Advances in Small Animal Total Joint Replacement

1 The History of Joint Replacement in Veterinary Surgery

Mariana Quina and Jeffrey N. Peck

Total joint replacement has gained an important place in veterinary orthopedic surgery. There are currently commercially available prosthetic components and instrumentation for canine and feline total hip replacement, canine total elbow replacement, and canine total knee replacement. Although many different implant systems have been developed for experimental use, descriptions of the implants in this chapter are limited to the commercially available systems.

Total hip replacement

Total hip replacement became commercially available in the dog in 1974 (Hoefle 1974). The implant system used was a cemented, fixed-head, stainless steel femoral component and polyethylene acetabular cup that was available in three sizes (Richards Manufacturing, Memphis, TN; Figure 1.1). The Richards II canine total hip prosthesis was the only commercially available canine system until 1990. Design modifications to the implants were made in the late 1970s in order to decrease the tendency for luxation, provide more consistent placement of the acetabular component, and reduce the possibility of damage to the femoral component during preparation of the femur. These changes included a 20-degree cutaway on the dorsal aspect of the acetabular component, establishment of a guide system for placement of the acetabular component, several minor changes to the femoral component design, and introduction of a femoral component trial prosthesis to be used during preparation of the femur.

In 1979, Leighton reported on the use of the Richards II system in nine experimental dogs. Each of the three available sizes of prostheses was implanted in three dogs each. Of the nine dogs, there was one failure due to infection resulting in acetabular component loosening. The remaining eight dogs reportedly had good or excellent function 1 year after surgery. Use of the Richards II system was reported in a clinical setting with good success (Lewis and Jones 1980; Olmstead et al. 1983). Lewis and Jones performed 20 total hip replacements in 15 dogs and reported the results with a minimum of 1-year follow-up. The most common complication was loosening of the acetabular component, the femoral component, or both. Causes of aseptic loosening were not clearly identified or understood at the time of the Lewis

Advances in Small Animal Total Joint Replacement, First Edition. Edited by Jeffrey N. Peck and Denis J. Marcellin-Little.

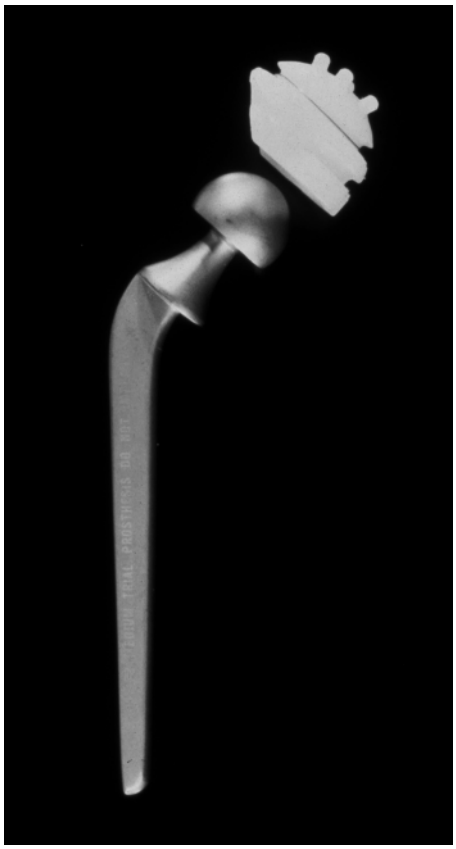

Figure 1.1 The Richards II canine total hip prosthesis. (Image courtesy of David DeYoung)

publication. Contributing factors to implant loosening that were identified included infection, inadequate preparation of the bone prior to cement placement, undersizing of implants, and improper positioning of the implants. Other complications included failure of the femoral component via bending or breakage at the stem–neck angle and luxation. Only six of the hips did not have postoperative complications. Four of the 20 hips were eventually explanted. Of the remaining 16, 75% were considered to have excellent outcome.

