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Kinematic parameter analysis and pilot clinical trial of dual-mobility semi-Knee prosthesis

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ABSTRACT

Background: To address large tumor-related defects and lower limb-length discrepancies during limb-salvage surgery in children with malignant tumors in the distal femur, a new custom-made dual-mobility semi-knee prosthesis (DMK) was made. This study aimed to provide a theory and references for further clinical applications of this prosthesis.

Methods: Based on computed tomography data from adult knee joint samples, we used Mimics/Geomagic/Pro-E software and computer numerical control milling technology to design and manufacture the DMK. An *in vitro* study was carried out to examine the related kinematic parameters in the normal knee, total knee arthroplasty and DMK groups of cadaveric specimens. Then, a pilot clinical trial was performed.

Results: The *in vitro* study revealed that the kinematics of the novel custom-made DMK are more similar to those of the normal knee than the total knee prosthesis. The pilot clinical trial showed that patients recovered well, and postoperative serial X-ray films did not demonstrate any disfigurements, loosening, dislocations or breaks in the prosthesis after a follow-up period ranging from 11 months to 5 years.

Conclusion: The DMK is a novel concept and method for the treatment of malignant tumors in the distal femur in children, and the device used for ligament reattachment provides a solution for knee ligament reconstruction. **However, DMK might be replaced by a total knee prosthesis after epiphyseal closure, because of incompatibility of tibial plateau with the prosthesis.**

1. Introduction

The number of pediatric patients with large tumor-related defects of the knee has rapidly increased. In China, the parents of children with a malignant tumor in a lower extremity traditionally refuse amputation or arthrodesis. With the development of chemotherapy, limb-salvage surgery has become a mainstream treatment and has shown favorable outcomes [1]. Knee function restoration in children involves tumor resection and maximum preservation of the growth capacity and functional integrity of the affected limb. In terms of treating a malignant tumor in the distal femur, total knee arthroplasty results in a compromised normal tibial epiphyseal plate and a severe length discrepancy in the affected limb. The use of an extendable prosthesis is a

suitable approach to relieve the limb-length discrepancy [7]; however, the medical cost of this procedure is relatively high, and realistically, the affected limb does not grow spontaneously. The problems involved with allogeneic semi-knee replacement include difficulty finding a matched donor and considerable postoperative complications, such as osteoarthritis and nonunion [2]. With the development of computer-aided technology, the fabrication of a customized semi-knee prosthesis for limb-salvage surgery has become possible, and has achieved a certain degree of clinical efficacy [4]. To a certain extent, a semi-knee prosthesis can relieve postoperative unequal limblengths; however, the results of animal experiments [4] have shown that semi-knee prostheses cause different degrees of erosion of the articular cartilage and tibial plateau after simple condylar replacement.

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After comprehensive analysis of these problems, our study first proposed the concept of a semi-knee prosthesis with dual flexion and extension (also known as a dual-mobility semi-knee prosthesis, DMK). This procedure refers to dividing the flexion of the semi-knee prosthesis into two stages with a dual-mobility mechanical structure. Normal knee flexion ranges from approximately 15°–65° during level walking [6]. The dual-mobility mechanical structure of the prosthesis is the major component responsible for frequent daily flexion. Meanwhile, the prosthesis remains in a static state in reference to the tibial plateau during flexion. When the knee flexes over a certain range (approximately 60°), the entire prosthesis begins to rotate in reference to the tibial plateau as a mechanism to reduce the erosion of the tibial plateau. The dual-mobility mechanical structure can effectively reduce friction between the prosthesis and the tibial plateau, and its kinematics are more similar to those of the normal knee than the total knee prosthesis. The dual-mobility mechanical structure can not only preserve the growth capacity of the epiphyseal plate in one side of the knee, but also effectively reduce erosion between the prosthesis and the tibial plateau.

Based on computer-aided design (CAD), rapid prototyping technology (RP) and computer numerical control (CNC) milling technology, the first-generation semi-knee prosthesis was designed and fabricated [4]. However, the first-generation semi-knee prosthesis has some limitations, especially because of the lack of an effective device for ligament reattachment. So, some improvements (Table 1) were made in the design of second-generation semi-knee prosthesis (DMK). An *in vitro* study was carried out to examine and compare the related kinematic parameters among the normal knee, total knee arthroplasty and DMK groups of cadaveric specimens. Therefore, optimization of the DMK design was achieved using CAD software; then, a pilot clinical trial was performed. This study aimed to provide theory and references for further clinical applications of the DMK in the treatment of distal femur malignant tumors in children.

