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Case Report

Modular Determinism in Shoulder Hemi arthroplasty: BG-Guided Fixed-Version, Proximal Cement-Restricted Short-Stem Design for Complex Proximal Humerus Fractures

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Abstract

Background: In fracture hemiarthroplasty, functional failure is frequently driven by kinematic reconstruction errors—particularly malreconstruction of head height and version—which contribute to tuberosity malposition/migration and poor outcomes [2]. Contemporary humeral stems may inadvertently couple diaphyseal fixation with articular reconstruction, increasing intraoperative variability ("system noise").

Methods: We propose an anchor–interface framework that decouples these tasks. The anchor is a proximal cement-restricted short stem designed to generate a circumferential 1.5–2.0 mm cement mantle and a low-stress polished distal segment. Fixation is achieved through a controlled fluid–thermal cementation protocol that standardizes cement viscosity and pressurization, informed by evidence that pressurization influences cement penetration and fixation strength [8] and by micromechanical modeling demonstrating that cement–bone interdigitation/contact area governs interface strength [9]. Version control is encoded as fixed retroversion referenced to the bicipital groove (BG) [6,7], allowing the surgeon to set retroversion by an anatomic alignment step during cementation. The interface consists of modular heads that permit independent adjustment of head height and offset using the pectoralis major tendon reference [3], with explicit attention to preserving subacromial clearance (avoid overstuffing) [10]. Integrated suture windows and longitudinal slots enable bridging plus cerclage tuberosity fixation [4].

Conclusions: By rendering diaphyseal fixation more deterministic through process control, the proposed system reduces the intraoperative "error budget" to its essential kinematic variables: version, height, and clearance. Preclinical testing and prospective clinical evaluation are required to determine whether reducing variability improves tuberosity healing and mitigates glenoid erosion.

Introduction

Proximal humerus fractures that require arthroplasty challenge conventional humeral stem paradigms. Unlike the hip, the dominant failure modes in fracture hemiarthroplasty are not diaphyseal subsidence but kinematic incompatibility and tuberosity healing. In the classic series by Boileau and colleagues, tuberosity malposition or migration after hemiarthroplasty was strongly associated with poor functional outcomes [2]. Two technical errors are particularly consequential: [1] inaccurate head version, which can generate eccentric glenoid loading and progressive posterior wear; and [2] inaccurate head height ("overstuffing"), which violates subacromial clearance and imposes an iatrogenic impingement constraint [10]. Many contemporary systems unintentionally couple these articular objectives to stem geometry and canal preparation: complex stems, variable metaphyseal fill, and broach-dependent version jigs can dictate final implant position, especially when proximal landmarks are fractured or comminuted. To reduce this variance, we propose a reductionist, first-principles framework that separates the operation into an "anchor" problem (reproducible diaphyseal fixation) and an "interface" problem (deterministic control of version, height, and clearance).

Implant concept and design rationale

Design concept: The proposed implant is a modular, cemented, proximal cement-restricted short-stem system that internalizes version control while preserving independent head modularity. The anchor consists of a 55-mm titanium alloy stem with fixed retroversion (35° for size S and 40° for size L) referenced to the bicipital groove, an anatomic landmark available on preoperative imaging and in the operative field [6,7]. The stem is elliptical (10 × 7 mm) and grit-blasted proximally to enhance cement interlock, while the distal segment is polished and reduced in profile to function as a generic load carrier and facilitate revision extraction. A proximal fin and collar-calcar support provide initial alignment and resist rotation, and a proximal PMMA-restricting cuff is designed to yield a circumferential 1.5–2.0 mm cement mantle. Fixation is conceptualized as a controllable process rather than a stochastic by-product of canal fill: cement viscosity (timing), pressurization, and thermal management are standardized to generate reproducible cement penetration and interdigitation—variables known to influence cement–bone interface strength [8,9,12]. The interface consists of modular humeral heads that permit independent restoration of head height and offset based on the pectoralis major tendon landmark [3] while selecting a head diameter that maintains subacromial clearance. Finally, the stem incorporates multiple suture windows and longitudinal slots to enable tension-band and bridging-plus-cerclage tuberosity fixation constructs [4].

