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Editorial

Mechanical alignment: The end of an era!

Half a century ago, Michael Freeman introduced the concept of right-angled femoral and tibial bone cuts in total knee arthroplasty (TKA)- mechanical alignment (MA) [1]. A little later, John Insall, raised the importance of balancing the resulting medial-lateral and flexion-extension joint gaps [2]. MA technique, subsequently, became the gold standard in total knee arthroplasty. The MA technique can be defined as “systematic”, in that all patients are implanted in a standardised fashion, without considering the individual native knee anatomy and physiological soft tissue laxities (Fig. 1). This non-physiological implantation was thought to be biomechanically-friendly, aiming to reduce the knee adduction moment and thus the risk of unbalanced prosthetic joint load (Fig. 1). This rationale made sense at a time when polyethylene quality, cementation technique and instrumentation were rudimentary. Over the decades that followed, multiple implant designs were developed, the quality of the polyethylene improved, the precision of implantation of components enhanced through advanced instrumentation and technological assistance (e.g. computational, robotics), and the implant fixation optimised. MA surgical technique was refined to reduce residual knee instability linked to modification of joint gaps: using soft tissue release algorithms with measured resection technique or the gap-balancing technique [3].

Robust clinical data emerged confirming the excellent long-term implant survivorship, with acceptable functional performance [4,5]. However, recent studies found that MA-TKA produces disappointing clinical results, particularly when compared to those of total hip replacement [5,6]. Rates of dissatisfaction and residual symptoms (e.g. pain, instability, stiffness) following MA-TKA have been reported to be approximately 15% and 50%, respectively [7]. In addition, patients’ perception of their prosthetic knees is rarely “natural” and forgotten joint scores are disappointing [6]. Interestingly, neither the use of technological assistance (to aid precision of implantation) nor new implant designs have solved these issues [5]. This highlights the technical limitations that are inherent to the MA technique, in that it produces a non-physiological prosthetic knee through alteration of the native anatomy, physiological ligament balance and kinematics [8–11] (Fig. 1).

Recent research has found the rationale supporting the MA technique to be questionable, resulting in a shift in beliefs within the orthopaedic community [12]. We now have a better understanding of the native knee anatomy and kinematics following the work from Eckhoff [13], which defined the three knee kinematic axes that dictate the motion of the tibia and patella around the femur. They showed that the tibia rotates around the cylindrical (or condylar) axis between 10 and 120 degrees of knee flexion, but not around the trans-epicondylar axis, as was always believed. Aligning the femoral component on the trans-epicondylar axis, as recommended by the MA technique, is therefore likely to be kinematically suboptimal. We have also learned that the post-operative standing frontal limb alignment (HKA angle) is of poor predictive value in assessing the risk of prosthetic failure [14] and predicting the knee compartment load [15]. Research from the Mayo Clinic has shown that slight varus or valgus limb deformity after MA-TKA did not impair the 20-year follow-up clinical outcomes [14]. Potential explanations are that the HKA angle varies when walking and thus should be seen as a dynamic value [16,17]; secondly, the two-dimensional X-rays measures of the frontal knee and limb alignments (short knee and long-leg, respectively) are a poor estimate of the true limb alignment as measured on three-dimensional images [18] even if digitized X-rays improve accuracy [19]. The one size fits all MA bone cuts may therefore not be the only way to achieve good long-term clinical outcomes [14].

It is clear we need to move beyond the simplistic concept that good long-term implant fixation can only be achieved by implanting TKA components within a pre-defined position, measured on antero-posterior radiographs of the lower limb. The systematic approach promoted by knee arthroplasty pioneers was sound for a period, but a paradigm-shift is developing. A patient specific and personalized surgical technique in which surgeons look to restore the individual knee anatomy, kinematics, and soft-tissue balance may improve clinical results while matching the MA implant survivorship.

Thirteen years ago, Stephen Howell developed an alternative technique for positioning TKA components, namely the kinematic alignment (KA) technique [8,10]. The KA technique aims to generate a more physiological, prosthetic knee, by aiming to restore the individual native knee anatomy and physiological soft-tissue balance (Fig. 1). KA aligns the femoral component on the cylindrical axis, anatomical rather than mechanical bone cuts are performed (true knee resurfacing), and no soft-tissue release is required. This personalised TKA implantation is intended to solve the aforementioned issues affecting MA-TKA (Fig. 1). KA is a new surgical technique composed of a series of well-defined steps, which carry little comparison to the original MA technique. Several studies have demonstrated the accuracy of the KA technique for correct component positioning [20], as well as the reproducibility in restoring the native knee’s anatomy [20,21] and physiological laxity [22,23]. Early- to mid-term safety (low complication rate)

