Research Square

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A Novel Classification System for Anterior Femoral Notching in Total Knee Arthroplasty

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Abstract

Background: Femoral notching in Total Knee Arthroplasty (TKA) is traditionally associated with an increased risk of periprosthetic fracture in cases of excessive anterior resection. Beyond fracture risk, notching can influence implant fit, patellofemoral and tibiofemoral balance, joint stability, and overall biomechanics. Despite its clinical importance, a standardized system for describing femoral notching is lacking. We propose a novel **Femoral Notch Classification**, based on resection depths and trochlear geometry, intended as a common language applicable both intraoperatively and on lateral radiographs, independent of alignment philosophy.

Methods: The classification was developed through clinical observation and biomechanical rationale, focusing on preserving anterior cortical integrity while permitting a controlled notch when required. Definitions relate resection depths to implant thickness, distal femoral anatomy, and trochlear geometry, with attention to balancing anterior and posterior gaps. Perpendicularity of the anterior cut relative to the cortex can be evaluated and adapted according to implant design and alignment technique. Four descriptive categories were established, providing a structured framework for assessment.

Results:

· **Type 0 – No Notch:** Anterior cortex remains intact with no visible notch. Anterior resection may match implant thickness precisely; if not, anterior overstuffing or posterior over-resection should be controlled.

· **Type 1 – On the Line:** Anterior resection is flush with the femoral cortex, creating a subtle notch that remains biomechanically stable without compromising the cortex.

· **Type 2 – Controlled Notch:** A deeper anterior resection (ideally <3 mm) is intentionally performed due to anatomic conditions to avoid overstuffing the anterior compartment while maintaining balance through appropriate posterior cuts. Posterior under-resection or overstuffing must be carefully controlled.

· **Type 3 – Critical Notch:** When trochlear geometry does not require a deep notch, excessive anterior resection weakens cortical integrity and may increase the risk of periprosthetic fracture or posterior compartment overstuffing. Surgeons should exercise caution and verify proper implant alignment.

Conclusion: The **Femoral Notch Classification** provides a practical, reproducible framework for assessing femoral notching in TKA, suitable for intraoperative guidance and radiographic analysis. It may help surgeons avoid over- or under-resection while allowing a controlled notch when required. Further clinical validation is needed to assess its impact on long-term patient outcomes.

Introduction

Anterior femoral notching (FN) during total knee arthroplasty (TKA) has historically been viewed primarily as a risk factor for postoperative supracondylar periprosthetic fracture, with large series

reporting fracture prevalence and clinical outcomes after notching [1]. Biomechanical studies have demonstrated that notches deeper than 3 mm can reduce distal femoral strength by approximately 18 to 31%, particularly when cortical integrity is compromised, or bone quality is reduced [2–4]. More recent clinical data, however, suggest that not all notches correlate with higher fracture incidence, indicating that risk is modulated by notch depth, cortical involvement, and patient factors rather than by the mere presence of a notch [5, 6].

Beyond fracture risk, femoral notching has implications for implant fit, patellofemoral balance, joint stability, and overall biomechanics. Computational finite element analyses and gait simulations demonstrate that notch depth alters distal femoral stress distribution during the gait cycle, underscoring the need to coordinate anterior and posterior resections to avoid over- or under-resection of the compartments [7]. Techniques prioritizing restoration of distal femoral anatomy with minimal compromise—such as anatomic or hybrid referencing—aim to balance anterior and posterior gaps, reduce unintended cortical violation, and optimize patellofemoral mechanics [8].

These decisions are best grounded in standardized radiographic documentation. The modern Knee Society methodology has formalized recording of alignment and bone status on routine antero-posterior and lateral radiographs, while calls for uniform assessments in revision arthroplasty highlight the value of shared criteria across centers and implant designs [9, 10]. In parallel, radiological taxonomies of distal femoral morphology demonstrate that reliable, image-based classification is feasible for establishing common terminology [11, 12].

