Department Of Orthopaedics & Traumatology
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Newsletter

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Computer assisted Navigation in Total Knee Replacement

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The Division of Joint Replacement Surgery of Queen Mary Hospital has recently set up a centre for performing total knee replacement under computer assisted navigation (Figure 1). The prosthesis implanted is the traditional one but the whole operation is done under computer guidance, aiming to improve the accuracy and consistency in each operation.

Figure 1. A scene of Computer Navigated Total Knee Replacement

It is estimated that there is a total of 800 total knee replacements (TKR) done in Hong Kong each year. The most common pathology is symptomatic end-staged osteoarthritis (Figure 2). In the past few years, we observed a progressive increase

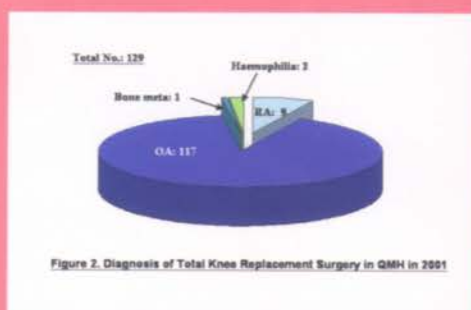

Figure 2. Diagnosis leading to Total Knee Replacement Surgery in QMH in 200

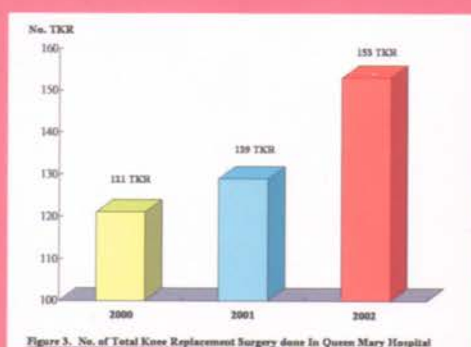

Figure 3. No. of Total Knee Replacement Surgery done In Queen Mary Hospital

in the number of total knee replacements performed in Queen Mary Hospital (Figure 3). This is likely related to the aging population of Hong Kong. As the total number of our senior citizens is expected to increase in the coming decades, it is not surprising to see a corresponding increase in the number of patients requiring total knee replacements in the future.

The aim of total joint replacement is to construct a pain free, stable and mobile joint, which can last for many years. The fifteen year survivorship of a replaced knee joint is around 90% - 95%. Re-establishment of correct alignment of the replaced knee joint is critical for achieving this. After the operation, the centre of hip joint, centre of knee joint and centre of ankle joint should lie in the same straight line in the coronal plane. The mechanical axis of femur (a line joining the centre of hip joint and centre of knee joint) should be co-linear with the mechanical axis of tibia (a line joining the centre of knee joint and centre of ankle joint). The joint surface of the artificial knee joint should be made perpendicular to these mechanical axes (Figure 4). This will ensure a symmetrical distribution of force during weight bearing and hence a prolonged survival of the prosthesis.

Figure 4. Mechanical axis of femur and tibia in Pre-operative and Post-operative Long films

Thus, during a total knee replacement operation, one of the major tasks is to produce bone cuts of the distal femur and proximal tibia at right angles to the mechanical axis of femur and the mechanical axis of tibia respectively.

The question comes: "How can these mechanical axes be defined accurately?"

The centre of the hip joint and the centre of ankle joint are far away from the operative field and not exposed. Traditionally, these two mechanical axes are identified by using either extra-medullary method or intra-medullary method. Extra-medullary method relies on the identification of bony landmarks, which are rather inaccurate, especially over the hip region and in obese patients. Intra-medullary method relies on identification of the relationship between the mechanical axis and axis of the medullary canal (anatomical axis) of femur and tibia on X-rays. Significant error will arise if there is deformity of the bone or inappropriate rotation of the X-ray.

The margin of error in performing these bone cuts is rather narrow (in term of one to two degrees). Hence, the learning curve of performing total knee replacement is rather long and many surgeons will consider themselves competent after performing hundreds of TKR. If there is significant deformity of the bone, suboptimal bone cuts will result even in the hands of experienced surgeons.

Computer assisted navigation for TKR helps surgeons to identify these **"invisible"** mechanical axes in a more accurate and reproducible manner. After establishing these axes, subsequent bone cuts over the distal femur and proximal tibia can be made accurately. The accuracy of these bone cuts can be reviewed repeatedly throughout the operative procedure.