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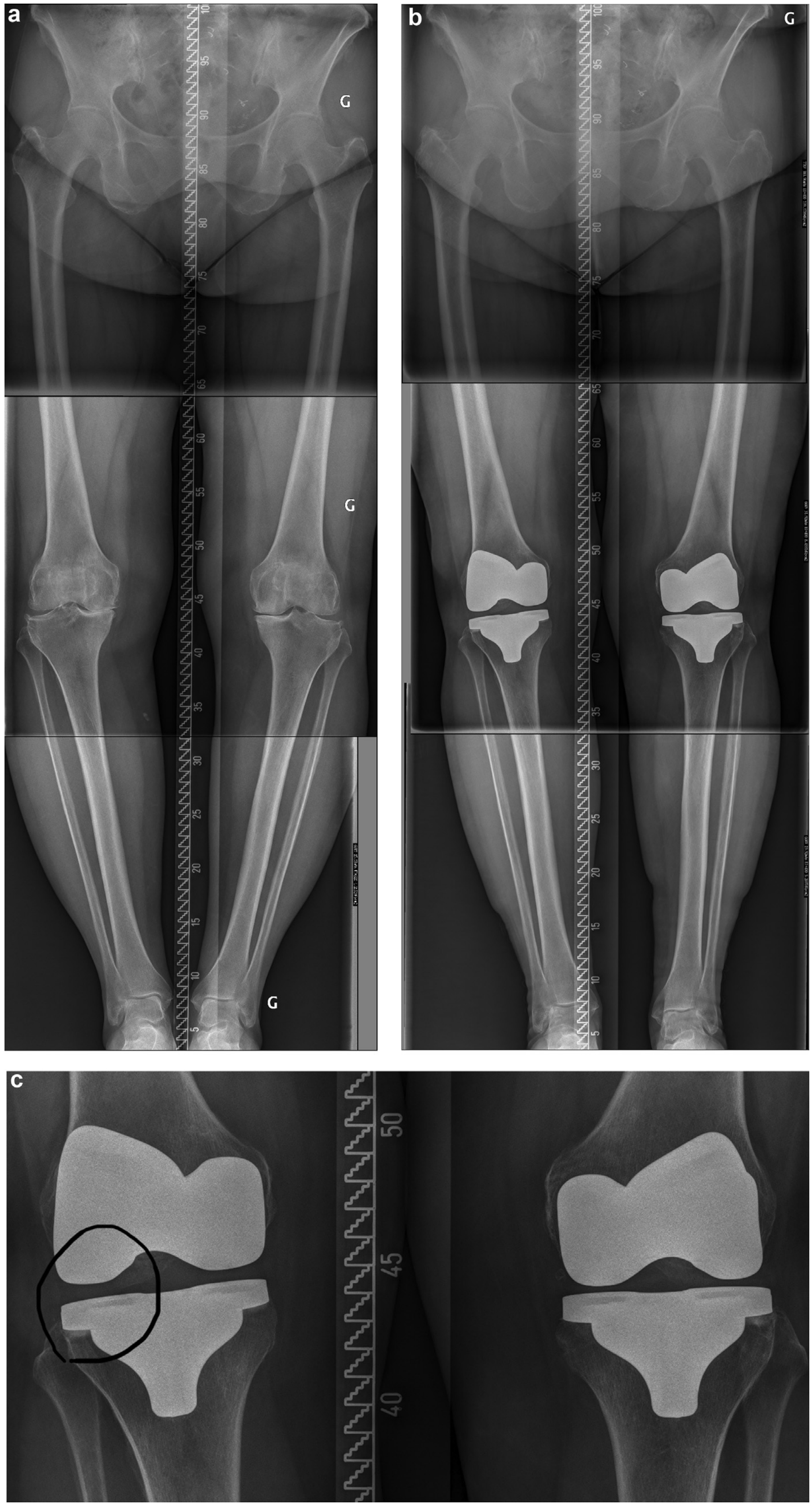

Fig. 1. a: standing lower limbs antero-posterior radiographs of a patient with preoperative bilateral medial knee osteoarthritis and varus hip-knee-ankle alignment; b: postoperative right total knee arthroplasty implanted with mechanical alignment and a left total knee arthroplasty implanted with kinematical alignment. Pre arthritic lower limbs alignment and native joint line orientation were reproduced with the left kinematic knee replacement; c: please remark lateral laxity during weight bearing on the right TKA using the mechanical alignment.

and efficacy (high function and satisfaction) have also been confirmed [24]. Today, 4 randomised controlled trials [25–28] and subsequent meta-analyses [29,30] comparing MA- and KA-TKA are available. They all reported better functional performance in the KA patients, however this was not statistically significant for 2 [27,28] of the 4 randomised studies. Additionally, the risk of developing anterior knee pain appears to be lower in KA patients, notably approximately five times less in one study [25]. KA patients have been shown to be three times more likely to report their knee as feeling "normal" in a national multi-centre survey in the USA [7].

