Total Knee Replacement Evaluation with Dynamic CINARTRO Method

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***Abstract*— Videofluoroscopy is used to evaluate the movement of the knee. The use of CINARTRO is here extended to Total Knee Replacement follow up, after incipient use in Anterior Cruciate Ligament repair. Tibial Femoral Contact Point (TFCP) migration is smaller (42%) in prosthetic knees with respect to normal knees (55%). Considering flexion-extension stages separately, the TFCP migration at full extension has a greater value (64%) than at mid extension and flexion (50% & 54%). The same behaviour is also observed for prosthetic knees, but all values reduced: a high of 50% at extension follows 37% & 41%. This can be interpreted as a prosthetic restored near-physiological behaviour.**

***Keywords*— Functional Dynamic Imaging, X Rays, Videofluoroscopy, Prosthesis, Total Knee Replacement.**

***Resumen*— La Videofluoroscopía se utiliza para evaluar el movimiento de las articulaciones, entre ellas la rodilla. La aplicación de CINARTRO se extiende a la valoración de las Prótesis Total de Rodilla a partir de su uso previo en lesiones de Ligamento Cruzado Anterior. La migración del Punto de Contacto Tibio-Femoral (PCTF) es menor (42%) en rodillas protesiadas respecto a rodillas "normales" (55%). Consideradando los movimientos de flexo-extensión en forma separada, la migración del PCTF en extensión completa tiene un valor mayor (64%) que, en extensión media y flexión, 50% y 54%, respectivamnte. Igual comportamiento se observa para las rodillas protésicas, pero todos los valores están reducidos: un valor de 50% en extensión es seguido por un 37% y un 41%. Esto puede ser interpretado como un comportamiento fisiológico restaurado cercano al normal.**

***Palabras clave*— Imágenes Funcionales Dinámicas, Rayos X, Videofluoroscopía, Prótesis, Remplazo Total de Rodilla.**

I. Introduction

Total Knee Replacement (TKR) is an effective way to treat knee arthropathies, being considered the definitive treatment for symptomatic end-stage osteoarthritis of the knee [1]. TKR is a successful treatment for most pain and dysfunction conditions in most patients [2]. The aim of this paper is to review the state of the art in TKR evaluation prior to defining current drawbacks in clinical follow up practice and finally setting original specifications for yet more precise assessment methods to be proposed. The first use of our new method, CINARTRO, is reported here giving first figures ever on TKR.

II. Clinical Assessment

Immediately after operation, the surgeon checks the wound status and the blood drainage allowing early weight bearing on cemented implants, with physical therapy help. During the first week, the patient is expected to reach 90º of active flexion. At every subsequent outpatient visit, the surgeon has to record the presence of pain, weakness or instability [3].

III. Radiographic Evaluation

A. Plain X-Rays

Radiographs of the knees (RoK) are standard in pre-surgical evaluation of candidates for TKR. Surgeons usually include weight-bearing anteroposterior (AP) and lateral radiographs of both knees to use them in surgical planning as well as to select the appropriate prosthesis size [4]. After surgery, RoK are routinely used to document the optimal appearance and position of the implant as one means of surveillance for possible complications [4].

There are no evidence-based guidelines on how an asymptomatic patient should be evaluated. Protocols for RoK monitoring are therefore surgeon-dependent and based on personal experience. This rule of thumb could lead to unnecessary imaging studies [1]. In our Country, surgeons usually ask for an immediate postoperative RoK and repeat it in the outpatient setting at 1, 3 and 6 months after surgery.

It has been questioned if there is a real need to order postoperative RoK images in an asymptomatic population. Verveli et al. found that pre-discharge RoK added no benefit nor improved on any abnormalities detection in 124 TKR patients [5]. In a series of 624 TKR patients scanned by immediate postoperative RoK, Murphy et al. found the following alterations in patients: 1 periprosthetic tibial fracture and 1 avulsion of the inferior patellar pole. Despite these findings, no treatment changes were adopted [6].