Surgical technique (BG-guided, jig-free)

After exposure and head excision, the bicipital groove is identified and used as the rotational reference. The diaphyseal canal is gently prepared to accept the appropriate stem size while targeting a circumferential cement mantle. The canal is irrigated and dried; a distal plug or built-in restrictor allows pressurization. PMMA is mixed under standardized conditions and introduced during a controlled viscosity window. Cement is pressurized to achieve consistent penetration while minimizing leakage and thermal burden. The stem is inserted with its rotational marker aligned to the bicipital groove to reproduce the predetermined retroversion, thereby decoupling version control from metaphyseal comminution. Head height is then set with modular heads using the pectoralis major tendon distance as a reproducible soft-tissue landmark [3], with explicit attention to preserving subacromial clearance and avoiding overstuffing [10]. The tuberosities are anatomically reduced and secured with heavy nonabsorbable sutures passed through the stem windows and reinforced with cerclage around the longitudinal slots to create a hybrid bridging construct [4].

Illustrative case

A representative use case is an elderly patient with a displaced 3- or 4-part proximal humerus fracture and compromised metaphyseal bone stock, in whom press-fit fixation is unreliable. By standardizing fixation with proximal cementation and encoding version relative to the bicipital groove, the surgeon's attention can be concentrated on two high-leverage variables: tuberosity reduction/repair and restoration of head height/clearance.

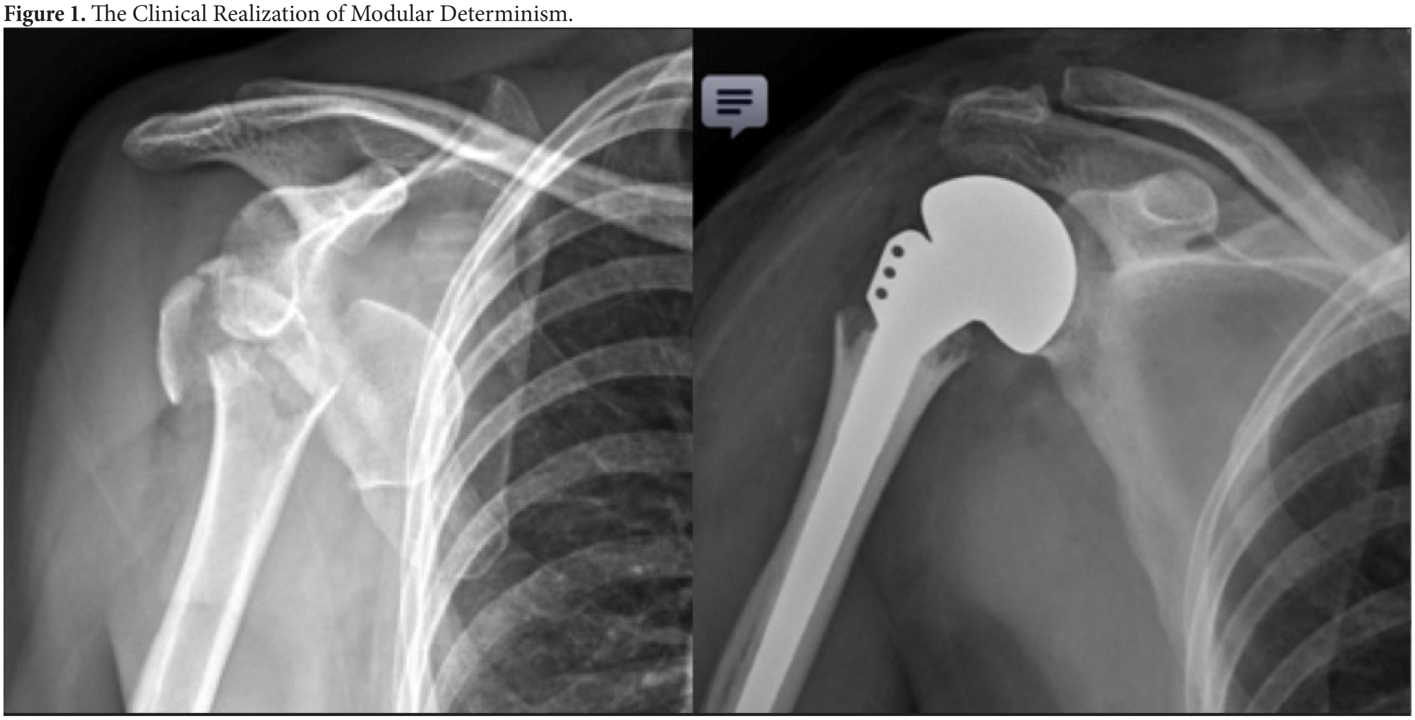
Preclinical verification plan

We propose a three-domain preclinical verification plan. (i) Cementation process: cadaveric or composite humeri instrumented with thermocouples and micro-CT will quantify cement penetration depth, mantle uniformity, and peak temperature profiles across viscosity/pressurization windows, leveraging evidence that pressurization magnitude affects penetration and fixation strength [8] and that cement–bone interdigitation/contact area governs interface strength [9], while acknowledging exothermic polymerization and thermal necrosis risk [12]. (ii) Construct mechanics: torsional and bending tests will compare the proximal cement-restricted stem to longer stems with respect to stress-riser behavior and simulated periprosthetic fracture initiation, a clinically relevant complication after shoulder arthroplasty [11]. (iii) Tuberosity fixation: cyclic loading will evaluate displacement and failure modes of the suture-window/cerclage configuration relative to conventional suture constructs, consistent with prior mechanical observations on cerclage augmentation [4].