2. Materials and methods

2.1. Optimization of the DMK design

Considering the poor customization of the first-generation semi-knee prosthesis and the lack of an effective device for ligament reattachment, the authors analyzed the structure and movement trajectory of the prosthesis and then designed and manufactured the second-generation semi-knee prosthesis (DMK) using Mimics/Geomagic/Pro-E software. The DMK not only maintains features of the first-generation device, such as its customizability and easy assembly, but also allows additional customization and exhibits a more sophisticated structure. The DMK consists of three components (Fig. 2): a femur-prosthesis

binding component, a customized femoral condyle component, and a shaft liner system (axis). The femur-prosthesis binding component was made of titanium alloy (Ti6Al4V). Because titanium alloy is characterized by good biocompatibility and light weight. The customized femoral condyle component and axis (The shaft liner system) were made of cobalt chromium alloy. Because cobalt chromium alloy has excellent wearing resistance besides good biocompatibility. Liner (The shaft liner system) was made of Ultra-high-molecular-weight polyethylene (UHMWPE). Because wear rate of bearing surface of metal-on-polyethylene is lower than that of metal-on-metal. Furthermore, metal-on-metal bearings actually produce a great number of debris, which has a high surface area could account for the relatively high rates of metal release into the surrounding tissues.

The length of the femur-prosthesis binding component consists of two parts (Fig. 3A): the intramedullary nail length and the femur amputation length. Bone cement could not be applied when the intramedullary nail was implanted during the operation because the femoral medullary canal of children is small. Several measures were taken to improve intramedullary nail stability in the early stage. First, the arc of the intramedullary nail was created to be similar to that of the femur. Second, the unique design of the anchorage component (Fig. 3B) in the distal intramedullary nail allowed firm prosthesis fixation. Third, the surface of the distal intramedullary nail was suitably roughened to support bone ingrowth, while that of the proximal intramedullary nail was kept smooth to facilitate future revisions (Fig. 2a). There are two rotational centers in the customized femoral condyle component, one for the prosthesis and one for the normal knee (Fig. 3C), allowing less shifting between the two rotational centers, and better knee joint function. **A simulated video of the DMK is shown in Animation 1.**

Most importantly, our study proposed the concept of a novel ligament reattachment device in the design of the DMK (Fig. 4). This concept was considered an important basis for ensuring the short- and long-term stability of the DMK after surgery. The shaft liner system (axis) is located on the lateral side of the prosthesis. Excessive extension of the DMK is restrained by the co-functionality of the anterior-inferior notching of the femur-prosthesis binding component and the anterior extension platform of the femoral condyle bionic components. Variations in the axis of motion of the DMK were controlled by the co-functionality of the posterior-inferior notching of the femur-prosthesis binding component and the posterior extension platform of the femoral condyle bionic components.

More options are available for customization of the femoral condyle, especially the patellar track. The patellar track of the bionic component and the femur-prosthesis binding component can be formed as an intact patellar track. In addition, the size of the bionic component was increased in the further design of a new ligament reattachment channel.

Table 1
Contrast of two generations semi-knee prosthesis.

	First-generation semi-knee prosthesis	Second-generation semi-knee prosthesis (DMK)
What materials made for prosthesis	Titanium alloy (Ti6Al4V)	Femur component was made of titanium alloy (Ti6Al4V). Femoral condyle component and axis were made of cobalt chromium alloy. Liner was made of UHMWPE.
Allograft	Yes. Massive distal femur allograft was implanted.	No.
Ligament reattachment device	No. Stability of the knee is by scar tissue.	Yes. Stability of the knee is by ligament reattachment device.
Femur component	Massive distal femur allograft was fixed by straight intramedullary nail and screws.	Length of femur component consists of two parts: intramedullary nail length and femur amputation length. Measures were taken to improve nail stability. First, arc of nail was similar to that of the femur. Second, unique design of anchorage component in distal nail allowed firm fixation. Third, surface of distal nail was roughened to support bone ingrowth, while that of proximal nail was kept smooth to facilitate future revision.
femoral condyle component	Inner surface of prosthesis matched outer surface of distal femur allograft. Outer surface of prosthesis matched femoral condyle.	Contour of prosthesis matched femoral condyle. There are two rotational centers, one for prosthesis and one for "normal knee". Less shifting between two rotational centers, less friction of the prosthesis will induced and better knee joint function.
Conjunction component	Cages and screws.	Shaft liner system (axis)
Profile	Fig. 1	Fig. 2