Olmstead et al. (1983) reviewed 221 total hip replacements over a 5-year period. Follow-up information was available for 216 of the cases. The minimum follow-up period for inclusion in the study was 4 weeks, and of the 149 hips that were not lost to follow-up at study completion, none had an evaluation period shorter than 25 weeks. At the final evaluation, 91% were reported to have satisfactory function, with owners reporting increased activity levels, improved muscle mass, and elimination of pain. Of the dogs with bilateral hip dysplasia, unilateral hip replacement resulted in enough improvement in clinical signs that surgery on the contralateral side was not deemed necessary for 80% of dogs. Complications included luxation, infection, aseptic loosening of the acetabular component, femoral fracture, and sciatic neurapraxia. The overall complication rate was 20%, with 58% of cases with complications eventually achieving a satisfactory outcome. Evaluation of follow-up radiographs, as well as what constituted a satisfactory outcome, was not discussed.

In June 1990, the BioMedtrix CFX® system (BioMedtrix, Boonton, NJ), a modular cemented total hip prosthesis and instrumentation set, was introduced (Olmstead 1995). The most significant change in this modular system compared with the fixed-head system was the introduction of a two-piece femoral component. The femoral component consists of a stem and a head secured together via a locking taper mechanism. This change allowed for three different neck lengths for each stem. The original CFX femoral stem was made of titanium alloy (TiAlVn) and was available in five sizes. The head was made of cobalt-chrome and available in three sizes. New instrumentation was also introduced, including power reaming of the femur and acetabulum to increase accuracy and the ease of the procedure. Olmstead (1995) reported preliminary clinical results for 52 total hip replacements using this system. Follow-up ranged from 2 months to 15 months (mean: 6 months) and consisted of owner questionnaires regarding the dogs' function following total hip replacement. Only two complications were reported, one luxation and one iatrogenic intrapelvic hematoma causing urethral compression, both of which were resolved successfully with additional surgical intervention. In 2004, Liska reported on 730 consecutive hip replacements using the BioMedtrix CFX system, with a mean follow-up of 3.9 years.[1] Complications included both craniodorsal and ventral luxation, infection, aseptic loosening, femur fracture, sciatic neuropraxia, pulmonary embolism, incision granuloma, extraosseous cement granuloma, medullary infarction, and osteosarcoma. The procedure was considered successful in 96% of cases. The Liska study included the most comprehensive

description of outcome and complications to date. While several of these complications had been described in case reports (Roe et al. 1996; Marcellin-Little et al. 1999a,b; Sebestyen et al. 2000; Bergh et al. 2006), this large study was the most comprehensive to date and it allowed a direct comparison of the rate of all complications. The BioMedtrix CFX system is discussed in detail in Chapter 7.

The original total hip replacement femoral implants were made of stainless steel. Newer generations of femoral implants were made of titanium alloy. Titanium is resistant to corrosion and is highly biocompatible, making it an attractive material for surgical implants. However, under certain conditions, particularly when used as a cemented stem, titanium alloys are more susceptible to severe abrasive corrosive wear than stainless steel or cobalt-chrome alloys (Agins et al. 1988). This is primarily associated with the elastic modulus mismatch between cement and titanium and the proclivity of titanium alloys to generate wear debris under such condition (see Chapters 3 and 6). Lee et al. (1992) found an unusually large amount of metal debris in the tissues around titanium alloy prostheses showing early failure as well as larger polyethylene particles in tissues from failed titanium alloy than from cobalt-chrome or stainless steel prostheses. These particles lead to wear debris, which stimulates macrophage recruitment and cytokine release and result in bone resorption and, therefore, aseptic loosening (Goldring et al. 1983).

