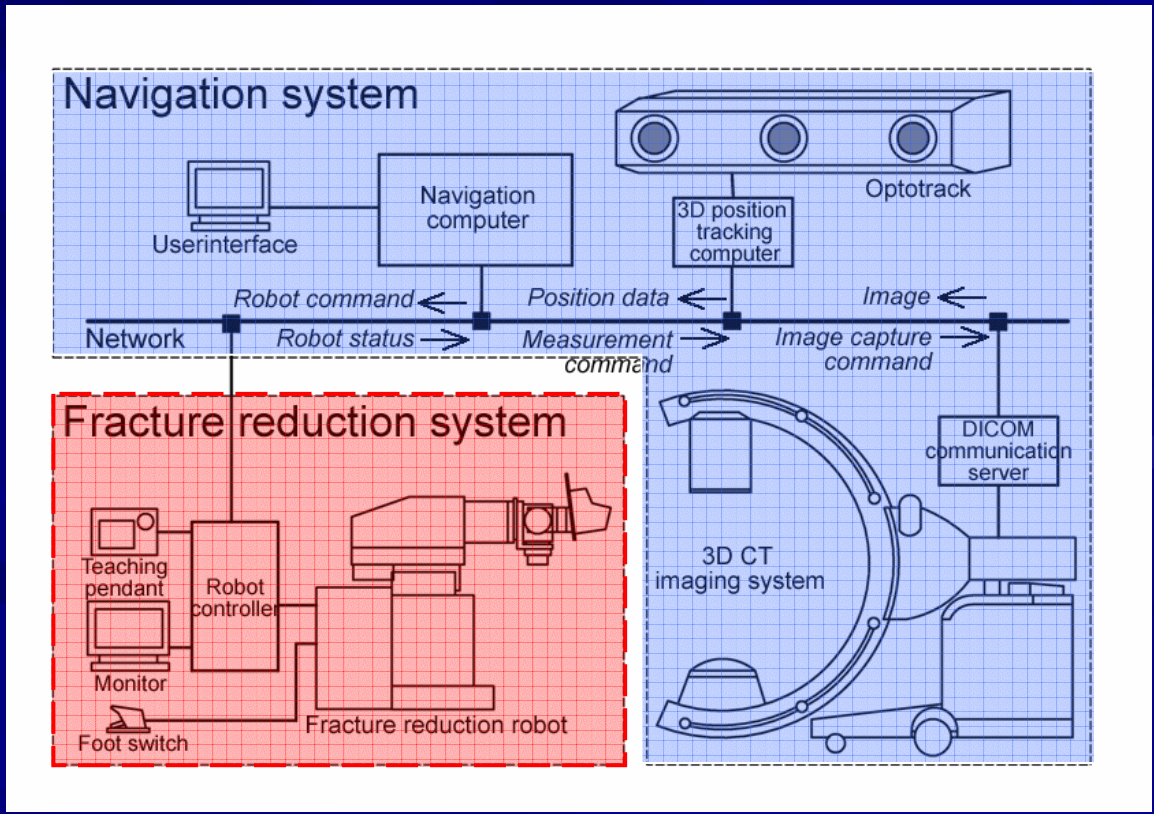
The force that must be exerted by the

(1) Separation of a piece of bone by pulling the leg (inferior branch)
(2) Reduction motion by pulling and rotation of an inferior branch
(3) Intra-operative confirmation by X-ray

Fracture reduction robot system construction

Schematic diagram of the system

- The optimum reduction path is calculated pre-operatively using the CT and X-ray images at the navigation system.
- The calculated path is sent to the reduction robot.
- The reduction motion is performed by the robot.