Despite its importance, no widely adopted, radiograph-based classification is dedicated to anterior FN in TKA. The Tayside scheme remains the most recognized for postoperative radiographic grading by extent of cortical and cancellous involvement, but it offers limited intraoperative guidance, and many reports still describe notching qualitatively (present/absent; mild/moderate/severe) without a standardized framework [6]. More broadly, preoperative planning principles and bone-defect classifications underscore why a common radiographic language matters: uniform description improves anticipation of technical challenges, supports reproducible restoration of femoro-tibial alignment and patello-femoral congruence, and facilitates comparison of outcomes across studies and implants [13, 14].

We propose a descriptive, radiograph-based Femoral Notch Classification intended as a common language for routine reporting after total knee arthroplasty. The present work defines the taxonomy and its radiographic criteria.

Methods

Development of the classification

The FN Classification was developed through biomechanical understanding and extensive clinical observation, with the primary goal of preserving maximal anterior cortical integrity while permitting a controlled notch when anatomically or mechanically indicated. Common indications for intentional

notching include variations in distal femoral anatomy—such as pronounced anterior curvature, a shallow or dysplastic trochlea, or mismatch between native trochlear geometry and implant design—that would otherwise lead to anterior overstuffing or compromised patellofemoral tracking if strictly avoided.

The concept arose from the consistent intraoperative observation that anterior femoral resection varies not only in depth but also in surgical intent: ranging from inadvertent over-resection (due to instrumentation or planning limitations) to deliberate, controlled contouring aimed at optimizing patellofemoral and gap balance without posterior compromise. The classification was therefore designed as a descriptive, radiograph-based framework applicable both intraoperatively (independent of implant design or alignment philosophy) and on postoperative lateral radiographs.

Radiographic assessment and classification criteria

All definitions are anchored to standard anteroposterior and lateral radiographs obtained according to the Modern Knee Society radiographic methodology for TKA [9]. On the true lateral projection, the anterior cortical line, the anterior resection plane, and the distal anterior flange of the femoral component are analyzed. The system relates the depth and configuration of anterior femoral notching (FN) to implant thickness, trochlear geometry, and the balance between anterior and posterior resections, thereby defining reproducible geometric patterns that reflect the degree of cortical preservation or violation.

The classification comprises four descriptive types (Table 1).

Type	Name	Key Radiographic Features	Clinical Implication
Type 0	No Notch	Anterior resection matches implant thickness; cortex fully intact, no visible step-off or indentation	Safe configuration with complete cortical preservation; posterior over-resection should be avoided to maintain flexion-extension gap balance
Type 1	On the Line	Resection flush with native cortex; subtle contact, minimal or no measurable cortical loss	Safe, biomechanically stable configuration with full cortical preservation; represents neutral balance of implant thickness and native anatomy
Type 2	Controlled Notch	Intentional shallow resection beyond cortical line (ideally < 3 mm); smooth with preserved continuity	Acceptable when anatomically indicated (e.g., trochlear mismatch); posterior gaps must be controlled to avoid overstuffing
Type 3	Critical Notch	Excessive resection (> 3mm) not justified by the underlying anatomy; cortical interruption	Potentially increased fracture risk and mechanical compromise; requires intraoperative verification of alignment and sizing

Validation of the classification

The reliability of the proposed Femoral Notch Classification was assessed using 80 anonymized true lateral radiographs from primary total knee arthroplasties performed at our institution. All radiographs met the standards of the Modern Knee Society radiographic evaluation system. Three independent observers (one senior orthopedic surgeon and two orthopedic fellows) classified each radiograph into one of the four types (Type 0–3) according to the provided definitions and example figures. Observers were blinded to clinical information and to each other's ratings. After an interval of four weeks, the same set of radiographs was presented in randomized order to determine intra-observer reliability.

Results

The Femoral Notch Classification

The proposed classification comprises four descriptive categories (Types 0–3) based on the geometric relationship between the anterior femoral resection plane, the native cortical line, and the anterior flange of the femoral component on true lateral radiographs (Figs. 1–4).