Uncemented total hip replacement techniques have been developed to avoid the use of cement, which, despite improvements in cementing techniques, continues to be implicated in irreversible infections and aseptic loosening (DeYoung et al. 1992; Marcellin-Little et al. 1999b). Skurla et al. (2005) investigated aseptic loosening in 38 total hip replacements from 29 client-owned dogs. The duration of implantation ranged from 8 months to over 11 years and all were postmortem retrieval specimens. Nine of the femoral components were grossly loose and 15 were mechanically loose, for a total of 63.2% loose implants. Stem loosening occurred more commonly at the cement–implant interface than at the cement–bone interface. No significant difference was found in loosening rates for implants retrieved in the short term (defined as less than 3 years) and in the long term. Edwards et al. (1997) also reviewed aseptic loosening in 11 total hip replacements in 10 dogs. Loosening of the femoral component occurred at the cement–implant interface at a mean of 30 months postoperatively. Radiographic changes associated with aseptic loosening included asymmetrical periosteal reaction along the femoral diaphysis, radiolucent zone at the stem–cement interface, altered implant position, and femur fracture. They found that aseptic loosening was significantly more common when the distal tip of the femoral component was in contact with the cortical endosteum than when there was no contact.

The clinical use of the PCA Canine Total Hip system (Howmedica, Mahwah, NJ) was reported, but was not commercially produced for the veterinary market (DeYoung et al. 1992; Marcellin-Little et al. 1999a). However, the PCA system is considered the predecessor for the BioMedtrix BFX® system. DeYoung et al. (1992) described the PCA implant design as well as the surgical technique for implantation. The femoral component of this system was available in four sizes, each made of cast cobalt-chromium alloy with porous coating at the proximal one-third of the stem. The modular femoral head allowed for two different femoral neck lengths and to be used interchangeably with the stems and acetabular components. The acetabular component was a cast cobalt-chromium alloy with a backing of three layers of beads and an ultrahigh-molecular-weight polyethylene insert. Two polyethylene insert depths were also available. Both the acetabular and femoral components were a press-fit with long-term stability imparted by porous bone ingrowth. A preliminary study was done on 60 experimental hips followed by 40 clinically affected hips in 32 client-owned dogs. The overall success rate for the 100 total hips was 98%. There were six complications including three luxations, two fissure fractures of the femur, and one displacement of the acetabular component due to improper positioning. Only two of the hips were eventually explanted. Marcellin-Little et al. (1999b) reported on 50 consecutive total hip replacements in 41 dogs. Mean long-term follow-up was 63 months. Radiographically, all cups and stems had bone ingrowth fixation and no evidence of osteolysis, late stem subsidence, or cup tilting. At the long-term follow-up, 74% of hips had normal function. Of those with abnormal function,

three had luxations and the remainder had unrelated problems causing abnormal hind limb gait.

The Zurich Cementless Total Hip Replacement system (Kyon, Zurich, Switzerland) has been available since the late 1990s (Guerrero and Montavon 2009). In this system, the femoral components are made of titanium and titanium alloy and the acetabular component is lined with ultrahigh-molecular-weight polyethylene. The femoral stem in this system is anchored to the medial cortex of the femur with locking screws. This design is intended to decrease complications resulting from subsidence, as well as micromotion at the bone–implant interface. Stress shielding of the bone is also meant to be minimized.[2] This prosthesis is discussed in detail in Chapter 7. The BioMedtrix BFX system is an uncemented total hip replacement system designed to be interchangeable with the BioMedtrix CFX system. It was commercially introduced in 2003. The femoral and acetabular components of the BFX system are press-fit and designed to allow porous ingrowth for long-term stability. This prosthesis is discussed in detail in Chapter 7.

The dog has been used as a model for human total hip replacement for decades. Total hip replacement in the dog as a model for the development of a prosthesis for human use was first reported in 1957 (Gorman 1957). Gorman implanted a cementless, stainless steel prosthesis in over 50 dogs. The acetabular component was stabilized using three toggle bolts and the femoral component was simply inserted into the femoral canal without fixation, although the first-generation stem was transfixed to the medullary canal (Figure 1.2). The femoral head was retained within the acetabular component by a retaining rim to prevent luxation. The author reported generally positive results.

