Total knee replacement (TKR) is now recognized as a viable surgical option for managing dogs with severe to end-stage stifle joint osteoarthritis. The goal of this presentation is to briefly review the biomechanics of the normal stifle joint and to describe how this information has been used to guide the design and manufacture of contemporary TKR implants. The influence of implant design, surgical technique and post-operative care on TKR function and survival will also be discussed, with particular reference to the critical issue of mechanical wear of the articular surfaces and disruption of the cement–bone or implant-bone interface.

Normal Knee Kinematics

The motions of the normal knee have been described extensively using both goniometry and two- or three-dimensional kinematic data collected from gait analysis. Passive range of motion in the Labrador stifle joint has been reported to be from 162 degrees in full extension to 42 degrees in full flexion. During normal walking, the femorotibial angle varies from 155 degrees at paw-strike to 135 degrees at the end of the stance phase and 90 degrees in the mid-swing phase. At the trot, the total sagittal plane angular excursion is around 60-75 degrees. Rotations in the intact stifle are reported to range from 8 degrees of external rotation to 5 degrees of internal rotation during the swing phase and from 2 degrees of external rotation to 2 degrees of internal rotation during the stance phase.

Design of Total Knee Replacement (TKR) Implants

Current canine TKR implants are manufactured from materials that have been shown to perform well in human TKR. For a modern condylar-style TKR implant, this means a femoral component fabricated from cobalt-chromium or titanium alloy, mated with a tibial bearing made from ultra-high molecular weight polyethylene (UHMWPE). In human TKR the trend is towards using a metal baseplate to reinforce the underside of the UHMWPE bearing, the rationale being that the metal backing will reduce the distortion of the UHMWPE implant under load. However, there is a long and very successful history of one-piece (monobloc) UHMWPE as the tibial component in human TKR. Of the two commercial canine TKR systems that are currently available, the BioMedtrix system uses a monobloc UHMWPE tibial component while the GenuSys knee (INNOPLANT Medizintechnik) uses a UHMWPE sitting within a titanium nitride-coated cobalt chromium alloy tibial tray. There are currently no long-term data to compare the performance of these two implants, although this will clearly be a topic of great interest as the field evolves.

The design of contemporary TKR implants is based on the goal of restoring normal motions of the knee, especially flexion-extension and internal-external rotation, while resisting varus-valgus angulation and cranial-caudal translation. Flexion-extension is controlled by the sagittal plane geometries of the femoral component and the UHMWPE tibial component. The femoral component incorporates two distinct radii of curvature, with a larger radius that captures the curvature of the patellofemoral joint, and a smaller radius that is based on the center of
rotation of the femoral condyle. When the two radii are combined into a fused curvature, the result is a smooth articulation that remains stable throughout the flexion-extension excursion.

The medial and lateral femoral condyles have the same radii of curvature in the sagittal plane and the current canineTKR implants have a symmetrical femoral trochlea so that one implant can be used for left or right femora. The trochlea is typically symmetrical and relatively deep in order to reduce the risk of patellar subluxation during flexion-extension. Use of an incorrect size of femoral component results in either instability (if the femoral component is too small) or excessive tightness and reduced flexion (if the femoral component is too large).

Rotational constraint within a condylar TKR is also determined by the geometry of the implants. The BioMedtrix canine TKR implant is designed to allow -15 to +15 degrees of rotation in order to provide normal or near-normal rotation during the stance and swing phases. Similar data are not currently available for the GenuSys knee.

Patellofemoral tracking is a significant issue in human TKR and a concern in canine TKR, especially in light of the significant variations in distal femoral geometry that are evident in dogs. The normal canine femoral trochlea is asymmetric in the transverse plane but the trochlea on the femoral component is usually symmetric. Even with selection of the correct size of implant, errors in positioning can profoundly influence patellofemoral tracking. Although the prosthetic trochlea is relatively deep as compared with the natural trochlea, rotational malalignment of the femoral component increases the risk of patellar luxation, while varus-valgus misalignment results in patellar maltracking and instability in extension due to an asymmetric extension gap. It is critically important to assess patellar tracking at the time of surgery so that any problems can be identified and resolved. If there is mild patellar instability, it may be sufficient to imbricate the joint capsule, but more significant instability may necessitate re-cutting of the femur in order to restore optimal alignment of the trochlea and extensor mechanism.

**Load Transfer across the Stifle**

Although a significant amount is known about the ground reaction forces in the canine hind limb under activities of daily living, detailed information regarding the specifics of load transfer across the femorotibial joint are not currently available. In humans, the medial compartment of the knee carries 60% of the load. Cadaveric studies on stifle joint loading in dogs have typically used medial:lateral loading ratios of either 50:50 or 60:40. Direct measurements of the loads seen in each compartment during *in-vivo* stifle function have not been obtained from dogs, although the technical approach to doing so (using thin-film sensors or miniaturized load cells) is feasible in dogs. Mathematical models of the stifle joint indicate that the femorotibial articulation carries a load of 2 x body weight at the end of the stance phase and the figures will be even higher for dogs undergoing high flexion and high impact activities such as running, jumping and climbing/descending stairs.