Discussion

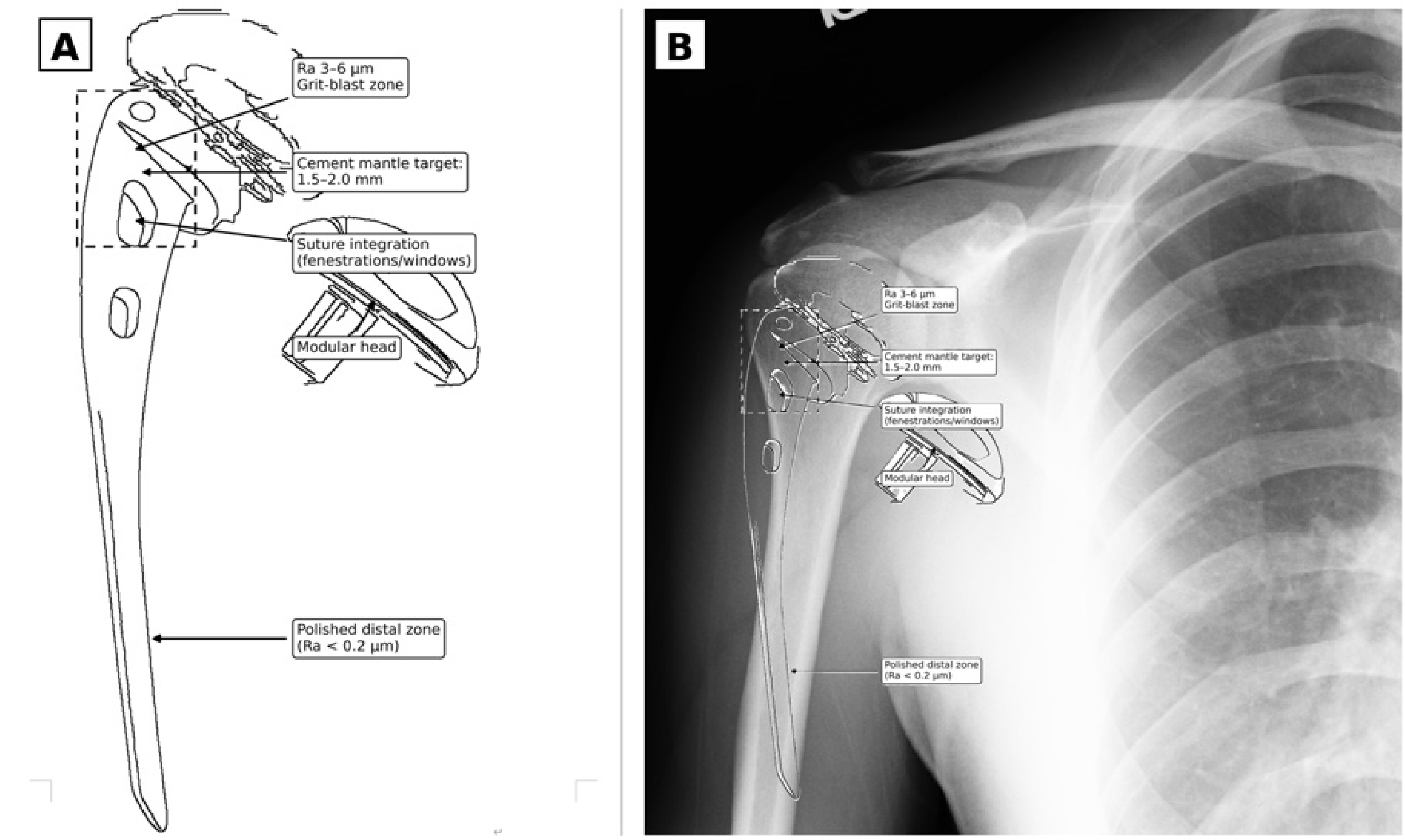
The central claim of this design is not that a novel stem geometry is inherently superior, but that surgical success can be made more reproducible by reducing the coupling between diaphyseal fixation and articular reconstruction. The bicipital groove has been investigated as a practical version landmark, with cadaveric and CT data describing its relationship to humeral head retroversion and its potential utility for reproducible intraoperative referencing [6,7]. Encoding a fixed retroversion relative to this landmark converts version control from an estimation problem to a deterministic alignment step. Likewise, using the pectoralis major tendon as a height reference shifts the objective from generic "length restoration" to functional clearance and soft-tissue tensioning [3], directly targeting overstuffing-related impingement risk [10]. On the fixation side, classical experimental work emphasizes that cement pressurization influences cement penetration and fixation strength [8], and micromechanical analyses demonstrate that greater interdigitation and contact area increase interface strength in both tension and shear [9]. These principles support the premise that fixation can be standardized through process control—cement viscosity window, pressurization, and thermal management—rather than through increasingly complex press-fit stems. However, PMMA polymerization is exothermic, and excessive thermal exposure may jeopardize adjacent bone viability; mitigation strategies and temperature monitoring should therefore be embedded in both protocol and validation [12]. If validated, a proximal cement-restricted short stem may also reduce distal stress risers and facilitate revision in an elderly fracture population, where periprosthetic humeral fractures remain a meaningful complication [11]. This manuscript is presented as a design and workflow hypothesis; prospective clinical studies are required to determine whether reducing intraoperative variability translates into improved tuberosity healing, decreased glenoid erosion, and better patient-reported outcomes.