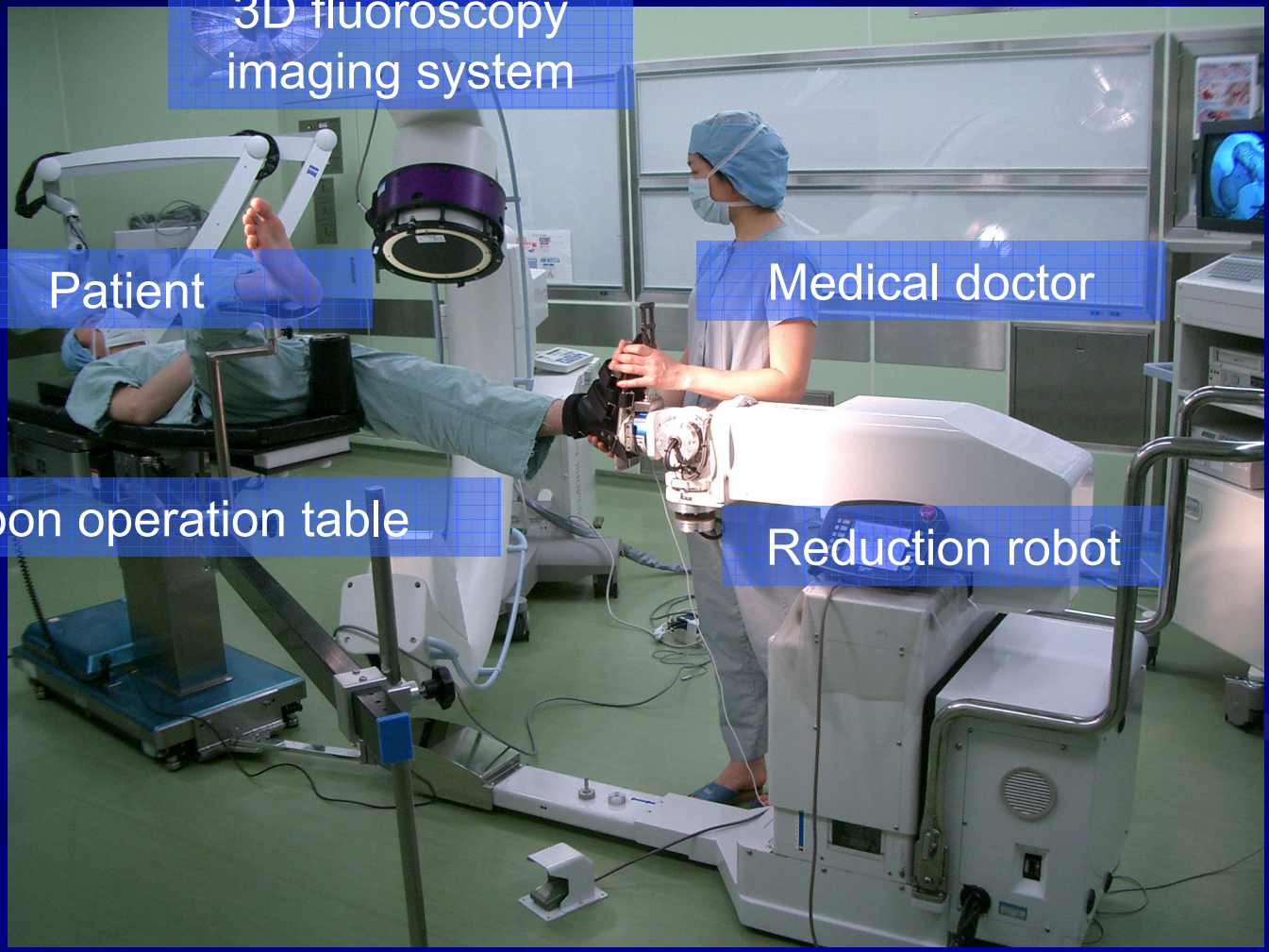


Solutions

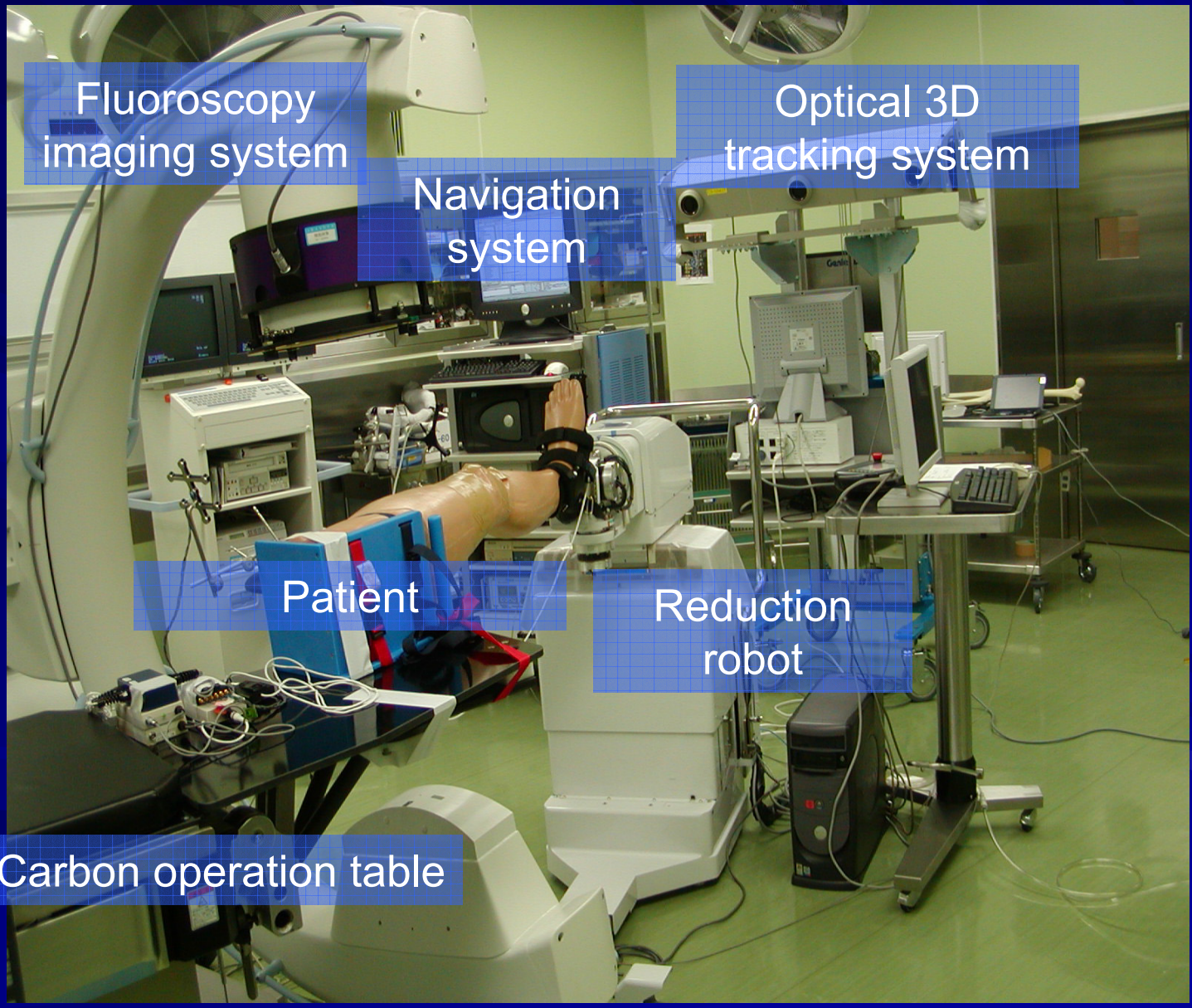
(1) Preoperative full 3D reconstruction
(2) Preoperative path planning
(3) 6 d.o.f. reduction robot
(4) Multi operation modes
(5) Fail-safe mechanism

Automatic mode Power assisted mode JOG mode

Layout of the system

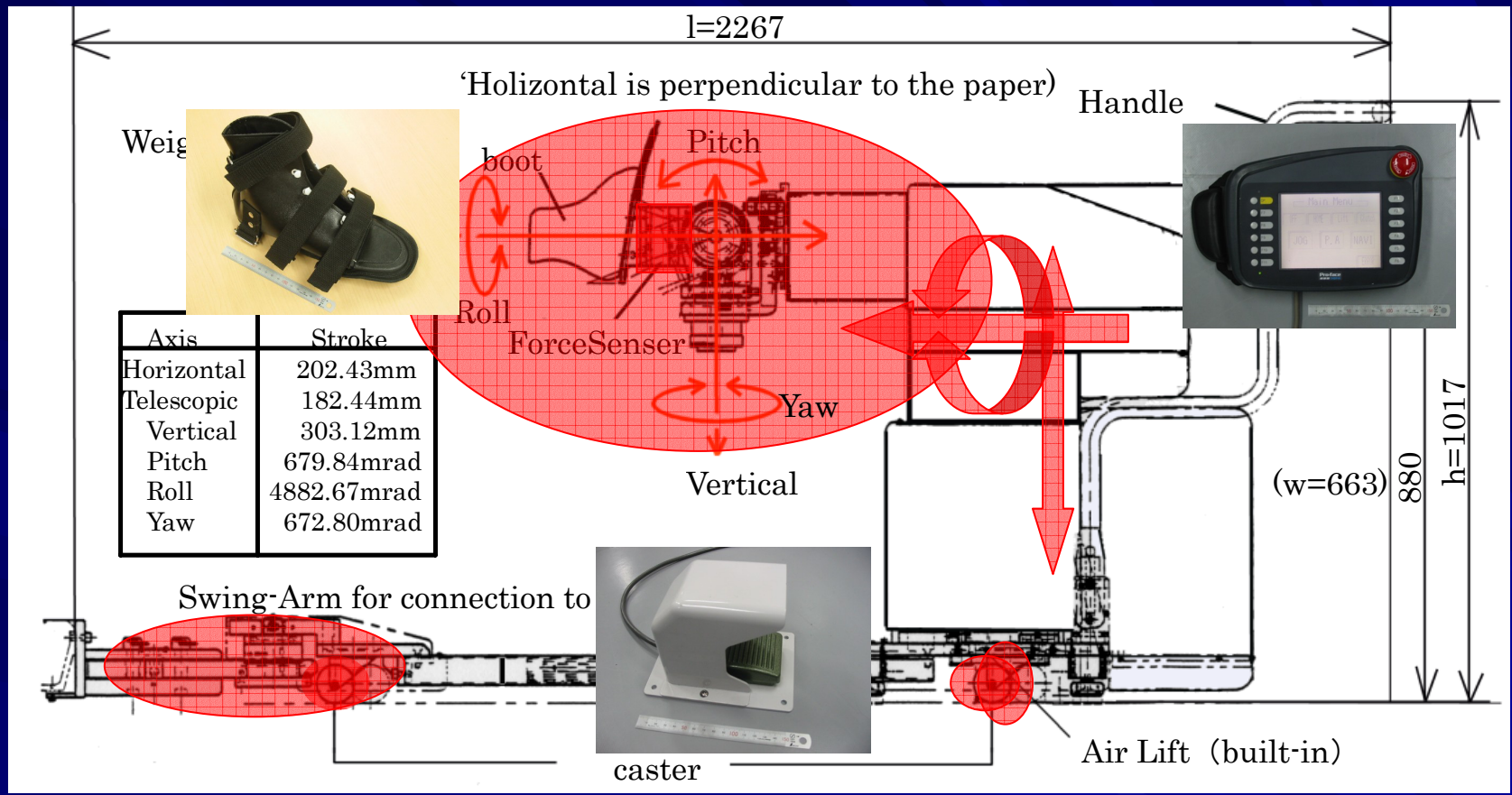


System overview



Fracture reduction system

Fracture reduction robot



Axis	Stroke
Horizontal	202.43mm
Telescopic	182.44mm
Vertical	303.12mm
Pitch	679.84mrad
Roll	4882.67mrad
Yaw	672.80mrad

- The axes of all the rotational d.o.f. intersect at the same point using a hollow motor.
- Attaching and detaching operations should be easy while the robot is connected with the existing operation table.
- Fail-safe mechanism is necessary.
- The same position can be maintained by a lift after the determination of a fracture reduction robot.
- The motion of the robot must be synchronized with that of an operation table while moving up and down.

Specification

- Stroke

  X：±150 mm, Y：-10～+300 mm, Z：-10～+300 mm

  A：±20 deg., B：±25 deg., C：±135 deg.