Chen et al. (1983) performed total hip replacement in 13 dogs. The cementless femoral component was square in cross section and with a titanium core and a 2-mm outer layer of unalloyed 50% fiber titanium composite. Seven dogs were implanted with a cementless acetabular component of ultrahigh-molecular-weight polyethylene and a cylindrical outer surface, coated with unalloyed titanium fiber. The remaining six dogs were implanted with cemented acetabular components. Bone ingrowth occurred in all porous-coated implants; however, no mechanical testing was performed in this study to evaluate the strength characteristics of the implants. All of the animals walked without functional deficits and all femoral stems and acetabular cups were stable at 6 months postoperatively.

Figure 1.2 The Gorman total hip prosthesis was used in canine patients as a model for human total hip replacement. (Image courtesy of David DeYoung)

Gitelis et al. (1982) studied the effects of weight bearing on the bone–cement interface in cemented total hip replacements in two groups of six dogs. A cobalt-chrome femoral component and ultrahigh–molecular-weight polyethylene acetabular component were implanted using acrylic cement. In one group, immediate weight bearing with unrestricted activity was allowed, while in the second group amputation distal to the knee was performed in order to prevent weight bearing. Three of the dogs in the weight-bearing group had postoperative luxation. These dogs were eliminated from the study and replaced with three new

dogs. Endosteal bone remodeling with a fibrous membrane located between the endosteal surface of the bone and cement was found in both weight-bearing and nonweight-bearing dogs. The study found that early postoperative weight bearing was not a factor in bone remodeling at the bone–cement interface and surrounding bone.

Dowd et al. (1995) investigated the role of implant motion, titanium alloy, cobalt-chrome alloy, and polyethylene particles in the process of osteolysis and aseptic loosening. Forty dogs had total hip replacements and were assigned to the control group or one of five experimental groups. The control group had a standard prosthesis implanted. The prosthesis was modified for the experimental groups to create a motion model, a gap model, and three particulate debris models (a titanium model, a cobalt-chrome model, and a high-density polyethylene model). Two dogs had intraoperative femur fracture during implantation and were excluded from the study. One dog had a postoperative luxation, underwent open reduction, and remained in the study. All dogs had a clinically normal gait by 2 weeks after surgery. After 12 weeks, the femurs were harvested. All control implants were stable with no obvious motion between the implant and bone. All of the experimental implants had some degree of motion and the femoral prosthesis was easily separated from the femur. Histological and biochemical assessment of the periprosthetic tissues from the control group had relatively acellular periprosthetic tissue with low levels of biochemical activity. In contrast, assessment of the motion group as well as all three particulate debris groups showed increased numbers of macrophages as well as increased levels of biochemical mediators of bone resorption consistent with osteolysis.

Among the most interesting uses of the canine model for human total hip replacement was the use of Robodoc, an industrial robot adapted for used in surgery (Paul et al. 1992). The purpose of this study was to determine whether robotic preparation of the femoral canal would result in improved implant–bone contact and fewer intraoperative cracks or fissures compared to hand broaching for a cementless total hip prosthesis. The clinical portion of this study included 25 canine patients with robotic femoral canal preparation and 15 patients with manual femoral canal preparation. Robotic preparation resulted in a higher implant–bone contact than manual preparation and resulted in no fissures or cracks.

Total elbow replacement

The first clinical case of total elbow replacement in small animals was reported in 1964 (Whittick et al. 1964). A custom-manufactured, hinged, constrained stainless steel prosthesis was implanted in a cat with comminuted fractures of the distal humerus and proximal radius and ulna. Due to inherent constraints of the implant design the cat had limited range of motion of the elbow postoperatively, but the results were considered acceptable. Three months postoperatively, the cat was estimated to use its leg at 80% of normal function and was able to resume its normal activities, including running and climbing trees.

Unlike total hip replacement and total knee replacement, there is no comparable human model for elbow osteoarthritis in dogs. In addition, the elbow presents the additional challenge of being a three-bone joint, with the inherent risks this poses to implant loosening. Nevertheless, the high incidence of end-stage elbow osteoarthritis in dogs with relatively few treatment options has encouraged several groups to work toward total or partial elbow (unicompartmental) replacement.

