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Research Article

The Use of Computer Assisted Technology to Illustrate Common Errors in Total Knee Arthroplasty

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Abstract

An experienced consultant arthroplasty surgeon within our department highlighted three common intra-operative technical errors that he observed during TKA performed by trainees: (1) altered tibial resection height by translation of tibial cutting block, (2) digression from planned bone resection by applying leverage on the saw and (3) component malposition by eccentric impaction of a cemented tibial tray. Using a combination of image free navigation, lower limb sawbone models, routine TKA jigs and implants, we aimed to see if computer assisted technology could be used to demonstrate and quantify these errors.

Sliding a posterior sloping tibial cutting block along the pins created a discrepancy of up to 4mm in the level of tibial resection. Poor saw technique such as introducing leverage led to adversely altered bone resections in all planes. The most notable errors seen were with the distal femoral cut, where 'hanging' or 'lifting' the saw demonstrated a range of +/- 4° flexion and +/- 2 mm distal femoral resection compared to the planned bone resection cuts. Eccentric impaction resulted in malposition in the coronal and sagittal planes.

Computer assisted technology can be used to objectively monitor performance while providing augmented feedback to trainees, allowing trainers to quality control and optimising the training environment.

Keywords: Surgical Training; Total Knee Arthroplasty; Computer Assisted Surgery

Introduction

Gaining competency in performing surgery is a multifactorial process which traditionally is taught and learnt by an apprenticeship system. The process of performing total knee arthroplasty (TKA) is an example of a surgical procedure which requires a comprehensive understanding of the anatomy, the pathology of the underlying disease process, an appreciation of knee and lower limb biomechanics and the design principles behind the joint replacement. The act of surgery then requires mastering hand eye coordination skills and motor control for procedures which will not have been previously learnt.

The traditional apprenticeship model of surgical training requires repeated exposure to procedures and learning the steps of the procedure while operating on real patients. In modern medicine, where there is a restriction on working hours and an increase in the number of surgical trainees, it is believed that this translates into less exposure and in turn less opportunity for learning and practicing the motor skills required to operate safely. This may mean that it takes surgeons a longer period to reach competency, or that lower levels of competency are achieved before the surgeon commences work in independent practice.

In other fields of performance which involve obtaining motor skills and hand eye coordination, such as pilots and athletes, there has been much research in to how performance can be optimised. In some instances simulation models are used to evaluate and train, both to improve performance and maximise safety [1].

It has been demonstrated that verbal and visual feedback can improve performance in motor skills. Tzetzis et al [2] demonstrated that the combination of visual modelling and verbal feedback had the greatest improvement in motor skills when compared to traditional verbal coaching or observation of a skilled performer. Direct feedback with knowledge of the results can also contribute to the development of motor skills. This is believed to be particularly beneficial when the new motor skills are similar to those already learnt. Thus learning by feedback can improve performance of experienced practitioners and not just novices [3,4].

There is some evidence to suggest that experienced surgeons can also benefit from using the augmented feedback provided by computer navigation. This reportedly leads to improved accuracy in freehand component placement [5].

Total knee arthroplasty is composed of several steps and in each of these there is the potential for errors to occur. During the planning and subsequent execution of bone cuts, followed by component implantation, an accumulation of errors could lead to component malposition. An experienced consultant arthroplasty surgeon within our department highlighted what he believed were common intra-operative technical errors observed during TKA performed by trainees. These were:

(1) Alteration to the planned tibial resection height by translation of a posterior sloping tibial cutting block towards or away from the tibia.

(2) Potential digression from planned bone resection by applying leverage on the saw.

(3) Potential component malposition by eccentric impaction of a cemented tibial tray in sagittal and coronal planes.

We aimed to see if computer assisted technology could be used to demonstrate and quantify these errors.

Materials and Methods

A sawbone model of the lower limb with elasticised bands to represent the collateral ligaments was used. The model enabled physiological hip movements, knee flexion and extension and allowed the ankle to be freely moved. An image-free navigation system (Stryker Vision®) was used according to the standard intra-operative TKA workflow with active infrared (IR) trackers rigidly fixed to the sawbone model using bicortical screws. Standard registration of the anatomical landmarks and kinematic hip centre were established. All experiments were performed by a single experienced orthopaedic trainee regularly performing TKA under supervision. At three stages (detailed below) deliberate errors were introduced, the effects of which the operator was blinded to.