Type 0 – No Notch

The anterior resection precisely matches the femoral component thickness, leaving the anterior cortex fully intact with no visible step-off or indentation on lateral radiographs. The anterior contour of the implant follows the native cortical line harmoniously, although slight proximal cortical exposure may occur (e.g., when the component is placed in higher flexion). In this configuration, posterior over-resection must be carefully avoided to preserve balanced flexion-extension gaps.

Type 1 – On the Line

The anterior resection is flush with the native cortex, resulting in subtle cortical contact with minimal or no measurable cortical loss. This configuration creates a faint "on the line" appearance without true indentation and is considered biomechanically stable, fully preserving cortical integrity. It typically represents a neutral configuration achieved when the anterior cut precisely accommodates both implant thickness and native femoral curvature.

Type 2 – Controlled Notch

A deeper anterior resection is intentionally performed to accommodate trochlear geometry or distal femoral anatomy, thereby preventing patellofemoral overstuffing while respecting the surgeon's chosen alignment philosophy (mechanical, kinematic, or restricted). The resection extends beyond the cortical line but should be deliberately smooth, shallow, and limited (ideally < 3 mm) to preserve cortical continuity. This configuration is considered acceptable when anatomically indicated. Independently, posterior under-resection must be carefully controlled to avoid overstuffing the posterior compartment.

Type 3 – Critical Notch

Excessive anterior resection (> 3 mm) occurs without anatomic justification (i.e., trochlear geometry does not necessitate a deep notch). On radiographs, the cortical line is visibly interrupted, thinned, or undercut beyond the expected implant contour. This configuration compromises distal femoral mechanical strength and may increase the risk of supracondylar periprosthetic fracture. When identified intraoperatively, surgeons should verify implant alignment and sizing before final implantation.

Across all types, the perpendicularity of the anterior resection relative to the native cortex can be independently evaluated on lateral radiographs. This feature allows adaptation according to implant design, referencing technique (anterior, posterior, or hybrid), and alignment philosophy. The classification thus provides a reproducible, visual framework for intraoperative decision-making and postoperative communication.

Reliability of the Femoral Notch Classification

Inter-observer reliability among the three observers, evaluated using Fleiss' kappa, was 0.80 (95% CI 0.73–0.86), indicating substantial agreement. Intra-observer reliability, measured by Cohen's kappa, was almost perfect, ranging from 0.87 to 0.94 (mean 0.91) (Table 2). These findings demonstrate that the proposed classification system is highly reproducible and reliable across observers with different levels of experience. In cases of doubt, particularly when distinguishing between Type 2 and Type 3, consultation of preoperative radiographs is recommended to better assess the underlying trochlear geometry and anatomic indication.

Table 2
Inter- and intra-observer reliability of the Femoral Notch Classification

Reliability type	Statistical measure	Kappa (95% CI)	Strength of agreement*
Inter-observer (3 observers)	Fleiss' κ	0.80 (0.73–0.86)	Substantial
Intra-observer (mean)	Cohen's κ	0.91	Almost perfect

*According to Landis and Koch criteria.

Discussion

Femoral notching (FN) in total knee arthroplasty (TKA) has traditionally been regarded as a complication to be avoided owing to its association with supracondylar periprosthetic fracture, particularly when depth exceeds 3 mm and cortical integrity is compromised [1, 2]. However, accumulating biomechanical and clinical evidence indicates that not all FN is detrimental; in selected cases, a controlled notch may be purposeful and advantageous. A deliberate, shallow resection can prevent anterior compartment overstuffing, enhance patellofemoral tracking, and facilitate flexion-extension gap balance—especially with implants featuring prominent trochlear flanges [3, 4].

Despite its clinical relevance, no widely accepted classification distinguishes accidental from purposeful femoral notching (FN) or provides guidance for intraoperative decision-making. The Tayside

classification, proposed by Gujarathi et al. [6], remains the most recognized system, grading postoperative notching into three levels based on depth and extent of cortical or cancellous involvement. While valuable for retrospective stratification of fracture risk—particularly for deeper notches that would correspond to Type 3 in the current system—it offers limited intraoperative utility, does not account for surgical intent or subtler configurations (Types 0–2), and, to our knowledge, has not achieved widespread clinical or research adoption.