Since the late 1990s, a constrained hinged system, a four-component nonconstrained system, and a semiconstrained system have been designed, tested, and abandoned prior to publishing any results due to high complication rates (see Chapters 11 and 12; Conzemius 2009). The TATE Total Elbow (BioMedtrix) consists of a preassembled, prealigned combined humeral and radioulnar implant. Preliminary trials using the TATE Total Elbow were reported by Acker and Van Der Meulen in 2008. The system was implanted in six client-owned dogs with elbow pain secondary to end-stage osteoarthritis.[3] Complications included an epicondylar fracture with pin migration, ulnar nerve transection, and implant malpositioning with a humeral crack. At the time of the report, none of the dogs had required explantation. The TATE prosthesis is discussed in detail in Chapter 12.

The BioMedtrix (Iowa State) Canine Elbow has been used clinically for more than 10 years. Conzemius and colleagues initially reported on its use in six normal dogs in 1998 and again in 2001. The 1998 prototype system was a cemented snap-fit semiconstrained system that yielded suboptimal results, with loosening of the radioulnar component in five of six dogs (Conzemius and Aper 1998). The system was modified to an unconstrained, cemented, two-component system consisting of a stainless steel humeral component and an ultrahigh-molecular-weight polyethylene radioulnar component (Conzemius et al. 2001). Three of six dogs in the later report had excellent results, with normal use of the operated limb 1 year after surgery (Conzemius 2009). Modifications to the BioMedtrix elbow were made based on these results, and the system was implanted in 20 client-owned dogs with severe radiographic elbow osteoarthritis and daily lameness from elbow pain unresponsive to medical management (Conzemius et al. 2003). The revised system was still an unconstrained, cemented, two-component system made from the same materials as previously. This system and its current (third-generation) design are described in detail in Chapter 12.

Total knee replacement

Dogs have been used as preclinical models for human total knee replacement for over 30 years (Bobyn et al. 1982; Turner et al. 1989; Sumner et al. 1994; Allen et al. 2009). Bobyn et al. (1982) investigated biological fixation in a canine total knee prosthesis in six beagle dogs. A custom-designed, unconstrained prosthesis with a wide bearing surface and a single radius of curvature was selected in order to facilitate fabrication and surgical implantation. The cobalt alloy femoral component had a porous-surfaced central stem with two small pins on either side to provide immediate rotational and translational stability. The tibial component was made of ultrahigh-molecular-weight, high-density polyethylene with a pentagonal projection at the base and a central stem with V-shaped circumferential grooves allowing for tissue ingrowth. The keel at the base was designed to fit into a similarly shaped recess in the tibial plateau in order to provide rotational and translational stability. Four of the six dogs regained normal function in the leg, including the ability to run and jump without lameness or gait abnormality. Of the two with residual deficits, one had a pronounced lameness and the other ambulated with the leg externally rotated. Four dogs were explanted, one each at 3, 6, 9, and 12 months. All four had loosening of the tibial component. Significant bony proliferation was present and a thin layer of fibrous tissue was present between the implant and the bone, suggesting micromotion during loading with eventual loosening. None of the four had loosening of the femoral component; however, there was substantial bone remodeling present. The authors concluded that the stability of the femoral implants was a positive achievement and that further changes to both components were needed. Turner et al. (1989) evaluated bone ingrowth into a porous-coated tibial component of a canine total knee replacement model. An unconstrained total condylar-type prosthesis was designed to model the available human prostheses and implanted in six dogs. The cobalt-chromium alloy femoral component was textured with cobalt-chromium alloy beads and cemented in place. The tibial component was composed of an ultrahigh-molecular-weight polyethylene articular surface bonded to a 1-mm-thick perforated titanium reinforcement plate and 2-mm-thick pad of 50% dense fiber porous metal composite with three cylindrical pegs. These pegs, along with a caudal screw, provided the initial stabilization for the tibial implant. After 6 months, extensive bone ingrowth was identified in all six tibial components. Fibrous tissue ingrowth was present in the areas of the pad that did not have bone ingrowth, suggesting that there was either a gap present at implantation or postoperative relative motion between the implant and bone. Unlike the Bobyn study, bony proliferation was not present in the dogs in this study. The authors concluded that precise attention to surgical technique to create intimate contact between the implant and bone, as well as implant design modifications to decrease the incidence of implant-bone relative motion, would be needed to improve the results for clinical total knee replacement. The development of jigs and cutting guides has improved the precision, and thus the fit, of knee prostheses.