- Force sensor

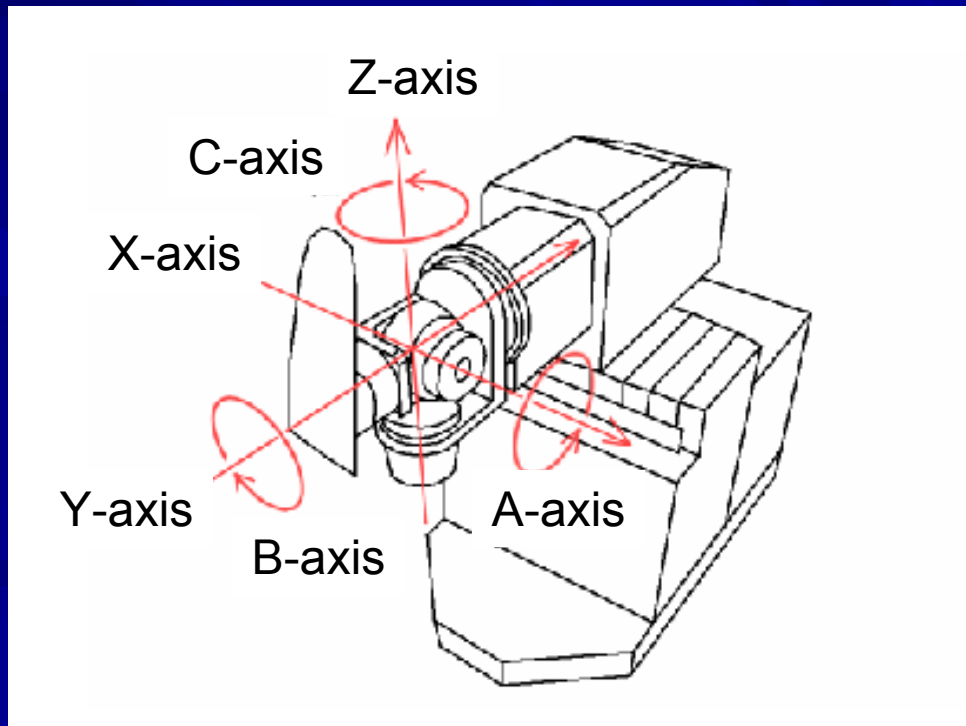
  Fx, Fy：400 N, Fz：800 N

  Mx, My, Mz：40 Nm

- Fail-safe mechanism

  Y：300 N, +100 mm, -30 mm

  B：28 Nm±135 deg.



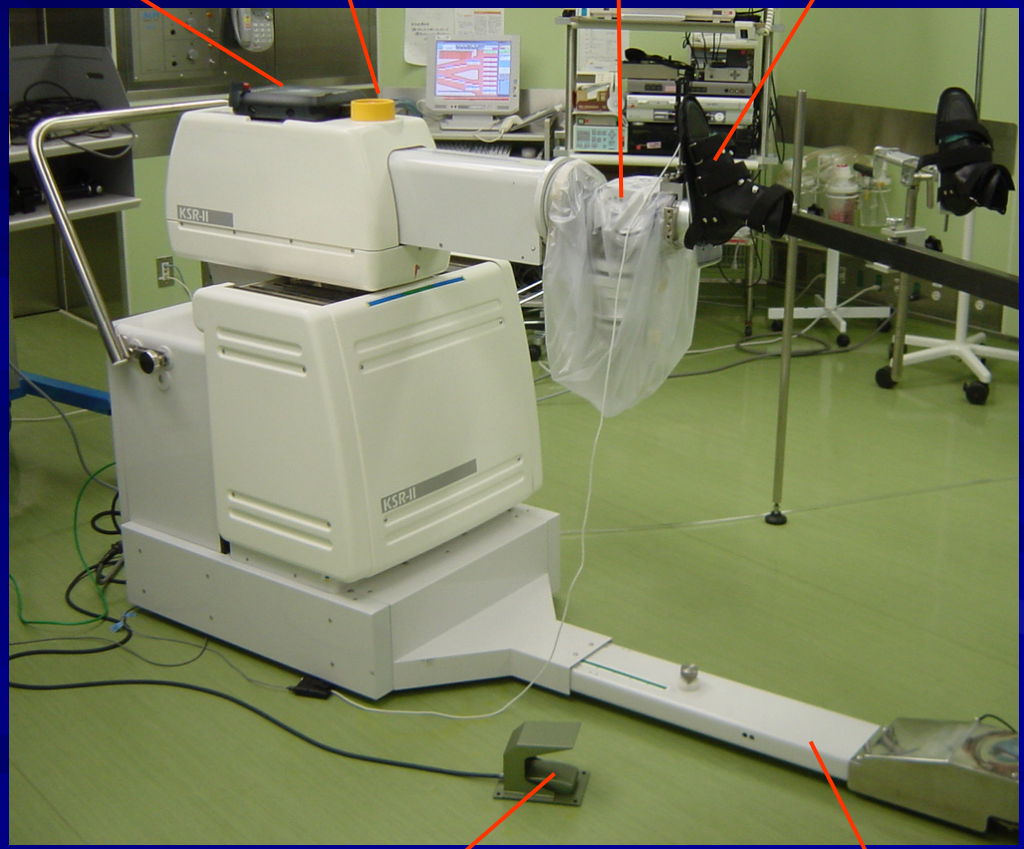
Overview of the fracture reduction robot