Experiment 1: To determine the effect of malpositioning a posterior sloped tibial cutting block by sliding it closer to, or further away from the tibia after establishing the required resection

Pins for the tibial cutting block were established with the navigation system at zero degrees posterior slope and varus - valgus angle was established at zero degrees. A conventional (non-navigation) cutting block with a 5 degree posterior slope was then positioned over the pins. A tracker applied to the slot of the cutting block demonstrated and quantified the proposed tibial resection. The cutting block was then moved further away from the tibia along the pins, and the planned new tibial resection was measured by the navigation system. The measurements were repeated with the cutting block advanced close to the tibia (Figure 1).

Experiment 2: Effect of poor saw technique by applying leverage on the cutting block with the saw blade

When using a saw through a cutting block it is possible to bend the blade which may apply leverage to the cutting block (Figure 2). A femoral cutting block was positioned using navigation. The planned resection of bone was 10mm from the most distal femoral condyle at zero degree of varus/valgus from the mechanical axis and 4 degrees of flexion as planned and determined by the navigation system. The cutting block was firmly fixed to bone with three pins; two parallel and one oblique in order to hold the cutting block as stable as possible. Using computer assisted navigation to demonstrate the subsequent line of the cuts the saw was extended or flexed to demonstrate any change in position of the cutting block as shown by the navigation system.

Experiment 3: Effect of eccentric impaction on cementation of tibial tray in the sagittal or coronal plane

When using cement it is possible to implant a component with an inconsistent cement mantle and we aimed to evaluate if this can lead to error in component position. Using a prepared tibial surface the tibial component was inserted with a cement substitute to represent bone cement. Surgeons have been observed to impact on the medial side and then the lateral side. In order to replicate this, a tibial tray was impacted using eccentric impaction in order to investigate the effect on component position.

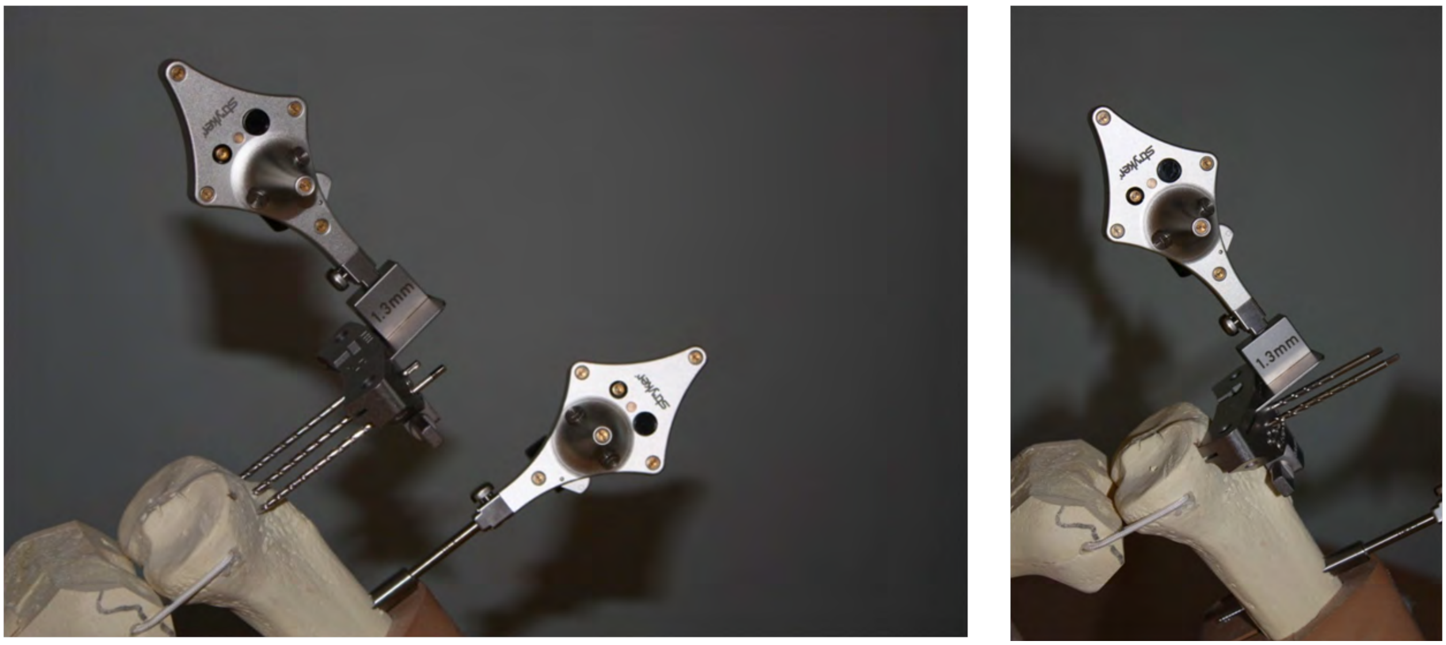

Figure 1. Cutting block positioned away from the tibia (left image) and advanced close to the tibia (right image).