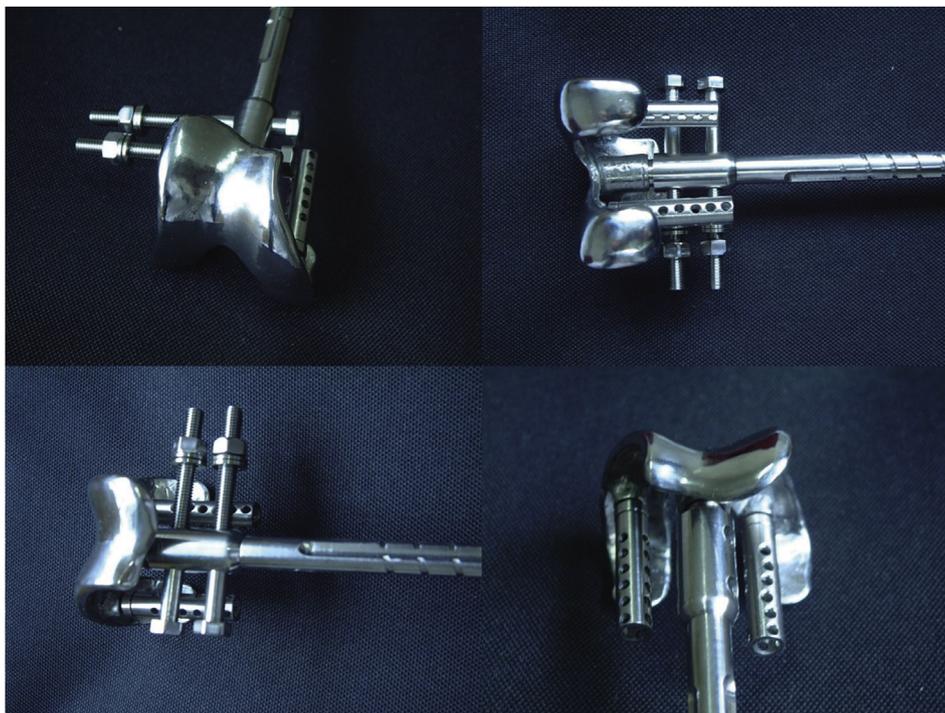


Fig. 1. Profile of first-generation semi-knee prosthesis.

For the first time, our study proposed the design principle and concept of a novel ligament reattachment channel, the opening of which corresponds to the femoral insertion of the collateral ligaments and the anterior and posterior cruciate ligaments. This ligament reattachment device solves the problem of postoperative prosthesis instability. The ligament reattachment principle is described below. Two longer artificial ligaments, the medial cruciate ligament (corresponding to the medial collateral ligament and the posterior cruciate ligament, MCL-PCL) and the lateral cruciate ligament (corresponding to the lateral collateral ligament and the anterior cruciate ligament, LCL-ACL), were used to substitute the function of the anterior and posterior cruciate ligaments and two collateral ligaments via the ligament reattachment channel. This reconstruction method can restore the ligament function of the knee to its maximum extent. In the subsequent pilot clinical trial, the easy implantation and efficacy of this ligament reattachment device were demonstrated during the operation.

2.2. Study on the movement trajectory of the DMK (in vitro)

There are two rotational centers in the DMK, one for the prosthesis

and the other one for the “normal knee”. Theoretically, rotation center of the prosthesis more approaching that of the “normal knee”, kinematics of the DMK will more similar to those of the normal knee. So, purpose of this experiment is to examine and compare kinematic parameters of DMK with normal knee and total knee prosthesis by cadaveric specimens.

2.2.1. Preparation of specimens

Six intact lower limb specimens (2 left knees and 4 right knees) dissected from adult cadavers were used in this study. All bones and soft tissue from the femoral head to the foot were preserved, and the integrity of the knee, including the joint capsule, patellar tendon and other ligaments around the joint, was maintained.

2.2.2. Experimental protocol

Computed tomography (CT) imaging data were generated with a lightspeed scanning system (Somatom Sensation 32, Siemens, Germany) adjusted for scanning from the distal femur 1/3 to proximal tibia, with a tube voltage of 120 kV and X-ray tube current of 100 mA at a voxel resolution of 512 × 512 pixel, and axial slice thickness of



Fig. 2. Composition of the dual-mobility semi-knee prosthesis (DMK).
 a. The femur-prosthesis binding component.
 b. The customized femoral condyle component.
 c. The shaft liner system (axis).