Teaching pendant

Emergency stop bottom

Force sensor

Fixture

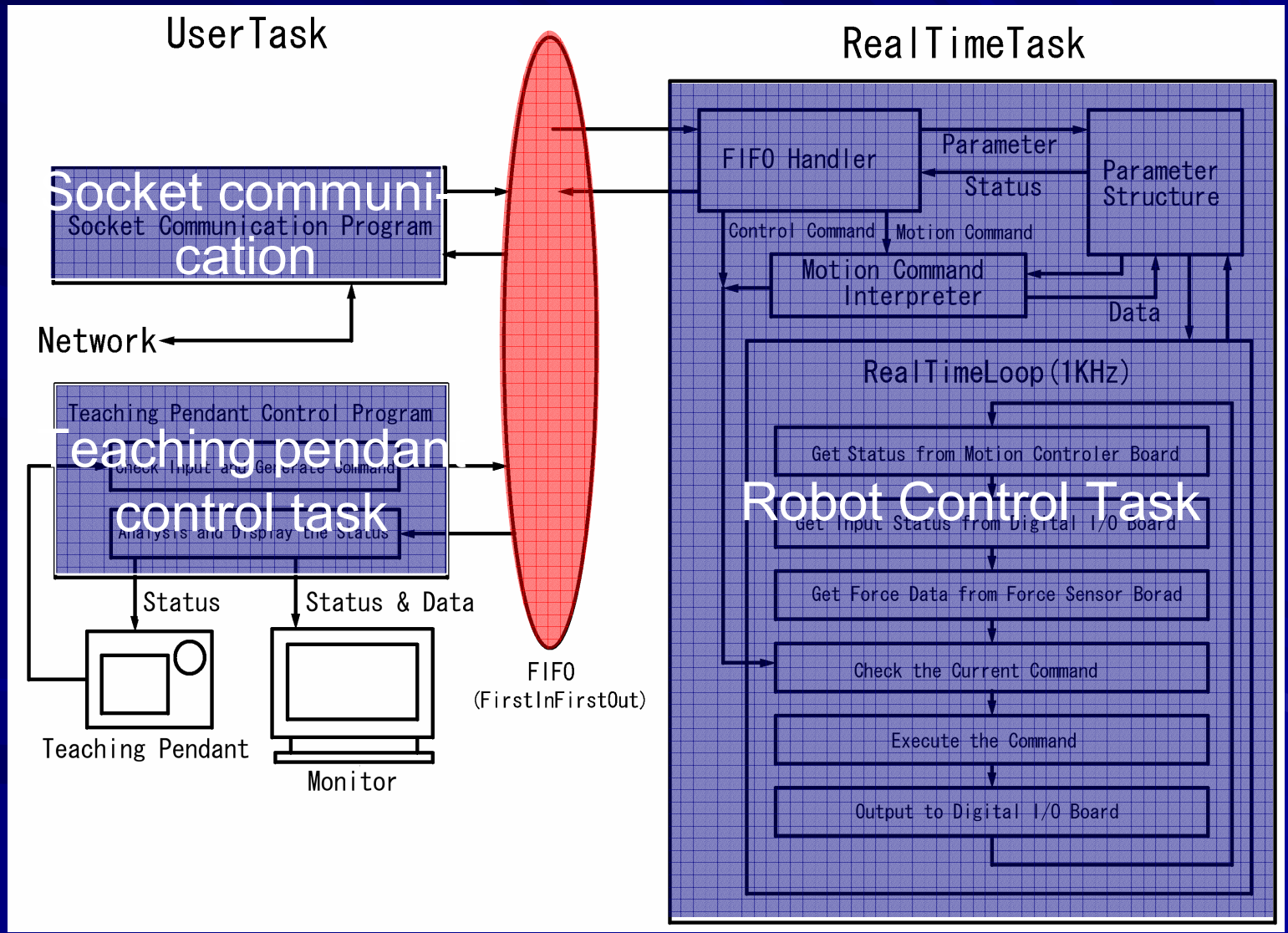


Foot switch for the power assisted mode

Connecting arm

Robot system controller

Real Time Linux

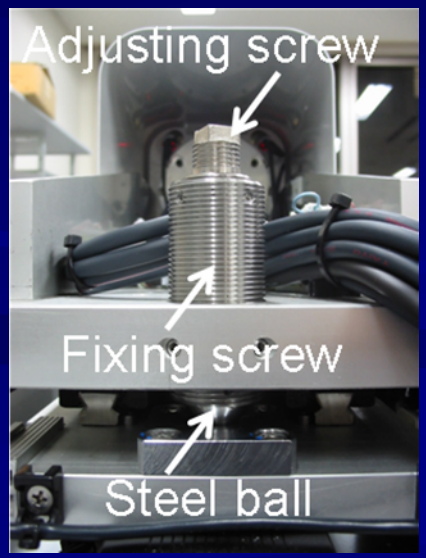


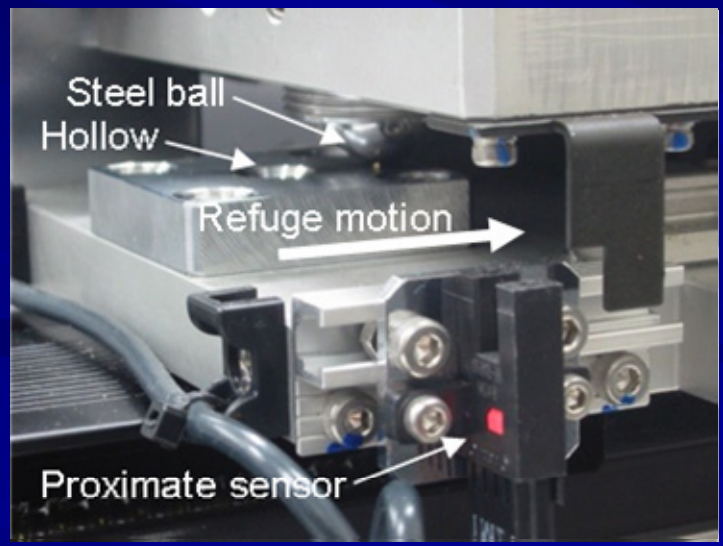
Fail-safe mechanism

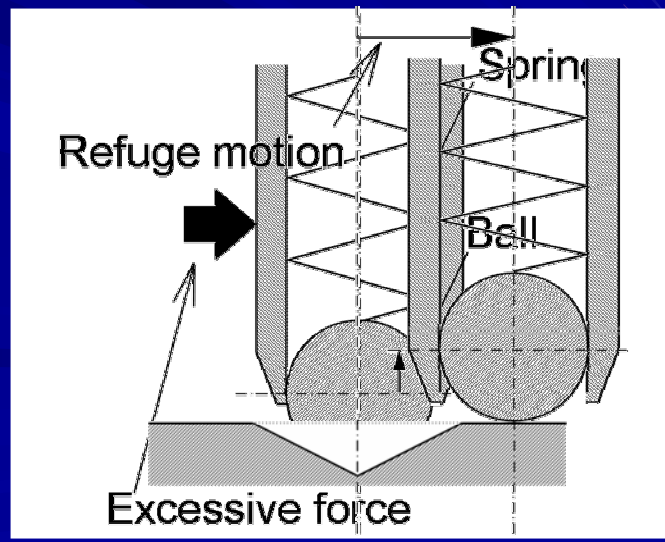
Concept

1. High rigidity should be maintained in the normal state.
2. Large displacement occurs when an excessive force is applied to the system.
3. Emergency signal is generated and the system is stopped.
4. The system returns to its normal state when the excessive force is removed.

Configuration







Operation modes

JOG mode

Power assisted mode

Automatic (NAVI) mode

JOG mode

- Interactive motion control using a teaching pendant
- Step motion
- Useful for preparation of the surgery

Power assisted mode

- To reduce the load on a surgeon when pulling and rotating the patient's inferior branch
  - Approaching the fixture device to a foot
- To provide the same adjustment environment as the conventional one by holding a fixture device
  - Separating fracture segments
- To move the inferior branch to an arbitrary position and posture

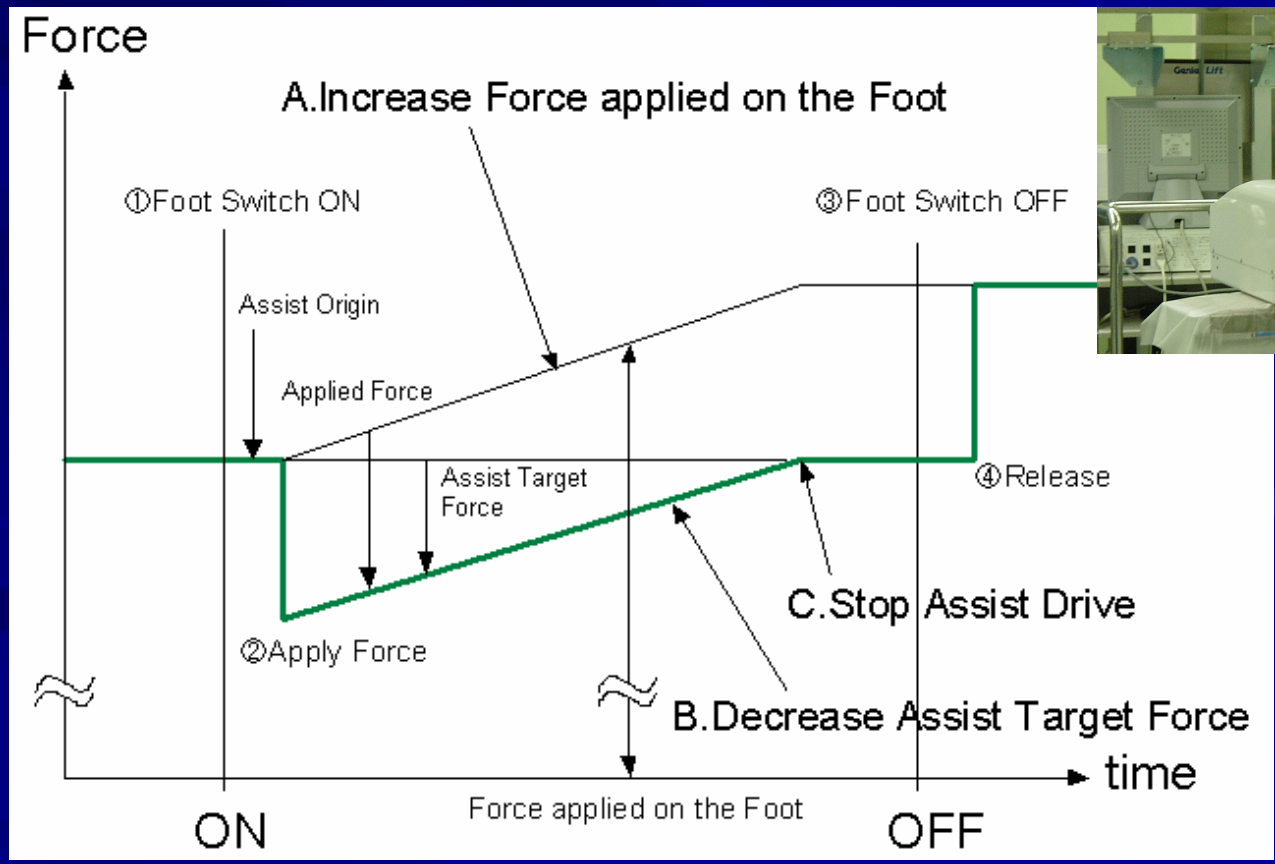
Power assisted mode

3 different viscosities were prepared.

1. Ultra-soft mode
   - Appropriate for the wide range motion (coarse positioning)
2. Soft mode
   - Not necessary
3. Hard mode
   - Suitable for the precise positioning

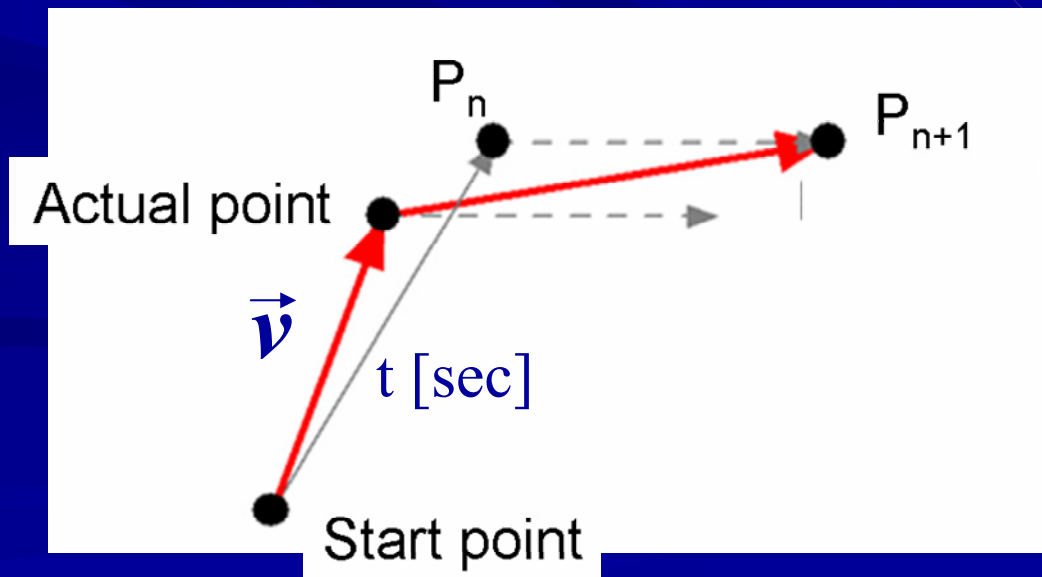
Control in power assisted mode

- The force which is applied to the patient's branch by a surgeon is detected by the multi-axis force sensor.
- The assist force is considered at the origin when the foot switch is pressed.
- The variance of the force while pressing the foot switch is considered as an assist force.
- The motion of the fracture reduction robot is controlled to make the variance force zero.