Figure 2. Bending of the saw blade by either 'hanging' the saw (left image) or 'lifting' the saw (right image).

The component was impacted using three different methods. In the first instance after tibial component introduction it was impacted with direct pressure on the lateral side of the component (Figure 3). The second time it was introduced with anterior pressure in the sagittal plane but centrally in the coronal plane and finally with consistent central impaction as recommended by the manufacturer. The component positions in all three settings were then referenced using the navigation system.

Figure 3. Eccentric impaction of tibial tray.

Results

Experiment 1: Malposition of tibial cutting block

This demonstrated that with the cutting block held out from the tibia on the end of the pins the resection of bone was 2mm from the medial tibial plateau and 6 mm from the lateral tibial plateau. When the cutting block was advanced up to the tibia the planned resection of bone was 6mm and 10mm respectively. This confirms that the level of tibia resection changes if the posterior sloped cutting block position alters while sawing.

Experiment 2: Effect of poor saw handling technique

Lifting the saw led to excessive resection of the distal femur. Furthermore, excess valgus and flexion were introduced. Hanging the saw led to under resection, and a reduced distal femur flexion angle (Table 1).

Table 1. The effect on the distal femoral cut when 'hanging' on the saw or 'lifting' the saw compared to neutral.

Saw position	Distal femoral resection MFC (mm)	Distal femoral resection LFC (mm)	Varus/ Valgus resection angle	Distal femoral flexion angle
Hanging	8	3	1.5° valgus	1°
Neutral	10	3	0°	4°
Lifting	12	6	3° valgus	8°

During tibial plateau resection, hanging on the saw resulted in less bone resection and also reduced the posterior slope of the cut and introduced some varus. Lifting the saw for the same bone cut resulted in greater resection than planned, while introducing some valgus and increasing the posterior slope (Table 2).

Table 2. The effect on the tibial plateau cut when 'hanging' on the saw or 'lifting' the saw compared to neutral.

Saw position	Medial tibial plateau resection (mm)	Lateral tibial plateau resection (mm)	Varus/ Valgus resection angle	Posterior slope angle
Hanging	9	8	1.0° varus	3.5°
Neutral	10	10	0.0° neutral	5.0°
Lifting	11	11	0.5° valgus	5.5°

Experiment 3: Eccentric cemented tibial component impaction

A summary of the results can be seen in Table 3.

Table 3. The effect of three different techniques during tibial component insertion.

Impaction position	Varus/Valgus resection angle	Posterior slope angle
Intended position, central impaction	0.0° varus	5.0°
Anterior impaction	0.0° varus	-0.5°
Lateral side impaction	2.5° valgus	5.0°

It was observed that the intended position was obtained when the component was inserted with central impaction, while anterior impaction or eccentric coronal plane impaction result in component malposition. During anterior impaction the planned 5 degree posterior slope was lost with a 0.5 degree anterior slope created. The asymmetrical cement mantle created can be visualised in the sawbone model (Figure 4).

Figure 4. After eccentric impaction in the sagittal plane.

Discussion

Total knee arthroplasty is composed of a sequence of steps which require accurate completion in order for the prosthesis to be implanted in the intended position. Computer assisted surgery has been shown to result in fewer outliers in joint alignment [6]. Our study on sawbone models shows how navigation can visually demonstrate errors which would be difficult to appreciate without the aid of navigation tools.

Anecdotally some surgeons will advance the cutting block towards the tibia after removal of the reference guide which can be positioned to indicate the level of resection at 2 mm or 10 mm. If there is a posterior slope on the cutting block then this will result in a greater resection of tibia than expected or desired. It was hypothesised that navigation could be used to visually demonstrate the effect of this.