Most of the TKR done in Hong Kong are surface replacement surgery. It means that we only remove the diseased articular surface and replace the gap created with the prosthesis. The whole picture can be simplified and be considered as turning the space between the cut surfaces into a **"gap" (Gap Theory)**. The aim is to produce a rectangular gap (so that the tension over the medial collateral ligament and lateral collateral ligament are the same) (Figure 5), which is equal in both flexion and extension **(Flexion gap = Extension gap)**. Flexion gap is affected by the posterior femoral cut and the tibial cut while extension gap is affected by distal femoral cut and tibial cut. The second major tasks for the knee replacement surgeon is to balance this flexion and extension gap by adjusting the extent of the distal femoral cut, posterior femoral cut and tibial cut. Computer assisted navigation help us to optimize the balance among the extents of these bone cuts and hence a perfect match between flexion and extension gap can be achieved.

Figure 5. Turning the cut surfaces in a deformed knee to a rectangular gap

Procedure of performing total knee replacement under computer guided navigation

There are several computer navigation systems available in the market. The basic steps are similar:

1. Set-up of reference arrays
2. Determination of mechanical axis of femur and tibia
3. Registration of important bony landmarks
4. Determination of soft tissue tension
5. Determination of size and position of prosthesis in the computer model
6. Performing bone cuts
7. Implantation of prosthesis

Surgical approach and soft tissue balance are carried out as in conventional TKR. Registration and bone cuts are started after completion of soft tissue dissection.

Set-up of registration arrays

The first step in navigation surgery is to set up registration arrays in both femur and tibia so that the computer can recognize the spatial three dimensional relationships of different parts of the bone. The registration arrays need to be securely anchored to the bone in a way that they will not obstruct the cutting blocks (Figure 6).

Figure 6. Registration Arrays and Cutting Blocks

Defining mechanical axes of femur and tibia

The mechanical axes of femur and tibia are defined. The center of femoral head is found by pivoting the femur around the hip joint (Figure 7). The error in determining the spatial orientation of femoral head centre can be minimized to less than 1 mm. The center of distal femur is already exposed in the surgical field and can be easily located.

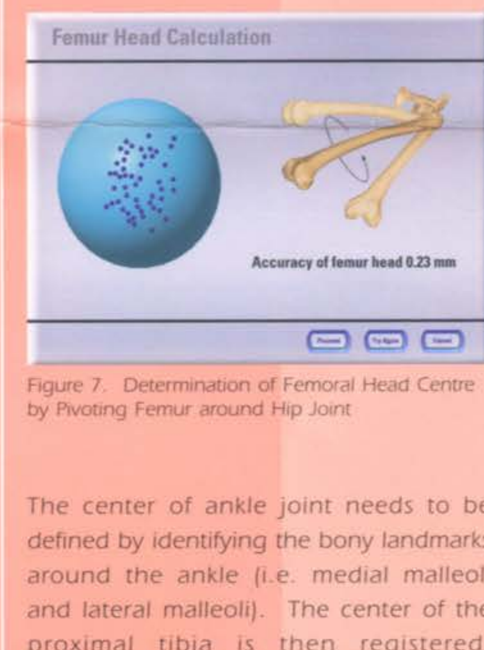

Figure 7. Determination of Femoral Head Centre by Pivoting Femur around Hip Joint

The center of ankle joint needs to be defined by identifying the bony landmarks around the ankle (i.e. medial malleoli and lateral malleoli). The center of the proximal tibia is then registered. Afterwards, the spatial orientation of these two important mechanical axes is stored in the computer.

Registration of bony landmarks

In order for the computer to determine the size and anatomical characteristics of the bones of each patient, important bony landmarks are registered (e.g. medial and lateral femoral epicondyle, anterior femoral cortex, anatomy of distal femoral condyles, anatomy of tibial plateau, tibial tuberosity, etc) (Figure 8 and Figure 9).

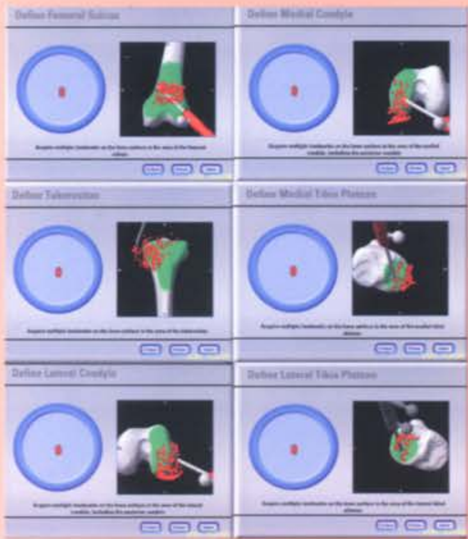

Figure 8. Registration of Bony characteristics

Figure 9. Adapting the bony characteristics to build up a Computer Model which represents the original bony anatomy

Soft tissue balancing

The amount of flexion and extension gap is found by stretching the knee joint in 0 degree flexion and 90 degrees flexion (Figure 10). The computer then calculates the most optimal combination of bone cuts (distal femoral, posterior femoral and tibial) which will produce a balanced flexion and extension gap.