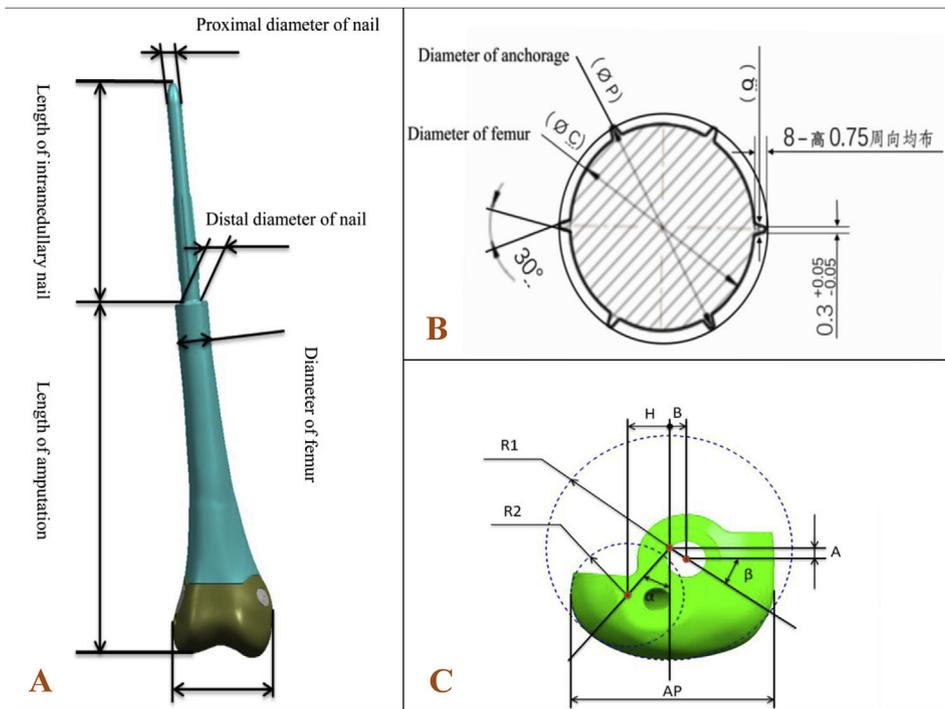


Fig. 3. Sketch and of the dual-mobility semi-knee prosthesis (DMK).

A. The length of the femur-prosthesis binding component consists of two parts: the intramedullary nail length and the femur amputation length.

B. The unique design of the cross section of the stem in the distal. Intramedullary nail allows firm prosthesis fixation.

C. R1 represents the radius of the prosthesis rotational center. R2 represents the radius of the normal knee rotational center. A and B represent the distance between the prosthesis conjunctive axis and normal knee rotational axis longitudinally and transversely, respectively.

1.0 mm. Using this system, a total of 235 slices were generated in digital imaging and communications in medicine (DICOM) format. The images were imported into MIMICS V10.01 software (Materialise, Ltd, Brussels, Belgium) and were segmented to binary stereolithography (STL) point cloud data with gray-scale density corresponding to different degrees of mineralization. After segmentation, STL data files were imported to GEOMAGIC STUDIO V 8.0 software (3D Systems, Ltd., Rock Hill, SC) to acquire nonuniform rational B-splines (NURBS) surfaces. Errors and regional burrs of the imported data were corrected, and cortical and cancellous bones were reconstructed individually to achieve accurate anatomical modeling. Output data were imported to the design modeler

(DM) module of Pro/Engineer V 3.0 software (Parametric Technology Corporation, America). A dynamic movie of one slice through the medial condyle and one slice through the lateral condyle was got by the digital subtraction X-ray machine. Imaging data were obtained according to the following sequence: the normal knee group, the DMK group and the total knee arthroplasty group, and were analyzed to identify any significant differences among the three groups.

(1) Dynamic tomography was performed to record the entire process of flexion and extension medially and laterally under non-weight-bearing conditions in the 6 dissected knees in the sagittal plane.

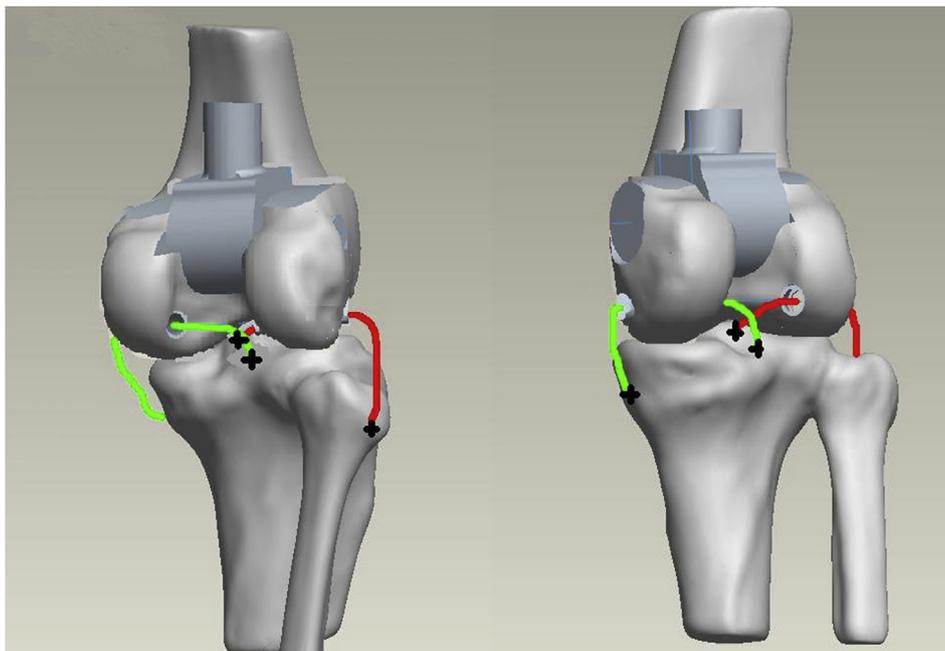


Fig. 4. Schematic diagram of the new ligament attachment system.

The green line represents the position of the medial collateral ligament-posterior cruciate ligament (MCL-PCL). The red line represents the position of the lateral collateral ligament-anterior cruciate ligament (LCL-ACL).