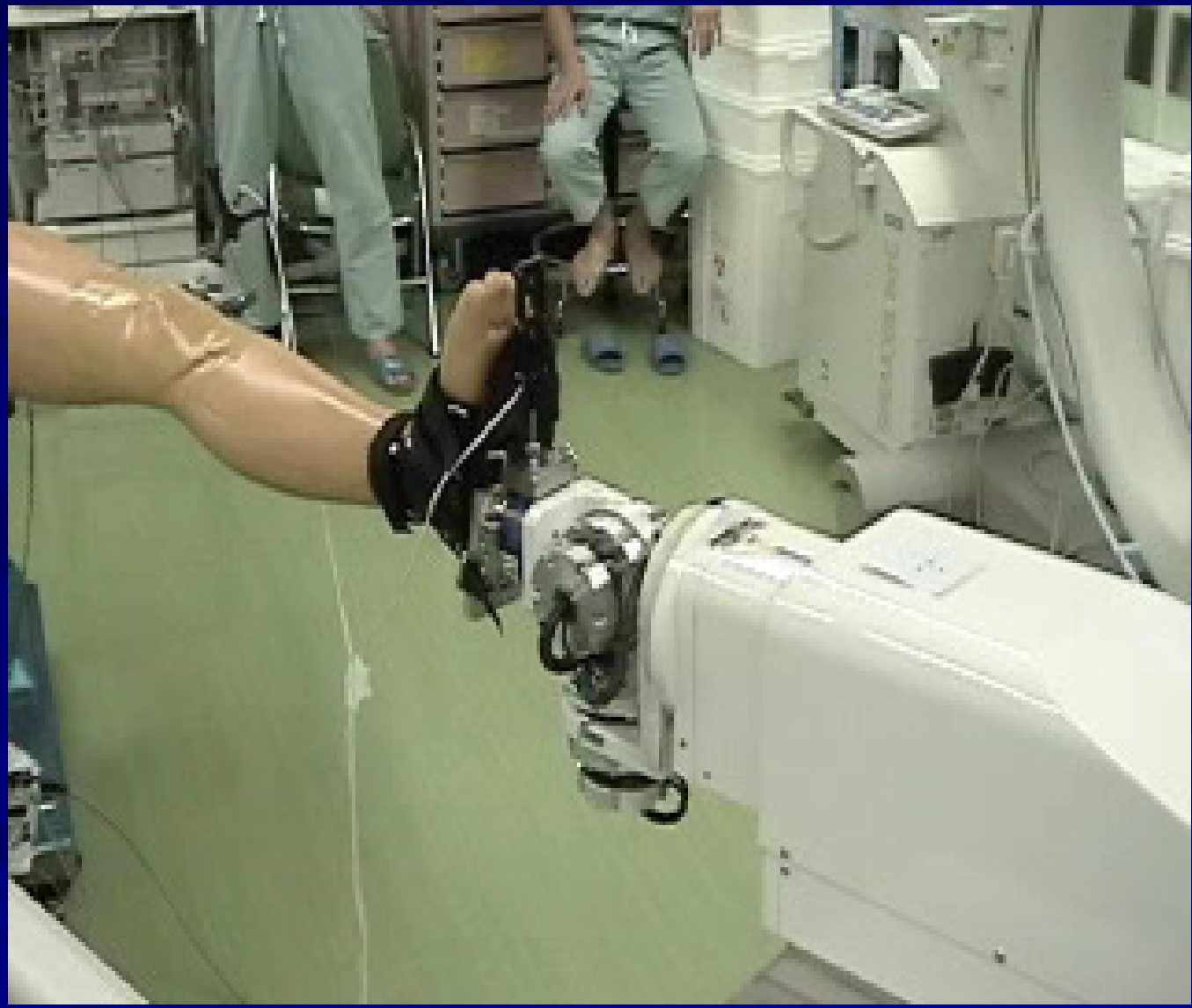


Automatic (NAVI) mode

- Used in the fracture reduction process
- Control points scheduled by NAVI
- Smooth motion required
- The third order spline curve interpolation
- Velocity control: position not guaranteed



Video of automatic mode



Experiments

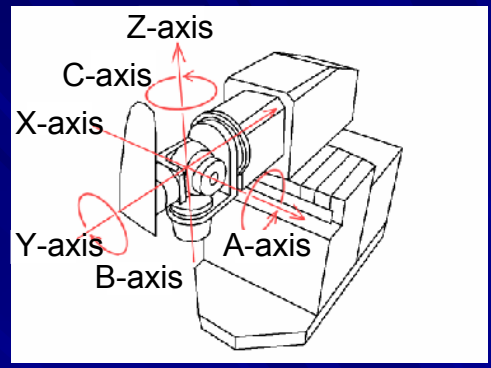
Synchronized motion of the robot with an operation table

- The fracture reduction robot moves up and down synchronitically with an operation table by the operation to the operation table.