The future challenge lies in determining if all patients' anatomies should be restored with KA-TKA. Some knee anatomies may be inherently biomechanically inferior, or may have been altered by metabolic bone disease, childhood deformity, etc. Concerns remain about restoring severe patho-anatomies, which may not be compatible with current TKA prostheses and fixation methods. One could argue that some of these outliers may in fact benefit functionally from a KA-TKA the most, whereas MA implantation would have greater anatomic alterations and soft tissue balance modifications [31]. However, this is also the group that may be at higher risk of aberrant biomechanics and subsequent implant failure (loosening, accelerated wear). Almaawi et al. [32] assessed the native knee/limb anatomy on 4884 three-dimensional lower limb models from osteoarthritic knee patients. They found that 18% of tibias had > 5° of varus, and 19% and 3% of limbs had a HKA angle > 5° (9% in varus and 10% in valgus) and > 10°, respectively. Currently there is a lack of evidence to help determine which native knee anatomies or biomechanics should not be fully restored when performing KA. Howell et al. [24] reported a 1.6% revision rate for aseptic failure (n = 3) in 207 consecutive KA-TKAs with 10-year follow-up. Only one tibial component was found to be loose, and four patients had severe patellar complications. In another study assessing KA-TKA, Nedopil et al. [33] reported that only 13 patients suffered patellofemoral instability out of 3212 consecutive KA-TKAs performed during a 9-year period; the authors were not able to find a relationship between pre-operative anatomic characteristics and the risk of patella instability. Other clinical reports [25–28] are of little use in determining the indications for a KA implantation, as patients with severe pre-operative frontal limb deformity were usually excluded. The good outcomes observed with component fixation may be explained by the relatively recent introduction of the KA technique (2006), and the fact that KA-TKAs seem to display a more horizontal joint line on single leg stance (reduced shear stress) [34,35] with acceptable knee compartment joint reaction forces during walking, similar to that of MA-TKA, despite frequently observed slight residual varus prosthetic limb deformity [34,36]. Recognized explanations for the acceptable in vivo KA-TKA biomechanics include: the reduction of the knee adduction lever arm when walking (more physiological gait for KA patients with limb more adducted during the stance phase when compared to MA patients) [34,37]; the decreased frequency and intensity of lift off [38] (Fig. 1); and the unpredictability of the dynamic HKA angles that are observed during walking from simplistic static standing HKA measurement [16].

Whilst we determine the optimal indications for performing KA-TKA, it seems reasonable to apply some arbitrary frontal alignment boundaries to adhere to when using the KA technique. The Restricted KA (rKA) protocol proposed by Vendittoli et al. [32,39] is an illustration of one such strategy. With rKA, the independent tibial and femoral cuts must be within ± 5° of the mechanical axis of the respective bone and the overall resulting Hip-Knee-Ankle angle (HKA) must fall within ± 3° of neutral. By applying the rKA protocol: approximately 50% of the cases will be unadjusted KA implantation (no anatomy modification, true KA); in 30% minimal anatomy modification (mean < 1 degree) will be required to bring the patient's anatomy in the safe range and; in the last 20% with outlier anatomies or pathological deformities, more important adjustments are needed [32]. By adhering to these rKA boundaries, it is possible to reliably produce a prosthetic knee with component/knee/limb alignments that always fall within an evidence-based safe alignment range [32,39].

To conclude, due to the significant deficiencies in both our knowledge and technology in the past, we were far from replicating normal knee kinematics with MA-TKA. With MA, the orthopaedic community commonly accepted many dogmas such that subsequent adoption of KA has been slow. Current limitations in TKA function and patient satisfaction should stimulate us to question our practice. Implant design and surgical techniques need to be advanced to better reproduce the anatomy and kinematics of native knees and ultimately provide a forgotten joint. Going back to the basic principle of respecting and recreating the human anatomy, KA is a sound solution. It is a simple and reliable technique that can be performed with or without the use of new technologies. Dorr et al. [40] have declared a death sentence on standardised acetabular alignment for hip replacement. We believe that MA technique for knee replacement has also survived much beyond its life expectancy and its death should be occurring in the very near future. We acknowledge that KA technique is still in its infancy and that further work is needed to obtain robust data on the good clinical outcomes observed with KA thus far.

Disclosure of interest

Charles Rivière declares being a paid-consultant for Medacta and Pascal André Vendittoli declares being a paid-consultant for Microport, Medacta, Stryker, Ethicon, and Johnson and Johnson. Jonathan Vigdorchik declares that he has no competing interest.

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