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Routine views of the knee are the AP, lateral, and tangential axial (Merchant) views. Both preoperatively and after surgery, RoK is better done in weight-bearing condition, because it accurately depicts the joint space of the TKR as well as any polyethylene wear with resultant joint space narrowing. The tibial articular surface should be parallel to the floor in a weight-bearing position. The femoral component should lie in 5-7° of valgus (inward knee displacement). The patellar button should be central and well embedded in cement. The joint-line height is drawn from the tibial tubercle to the superior surface of the tibial component on the lateral radiograph. A low joint line causes a low patella and may result in patellar component wear or patellar tendon ruptura [7].

The three-foot standing AP view of the lower extremities (i.e., the three-joint view, with the hip, knee, and ankle on the same plate) may be helpful for preoperative assessment of the anatomical and mechanical axes, and postoperatively to confirm the proper anatomical postoperative alignment of the lower extremity [8]. The alignment objective in TKR is to restore a projected AP weight-bearing axis of the lower limb. On the three-joint view, a line drawn from the centre of the femoral head to the middle of the talar body (mechanical axis) should intersect the centre of the prosthetic knee, and the femoral and tibial components should be perpendicular to this line [3]. The anatomical axis of the femur is the line along its shaft that passes through the centre of the distal femoral methaphysis. On the femur, the angle between the mechanical axis and the anatomical axis ranges from 4° to 7°. This angle is equivalent to the valgus angle set on the distal femoral cutting guide, thus achieving a distal femoral cut perpendicular to the mechanical axis of the femur (not the anatomical axis). On the tibia, its upper part is cut exactly perpendicular to its long axis [9]. Once in place, the resultant geometry of the implants should give a 4–7° valgus [7].

On the lateral view, the horizontal portion of the femoral component should be 90° ± 3° relative to the long axis of the femur. In lateral view both mechanical and anatomical axes have the same projection. The tibial plateau of the prosthesis should be horizontal or slope downwards 10° posteriorly, [2] and its position should be either central or posterior relative to the centre of the tibial shaft. The femoral part of the prosthesis has to be inserted in the right position; otherwise it can lead to excessive soft tissue tension and decreased range of motion. The prosthesis should be of the right size, because if oversized it can produce instability in flexion [10]. The tibial component should match the size of the native plateau; if it is oversized it may irritate the adjacent tissues. If undersized a high risk of collapse is to be expected [2]. The joint line (distance from the tibial tubercle to the tibial component) should be altered at most 8 mm, and the patella height (distance from the inferior edge of patellar component to the tibial articular surface) should be 10–30 mm to have good results [11]. The combined AP thickness of the patella and patellar polyethylene should not exceed that of the native patella to avoid stress on the extensor mechanism [8].

Merchant´s view of the knee is useful for assessing patella-femoral alignment, it should be performed at a standard degree of flexion, usually 30–45° [12]. This shows the prosthetic patellar disc over the middle of the trochlea (femoral groove). Rotational malalignment of the femoral and tibial components may cause excessive polyethylene wear [13] and other complications, including alteration of the foot progression angle and complications associated with the patellofemoral joint [14]. Rotational alignment of the components is best assessed on cross-sectional images (usually CT) where the necessary landmarks are clearly depicted. Femoral component rotation is measured relative to the transepicondylar axis, and tibial component rotation is measured relative to the tibial tubercle. Normal rotation for the femoral component is 0.3° ± 1.2° internal rotation for women and 3.5° ± 1.2° internal rotation for men relative to the surgical epicondylar axis. The normal rotation value for the tibial component, which corresponds to the native articular surface, is 18° ± 2.6° internal rotation from the tip of the tubercle [1]. Internal rotation of the femoral or tibial components has been shown to be associated with increased patellofemoral complications, but external rotation of the femoral component is usually well tolerated [15]. In unicompartmental arthroplasty, the tibial component should be implanted perpendicular to the long axis of the tibia in the coronal plane to facilitate implant congruence throughout the flexion-extension arc [13]. The tibial component should match the native tibial slope in the sagittal plane to protect the anterior cruciate ligament from degeneration and rupture. In general, the femoral component should be placed perpendicular to the tibial component in the coronal plane [1]. The valgus alignment on standing films should be neutral or slightly undercorrected [8].

