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Design concept of an extracortical implant for canine total hip replacement: A technical note

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Abstract

Canine hip dysplasia (CHD) is a prevalent condition that often leads to progressive degeneration of the coxofemoral joint, ultimately requiring total hip replacement (THR) as a conclusive treatment. Although traditional intramedullary femoral stems are regarded as the gold standard, these systems are frequently linked to various clinical complications, such as stress shielding, periprosthetic bone resorption, iatrogenic fractures during the broaching process, and irreversible obliteration of the medullary canal, which limits future revision possibilities. This technical note presents the Prime Hip Barrel-Plate System, an innovative extracortical fixation approach targeting the proximal metaphysis for canine THR. The system incorporates a metaphyseal barrel that is positioned through a controlled osteotomy of the femoral neck and is stabilized by a lateral extracortical plate, thus ensuring the complete preservation of the intramedullary canal. The biomechanical design is based on three fundamental principles: proximal load transfer, conservation of the femoral canal, and extracortical mechanical stabilization. This article elaborates on the design rationale, surgical techniques, potential clinical benefits, observed failure modes, and expected future advancements in the utilization of this technology.

Keywords: Canine total hip replacement, extracortical implant, femoral barrel-plate, proximal metaphyseal fixation, hip dysplasia

1. Introduction

Canine hip dysplasia (CHD) is a complex developmental disorder that affects dogs of all sizes, characterized by looseness in the hip joint and the gradual onset of osteoarthritis (OA). Its prevalence can vary widely, ranging from 1% to 80% [1-3]. As the condition progresses, it leads to significant changes in the joints, such as the breakdown of articular cartilage, the formation of bone spurs, and alterations in the subchondral bone, all of which can severely impact a dog's mobility and overall quality of life [4-5]. While conservative treatments like weight management, physical therapy, non-steroidal anti-inflammatory drugs (NSAIDs), and intra-articular biologics can help alleviate some symptoms, they don't stop the degeneration of the joints [6-7]. Surgical options vary, from preventive measures like juvenile pubic symphysiodesis and double/ triple pelvic osteotomy for younger dogs to more invasive procedures like femoral head and neck excision arthroplasty and total hip replacement (THR) for those with advanced disease [8-9]. THR is the best choice for dogs with canine hip dysplasia and in the late stages of CHD, with success rates nearing 90% when performed by skilled surgeons, whether using cemented, cementless, or hybrid systems [10-11]. However, all these methods have a common drawback: they require occupying the intramedullary canal, which can lead to issues like stress shielding, periprosthetic fractures during the procedure, stem subsidence, and permanent damage to the canal that limits future revision options [11-12]. The Prime Hip Barrel-Plate System was developed to overcome these challenges by focusing on a completely extracortical, canal-sparing approach to femoral fixation. This technical note outlines the design rationale, biomechanical principles, suggested surgical technique, potential benefits, and a review of the current limitations.

2. Implant Concept and Design

2.1 Conceptual Framework

The Prime Hip system is designed to be extra-medullary, meaning that femoral fixation is achieved using a proximal metaphyseal bone tunnel along with a lateral extracortical plate, all without needing to broach or occupy the femoral diaphysis or without disturbing the intramedullary canal which houses the bone marrow. It consists of three interdependent components that work with each other: the threaded bolt along with disc nut, which acts as a biological anchor and load transfer/ load distributor, and the plate along with barrel, which serves as a mechanical stabilizer as well as mechanical anchor. The bolt helps define the three-dimensional relationship between the head and acetabulum, creating a solid bone-implant interface, while the plate and barrel manages bending, torsion, and lateral load distribution with assisting the biological role of the bolt.