- (2) The DMK was implanted in six dissected knees. According to the pre-planned osteotomy plane, the femoral condyle was removed to match the inner interface of the prosthesis via necessary trimming. Then, the DMK was implanted. Dynamic tomography was performed to record the process of flexion and extension medially and laterally in the sagittal plane under non-weight-bearing conditions.
- (3) According to the size of the DMK, a same-sized total knee prosthesis (**rotation hinged tumor total knee prosthesis, LINK, Germany**) was implanted after proper osteotomy at the pre-planned plane. Dynamic tomography was performed to record the process of flexion and extension medially and laterally in the sagittal plane under non-weight-bearing conditions.
- (4) The data were exported and measured via the method described by Iwaki [3]. The articular surface superior-anterior to the femoral condyle was defined as the extension facet (EF), and that posterior to the femoral condyle was defined as the flexion facet (FF). The centers of the two spheres were respectively defined as the extension facet center (EFC) and flexion facet center (FFC). According to geometric principles, the tangent line through any point of a circle is perpendicular to the radius from the center of the circle to the point of tangency. The tangent lines at each point of the articular surface were made in a sequence. The center of the facet was determined by locating the intersections of multiple vertical lines with these tangent lines.

The distance between the posterior margin of the tibial cortex and the spherical center posterior to the femoral condyle was measured at different flexion angles. A straight line was made through the two most prominent points of the subchondral bone in the tibial plateau. Subsequently, a second straight line was made perpendicular to the former straight line through the posterior margin of the tibia. The perpendicular line from the FFC to the second straight line was defined as d1, the perpendicular line from the EFC to the second straight line was defined as d2 and the lengths of d1 and d2 were measured at different flexion angles in each experimental group. The absolute value of the changes in d1 and d2 at various knee flexion angles was determined and defined as the relative range of motion between the femoral condyle and the tibia (Fig. 5).

2.3. Pilot clinical trial

The pilot clinical trial was approved by the Ethics Committee of Xijing Hospital of Fourth Military Medical University. Written informed consent was obtained from parents, who incurred no medical costs related to the study.

Case 1. a 8-year-old girl, with no relevant family history, was admitted in November 2010 for the treatment of right distal femoral carcinoma (stage IIB, Fig. 6A and B).

Case 2. a 9-year-old girl, with no relevant family history, was admitted in November 2012 for the treatment of right distal femoral carcinoma (stage IIB, Fig. 7A and B).

Case 3. a 8-year-old girl, with no relevant family history, was admitted in November 2013 for the treatment of right distal femoral carcinoma (stage IIB, Fig. 8A and B) with pathological fracture.

Staging studies, including plain films, magnetic resonance imaging (MRI), chest CT, and full-body scintigraphy, showed no metastasis in any of these patients. The patients received neoadjuvant chemotherapy as per the existing hospital protocol. According to the laboratory examinations, limb-salvage surgery was performed between weeks 1 and 3 when the patient underwent the 4th chemotherapy session. Adjuvant chemotherapy was continued after the operation. During the operation, the lesion was exposed and widely resected, and the custom-made DMK (WEGO Joint, Beijing Weigao Yahua Artificial Joint Development Co.,Ltd.) was implanted using a non-cement-based technique (Fig. 6F).

Ligament reconstruction was performed with an Endo-button (Smith&Nephew) and a ligament reattachment channel (Johnson & Johnson). After the surgery, the affected limb was immobilized with plaster. A follow-up examination was performed to assess postoperative functional recovery.

3. Results

3.1. In vitro study

The relative ranges of motion (ROMs) between the medial and lateral femoral condyles and the tibia, and the relative rotation angles of the connecting lines between the medial and lateral femoral condyles in reference to the tibia were obtained and compared among the groups (Fig. 9A–C).

In the three groups, the shifting of the FCC within 50° of knee flexion was 0 mm and appeared toward the posterior side at 50–140° of knee flexion. Compared with the shifting (1.18 ± 0.43 mm) in the total knee arthroplasty group, the shifting (2.22 ± 0.52 mm) in the DMK group was more similar to that in the normal knee group (2.59 ± 0.43 mm). In the DMK group, the lateral condyle started rotating forward and shifting at 10° of knee flexion. The range of shifting (11.25 ± 6.19 mm) and the motion pattern in the DMK group were similar to those in the normal knee group (11.95 ± 6.62 mm). However, in the total knee arthroplasty group, the lateral condyle started rotating forward and migrating at 50° of knee flexion (1.26 ± 0.42 mm). In terms of rotational movement in the three groups, the maximum rotation angle between the femur and the tibia was $11.69 \pm 6.49^\circ$ in the DMK group, $13.17 \pm 7.58^\circ$ in the normal knee group and $5.40 \pm 1.29^\circ$ in the total knee arthroplasty group, in which the rotation was induced by the patellar track.