B. Other Studies

Patients may have complaints about their prosthetic joints, including pain and other symptoms, for which no cause may be found. This is especially true in case of a TKR. In addition, not all abnormal joint replacements are associated with clear symptoms.

Aside from making regular blood tests looking for increases in white blood counts (WBC), eryhrosedimentation rate (ESR) and C reactive protein (CRP), as well as getting the antero posterior (AP) and lateral views, there is a broad scope of studies to choose from, when dealing with a symptomatic patient. Depending on each clinical case, the surgeon has to focus on the propaedeutic approach looking for possible loosening (septic or not), abnormal alignment, instability, peri-prosthetic fractures, wear, small-particle disease (granulomatous reaction) sometimes confused with tumours around the prosthesis [7].

Appropriateness criteria developed by the American College of Roentgenology (see National Guideline Clearing House) are graded from 1=least useful to 9=most useful. For possible loosening, with or without infection, RoK compared to previous RoKs is rated 9, and all other imaging studies with no previous reference as low as grade 1. For possible loosening, with or without infection, and normal RoK, a joint aspiration (with or without arthrogram) is graded 8, while all other studies have a low usefulness of only 1.

RoKs suggest loosening, but is the joint also infected? Aspiration (with or without arthrogram) is graded 9, all other studies 1. Nevertheless, these criteria are currently being re-evaluated [7]. CT and MRI are techniques that can show more accurately the relative position of the components to each other, but always in a static way. Furthermore, they are used to build preoperative templates that permit the surgeon cut the bones with the exact angles.

C. *Fluoroscopic Knee Analysis*

Despite its wide use in other therapeutic procedures, Videofluoroscopy (VFC) has been rarely taken into account for TKR patients. Due to its properties, VFC provides images of radio-opaque structures (in 2D) and their movements in real-time. This dynamic study has been used only as an experimental tool for TKR evaluation in cadaveric limbs. It shows structures but does not give any force or load measurement across the joints.

The main role for TKR kinematic studies is in Gait analysis in Human Motion Laboratories. Skin markers give the clinician accurate joint assessment; however, soft tissues around the joints and skin movement could lead to wrong data capture, especially in obese subjects. To further evaluate both the intact joint and TKR, VFC is a dynamic view consisting of a series of images taken during the natural movement of the knee. The silhouette of a specific prosthesis (with a known size and shape) is easily mapped on the images. This can give accurate and unbiased estimations of the relative bone movements under load [16].

We have developed a new methodology, called CINARTRO, to evaluate knee kinematics [17]. This is performed by identifying anatomical landmarks on serial RoKs. Standard tasks are stair climbing and walking downstairs as well as flexion & extension in open chain. CINARTRO was found to be useful in measuring the active movements of the knees in patients who underwent surgical reconstruction of the anterior cruciate ligament (ACL) [18].

IV. Methods

CINARTRO was used to evaluate TKR patients for the first time, after securing Ethics Committee approval of the “Hospital de Clínicas”. The patient (male, 70 years old) gave his informed consent and had no known co-morbidities. His TKR was successfully implanted in 2012, allowing a normal life including amateur cycling. The patient was instructed to climb up a stair using the knee with TKR, close to the C-arm so as to be recorded by VFC. Figure 1 depicts the patient as his movement in open chain reaches full extension. VFC sequences were fragmented into 30 images, evenly distributed over the 2 seconds extension movement [19]. Figure 2 shows one of the 30 images with the points marked by the operator. The information of both segments (straight line for tibial plateau and three-points curve for the femoral condyle profile) is used to determine the Tibio-Femoral Contact Point (TFCP), according to the Baltzopoulos method [20]. Additionally the distance between the TFCP and the quadriceps ligament, defined by the patella and the tibial tuberosity, is calculated by CINARTRO [21] for every available flexion angle and is known as the Moment Arm (MA).

