



Viewpoint

Restricted Kinematic Alignment in Total Knee Arthroplasty: Scientific Exploration Involving Detailed Planning, Precise execution, and Knowledge of When to Abort

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Not long ago, we were all transfixed by 50th anniversary tributes to humankind's most daring achievement to date, the Apollo 11 moon landing. At 2 hours 44 minutes and 19 seconds after launch, the crew performed another jaw-dropping procedure. Translunar injection, a 6-minute burst of Saturn V engines, thrust Apollo 11 out of a low, circular parking orbit around Earth and catapulted it at 25,000 mph toward its precise target: the Moon.

The 1969 Moon landing was a monumental feat of human perseverance, technological precision, and risk management. But behind the thousands of protocols and backup systems were hundreds of commands for "Mission Abort". First and foremost was the safety of the 3 occupants.

Exploration of scientific frontiers involves detailed planning, precise execution, and the awareness of when, for safety purposes, to say when. One of the most exciting frontiers in *our* field is the healthy debate about kinematic alignment (KA), which advocates positioning prosthetics relative to individual constitutional anatomy. Evidence suggests a myriad of benefits over the previous

mainstay, mechanical alignment (MA), including significantly improved soft-tissue balance requiring fewer releases [1–5] and enhanced restoration of physiologic gait patterns, adduction moments, and native knee kinematics [6–8]. Comparative clinical studies have demonstrated either equivalence or superiority to MA [3,9–14]. Single-surgeon series [15] and 7-year registry data [16] have alleviated concerns of premature prosthetic failure.

So, is there a problem, Houston? It is certainly hard to argue against the survivorship of MA, as 90% of MA patients still have a functioning prosthesis after 20 years [17,18]). Is it too early to throw away this technique founded on the fundamental principle of "first, do no harm"? Unfortunately, the one-size-fits-all approach of MA does not consider the wide range of normal knee anatomy, often resulting in significant gap asymmetry, soft-tissue imbalance, and unnatural joint line obliquities and heights. These factors may well contribute to the nearly 20% dissatisfaction rates reported by our MA patients.

So yes, Houston, we do have a problem ...but truly unbounded KA is probably not the answer either, particularly in patients with extreme anatomies. In these patients, bony landmarks can no longer be trusted to provide a target for a patient's constitutional knee alignment.

Therefore, where to from here? Well, as with any scientific endeavor, accurate planning, precise execution, and knowing when to abort must be the mantra as we explore options such as restricted KA (rKA).

Detailed preoperative planning

Detailed premission planning in 1969 ensured Apollo 11 would enter lunar orbit with pin-point accuracy. In 2021, preoperative planning using high-quality imaging (long leg radiographs, computed tomography scans, magnetic resonance images) provides the accuracy to hit the correct alignment targets.

This sort of imaging can quantify the 2 independent variables of joint line obliquity and prearthritic limb alignment (arithmetic hip-knee-ankle angle) [19]. These parameters define each patient's

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Coronal Plane Alignment of the Knee phenotype [20], a critical categorization for understanding how knee soft-tissue laxities will behave once implants are positioned ...in MA or KA. Furthermore, when target boundaries are imposed, these data allow predictions for when minor soft-tissue releases will be required.

However, it is important to acknowledge that both MA and KA reference bony anatomy. Future planning must go beyond describing constitutional phenotypes and, with the assistance of intraoperative algorithms, begin quantifying native soft-tissue laxities.

Precise execution

Unfortunately, many current intraoperative techniques fall short of ideal execution in total knee arthroplasty. Conventional cutting guides lack the required precision, as 30% of knees will have errors >3° off target [21,22]. Patient-specific cutting guides have not proven to be any more effective, and neither technique allows for intraoperative resection validation or assessment of soft-tissue laxities [23].

Precision technologies can mitigate real-world risks. Apollo spacecrafts used 3 sophisticated positioning systems to stay on target. Computer-assisted surgical navigation (CAS), with or without the use of robotic cutting arms, is the current undisputed gold standard for knee alignment precision, as it minimizes deviations from the intended target [21,22]. Most robotic platforms also provide virtual gap balancing algorithms that can restore native soft-tissue laxities and reduce the requirements for soft-tissue releases before any bony resections. The risk of “Mission abort” is minimized now that true precision is available in the operating room.

Restricted boundaries

Nevertheless, routine restoration of constitutional alignment should not be the goal for every patient. For those with atypical anatomy (eg, trauma, extra-articular deformity), KA without boundaries has the potential to inappropriately restore angles that are biomechanically unsound (eg, constitutional varus of 9°). Worse, imprecise guides can easily compound alignment errors, increasing the original deformity (say, to 12°).

rKA provides important protections by imposing “safe zone” alignment boundaries to avoid extreme outliers [3,13,24]. With CAS or robotic techniques, we now use Food and Drug Administration–approved boundaries of 6° varus to 3° valgus for final HKA and tibial coronal resections; 6° valgus to 3° varus for distal femoral resections; and ±6° to the surgical TEA for femoral rotation. These boundaries encompass 85% of normal individuals [25]. With an rKA philosophy, preoperative planning and intraoperative CAS validation will minimize implant failure risk and maximize chances that the correct target alignments are achieved, bone resection thicknesses are minimized, and as a result, normal soft-tissue laxities are restored.

Keep the journey on course

Full optical navigation, ideally with robotic cutting arms, allows for virtual implant adjustments before any resections to optimize restoration of soft-tissue laxities. Surgeon-defined assessment of soft-tissue balance has been shown to be a poor predictor of the true state of knee balance [26,27], but pressure sensors and other balancing instruments offer more objective means to quantify soft-tissue laxities.

Buzz Aldrin said, “Your mind is like a parachute: If it isn’t open, it doesn’t work.” We must keep an open mind in this evolving field of

research as adoption of rKA increases. High-quality randomized trials are needed to determine clinical effectiveness, and registry surveillance is needed to track implant survivorship. We will all have the fortune of working in a more reliable total knee arthroplasty universe when we use modern imaging to understand more about our patients, modern surgical technologies to precisely navigate the limb ...and modern restricted boundaries to know when to abort.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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