# When to stop hammering

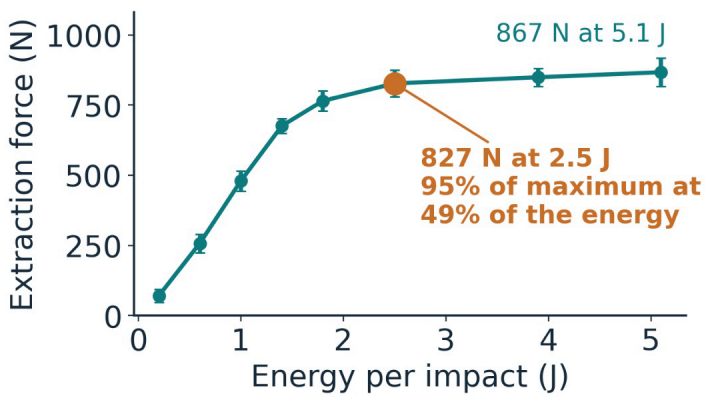
Tested across **1 million virtual bones** on an **NVIDIA GPU digital twin**, a force-plateau stopping rule achieved a **median 30% reduction in peak force**.

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## The fixation problem spans the femur and acetabulum.

**Nearly half of hip revisions** in worldwide registries are for aseptic loosening (35%) or periprosthetic fracture (11%) [5]: too little initial stability at one end, excessive interference or impaction at the other. Fractures also occur during surgery and often go unseen: intraoperative femoral fractures in 1.0% of 218,423 registry hips, more often with cementless stems [6], and CT studies find hidden acetabular fractures in roughly 7–16% of cementless cups, most invisible on X-ray [7]. AO aims to make each impact a measured decision toward **Best Fixation Short of Fracture**.

### 01 / THE BONE RESPONSE CONTAINS A SIGNAL



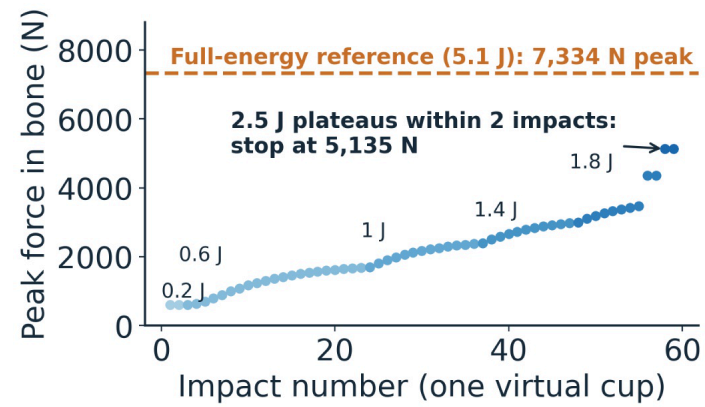

**95% of the highest measured mean extraction force at 49% of the impact energy.**

40 foam specimens; 8 energies; one cup and press-fit. Means ± SD. [1]

**0.70×**
median peak force vs the 5.1 J full-energy reference, $10^6$ virtual cups [2]

**≥97%**
relative fixation in evaluated virtual cups, estimated from depth [2]

### 02 / THE WRITTEN RULE NOW RUNS IN SIMULATION




One virtual cup: energy is raised only after each plateau. The 2.5 J level plateaus within 2 impacts, so the rule stops at 5,135 N. [2]

**WHEN TO INCREASE. WHEN TO STOP.**

Methodical, stepwise force, measured in bone and tracked against the number of impacts:

**When (first derivative):** as ΔF between successive impacts approaches zero, the chosen energy is no longer doing work of insertion. Step up.

**How fast (second derivative):** how quickly the plateau arrives. A plateau within about 2–3 impacts, or a step-cut rise in force as measured force approaches applied force, signals the bone nearing its elastic limit. Stop. [1]

**WHY NOW** Powered impactors standardize delivery, and HAMMR offers selectable energy, but the surgeon still selects the input and stops the sequence [4]. **AO adds decisions based on the measured response: how much energy to deliver, and when to stop.** Many small, measured impacts suit a powered system.

## A validated installer could become a reason surgeons choose your implant platform.

Proposed: instrumented impaction, independent fixation testing and a joint technical and IP review, within an approximately $5M staged plan.

**Next step: a 30-minute technical and IP briefing · kb@behzadimedicaldevice.com**

Continue to page 2: GPU performance and the evidence behind the result →

AO U.S. patent applications filed; pending and unpublished. References on page 2.