Figure 10. Determining soft tissue balance of extension gap and flexion gap

Calculating Bone cuts and Size of prosthesis

The computer calculates the most suitable size and position of the prosthesis, basing on the input anatomical characteristics around knee joint (Figure 11). The position, orientation and size of the prosthesis can be fine-tuned by the surgeon to suit the need of individual patient (Figure 12).

Figure 11. Suggested Position and Size of prosthesis in the computer animated model

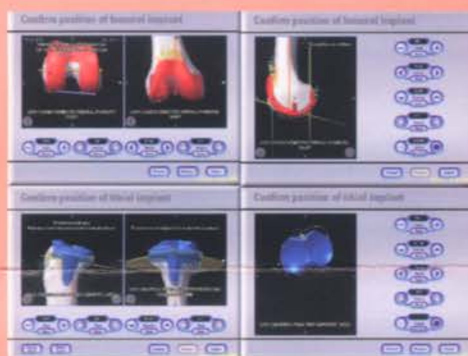

Figure 12. Fine adjustment of size, position and rotation of prosthesis

Performing bone cuts

The position of the cutting block is adjusted under computer navigation until it reaches the planned position (Figure 13 and Figure 14). Bone cut is done with the cutting block as usual. The accuracy of the cut can be verified (Figure 15). If the cut is suboptimal (e.g. due to surgeon technique), re-cut can be done under computer navigation (Figure 16).

Figure 13. Placement of cutting blocks under computer navigation

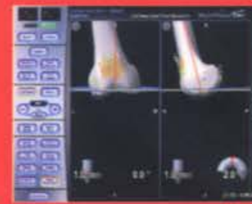

Figure 14. Performing distal femur bone cut and tibial cut under computer navigation

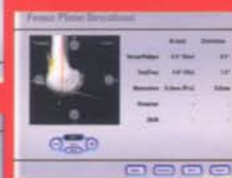

Figure 15. Verifying accuracy of bone cuts

Figure 16. Bone cuts under computer navigation

After all the bone cuts are completed, the prosthesis can be implanted as usual.

Status of Computer Navigation Surgery in Queen Mary Hospital

The first computer assisted navigation total knee replacement in Queen Mary Hospital was done in January 2003. At the present moment, research project is carried out in both cadaveric models and clinical cases to study the efficacy and accuracy of performing total knee replacement under computer navigation. A laboratory is set up in the Professorial Block of Queen Mary Hospital for this purpose. In the future, we plan to collaborate with surgeons in Mainland China and other parts of Asia Pacific in both clinical and basic research. We hope that our patients can benefit from this latest advance in technology.

Radiographic Quiz

Dr. Lisa L.S. Wong
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A 4 year-old boy sustained injury to the elbow after a fall on the outstretched hand. What are the radiological findings and the diagnosis?

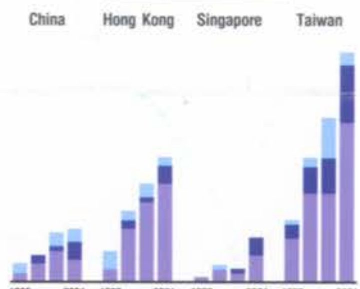
News in Flash

The Department has received new found encouragement and enthusiasm from the report published by Clinical Trials Centre, Faculty of Medicine, The University of Hong Kong. The graphs suggest the publications by the Department account for a significant portion of the international orthopaedic publications.

Orthopedics

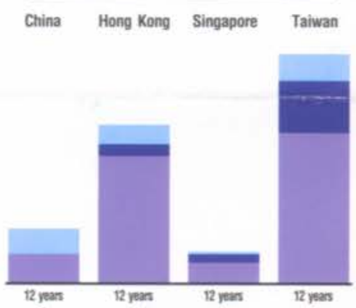
Number of full papers (with impact factor) in Medline