3.2. Pilot clinical trial

The patients performed rehabilitation exercises after removal of the plaster and were followed for 11 months (Case 1, Fig. 6C–E,G), 5 years (Case 2, Fig. 7C–F), and 4 years (Case 3, Fig. 8C–F) postoperatively. No redness or swelling of the skin, hydrops, or pains around the prosthesis was observed in any patients, and all wounds healed satisfactorily. Postoperative serial X-ray films did not demonstrate any disfigurements, loosening, dislocations breaks in the DMK, indicating that the internal fixation was effective. The patients exhibited a normal gait and reported no pain in the inferior extremity (Case 2, five years after the operation, as shown in Animation 2). The ROMs of knee extension and flexion were 0–65° and 90–100°, respectively. Passive flexion and extension were close to normal. (Table 2).

4. Discussion

4.1. In vitro experiment

In the analysis of DMK flexion parameters, the posterior cortex of the tibia served as the reference point. The changes in distance from the posterior tibial cortex to the two spherical centers (d1 or d2) were used to reveal the movement patterns of the femoral condyles. The EFC or FFC can be used to observe the rotation angle of the femoral condyles relatives to the tibia in the cross-section during knee flexion when the tibia is in a static state and to observe rotation of the femur among the groups. In this study, the average posterior shifting of the femoral medial condyle and the femoral lateral condyle from 90° to $133 \pm 9^\circ$ of knee flexion differed from the data (2 ± 2 mm and 13 ± 6 mm) reported by Nakagawa [5]. One possible reason for this difference may be related to the increased mobility of the knee due to the removal of muscle and soft tissue around the knee in this study, as well as differences in the race and individual conditions of the cadaveric samples. In

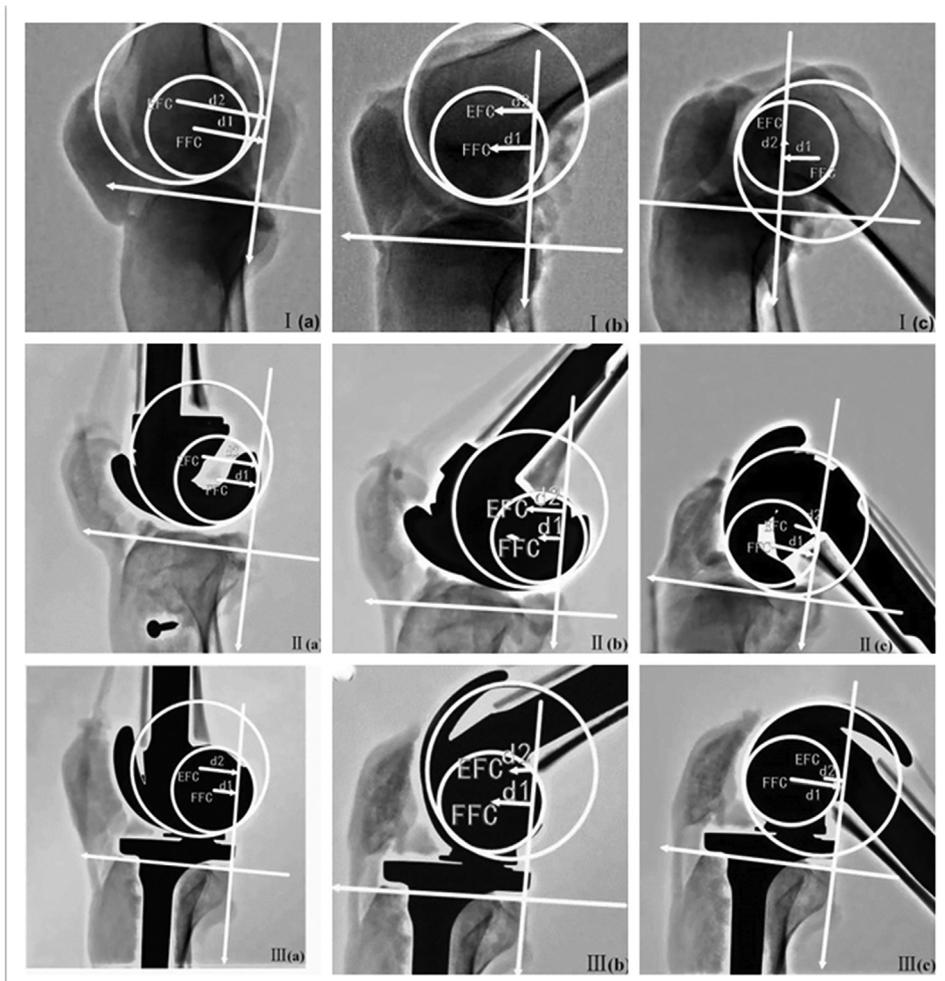


Fig. 5. Motion of each group shown by X-ray and analysis of the EFC/FFC distance.