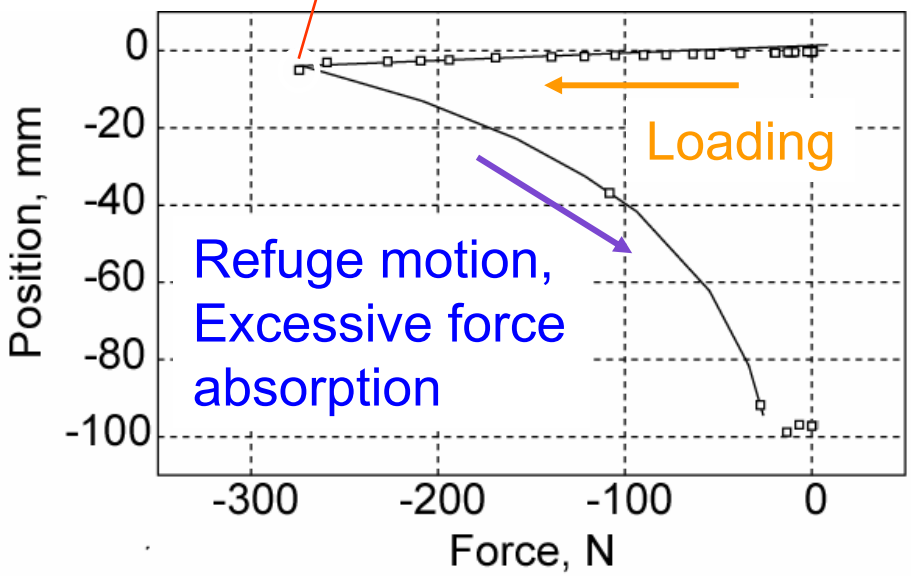
Fail-safe mechanism

Evaluation of the fail-safe mechanism

Rated value
Y-axis: 300 N
B-axis: 28 Nm

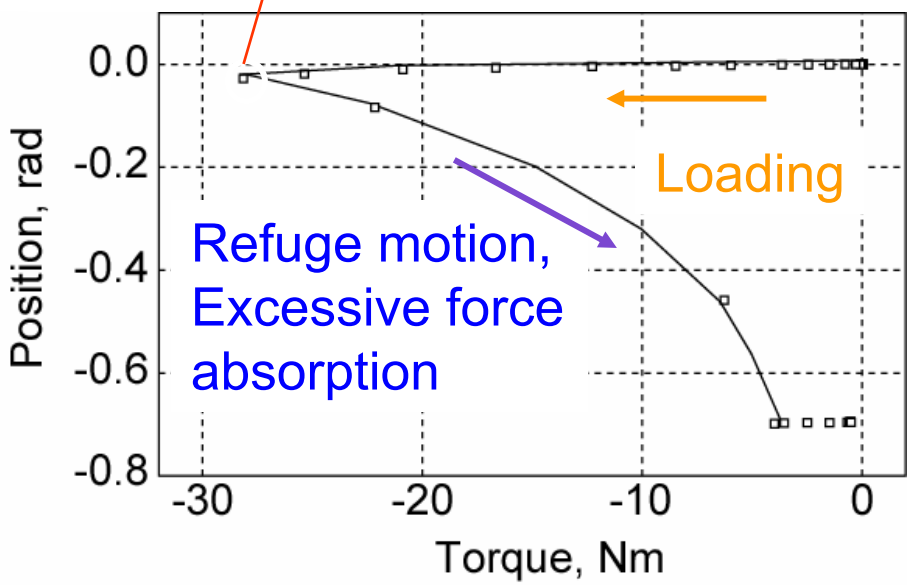


Active point



(1) Y-axis, minus direction

Active point

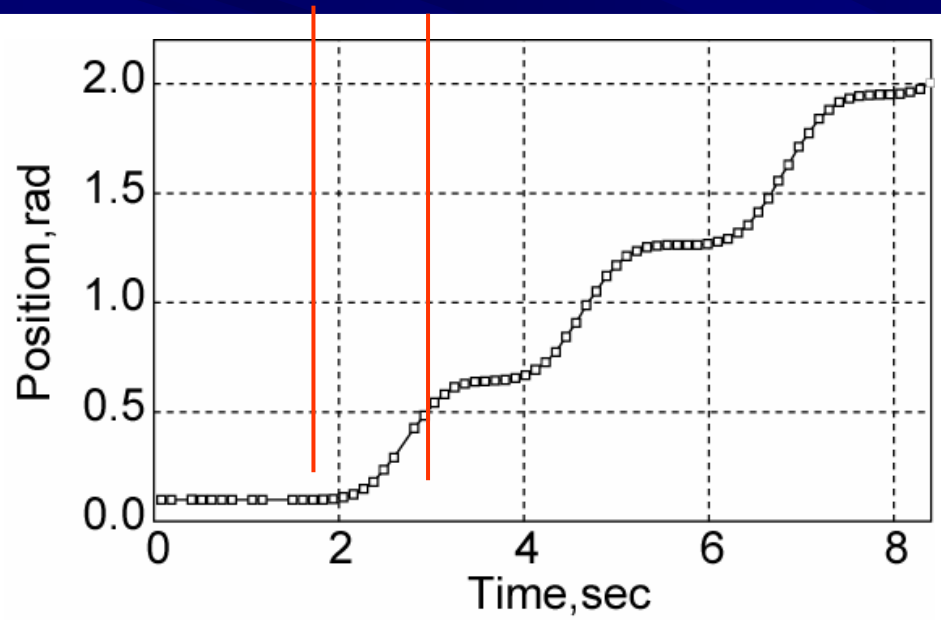


(2) B-axis, minus direction

Power assisted mode

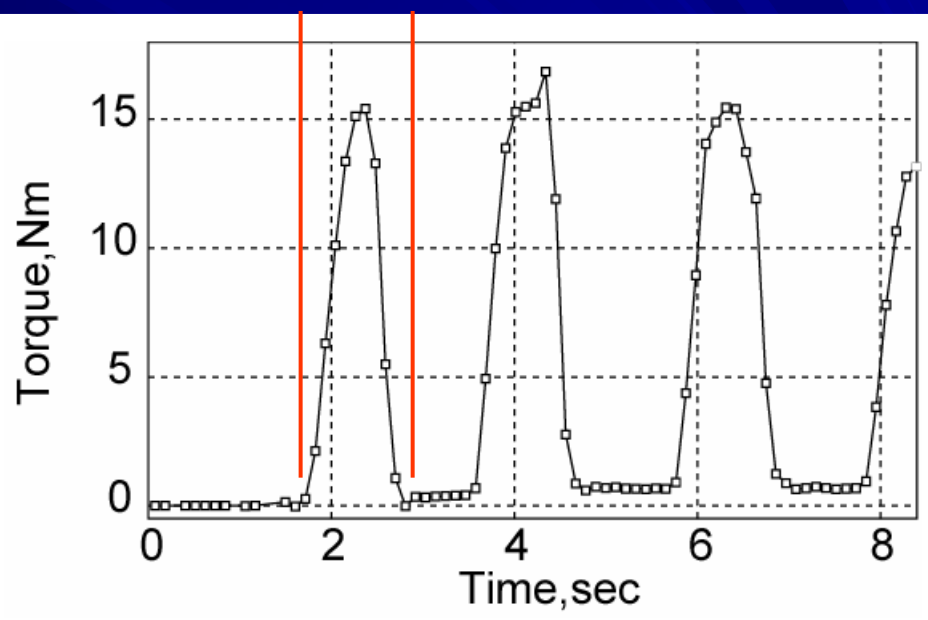
Evaluation of the power assisted function (B-axis, ultra-soft mode)