Fig. 1 Patient with Total Knee Replacement (TKR) during CINARTRO Videofluoroscopic procedure to evaluate dynamic functional knee parametre in open chain, i.e. under n.

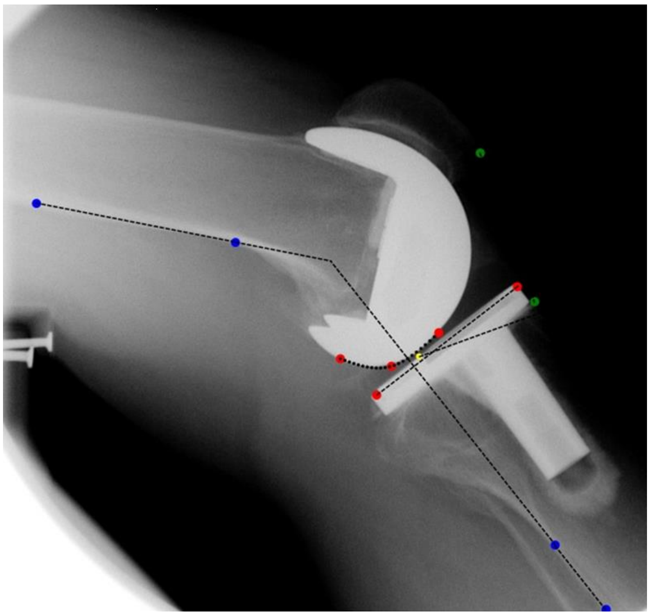

Fig. 2 Anatomical points marked by the user with CINARTRO. The line between patella an anterior tuberosity identifies the quadriceps ligament.

V. Results

Table 1 shows the first results we obtained on a TKR with CINARTRO equipment. The comparison is made with respect to mean values of normal knees. The migration of the TFCP is given for four different knee flexion angles. In the same Table, MA values are also given for the same angles.

TABLE 1
TIBIOFEMORAL CONTACT POINT
AND QUADRICEPS MOMENT ARM.

	Patient Condition	Position of leg			
		90º Hanging leg	**45º ± 8º**	**22º ± 9º**	**0 º Fully ext.**
*TFCP (%)	Normal	**50**	**52**	**54**	**67**
	TKR	**40**	**37**	**41**	**50**
**Moment Arm (mm)	Normal	**39**	**45**	**43**	**44**
	TKR	**35**	**35**	**32**	**30**

* TFCP: Migration of Tibiofemoral Contact Point (%) with respect to tibial plateau from back to front in sagittal plane.

** MA: Moment Arm of ligament Quadriceps (mm) as distance from TFCP to the line between patella and tuberosity.

VI. Discussion and Conclusions

We have used CINARTRO to study TKR for the first time, which widens the clinical usefulness of the method and the instrument after its validated results with reconstructed ACL follow-up. [18, 21] As could be expected, we find here that the TFCP migration is smaller for TKR with respect to normal knees. A mean TFCP migration of 55% for normal knees is reduced to 42% for a TKR (Table I). Similar to previous comparisons of normal knees to reconstructed ACL joints, [19] the last TFCP position in extension shows a greater value (64%) than at previous angles (50% to 54%), as shown in Table I. The same behaviour is observed for the TKR, but all values reduced: a high value of 50% at extension follows 37% to 41% TFCP positions with respect to the back end of the Tibial Plateau. This can be interpreted as a near-physiological behaviour, of TKR knees as a result of the mechanical design of the implant, because the laxity of the joint is greater at full extension than during the active movement. This first results will allow to design a follow up protocol for TKR patients giving dynamic and objective functional information to surgeons and physiotherapists alike.

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