# Evidence behind the next impact

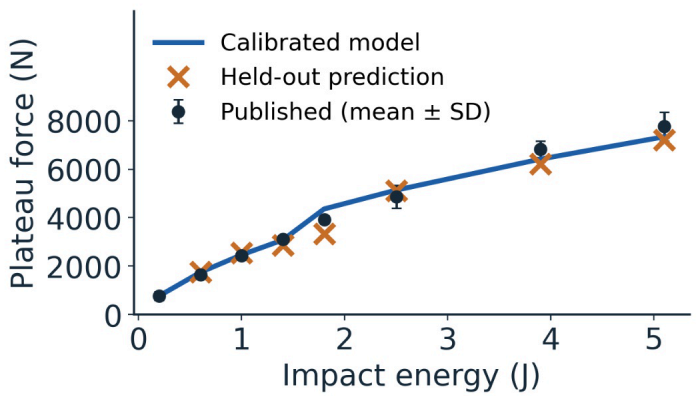
Calibration against bench data, resistance sensitivity, and a 1-million-cup outcome study, reproduced on two NVIDIA GPU systems. [2]

**29×**
GPU speed-up vs CPU, NVIDIA A100

**0.89 s**
for 10 million virtual cups

03 / CONNECTING PHYSICAL DATA TO SIMULATION

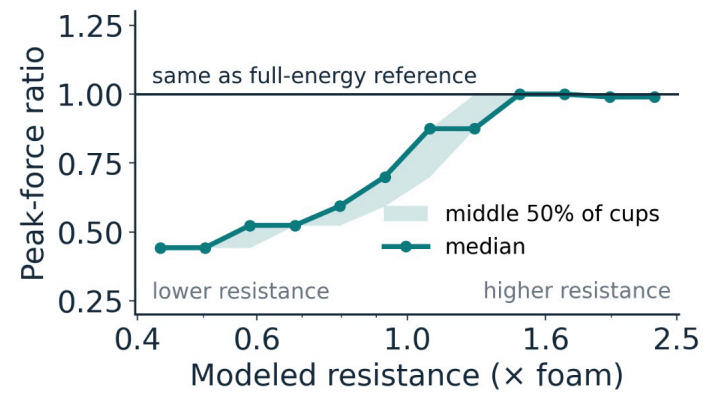
## Model calibrated against published bench data.




Published means ± SD against the calibrated model and held-out predictions; plateau force predicted within 4–15% when each energy level is held out. NVIDIA Warp runs one GPU thread per cup, so the rule can be tested across a million virtual cases. [1, 2]

04 / TESTING WHERE THE RULE MAY MATTER MOST

## Largest force reductions where resistance is lowest.




If this holds in physical testing, the benefit would be greatest in weaker bone: the older, osteoporotic patients at highest fracture risk. The resistance scale is not yet a validated measure of patient bone strength. [2]

PROPOSED AO PATH: A TWIN INFORMS THE NEXT ACTION [3]

**01 Measure**
APIM impaction; ESSOB bone preparation

**02 Update**
Patient-specific twin, blow by blow

**03 Predict**
BONES weighs benefit and risk of another impact

**04 Act**
Guide or control; surgeon supervising

**05 Learn**
Shared or federated data; validated before release

EVIDENCE BOUNDARY

A one-dimensional model calibrated to foam-proxy bench data; fixation is estimated from depth. No bone-yield or fracture mechanism is modeled, so these results do not establish an elastic limit or reduced injury risk; a rapid plateau is a proposed warning, not a validated fracture threshold. Peak force was lower in 81% of virtual cups; 1.7% (higher modeled resistance) exceeded the reference by more than 5%. [2]

NEXT PROOF: FIXATION AND BONE PRESERVATION

Vary foam density and cup fit; measure independent fixation, bone damage and sensor-noise robustness; then advance to cadaveric bone and the femoral stem. Proposed as a funded first stage with a joint technical and IP review, within an approximately $5M staged plan. Code available on request. [1–3]

[1] Behzadi K, Rusk J. J Med Devices 2021;15:021001. doi:10.1115/1.4049085. Table 2; Figs. 7–8, methodical loading and stopping.

[2] AO GPU digital-twin study, October 2026. NVIDIA Warp; same kernel on CPU vs NVIDIA A100 (Google Colab), including host–GPU transfer; results reproduced on two NVIDIA GPU systems.

[3] Behzadi K. The Autonomous Hip Installer Needs a Manhattan Project. October 2026.

[4] Johnson & Johnson, KINCISE 2 announcement, June 3, 2025. HAMMR Operation and Maintenance Guide, Rev. 8, Dec. 2024, pp. 16, 19, 25.

[5] Hauer G, et al. Septic complications are on the rise and aseptic loosening has decreased in total joint arthroplasty. Arch Orthop Trauma Surg 2024;144:5199–204. doi:10.1007/s00402-024-05379-2.

[6] Brüggemann H, et al. Intraoperative periprosthetic femoral fractures during primary THA: 218,423 cases, Norwegian Arthroplasty Register. Acta Orthop 2022;93:405–12. doi:10.2340/17453674.2022.2431.

[7] Occult acetabular fractures on CT after cementless cup insertion: 41 of 486 hips (8.4%), PMID 27800574; 16 of 232 hips (6.9%), PMID 33585969; 40 of 250 hips (16%), Kim SC, et al., AAOS 2023 (abstract).