The proposed Femoral Notch Classification addresses these gaps by providing a framework applicable both intraoperatively and on postoperative lateral radiographs, independent of alignment philosophy. Unlike depth-focused systems, it categorizes FN according to functional characteristics—cortical integrity, resection intent, trochlear accommodation, and gap balance. This approach reflects clinical reality: a shallow, symmetrical, anatomically indicated notch (Type 2) may be biomechanically stable or even beneficial, whereas an unplanned, excessive notch (Type 3) risks cortical compromise and elevated fracture potential.

Additionally, the classification accommodates variations in implant design and referencing technique. Posterior-referenced systems, for instance, may predispose to unintended notching when external rotation or sizing mismatches shift the anterior cut relative to the native cortex [15].

With the increasing adoption of robotic-assisted surgery, these technologies have demonstrably reduced the incidence of unintended FN through improved cut precision and preoperative planning. Nevertheless, a subtle, controlled notch may still be intentionally performed—even with robotic assistance—when required to accommodate challenging trochlear geometry or prevent anterior overstuffing, underscoring the continued relevance of a nuanced classification system.

Because FN type is defined by reproducible geometric relationships visible on standard lateral radiographs, the classification supports standardized reporting in research and registry data. This may facilitate more consistent outcome studies compared with current qualitative or depth-only descriptions.

In the present study, the classification achieved substantial inter-observer agreement despite including observers with different levels of experience. However, distinguishing between a controlled (Type 2) and a critical notch (Type 3) occasionally might be challenging on postoperative radiographs alone. In such cases, review of preoperative radiographs can provide valuable information regarding native trochlear geometry and help determine whether the notch was anatomically justified.

Certain limitations of the classification should be acknowledged. Distinguishing between a controlled notch (Type 2) and a critical notch (Type 3) may occasionally prove challenging on postoperative radiographs alone, particularly when notch depth approaches 3 mm or cortical continuity is borderline. Additionally, assessment of surgical “intent” and anatomic indication might be inherently subjective and vary between surgeons. Finally, while the classification is designed to be implant- and technique-agnostic, subtle differences in trochlear flange design across manufacturers could influence radiographic interpretation.

Future investigations should assess external validity, and correlations with clinical outcomes including supracondylar fracture rates, anterior knee pain, patellofemoral complications, and implant survival. By providing a common language for both surgical decision-making and postoperative evaluation, this classification offers a practical step toward a more refined understanding of femoral notching in contemporary TKA.

Conclusion

The proposed Femoral Notch Classification provides a practical, reproducible framework that integrates biomechanical principles, surgical intent, and radiographic assessment to characterize anterior femoral notching in total knee arthroplasty. By distinguishing harmless or intentional configurations from those potentially compromising cortical integrity, it offers surgeons a common language for intraoperative decision-making and postoperative evaluation, independent of implant design or alignment philosophy. Although promising in concept, prospective validation of its reliability and clinical impact is required. Ultimately, this classification may facilitate clearer and more standardized description and contribute to a more nuanced management of femoral notching, reducing unnecessary concern over controlled resections while maintaining vigilance against excessive cortical violation.

Declarations

Ethics declaration

Not applicable.

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Author Contribution

AA conceptualized the classification system and drafted the manuscript. TR, JM, and JW participated in the validation of the classification, analyzed the radiographs, and critically revised the manuscript. All authors reviewed the manuscript.