2.2 The Proximal Metaphyseal Bolt

The bolt is carefully placed through a tunnel that's drilled along the natural axis of the femoral neck, matching the unique neck-shaft angle i.e., 145° as determined during preoperative planning. It makes contact with the femoral neck cortex and the upper part of the cancellous bone. the bolt have outer surface learning/ threads in positive profile on which the disc nut gets attached maintaining a uniform weight distribution over the whole bone and the disc nuts can be of variable sizes as per the bone size. The bolt length is also available in different sizes to eradicate the chances of implant luxation. The bolt's proximal surface is tapered to allow it to get lodged in the head component and distal end have hollow cannulation due to which it can be locked with the barrel of lateral extracortical plate by using a lateral screw. the length of bolt can be selected intra-operatively from 35 mm, 40 mm, 45 mm, 50 mm, 55 mm, 60 mm, 65 mm and 70 mm respectively as per the patient's requirement. This co-related with the neck length selection in the conventional implant systems.

2.3 The Lateral Extracortical Plate

The plate is placed on the caudo-lateral surface of the femur, stretching from the point of entry below the greater trochanter to the distal part of the diaphysis depending of the pre-operative calculations and measurements on the radiographs. It serves as an extracortical support, helping to prevent varus collapse, reducing rotational movement at the barrel-bone interface, and spreading bending forces along the outer cortex. The plate is secured with locking cortical screws only after the barrel has been positioned and its trajectory confirmed in the bone tunnel made by specialized instruments that are meant to create a tunnel exactly as per the neck shaft angle i.e., 145° and the trajectory is as per the natural anteversion of the femur. The bolt fits inside the barrel of the plate and both are being locked together by using a lateral screw. There are specialized learning on the inner surface of plate and outer surface of the barrel to facilitate early osteointegration of the bone and implant interface. The barrel plate comes in different sizes.

2.4 Acetabular Component

The acetabular component is designed as a hemispherical shell coated with titanium oxide available in different sizes as per the patient's acetabular size, featuring a textured outer surface that aligns with the principles of cementless cup design [11]. Additionally 2-4 screw holes are provided to facilitate the fixation of acetabular cup with acetabulum in case of poor press fit conformation. An ultra-high molecular

weight polyethylene (UHMWPE) liner serves as the articular bearing surface. We expect osseointegration, where bone grows into the shell, to occur over a period of six to twelve weeks, which is in line with existing data on cementless acetabular fixation [13].

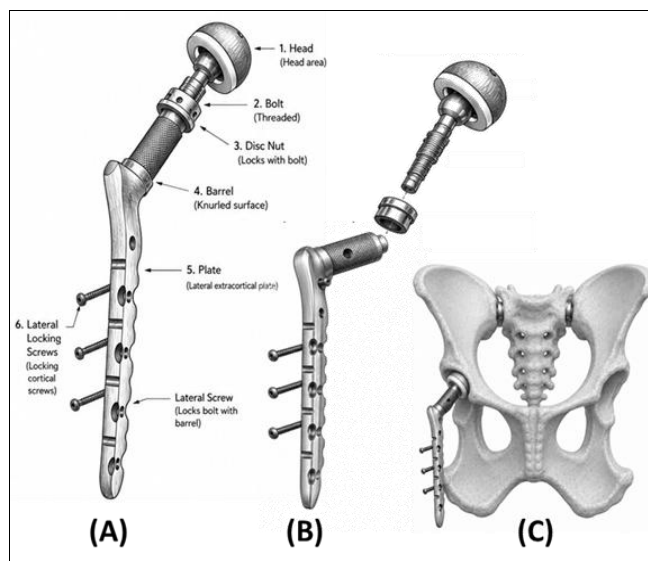


Fig 1: Prime Hip System- Extracortical Total Hip (A) Extracortical implant (B) Exploded view of implant (C) Implant positioned on the canine pelvis

3. Design Rationale

3.1 Limitations of Intramedullary Stem Systems

Conventional intramedullary stems mainly transfer the load to the diaphysis, skipping over the proximal cortex and metaphysis. This can lead to stress shielding in the calcar and greater trochanter, resulting in bone loss in the proximal area over time [14]. When using cementless systems, femoral broaching has an intraoperative fissure or fracture rate ranging from 4.4% to 15% [11]. Additionally, stem subsidence—where a cementless stem that hasn't fully integrated moves downward—can lead to issues like cup-stem mismatch, luxation, and the need for revision [15]. Most importantly placing an intramedullary stem permanently occupies the canal, making any future intramedullary procedures impossible.