Foot switch
ON OFF



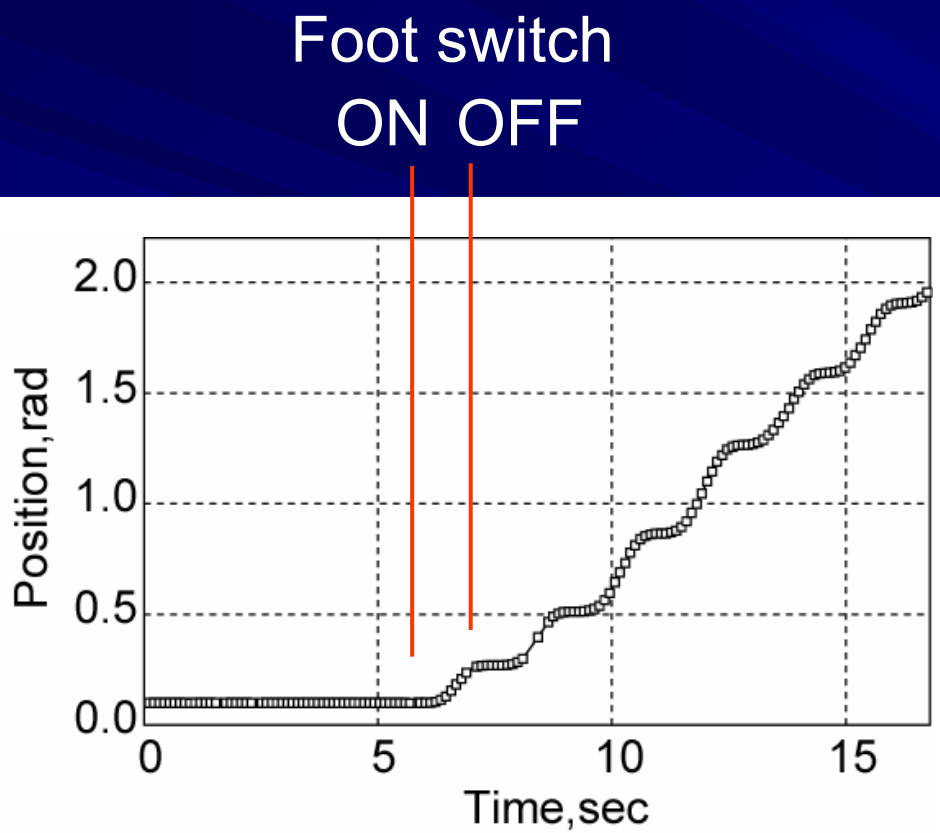
(1) Position

Foot switch
ON OFF

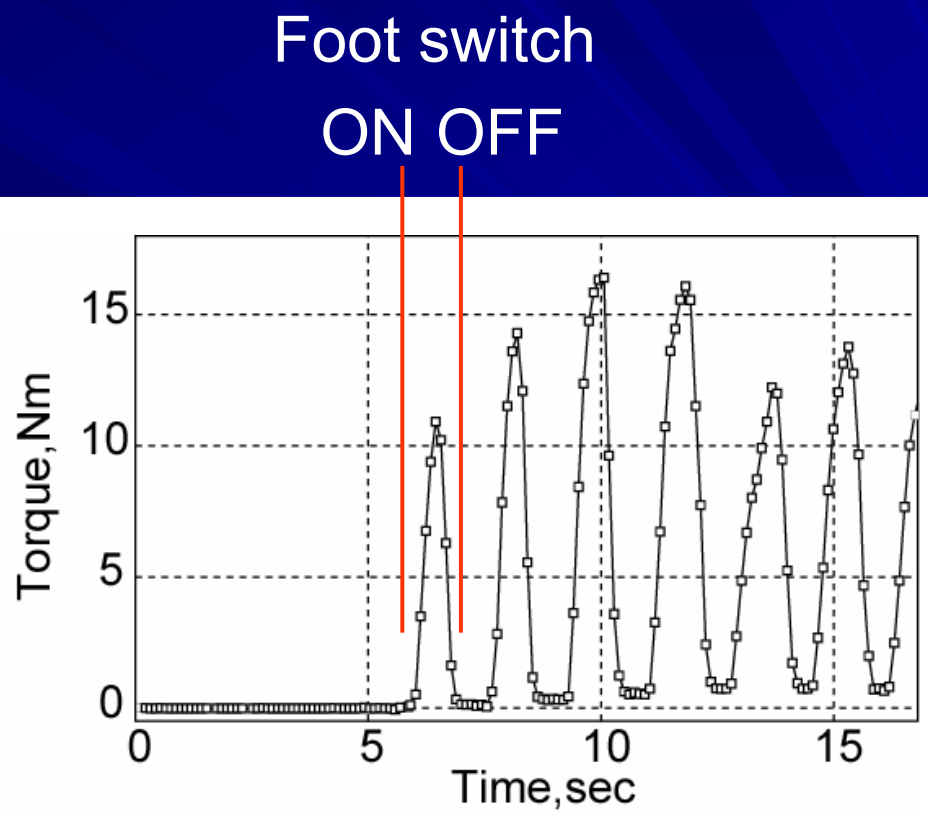


(2) Force

Evaluation of the power assisted function (B-axis, hard mode)



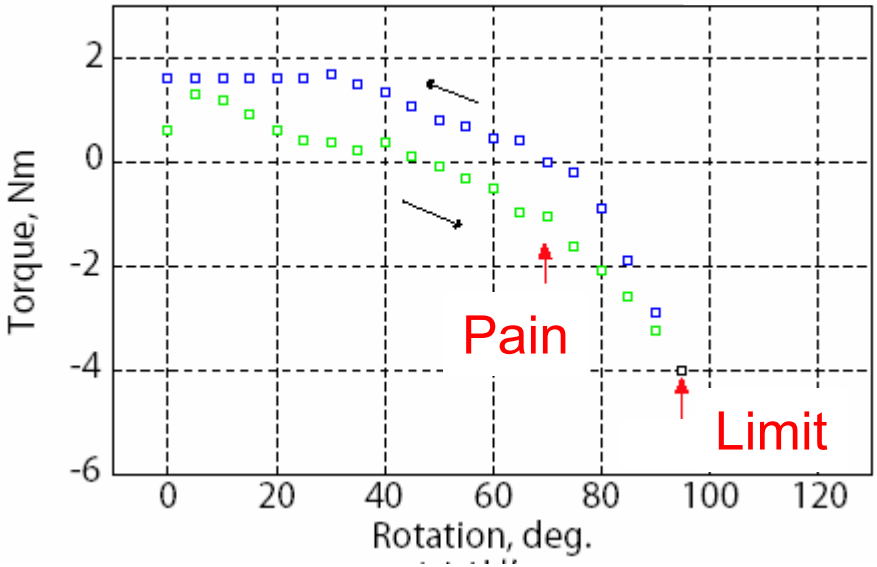
(1) Position



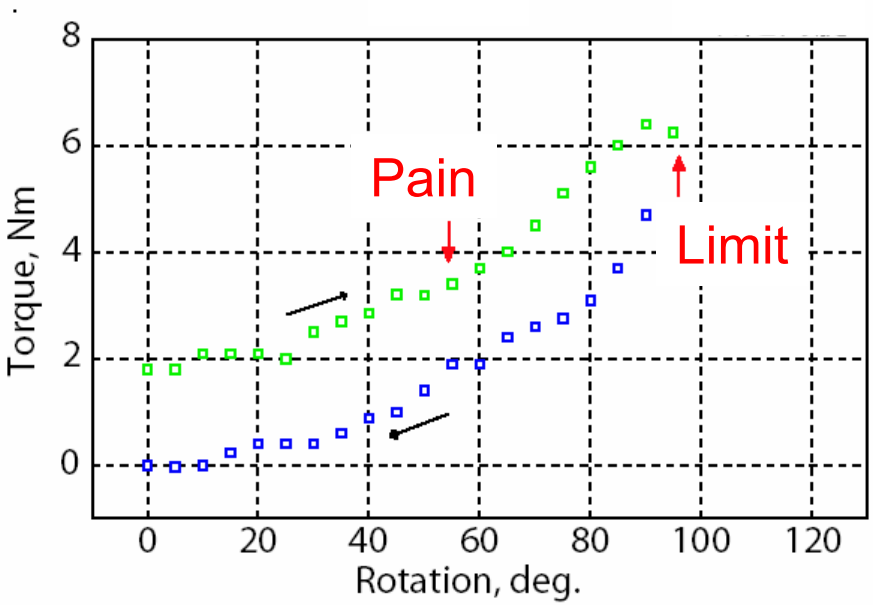
(2) Force

Biomechanical data acquisition to apply the developed system for the clinical use

Motion range of the inferior branch (Subject A: Female, Normal volunteer)