**Implant Stability and the Issue of Constraint**

The majority of dogs presenting for TKR surgery have experienced rupture of the cranial cruciate ligament (CrCL). The mechanical consequences of CrCL rupture have been studied and described extensively and will not be restated here. During TKR surgery, both the cranial and caudal cruciate ligaments are excised, along with the menisci. It should therefore be evident that stability of the stifle joint is significantly compromised when TKR is performed. Following TKR, stability of the stifle joint is determined by the inherent stability of the “new” joint,
consisting of the articulating TKR implant and the surrounding ligaments (medial and lateral collateral ligaments) and soft tissues (patellar tendon, popliteal tendon and joint capsule). The relative contributions of the implant and the periarticular soft tissue to knee stability vary according to knee design, and are best described in terms of degrees of constraint.

Early human TKR designs focused on recreating the hinge (ginglymus) function of the joint using a constrained linked implant. These implants had poor long-term survival (only 65% at 5-6 years) as a result of complications such as loosening, infection and fracture. The fixed hinge allowed flexion-extension but prevented varus-valgus tilt, internal-external rotation and axial joint distraction. Loads applied to the implant therefore resulted in high stresses through the hinge joint and increased load transfer across the interfaces between the implant, cement and bone, resulting in loss of implant fixation. More recently, rotating hinge implants have been introduced to overcome the limitations of the earlier fixed hinged designs. In humans, these implants are used in patients with significant bone or soft tissue deficits secondary to aseptic or septic loosening, trauma or neoplasia. In the veterinary arena, there have now been a limited number of reports on the use of custom fixed and rotating hinge designs in the management of dogs with stifle joint derangement and primary bone neoplasms.

Constrained, unlinked condylar TKR implants have been used in humans but have yet to find an application in canine TKR. In these implants, a central spine made of UHMWPE projects up from the tibial component and engages within the intercondylar region of the femoral component. Varus-valgus and anterior-posterior movements are constrained by contact between the plastic eminence and its enclosure. In humans, concerns remain over the potential for wear debris generation secondary to mechanical wear of the UHMWPE spine.

The commercial canine TKR implants that are currently available incorporate a semi-constrained design in which the radius of curvature of the concavity in the UHMWPE tibial components is slightly larger than that of the femoral counterface in both the sagittal plane and the frontal plane, resulting in an articulation that allows for some degree of stifle joint rotation, especially in flexion. The sloped cranial-caudal and medial-lateral contours of the tibial concavities reduce the ability of the femoral component to translate out of the articulation.

Effects of Implant Malalignment

Load transfer through the femorotibial articulation occurs through regions of contact between the femoral and tibial components. As is the case in the natural stifle, the location of these pressures varies with motion of the joint. In high flexion, there is relatively less femorotibial contact but the load transfer is high, leading to high contact pressures. In humans, high contact pressures have been linked to mechanical wear of the UHMWPE bearing surface, particularly when the UHMWPE component is thin. In humans, thick UHMWPE implants are used to try to mitigate the adverse effects of contact pressures but in dogs there is a physical limit to the thickness of the UHMWPE that can be introduced into a joint. It remains to be seen whether contact pressures are an issue in canine TKR and the answer will require retrieval studies to quantify and map implant wear in explanted canine TKR implants. However, malalignment of the femoral and/or tibial components will result in increases in contact pressure that risk the integrity of both the articular surface (through wear) and the interface between implant and bone (or cement and bone). Clinical studies in humans show that varus-valgus malalignment is an important predictor of long-term success of TKR implants and one anticipates that a similar relationship will be confirmed in dogs.
The Importance of Wear

An exhaustive review of the importance of wear as a cause of implant failure is beyond the scope of this proceedings article but it is critical to understand that mechanical wear of the articular surfaces of any total joint implant leads to the release of particulate wear debris that has the potential to incite inflammatory changes in periarticular bone and soft tissues\(^{11}\). In a recent study on a series of well-functioning canine TKR implants we identified evidence of several different forms of wear on the UHMWPE implant, but in no case was the wear of a severe nature\(^{12}\). However, these implants were retrieved at time points of up to 12 months and additional, longer-term retrieval studies will be needed to determine the significance of wear in canine TKR. If wear is suspected, removal and replacement of the tibial component can be considered, although this is technically easier with a metal-backed tibial component as it only involves removal and replacement of the UHMWPE liner, rather than complete explantation of a cemented monobloc tibial component.

References