3.2 Biomechanical Rationale for Proximal Load Transfer

The Prime Hip system is designed to channel mechanical forces to the metaphyseal and femoral neck areas, which helps mimic the natural loading of the proximal region and minimizes the risk of bone loss due to stress shielding. The extracortical plate plays a key role in spreading out bending loads along the outer cortex, acting like a tension band to prevent varus collapse similar to how the greater trochanteric tension band works in a healthy canine hip. By keeping the medullary canal intact, it ensures that there are options for future fixations, whether that's intramedullary fracture repair or revision arthroplasty.

3.3 The Safe Cortical Envelope

The "safe cortical envelope" refers to the three-dimensional bony cylinder that surrounds the planned barrel axis, and it's crucial that this structure stays intact. Unlike intramedullary systems, where this envelope covers the entire diaphysis, in the Prime Hip system, it's limited to the proximal metaphyseal tunnel. To maintain its integrity, we need: (i) a femoral neck cortex that is intact all the way around; (ii) enough cancellous metaphyseal bone to handle the insertion

hoop stress; and (iii) drilling that is axially centered to keep the cortical margins symmetrical. The key limiting area is usually the junction between the femoral neck and calcar, as well as the caudal cortex, especially when there's an anteversion error. If the envelope is violated—due to oversizing, off-center drilling, or poor bone quality—it can seriously compromise the integrity of the construct.

4. Proposed Surgical Technique

4.1 Preoperative Planning and Templating

Calibrated ventrodorsal, 'frog-leg' (lateral oblique), and lateral pelvic views—complete with a magnification marker—were obtained following established protocols for canine total hip replacement (THR) templating^[11]. If available, we prefer to use CT with multiplanar reconstruction, as it offers a much clearer assessment of neck geometry, anteversion, cortical thickness, and the quality of the metaphyseal bone. The entry points are decided as per the patient's neck shaft angle and anteversion of femoral head.

4.2 Patient Positioning and Surgical Approach

The patient is placed in lateral recumbency with the operative limb uppermost, secured in a positioning device to maintain stable pelvic orientation^[11]. A craniolateral approach provides access to the femoral neck, greater trochanter, and proximal lateral femoral shaft, accommodating both barrel insertion and plate application.

4.3 Lateral plate Insertion and fixation — The Inviolable Sequence

The following sequence must not be deviated from:

- Plan trajectory on preoperative templating.
- Create a pilot hole from the lateral femoral cortex along the planned neck axis.
- Confirm centricity in both AP and lateral planes before proceeding.
- Verify anteversion against the preoperative plan.
- Progressively enlarge the tunnel, confirming cortical margin integrity at each step.
- Seat the barrel to final depth, ensure proper plate alignment over the lateral surface of the femur.
- Then the lateral plate shall be fixed with cortical screws. The first 2 screws shall be fixed in bicortical fashion and rest remaining holes needs to be fixed monocortically.
- The plate length can be cut or kept the same length depending on the patient's bone length.

If the pilot is eccentric or mal-angled, it must be redirected before enlargement an incorrect axis enlarged to final diameter is irreversible. The plate can only stabilise a correct tunnel orientation; it cannot rescue a malpositioned one.

4.4 Acetabular Preparation

Acetabular preparation is all about following the established guidelines for cementless cup placement^[11]. By sequentially reaming, we can expose the healthy cancellous bone at the cranial, dorsal, and caudal poles. We make the bed 1 mm smaller than the selected cup diameter to achieve a proper press-fit. Once that's done, we impact the cup to its full seating depth, ensuring the retroversion, inclination, and closure angle are spot on.

4.5 Bolt Selection, fixation and implantation of disc nut

Proper size of bolt is selected as per the patient; it is then fixed with the barrel of extracortical plate with the use of lateral screw. After fixation the disc nut is fixed over the

positive profile learnings of the bolt which facilitates proper load sharing of the femur.