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Figures





Figure 1

1A, 1B: Type 0: Anterior resection matches implant thickness, cortex fully intact



Figure 2

Type 1**:** Resection flush with native cortex; subtle contact, minimal or no measurable cortical loss



Figure 3

Type 2: Intentional shallow resection beyond cortical line (<3 mm) due to the trochlear geometry

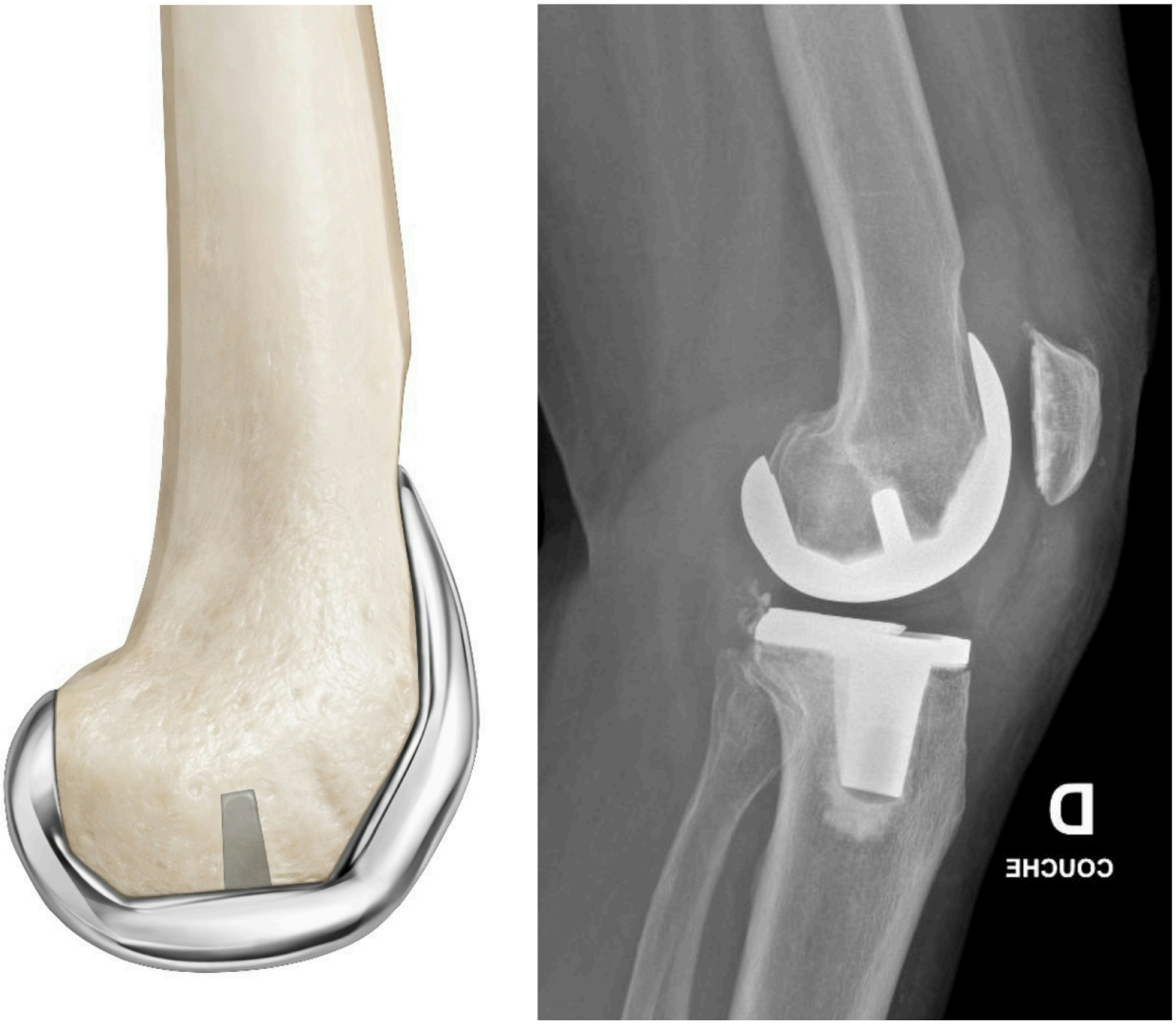


Figure 4

Type 3 Excessive resection without justification; cortical interruption