Canine total knee replacement in a clinical setting is still relatively new. In 2007, Liska et al. described the use of a custom total knee replacement in a dog with a nonunion of the medial femoral condyle. The cobalt chrome femoral component and ultrahigh-molecular-weight polyethylene tibial component of the BioMedtrix system (Canine Total Knee, BioMedtrix) were used along with a titanium and porous tantalum augment to the femoral component to address the femoral bone defects present. The outcome in this case was successful. Seventeen months postoperatively, the dog had returned to his normal activities, including moose hunting, with lameness occurring only after strenuous exercise (see Chapter 14). The BioMedtrix Canine Total Knee system that is currently commercially available is a modular hybrid press-fit and cemented system. This prosthesis is discussed in detail in Chapter 10.

Conclusion

Regardless of the joint being replaced, continued progress in the arena of joint replacement for companion animals will require a consistent means of outcomes assessment. Further, the need for improvement will only be recognized by a critical evaluation of outcomes, and what is meant by a "successful" or "unsuccessful" outcome. A low revision rate does not equal a high success rate, unless it is clear to the reader that the prostheses are functioning at the level expected. We anticipate that, in the future, validated joint scores will be a key component of the decision making for patients with severe joint disease and the outcome assessment of total joint prostheses.

Endnotes

1. Liska WD. Cemented total hip replacement: Experience in USA with the BioMedtrix prosthesis. In: *Proceedings of the Pre-congress of the European Society of Veterinary Orthopaedics and Traumatology*. Munich, Germany, 2004.
2. Tepic S, Montavon PM. Concepts of cementless Zürich prosthesis. In: *Proceedings of the Pre-congress of the European Society of Veterinary Orthopaedics and Traumatology*. Munich, Germany, 2004.
3. Acker R, Van Der Meulen G. TATE Elbow preliminary trials. In: *Proceedings of the 35th Annual Conference of the Veterinary Orthopedic Society*. Big Sky, MT, 2008.

References

Agins HJ, Alcock NW, Bansal M, et al. Metallic wear in failed titanium-alloy total hip replacements. J Bone Joint Surg Am 1988;70:347–356.

Allen MJ, Leone KA, Lamonte K, et al. Cemented total knee replacement in 24 dogs: Surgical technique, clinical results, and complications. Vet Surg 2009;38: 555–567.

Bergh MS, Gilley RS, Shofer FS, et al. Complications and radiographic findings following cemented total hip replacement: A retrospective evaluation of 97 dogs. Vet Comp Orthop Traumatol 2006;19:172–179.

Bobyn JD, Cameron HU, Abdulla D, et al. Biologic fixation and bone modeling with an unconstrained canine total knee prosthesis. Clin Orthop Relat Res 1982;166:301–312.

Chen PQ, Turner TM, Ronnigen H, et al. A canine cementless total hip prosthesis model. Clin Orthop Relat Res 1983;176:24–33.

Conzemius MG. Nonconstrained elbow replacement in dogs. Vet Surg 2009;38:279–284.

Conzemius MG, Aper RL. Development and evaluation of semiconstrained arthroplasty for the treatment of elbow osteoarthritis in the dog. Vet Comp Orthop Traumatol 1998;11:54a.

Conzemius MG, Aper RL, Hill CM. Evaluation of a canine total-elbow arthroplasty system: A preliminary study in normal dogs. Vet Surg 2001;30:11–20.

Conzemius MG, Aper RL, Corti LB. Short-term outcome after total elbow arthroplasty in dogs with severe, naturally occurring osteoarthritis. Vet Surg 2003;32: 545–552.

