

Cruciate retaining and cruciate substituting ultra-congruent insert

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Abstract: The posterior cruciate ligament (PCL) conservation and the polyethylene insert constraint in total knee arthroplasty (TKA) are still debated. The PCL is one of the primary stabilizers of the joint, but cruciate retaining (CR) implants have the disadvantage of a difficult balancing of the PCL. Postero-stabilized (PS) implants were introduced to reduce this problem. However, also the PS implants have some disadvantages, due to the cam-mechanism, such as high risk of cam-mechanism polyethylene wear. To minimize the polyethylene wear of the cam-mechanism and the bone sacrifice due to the intercondylar box, different types of inserts were developed, trying to increase the implant conformity and to reduce stresses on the bone-implant interface. In this scenario ultra-congruent (UC) inserts were developed. Those inserts are characterized by a high anterior wall and a deep-dished plate. This conformation should guarantee a good stability without the posterior cam. Few studies on both kinematic and clinical outcomes of UC inserts are available. Clinical and radiological outcomes, as well as kinematic data are similar between UC mobile bearing (MB) and standard PS MB inserts at short to mid-term follow-up. In this manuscript biomechanics and clinical outcomes of UC inserts will be described, and they will be compared to standard PS or CR inserts.

Keywords: Total knee arthroplasty (TKA); polyethylene insert; posterior cruciate ligament (PCL); ultra-congruent (UC) insert; total knee arthroplasty kinematics

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Introduction

The role of posterior cruciate ligament (PCL) conservation and the choice of the level of constraint of polyethylene insert in total knee arthroplasty (TKA) are still debated in literature. The PCL is considered one of the primary stabilizers of the joint (1) and its retention may influence knee stability, kinematic, proprioception and it may reduce the shear forces on the tibia. However, cruciate retaining (CR) implants have some disadvantages, first of all the possible difficulty to obtain a good balancing of the PCL. For those reasons, the so-called postero-stabilized (PS) implants were introduced (2,3).

Theoretically the PS insert should prevent posterior

dislocation of the tibia through a cam-mechanism, allowing also an increased range of motion (ROM), reproducing the physiological posterior femoral rollback and increasing the moment arm of the quadriceps. There are evidences that PS implants have less physiological kinematics, but soft tissue balancing and joint stabilization is simplified (4-6). In literature, similar outcomes are reported for CR and PS implants (7,8).

However, the PS implants have some disadvantages, mainly due to the cam-mechanism. This mechanism guarantees the posterior stability of the implant, resulting in more stresses on the insert, and high risk for polyethylene wear at the level of the cam-mechanism, most of all in fixed bearing (FB) implants (9). Furthermore, PS implants need

a greater amount of bone cut in the intercondylar box. To minimize the polyethylene wear of the cam-mechanism and the bone sacrifice due to the intercondylar box, different types of inserts were developed, trying to increase the implant conformity and to reduce stresses transmitted to the bone-implant interface (10). Mobile bearing (MB) inserts were developed to overcome this issue, in order to provide a more physiological motion of the implant and to correct small tibial rotational misalignment, in order to minimize polyethylene wear (11,12). Nowadays no differences in clinical outcomes or survivorship were found between FB and MB (13-15).

However, the introduction of those new inserts did not solve the problem: how contact stresses transferred on the polyethylene and resulting polyethylene wear could be reduced without sacrificing the stability and the physiological kinematic? How can the implant design avoid the problem of cam-mechanism wear? In this scenario it has been hypothesized that increasing the congruence of the implant may guarantee the stability avoiding the use of the cam-mechanism. For this reason ultra-congruent (UC) inserts were recently developed. Those inserts are characterized by a higher anterior wall and deeper trough compared to the standard PS inserts. These inserts should assure stability avoiding the posterior cam-mechanism, potentially diminishing polyethylene wear rates and consequently possible TKA aseptic loosening.

The state of art and clinical results of these UC inserts will be described in this manuscript.

Background: the cruciate retaining (CR) and postero-stabilized (PS) inserts

The choice between CR and PS inserts is still debated. CR inserts theoretically guarantee a more physiological proprioception and control of knee flexion, resulting in good knee stability and high functional outcomes in daily activities such as kneeling and climbing stairs. Furthermore the CR design does not require the sacrifice of an intercondylar box, preserving femoral bone-stock (16-18). The physiological kinematics of the PCL is not easy to reproduce in the joint arthroplasty. Furthermore, in cases of PCL laxity or flexion contracture to use the CR inserts can be extremely challenging, because of the difficult ligament balancing (19). In these cases a PS insert may be useful. PS inserts are characterized by a cam-mechanism engaging in a femoral intercondylar box, which stabilizes the posterior translation of the tibia. PS implants, because of the post-

cam mechanism, allow an easier ligament balancing compared to CR implants, in which it is mandatory to achieve a good PCL balancing (20,21). Furthermore, the mechanical enforcement of femoral rollback seems to modestly increase the ROM in posterior-stabilized implants (22-24).