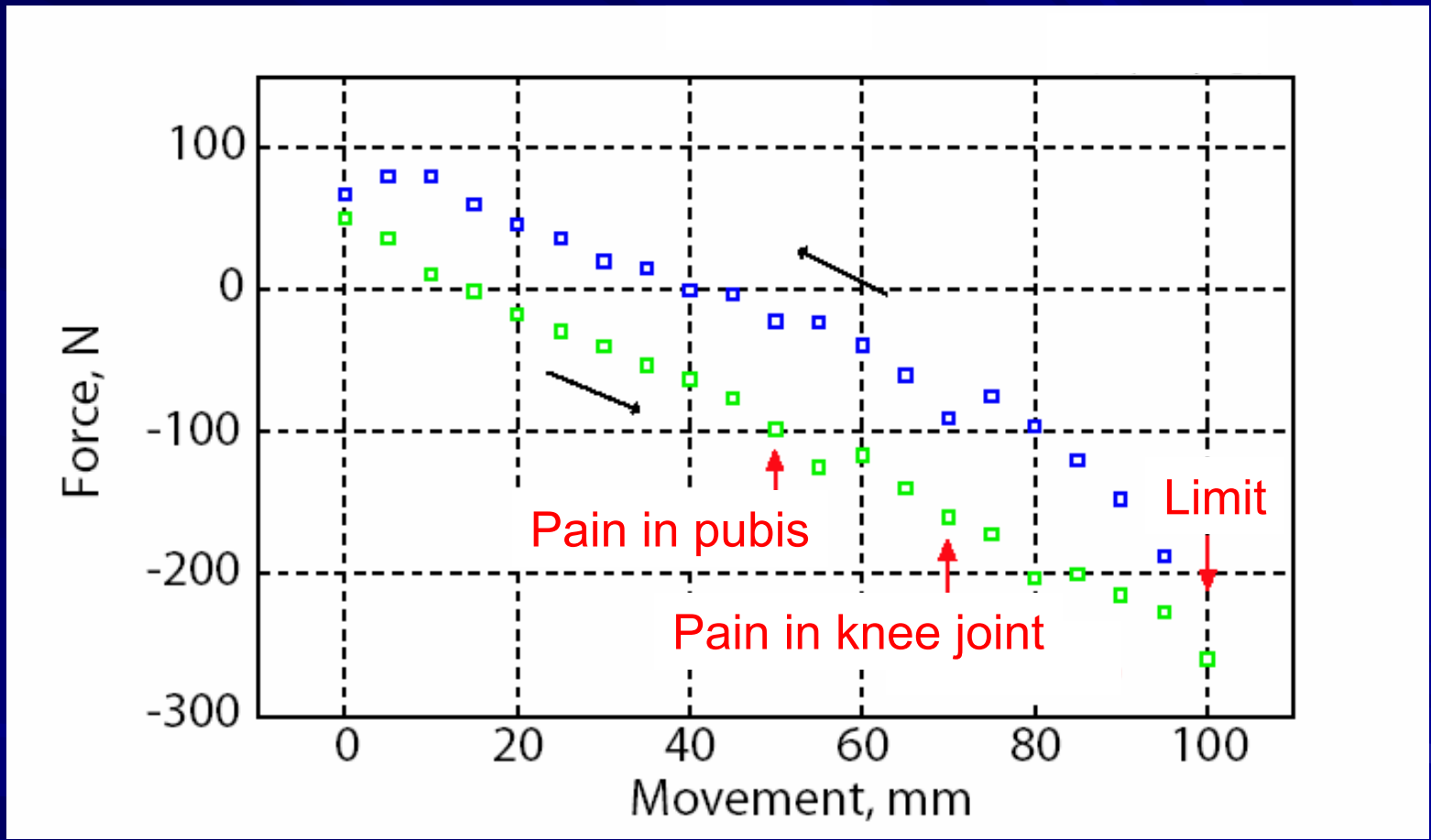


(a) Right leg external rotation

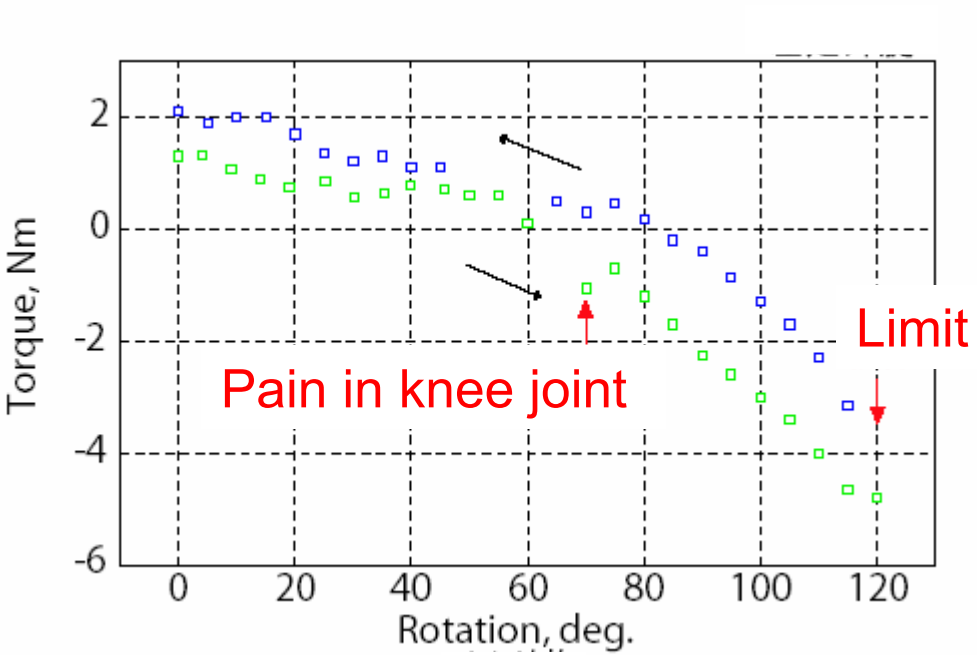


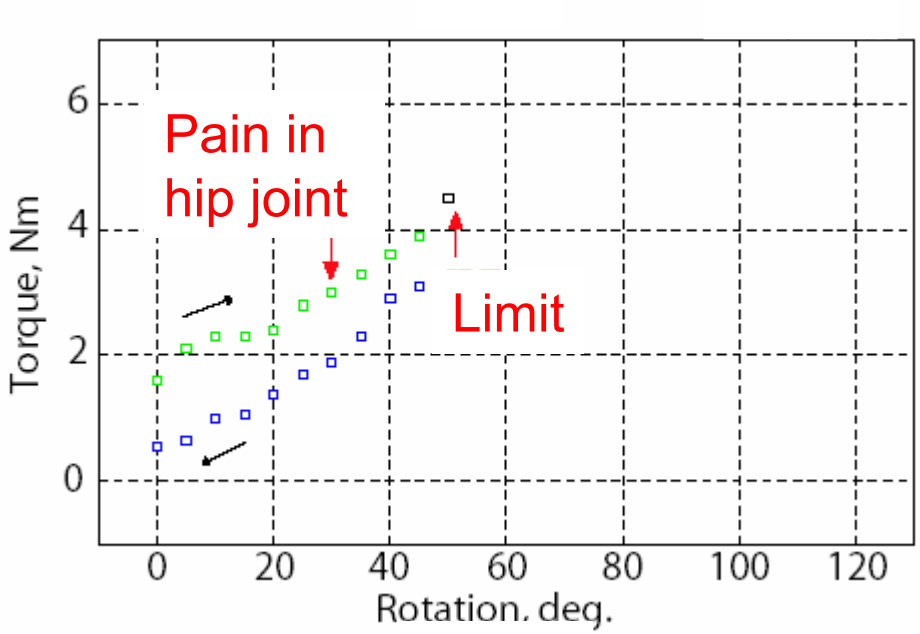
(b) Right leg internal rotation

Motion range of the inferior branch (Subject A: Female, Normal volunteer)



(c) Right leg traction





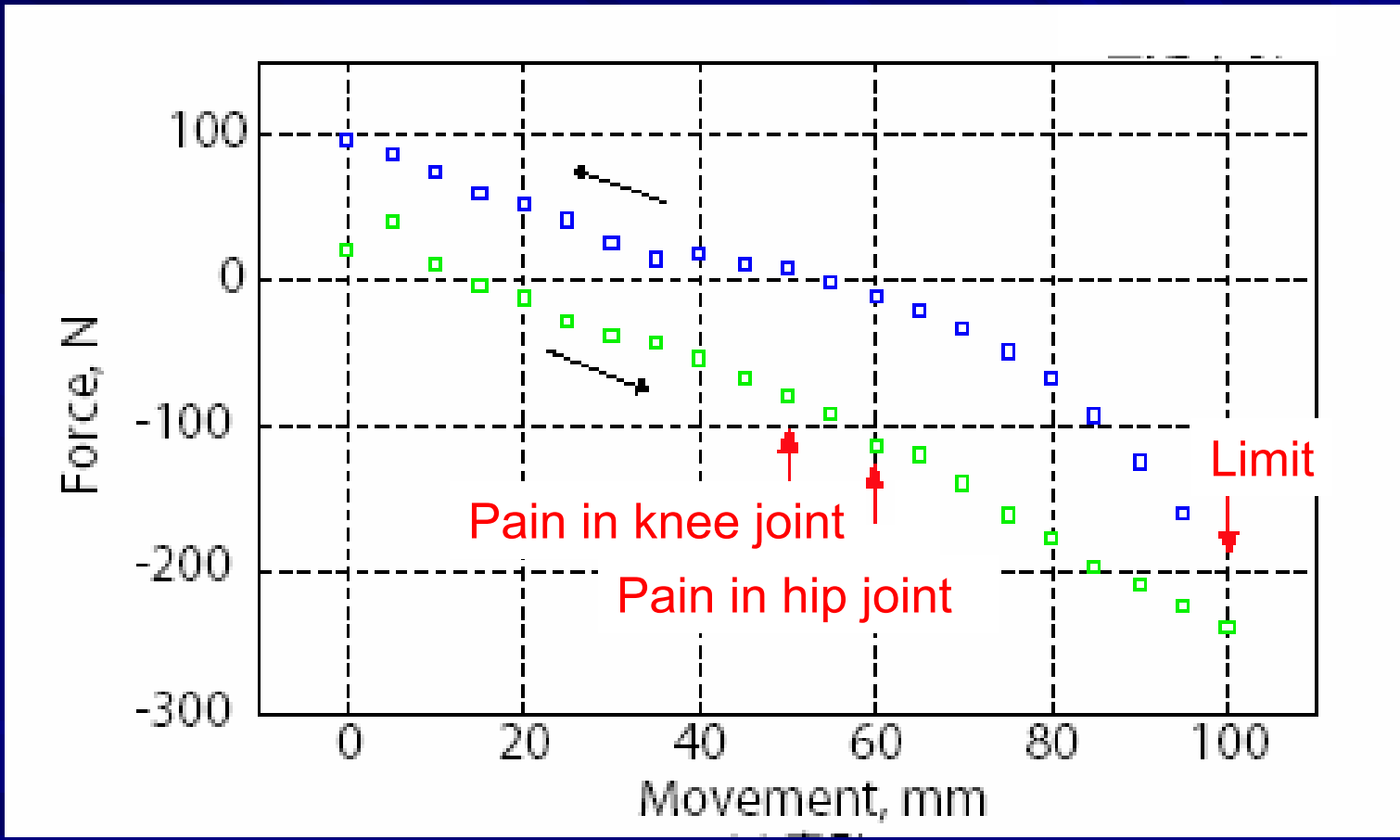
Motion range of the inferior branch (Subject A: Female, Normal volunteer)

(d) Left leg external rotation

- Limit value for internal rotation is smaller than that for external rotation.
- Limit value is different for the right and the left legs.

(e) Left leg internal rotation

Motion range of the inferior branch (Subject A: Female, Normal volunteer)



(f) Left leg traction

Conclusions

- The authors have developed a robot system for femoral head fracture reduction.
- The system consists of a navigation system, a robotic system, an X-ray system, and an operation table.
- The robot has 6 d.o.f., such as three translation d.o.f. and three rotational d.o.f.
- Three operating modes were prepared: JOG mode, power assisted mode, and an automatic mode.
- The biomechanical data to apply the developed system for clinical use were obtained.