Figure 1. The Clinical Realization of Modular Determinism.



(A) Preoperative radiograph of a complex proximal humerus fracture (Neer 3-part/4-part equivalent) in a geriatric patient. The loss of bony landmarks represents a high-entropy state with geometric collapse.
(B) Postoperative reconstruction demonstrating the restoration of the "**Gothic Arch**" and anatomical head height. Note the clean restoration of the tuberosity envelope without the use of cement in the distal canal. This image validates the concept of "**Geometric Determinism**"—where the implant's design forces the reconstruction into a stable, predictable configuration despite the poor bone quality.

Figure 2. The Engineering Logic: Decoupling Anchor from Interface.



Left: The "**Anchor**" component. The short-stem design features a proximal porous-coated zone for biological integration and a polished distal tip to prevent stress shielding. **Right:** The "**Interface**" mechanism. The prominent lateral fins are designed to engage the bicipital groove (BG-Guided), locking the stem's version (rotation) deterministically. This "**Key-and-Lock**" geometry eliminates the intraoperative guesswork of version control, reducing the "error budget" and ensuring that the tuberosity repair (the interface) has a stable, non-migrating foundation.

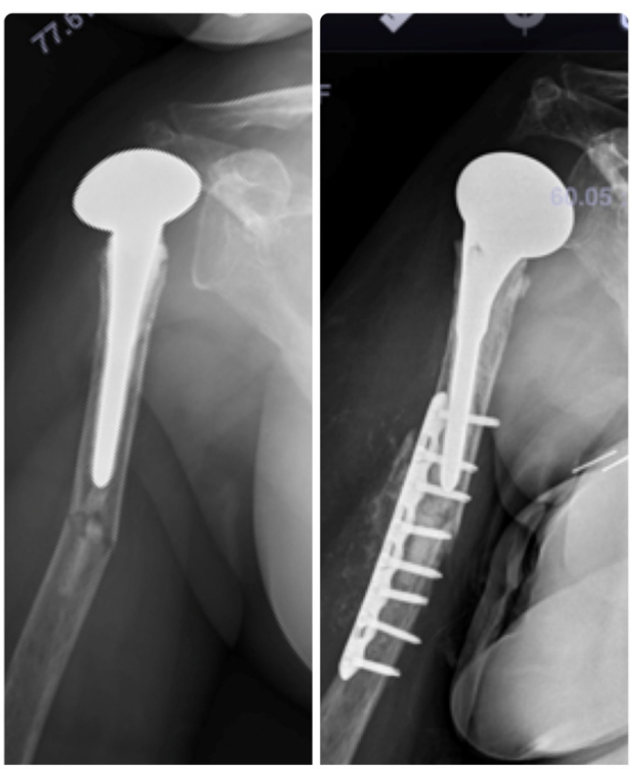


Figure 2B. Representative periprosthetic humeral fracture with a current long-stem design, highlighting a stress-riser at the stem–diaphyseal junction.

Ethics and funding

The patient provided written consent for publication of de-identified images. No external funding influenced this work.

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