Quantifying Joint Laxity in Total Knee Arthroplasty: A Comparative Analysis of Digital Tensioners and Surgeon-Guided Assessment

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INTRODUCTION:

Consistent ligament balancing is critical to the success of total knee arthroplasty (TKA), as suboptimal tensioning is associated with pain, instability, stiffness, early implant wear, and revision surgery. Traditionally, soft tissue balancing relies on subjective surgeon-led tactile assessment, introducing variability influenced by patient factors, intraoperative conditions, and applied varus-valgus moments, particularly in mid-flexion. This variability contributes to inconsistent insert selection and balancing outcomes. A digital tensioning device introduced in 2023, applies surgeon-defined, quantifiable forces (50±10 N, 100±10 N, or 150±10 N) to standardize ligament assessment. While a small premarket case series (N = 4) reported a 64% reduction in balancing variability, no large-scale clinical studies have yet validated its effectiveness. This study reports the first clinical evaluation of the digital tensioner in robotic-assisted TKA.

METHODS:

We conducted a retrospective analysis of 50 consecutive robotic-assisted TKA cases. Each knee served as its own internal control, with intraoperative ligament gaps assessed under both surgeon-led manual tensioning and digital tensioning. Gaps were measured in extension (0–3°) and deep flexion (87–90°). Intra-rater reliability was evaluated using intraclass correlation coefficients (ICC), and correlations between gap measures and patient variables (age, BMI, range of motion) were analysed.

RESULTS:

Digital tensioner-assisted balancing demonstrated reduced variability in medial extension (SD 3.34 mm vs 3.13 mm) and medial flexion gaps (SD 3.43 mm vs 3.34 mm) compared to manual surgeon-led techniques. Surgeon-led balancing showed significant correlations between age and medial extension gaps ($r = 0.308$, $p = 0.030$), and between BMI and both extension medial ($r = –0.330$, $p = 0.019$) and flexion lateral gaps ($r = –0.323$, $p = 0.022$); these associations were not present with digital tensioning. Intra-rater reliability was excellent for extension medial (ICC 0.876) and extension lateral gaps (ICC 0.899), but only moderate for flexion lateral gaps (ICC 0.575).

Under surgeon-led balancing, patients with full extension exhibited significantly tighter flexion medial gaps (mean –1.60 mm) compared to those without full extension (mean +0.82 mm; $p = 0.008$). Among patients achieving full flexion, surgeon-led techniques produced wider lateral extension gaps (mean 1.07 mm vs–0.85mm; $p = 0.022$) and flexion lateral gaps (mean 3.89 mm vs 1.94 mm; $p = 0.036$). In contrast, digital tensioner balancing showed no significant differences based on extension status (all $p > 0.05$), though lateral extension gaps differed between full and limited flexion groups (mean 0.83 mm vs –1.16 mm; $p = 0.023$).

Valgus knees showed significantly larger medial gaps and smaller lateral gaps compared to varus knees under both surgeon-led and digital tensioning. No significant differences were found in flexion lateral gaps for either method.

DISCUSSION AND CONCLUSION:

Digital tensioner-assisted balancing improves reproducibility and reduces the influence of patient-specific factors compared to traditional tactile surgeon-led techniques in robotic-assisted TKA. Incorporating objective tensioning tools may enhance the standardization of soft tissue management, particularly in medial compartments, although persistent lateral variability highlights the need for further refinement.