Despite to the original advantages hypothesized for the PS insert, a clear supremacy towards the CR inserts is still not established. A recent meta-analysis concluded that the use of CR or PS depends mostly on the surgeon choice (25). The 2005 Cochrane systematic literature review by Jacobs *et al.* failed to prove a clear consensus in prosthesis design choice, except for enhancing a slight better knee flexion in PS TKA and a higher Hospital for Special Surgery score compared to CR implants (26). Recently another meta-analysis of randomized controlled trials carried out by Li *et al.*, shows similar results with a comparable clinical efficacy and prosthesis survival of the two inserts (8).

Ultra-congruent (UC) inserts: rationale and biomechanics

The rationale of modern designs is to minimize polyethylene wear by improving its conformity and reducing stress forces transmitted to the metal interface. The cam-mechanism of the PS inserts may lead different problems. This mechanism allows for more stability, but torque forces around it are enhanced, leading to polyethylene debris of the cam-mechanism. MB TKA is also characterized by a similar problem: those inserts are able to correct tibia rotational alignment, but their rotation on the tibial tray may increase the polyethylene debris (backside wear). Since long-term survival of implants is the primary aim in TKA, with polyethylene wear and implant loosening recognized as major causes of current TKA late failure (27,28), to reduce the risk related to the cam-mechanism wear, UC inserts were developed. These inserts are characterized by an elevated anterior lip and deep-dish through, in order to theoretically prevent anterior subluxation of femoral condyles during flexion (19,29). Furthermore, this increased congruence should theoretically avoid contact stress peaks providing better stress forces distribution.

Using these inserts, the stability of the knee is guaranteed by a more conforming articulation in conjunction with a correct soft-tissue tension. These implants do not need a cam-mechanism, avoiding the risk of cam impingement, wear or breakage, and reducing the risk of condylar fracture and excessive bone resection due to the intercondylar box (30,31).

Firstly UC FB inserts were introduced, but the early loosening due to the high congruence and low mobility of the implant suggested the development of a MB model (32). The UC MB inserts are characterized by the same benefits of a classical MB design, with shrunk shear stress on tibial surface and rotational freedom of the femur, in association to theoretical improved clinical outcomes and more physiological joint kinematic (33,34).

Little studies are published about UC insert clinical outcomes at short to mid-term follow-up. Similar outcomes at short term follow-up are reported when comparing UC MB and standard PS MB inserts. Concerning the radiographic analysis, lesser radiolucent lines in UC MB were evidenced at short-term follow-up compared to PS MB inserts, with similar survivorship reported at mid-term follow-up (35). However, flexion reduction using UC inserts was also reported compared to PS TKA (36). Moreover, fluoroscopic studies investigating the *in vivo* kinematics during active knee motion, demonstrated not perfect femoral rollback in both UC and PS inserts (37).

Biomechanics

There are few papers analyzing UC inserts kinematic. Most of those studies compared standard PS or CR implants to PS UC inserts, to evaluate hypothetical advantages concerning ROM and stability. In PS TKA the function of the PCL is substituted by the cam-mechanism that should provide a more physiological femoral rollback and wider ROM (38). Comparing fixed-bearing UC and PS inserts, similar kinematics patterns were found. Both the inserts showed reduction of the rotation of the femur on the tibia and slightly increase of shear stress forces, potentially correlating to higher risk of aseptic loosening (29,33). To improve kinematics and reduce the risk of polyethylene wear, mobile-bearing UC inserts were developed. A recent randomized controlled trial (RCT) compared MB PS UC and standard MB PS inserts. The UC group showed more anterior femoral translation from 80° to 120° of knee flexion compared with the PS group. Furthermore, the UC groups showed lower paradoxical internal rotation and greater external rotation from 40° to 120° of knee flexion compared with the PS group. No statistical differences were detected between the two groups in terms of coronal alignment. The authors concluded that, even if small intra-operative kinematic differences between mobile UC and mobile PS TKA can be detected, both designs are not able to fully reproduce physiologic knee kinematics (39).

Another recent study compared CR standard inserts to UC inserts in 39 patients. The authors analyzed both intra-operative stability and ROM after implantation of a CR insert and after the resection of the PCL and substitution with an UC insert. All data were collected using a navigation system. The authors demonstrated similar stability between the inserts, concluding that UC may be useful to preserve bone stock in case of PCL deficiency, but they do not increase the ROM (40).