Three year groups



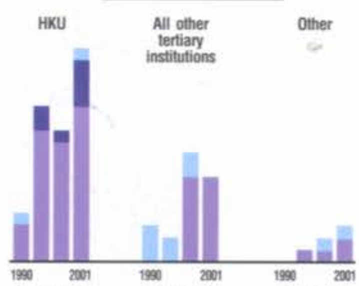
	China				Hong Kong				Singapore				Taiwan			
	1990			2001	1990			2001	1990			2001	1990			2001
Low	2	0	3	3	4	2	3	2	0	1	0	0	1	2	9	3
Good	0	2	1	4	0	2	1	4	0	0	1	4	3	6	8	13
High	2	4	7	5	3	12	18	22	1	3	2	6	10	20	20	36
Total	4	6	11	12	7	16	22	28	1	4	3	10	14	28	37	52

12 year period - 1990 to 2001



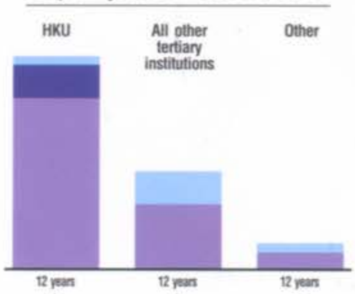
	China	Hong Kong	Singapore	Taiwan
	12 years	12 years	12 years	12 years
Low	8	11	1	15
Good	7	7	5	30
High	18	55	12	86
Total	33	73	18	131

Three year groups



	HKU				All other tertiary institutions				Other			
	1990			2001	1990			2001	1990			2001
Low	1	0	0	1	3	2	2	0	0	0	1	1
Good	0	2	1	4	0	0	0	0	0	0	0	0
High	4	11	10	13	0	0	7	7	0	1	1	2
Total	5	13	11	18	3	2	9	7	0	1	2	3

12 year period - 1990 to 2001

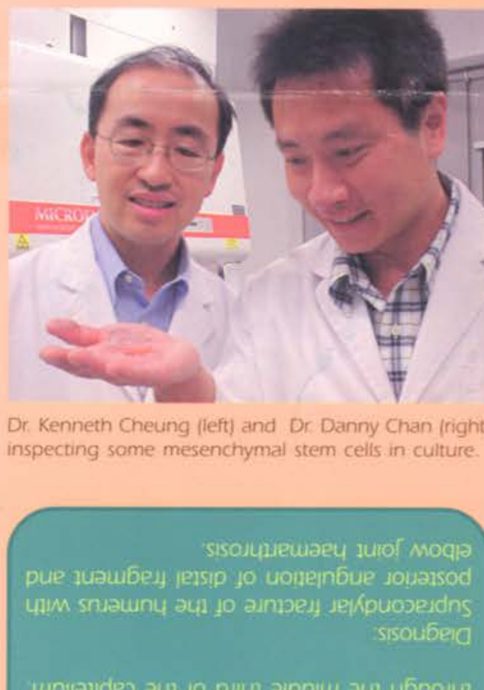


	HKU	All other tertiary institutions	Other
	12 years	12 years	12 years
Low	2	7	2
Good	7	0	0
High	37	14	4
Total	46	21	6

Orthopedics subject category. The number of Medline publications with an Impact Factor listed in the Journal Citation Reports 2000 version from 1990 to 2001 (12 year period) and for three-year groups (1990-1992, etc). The upper panel is for China, Hong Kong, Singapore and Taiwan. The lower panel is for Hong Kong institutions; The University of Hong Kong (HKU), all other tertiary institutions, and non-academic institutions or organizations (Other).

(Adapted with permission from Karlberg, J: Life Science Academic Output in Predominantly Chinese Communities 1990 to 2001 - China, Hong Kong, Singapore and Taiwan. 2003. Clinical Trials Centre, Faculty of Medicine, The University of Hong Kong.)

Congratulations to Drs Kenneth Cheung and Danny Chan, co-investigator from Department of Biochemistry, who have successfully obtained approval for allocation of Seed Grant of $0.5M from The University of Hong Kong Foundation for Educational Development and Research on their project, "Setting up of a Stem Cell Research Programme for Musculoskeletal Tissue Repair". In this year, only 9 out of 47 projects were funded by the Seed Grant.



Dr. Kenneth Cheung (left) and Dr. Danny Chan (right) inspecting some mesenchymal stem cells in culture.

Answer to Radiographic Quiz

A horizontal radiolucent fracture line is noted across the supracondylar region of the humerus on the frontal projection. Haemarthrosis is evident by elevation of the anterior and posterior fat pads of the elbow on the lateral projection. There is posterior angulation of the bony fragment with the capitellum situated posterior to the line extending from the anterior cortex of the shaft of humerus. Normally, this line will pass through the middle third of the capitellum.

Diagnosis:
Supracondylar fracture of the humerus with posterior angulation of distal fragment and elbow joint haemarthrosis.

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