In the first experiment the tibial cutting block with a built in 5 degree posterior slope was translated in the antero-posterior (AP) plane relative to the planned resection position. The conventional level of resection is 2 or 10mm of bone from a chosen point depending on the degree of bone loss in the arthritic joint. We demonstrated that sliding the tibial cutting block along the pins can create up to a 4mm discrepancy in the level of tibia resection. This situation may be replicated in situations where soft tissue bulk limits the proximity of an extra-medullary alignment tower to the tibia and the surgeon may then attempt to move the cutting block closer to the bone once the alignment tower is removed. Furthermore, if required to make a second cut to remove more bone by repositioning the cutting block over the pins in the '+2' or '+4' holes, then it is possible to over or under resect bone unless the cutting block is positioned exactly the same distance from the tibia in the AP plane.

The second experiment demonstrated the effect of poor saw technique. Anecdotally some surgeons are taught to apply a bend to the saw and whether doing this deliberately or inadvertently this study demonstrates that this may result in incorrect cuts being made. The cutting blocks were pinned to the sawbones with three pins in order to optimise stability (two AP and one oblique). It is apparent that the distal femoral and tibial resections were adversely affected in all three planes; the axial, coronal and sagittal. It is believed that the cutting blocks must move by flexing and extending in relation to the bone but also pivot around the three pins thus creating the changes in varus or valgus. Most notable was the potential range of error seen with the distal femoral cut where the effect of lifting or hanging demonstrated a range of +/- 4° flexion and +/- 2 mm distal femoral resection compared to the planned bone resection cuts. It is likely that these effects are not fully appreciated without navigation systems to demonstrate the effect of different cutting techniques. However the effect of this on trying to intra-operatively balance the extension gap may be clinically or surgically significant.

The third experiment demonstrates that the desired component position may fail to be achieved if the impaction is done in an eccentric way. In the operating theatre it is difficult to visualise 360° around the tibial component as the view is often obscured by soft tissues and the femur, therefore it is possible that errors, particularly in the sagittal plane, may go un-noticed. This type of error is visible when practicing on saw bones and can be quantified and graphically illustrated on the computer monitor.

During the period of training surgical trainees are developing motor learning skills which depend on the intrinsic feedback gained from sensory stimulation during completion of the tasks. Extrinsic feedback comes from the trainer or can come from a computer navigation system. In the field of motor learning it is this combination of intrinsic and extrinsic feedback which is the most important variable affecting outcome [7]. In other professions computer simulators are used as part of the revalidation or recertification process. Our sawbone demonstrations show that this can be used to check cutting technique and in future computer navigation may have a role in assessing competence with stages of TKA as has recently been suggested [8].

With traditional arthroplasty methods the feedback on performance of surgical technique may only be assessed on the post-operative long leg x-ray. Current standards would suggest that an AP and lateral radiograph is done in the post-operative period and some surgeons would use this to analyse performance. It is accepted that there are limitations in what can be interpreted especially if the xray is a non-weight bearing short leg film [9]. The effects of a poorly implanted TKR may take many years to come to light and is therefore not an effective way of learning from mistakes which in practical terms will not be appreciated this far after the event. It could be argued that even using the post-operative radiographs result in an inappropriate delay between motor task and results feedback and in this respect this is not constructive for learning and not suitable for feedback on performance.

Our study has limitations as it is based on saw bone demonstrations of technique. In real bone the degree of variation may be different and may be affected by the quality of the patients' bone. Hard bone may lead to deflections in the trajectory of the saw blade, while soft bone may allow greater movement of the pins and therefore greater error in the cuts. It is difficult to quantify the effect making these errors would have on the function of the knee replacement. However, in either setting of sclerotic or porotic bone, the navigation system would enable immediate feedback. This would allow the surgical team to take steps to minimise the error, or indeed to correct it.

We have demonstrated several potential errors that can be introduced during TKA surgery. The magnitude of these errors are visually demonstrated and quantified by the computer, which we believe allows greater appreciation of the error and this type of extrinsic feedback is a valuable tool in learning and training. It is unlikely that an observer trainer would be able to quantify the degree of error in a trainee's performance to the same degree of accuracy as a navigation system. It is also possible that the errors we have demonstrated may go unnoticed as they are difficult errors to appreciate.

There is an obligation on the orthopaedic community to strive to improve standards including in patient care, surgical training and patient safety. It would appear from saw bone experiments that computer assisted surgery can be used as a way of objectively monitoring performance while providing augmented feedback to trainees, allowing trainers to quality control and optimising the training environment.

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