(5) The tibial rotation angle was evaluated in reference to the medial and lateral axes of the femoral condyle. The line connecting the medial or lateral condyle to the EFC or FFC was determined to measure the rotation angle between them, which could then be converted to the relative rotation angle. d1 and d2 were marked on the diagram of the tibial cross-section in the three experimental groups at various knee flexion angles. The rotation angles of the intercondylar axis line in reference 0° were measured. A statistical analysis of the data from the 6 specimens of each group was performed to investigate the relative rotation movement between the femur and the tibia.

I(a) Normal knee in extension. I(b) Normal knee in flexion of 60°. I(c) Normal knee in deep flexion.

II(a) DMK in extension. II(b) DMK in flexion of 60°. II(c) DMK in deep flexion.

III(a) Total knee arthroplasty in extension. III(b) Total knee arthroplasty in flexion of 60°. III(c) Total knee arthroplasty in deep flexion.



Fig. 6. Pilot clinical trial, case 1.

A-B. A 8-year-old girl was admitted in November 2010 for the treatment of. Right distal femoral carcinoma (stage IIB).

C-E. Eleven months after the operation, X-ray films showed no dislocation, loosening or displacement of the prosthesis. The patient could squat down freely, suggesting excellent recovery of knee function.

F. The lesion was widely resected, and the custom-made DMK was implanted during the operation.

G. Motion of the DMK *in vivo*.



Fig. 7. Pilot clinical trial, case 2.

A-B. A 9-year-old girl was admitted in November 2012 for the treatment of right distal femoral carcinoma (stage IIB).

C-D. The lesion was widely resected, and the custom-made DMK was implanted.

E-F. Five years after the operation, the growing tibial plateau became incompatible with the DMK. Another DMK implantation may be needed for tibial epiphyseal closure.



Fig. 8. Pilot clinical trial, case 3.

A-B. A 8-year-old girl was admitted in November 2013 for the treatment of right distal femoral carcinoma (stage IIB) with pathological fracture.

C-D. The lesion was widely resected, and the custom-made DMK was implanted.

E-F. Four years after the operation, the growing tibial plateau became incompatible with the DMK. Another DMK implantation may be needed for tibial epiphyseal closure.

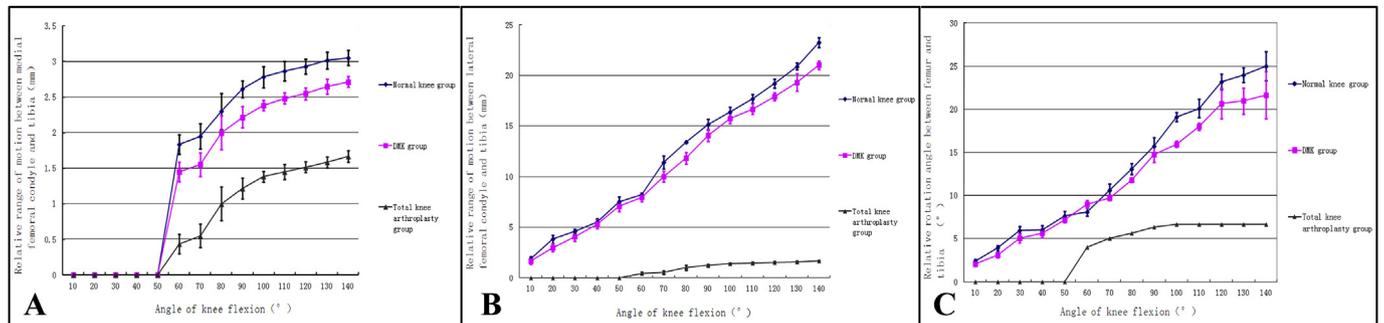


Fig. 9. *In vitro* study of the related kinematic parameters among the three groups of cadaveric specimens.

A. The relative range of motion between the medial femoral condyle and tibia in all three groups when the knee was flexed.

B. The relative range of motion between the lateral femoral condyle and tibia in all three groups when the knee was flexed.

C. The relative rotation angle between the femur and tibia in all three groups when the knee was flexed.

Table 2
Follow-up of pilot clinical trial.

Cases	How long follow-up	Complications					ROMs of knee
		Soft-tissue failure	Aseptic loosening	Structural failure	Infection	Tumor progression	
Case 1	11 months	No	No	No	No	No	Extension 0–60°, flexion 90–95°
Case 2	5 years	No	No	No	No	No	Extension 0–65°, flexion 85–100°
Case 3	4 years	No	No	No	No	No	Extension 0–65°, flexion 90–100°

addition, the imaging data may also differ, mainly due to medical imager properties and measurement errors. In this study, the data obtained before replacement in the normal knee group showed that the ROM of the femoral lateral condyle was 11.95 ± 6.62 mm, higher than that of the medial condyle, at 2.59 ± 0.43 mm. This difference causes rotation of the femoral lateral condyle around the medial condyle during knee flexion; rotation stops when the knee is completely flexed. Therefore, the knee is very stable without rotation or lateral migration.