4.6 Reduction and Final Closure

A metal polished femoral head is placed onto the bolt and the femoral assembly is reduced into the acetabular cup, after which we must evaluate reduction tension, range of motion, and joint stability. Once we confirm that the range of motion is appropriate and impinged, we perform a layered closure of the soft tissue. Postoperative radiographs are taken to verify the position of the implant and to check the proximal femur for any intraoperative fissures.

5. Potential Advantages

5.1 Femoral Canal Preservation

Avoiding the canal completely helps to keep the femoral diaphysis intact for any future procedures. If an implant fails, if there's a periprosthetic fracture, or if revision arthroplasty is needed, using intramedullary fixation is still a solid option—something that's not possible if a conventional stem has already been placed. This benefit is especially important for younger patients who are likely to outlive their implants.

5.2 Reduced Stress Shielding

Proximal load transfer may preserve physiological loading of the proximal femoral metaphysis, mitigating the stress shielding-mediated bone loss documented with conventional intramedullary stems^[14]. Maintained proximal bone stock improves long-term implant survivorship and facilitates revision feasibility.

5.3 Elimination of Femoral Broaching Risks

The Prime Hip system completely removes the need for femoral broaching, opting instead for a precise drill-and-tunnel method that focuses on the upper part of the femur. This approach helps to prevent the intraoperative femoral fissures and fractures that can occur in as many as 15% of cementless total hip replacement cases, especially in patients with a low canal flare index or subpar cancellous bone quality^[11-16].

5.4 Applicability in Poor Diaphyseal Bone Quality

In cases where patients have osteopenia, stovepipe femoral morphology, or other issues that prevent a good intramedullary press-fit, the Prime Hip system might be a suitable option. Just make sure there's enough proximal metaphyseal bone stock to support barrel fixation within the safe cortical envelope.

6. Limitations and Future Directions

6.1 Limited Clinical Outcome Data

The Prime Hip system is still in the early stages of development, with very less clinical studies, cadaveric biomechanical research, or *in vivo* outcome data available yet. In contrast, established cemented and cementless canine total hip replacement (THR) configurations have decades of evidence backing them, boasting success rates of around 90%. Therefore, limited number of studies highlights the need for scientific humility and means we can't make any claims about efficacy until further investigations are conducted.

6.2 Failure Modes Unique to Extracortical Systems

Failure modes of the implant are expected to be predominantly trajectory-driven. A caudally directed barrel trajectory may result in excessive loading of the caudal femoral cortex, predisposing the neck-calcar junction to cortical fissuring or fatigue fracture. Additionally, inadequate

metaphyseal bone stock, particularly in cases of advanced osteopenia, may compromise biological fixation of the barrel and reduce the long-term stability of the implant.

6.3 Learning Curve and Technical Demands

The process of verifying a three-plane trajectory and mastering the tricky barrel commitment point presents a significant learning challenge, similar to what's faced with standard cementless total hip replacements. To tackle this, you really need to go through surgical simulations, structured training, and gain some mentored clinical experience before you can operate independently.

6.4 Patient Selection

Suitable candidates should have sufficient proximal metaphyseal bone stock, an intact femoral neck cortex, and no issues that would prevent the reliable creation of a tunnel, like severe osteolysis, pathological neck fractures. Patients who are very large or very small, or who have significantly weakened metaphyseal bone, are unlikely to be good early candidates.

7. Conclusion

The Prime Hip Barrel-Plate System presents a well-thought-out, canal-friendly alternative to traditional intramedullary canine total hip replacement (THR). It tackles some of the known issues with existing systems, like femoral canal compromise, stress shielding, and the risk of fractures related to broaching. The reasoning behind its design for transferring load to the proximal area is quite convincing, and preserving the canal for future revisions is a significant clinical advantage. That said, this system requires precise trajectory, a strict barrel-before-plate surgical order, and thorough preoperative assessments of bone stock. Currently, there's a lack of clinical outcome data, and its effectiveness will ultimately hinge on detailed clinical studies. If these studies validate its safety and effectiveness, the Prime Hip concept could offer surgeons a biologically sound, canal-sparing choice for carefully chosen patients where traditional THR might not be the best fit.

Conflict of Interest

Not available

Financial Support

Not available

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