Towards a height and inclination adjustable tibial plate to postoperatively correct the residual ligament imbalance

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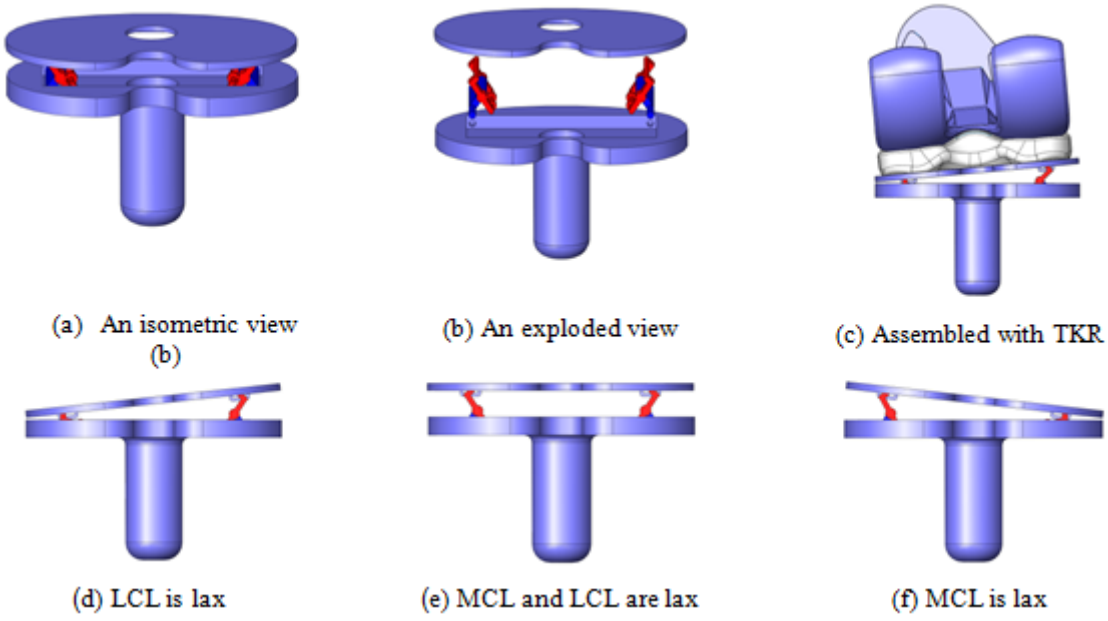
Introduction: Collateral ligament balancing during Total Knee Arthroplasty (TKA) aims to distribute the tibiofemoral load symmetrically between the medial and lateral sides of a well-aligned knee. It has also the objective of reestablishing a rectangular and identical tibiofemoral space in both knee flexion and extension. Currently, the proper tibiofemoral alignment and the perfect gap equalization are ensured thanks to Computer-Assisted Orthopedic Surgery (CAOS). Nonetheless, any residual ligament imbalance at the time of TKA can develop into an excessive imbalance in the postoperative period due to the weight-bearing daily life activities subjecting these ligaments to increased loading. Accordingly, this results in an accelerated polyethylene wear and consequently in an early failure of Total Knee Replacement (TKR). The poor ligament balance caused intraoperatively is principally due to the utilisation of an inaccurate ligament balancer which tenses the medial and lateral collateral ligaments in an uncontrolled way. The aforementioned shortcoming of the surgical instrument intraoperatively-used to balance the collateral ligaments raises the need for a postoperatively-adjustable tibial device. This device may be embedded within the tibial component of TKR and implanted along with the other components of TKR into the human knee. The purpose of such a device is to correct the residual mediolateral ligament imbalance of the prosthetic knee during the postoperative follow-up visits.

Materials: A detailed 3D CAD model (Fig. 1) of the proposed device has been designed and developed under ANSYS DesignModeler tool (ANSYS, Inc.) in order to describe its operation. The device consists of a fixed baseplate, a mobile plate and an in-between mechanism to adjust the height and inclination of the mobile plate with repect to the fixed baseplate.



The adjustable tibial plate for the postoperative correction of residual ligament imbalance

The lower baseplate is connected to the top plate by means of two scissor lifting mechanisms; one in the medial compartment and another in the lateral one. Each scissor mechanism is supposed to be operated by a miniature linear actuator. The actuator located at the bottom of the baseplate compartment is supposed to drive one sliding pin of the scissor mechanism towards and away from the other in order to move the upper plate upwards and downwards. The two actuators must automatically be driven by a microcontroller in response to the command signal sent by the surgeon and to the force and position values measured by adequate force and position sensors embedded within the device. Three force sensors must be embedded within the mobile plate to continuously measure the amplitude and location of the contact force. One position sensor must be embedded within each compartment of the baseplate to accurately measure the distance between each end of the upper plate and the lower baseplate at any time of the balancing procedure.

Methods: Postoperatively, the adjustable tibial implant could be used during or after the rehabilitation period to correct any residual imbalance. The patient must be in a dorsal supine position. At full extension of the prosthetic knee, the clinician must send a command signal in order to measure the amplitude and location of the tibiofemoral force applied by the prosthetic femoral condyles to the medial and lateral sides of the mobile plate through the polyethylene insert. If the distance between the measured location of the contact force and the reference location, measured immediately after the operation, is not negligible, the end of the mobile plate close to the lax ligament must be moved upwards in order to tension this ligament in such a manner that the two collateral ligaments are once again balanced. The increase in the vertical distance between the moved end of the upper plate and the lower tibial baseplate must not exceed 2 mm maximum in order to respect the tibiofemoral gap intraoperatively achieved and to maintain the mechanical alignment of the prosthetic tibiofemoral articulation. This step must be repeated at 90° of flexion without influencing the balance at full extension. This means that the balance of the collateral ligaments must be verified several times at both full extension and 90° of flexion until a satisfying compromise between the extension and flexion balances is reached.

Discussion & Conclusion: The need to correct the residual imbalance in the postoperative period by means of an adjustable knee implant arises from the fact that the ligamentous balance cannot be perfectly achieved during TKA, even with considerable release of one of the two collateral ligaments. In addition, the residual imbalance changes and increases after TKA due to multiple patient-specific factors such as age, weight, and activity level.

As a first step, we have proposed, designed, developed and tested a tibial component incorporating four piezoelectric elements used simultaneously as force sensors and energy generators. On the one hand, these elements used as autonomous sensors can accurately measure the load distribution among the anteromedial, posteromedial, anterolateral and posterolateral parts of the tibial plate through an original approach that we have also proposed [1]. On the other hand, these elements used as energy harvesters can produce a sufficient amount of electrical energy [2] to power a low-power consumption system that will be incorporated in the implant stem for the acquisition, processing and wireless transmission of data [3].

To the best of our knowledge, the adjustable knee implant proposed in this paper for future research will be the first one to quantitatively assess the residual mediolateral ligament imbalance and to postoperatively correct it by adjusting the height of one of the two scissor mechanisms and accordingly the inclination of the upper plate in ordre to tension the lax ligament in such a manner that the tibiofemoral alignment is not influenced.

References

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