The results of the *in vitro* study showed that the kinematics of the novel custom-made DMK are more similar to those of the normal knee than the total knee prosthesis. These results were confirmed by the key parameters described above; the ROM and rotation angle of the medial and lateral condyles in reference to the tibia in the DMK group were similar to those in the normal knee group. Moreover, the movements during flexion and rotation were simultaneously followed by rotation medially or laterally as well as varus and valgus. In contrast, the hinge knee prosthesis can only perform flexion and rotation medially and laterally due to the intrinsic hinge design and the symmetrical design of the medial and lateral condyles; its kinematics are completely different from those of the normal knee.

4.2. Pilot clinical trial

The DMK is a novel concept for a next-generation semi-knee prosthesis proposed in our study and is based on a dual-mobility hip prosthesis. In this study, the optimization of its design was evaluated, particularly to solve the problem of erosion and damage to the cartilage that occurs with conventional femoral semi-knee prostheses on the tibial plateau. Leveraging the technical features of Mimics/Geomagic/Pro-E software, we successfully designed and created the DMK. Furthermore, we designed and created two generations of the semi-knee prosthesis and added a ligament reattachment device in the second generation. Moreover, the concept of the ligament reattachment device was proposed and applied in practice for the first time. After repeated *in vitro* experiments, the key parameters were determined, and the subsequent pilot clinical trial achieved satisfactory results. This trial represents the translation of the DMK from research to clinical practice. The combination of these experiments and this clinical trial provides the complete theory of the DMK.

The DMK can preserve the tibia growth capacity as well as the function of the cartilage, increasing the short- and long-term stability of the prosthesis. However, the lack of available cases and evaluation criteria prevent comparison of this approach with other approved treatments (such as extendable prostheses) for statistical analysis. As a novel concept and treatment, the DMK presents unique advantages and potential research value. However, one limitation of the DMK is that it can affect the tibial growth (approximately 4–5 years later, Fig. 7E and F, Fig. 8E and F) after implantation because of tibial plateau growth, which leads to incompatibility with the prosthesis. Another DMK implantation may be needed before tibial epiphyseal closure, after which total knee replacement can be performed.

4.3. Wear in hinged prosthesis

The distal femur is the most common site for osteosarcoma. Rotation hinged total knee prosthesis is one of the most commonly used methods for limb salvage following surgical excision of malignant bone tumors and is accepted as a suitable method of reconstruction, giving stability, early weight-bearing and good function [8]. However, rotation hinged total knee prosthesis is associated with a greater risk of complications and subsequent operations compared to amputation. The patients endure long-term problems of wear, aseptic loosening, mechanical failure, infection and local recurrence [9]. Recent studies have suggested that aseptic loosening has replaced infection as the most frequent cause of failure. It has become evident that fine wear particles

of UHMWPE is known to be a major contributing factor to osteolysis and loosening [10]. Therefore, management of wear in the hinged prosthesis has become the major concern in endoprosthetic reconstruction in limb-salvage surgery. Unlike solution to the wear in the semi-knee prosthesis is dual-mobility mechanical structure, the solution to wear in the hinged prosthesis is bearing surface. This is the decade where engineering, material science and biology converge. Improvements in bearing surfaces including HXLPE, hard-on-hard bearings and novel combinations have reduced wear dramatically [11]. Current generations of hinged total knee prosthesis are designed to last much longer than their earlier counterparts. However, the biological reactions to debris from new bearings must be clearly understood.

5. Conclusion

In summary, this successful pilot clinical trial of the DMK demonstrates the promise of this novel method for the treatment of children with malignant tumors in the distal femur. The DMK can help orthopedic surgeons address this disease with more personalized treatments.

Development of the semi-knee prosthesis is ongoing. We have begun to design and fabricate the third-generation semi-knee prosthesis. The bionic condyle component of the DMK may swing slightly in reference to the tibial plateau during knee flexion and can cause erosion of the tibial cartilage. Some measures maybe helpful to deal with wear between prosthesis and contralateral cartilage: First, contour of femoral condyle component could match original femoral condyle very well by three-dimensional (3D) printing technology. Second, improvements in bearing surface. Some new bearings (novel biomaterial) be found for femoral condyle component to reduce erosion of the tibial cartilage. In an interesting development, the implant company Biomet Inc. (IN, USA) has teamed up with Diamicron Inc. (UT, USA) to develop a novel bearing surface in hip and knee replacements using polycrystalline diamond. This coating has the lowest coefficient of friction and is the hardest natural material known, but it is very costly and the product is currently in development and no human trials have started [12]. Third, the extent of erosion and decreases in erosion require further biomechanical testing such as friction test, especially on the wear of the cartilage, which will be useful for guiding the design of the semi-knee prosthesis. In addition, coatings in the distal intramedullary nail maybe useful for firm prosthesis fixation.

6. Conflicts of interest

None.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.suronc.2019.05.020>.

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