DeYoung DJ, DeYoung BA, Aberman HA, et al. Implantation of an uncemented total hip prosthesis: Technique and initial results of 100 arthroplasties. Vet Surg 1992;21:168–177.

Dowd JE, Schwendeman LJ, Macaulay W, et al. Aseptic loosening in uncemented total hip arthroplasty in a canine model. Clin Orthop Relat Res 1995;319: 106–121.

Edwards MR, Egger EL, Schwarz PD. Aseptic loosening of the femoral implant after cemented total hip arthroplasty in dogs: 11 cases in 10 dogs (1991–1995). J Am Vet Med Assoc 1997;211:580–586.

Gitelis S, Chen PQ, Andersson GBJ, et al. The influence of early weight-bearing on experimental total hip arthroplasties in dogs. Clin Orthop Relat Res 1982;169:291–302.

Goldring SR, Schiller AL, Roelke M, et al. The synovial-like membrane at the bone-cement interface in loose

total hip replacements and its proposed role in bone lysis. J Bone Joint Surg Am 1983;65:575–584.

Gorman HA. A new prosthetic hip joint; experiences in its use in the dog, and its probable application to man. Mil Med 1957;121(2):91–93.

Guerrero TG, Montavon PM. Zurich cementless total hip replacement: Retrospective evaluation of 2nd generation implants in 60 dogs. Vet Surg 2009;38:70–80.

Hoefle WD. A surgical procedure prosthetic total hip replacement in the dog. J Am Anim Hosp Assoc 1974;10:269–276.

Lee JM, Salvati EA, Betts F, et al. Size of metallic and polyethylene debris particles in failed cemented total hip replacements. J Bone Joint Surg 1992;74-B: 380–384.

Leighton RL. The Richard's II canine hip prosthesis. J Am Anim Hosp Assoc 1979;15:73–76.

Lewis RH, Jones JP. A clinical study of canine total hip arthroplasty. Vet Surg 1980;9:20–23.

Liska WD, Marcellin-Little DJ, Eskelinen EV, et al. Custom total knee replacement in a dog with femoral condylar bone loss. Vet Surg 2007;36:293–301.

Marcellin-Little DJ, DeYoung BA, Doyens DH, et al. Canine uncemented porous-coated anatomic total hip arthroplasty: Results of a long-term prospective evaluation of 50 consecutive cases. Vet Surg 1999a;28: 10–20.

Marcellin-Little DJ, DeYoung DJ, Thrall DE, Merrill CL. Osteosarcoma at the site of bone infarction associated with total hip arthroplasty in a dog. Vet Surg 1999b;28:54–60.

Olmstead ML. The canine cemented modular total hip prosthesis. J Am Anim Hosp Assoc 1995;31:109–124.

Olmstead ML, Hohn RB, Turner TM. A five-year study of 221 total hip replacements in the dog. J Am Vet Med Assoc 1983;183:191–194.

Paul HA, Bargar WL, Mittlestadt B, et al. Development of a surgical robot for cementless total hip arthroplasty. Clin Orthop Relat Res 1992;286:57–66.

Roe SC, DeYoung D, Weinstock D, Kyles A. Osteosarcoma eight years after total hip arthroplasty. Vet Surg 1996;25:70–74.

Sebestyen P, Marcellin-Little DJ, DeYoung BA. Femoral medullary infarction secondary to canine total hip arthroplasty. Vet Surg 2000;29:227–236.

Skurla CP, Pluhar GE, Frankel DJ, et al. Assessment of the dog as a model for human total hip replacement. J Bone Joint Surg Br 2005;87:120–127.

Sumner DR, Berzins A, Turner T, et al. Initial in vitro stability of the tibial component in a canine model of cementless total knee replacement. J Biomechanics 1994;27(7):929–939.

Turner TM, Urban RM, Sumner DR, et al. Bone ingrowth into the tibial component of a canine total condylar knee replacement prosthesis. J Orthop Res 1989;7: 893–901.

Whittick WG, Bonar CJ, Reeve-Newson JA. Two unusual orthopaedic prostheses. Can Vet J 1964;5:56–60.