Daniilidis *et al.* evaluated 31 patients (50 knees) who received a fixed-bearing CR TKA, 22 who received a flat polyethylene inlay (PE), 9 who received a deep dished PE and 19 patients with healthy knees were used as a control group. The authors concluded that highly conforming polyethylene inserts improved antero-posterior stability. No significant differences were observed between antero-posterior translation and femoral rollback. However, those inserts did not allow to restore a physiological kinematic, and the little differences between the inserts did not influence the outcomes (37).

Analyzing the existing literature on UC inserts compared to both CR and PS inserts, a greater antero-posterior translation can be achieved using UC inserts. However, despite those little differences in kinematics between the inserts, no differences on clinical outcomes between UC, CR and PS inserts can be detected.

Literature evaluation and clinical outcomes of ultra-congruent (UC) inserts

There are few papers focused on UC inserts clinical outcomes, and most of them are level IV studies (*Table 1*). This is due mainly to the recent introduction of those inserts.

In 2009 Wajsfisz *et al.* evaluated intra-operative flexion achieved with three different TKA designs (UC, PS and PS Flex), concluding about a slight superiority of PS models over the UC designs in terms of maximum flexion reached (36). More recently Kim *et al.* evaluated the intra-operative motion and mid-term clinical outcomes of MB UC TKAs *vs.* standard PS inserts. The authors observed a more physiological intra-operative kinematic of the PS inserts, without significant differences in clinical outcomes at three years of follow up (39).

Lützner *et al.* in 2013 compared the intra-operative stability and ROM before and after PCL resection, using a standard CR insert and a UC PS insert in the same TKA. The authors observed an about comparable medio-

Table 1 Summary of literature analysis about ultra-congruent (UC) inserts

Authors	Year	Knees	Type of study	Results
Argenson <i>et al.</i> (41)	2013	846	Retrospective analysis of different TKA models survivorship at a minimum 10-year follow-up	No significant differences in survivorship depending on models
Massin <i>et al.</i> (42)	2012	10	Intraoperative kinematic study of UC	UC decrease AP translation and femorotibial rotation. No differences in ROM. Some kind of posterior impingement in absence of rollback in UC
Wajsfisz <i>et al.</i> (36)	2010	72	Evaluation of intraoperative motion UC vs. PS vs. LPS	Better intraoperative flexion using PS models vs. UC
Kim <i>et al.</i> (39)	2015	90	Intraoperative kinematics and clinical outcomes comparison of UC vs. PS	UC decrease axial rotation. PS reduce AP translation and reproduce more physiological femoral rollback. No differences in clinical outcomes. Neither UC or PS reproduce perfectly the normal knee kinematic
Ko <i>et al.</i> (43)	2015	231	Clinical and radiographical results of UC vs. LCS-RP	No differences in clinical scores, ROM or radiologic results
Chavoix <i>et al.</i> (35)	2013	32	Functionality and clinical outcomes of UC at 5 years of follow-up	Good safety of UC. Mid-term functionality and clinical outcomes of UC similar to LCS
Machhindra <i>et al.</i> (44)	2015	202	Functional outcomes of UC vs. PS at 2 years of follow-up	Similar functional outcomes, patient satisfaction, adverse events but smaller motion of UC
Lützner <i>et al.</i> (40)	2015	39	Analysis of stability and ROM in UC-PS versus standard CR in the same TKA	Intraoperative similar stability, degrees of knee flexion, mediolateral and AP stability of UC and CR (before and after PCL cut)
Roh <i>et al.</i> (45)	2013	90	Evaluation of kinematic and functional outcomes in UC CR vs. UC PS	Preservation of PCL is not helpful in improve kinematics and clinical outcomes. No difference in ROM, functional scores and radiological results. CR has more varus rotation over 90° of flexion and more anterior translation. No difference in internal/external rotation
Peters <i>et al.</i> (46)	2014	468	KSS, radiographic results, revision and complication rates of UC vs. CR	All variables comparable between UC and CR
Uvehammer <i>et al.</i> (47)	2001	47	Radiostereometry evaluation and clinical outcomes of UC vs. PS	No differences in tibial rotation, maximum femoral AP motion, and lift-off between UC and PS TKA in radiostereometry
Daniilidis <i>et al.</i> (37)	2012	50	Fluoroscopic study investigating <i>in vivo</i> kinematics with a highly conforming and a flat inlay in CR TKA	The deep-dish inlay resulted in lower AP translation and a non-physiological rollback. Neither inlay types could restore physiological kinematics of the knee. Slight increased metal/bone interface stress in UC, reducing implant survival rates
Heyse <i>et al.</i> (48)	2010	8	Kinematic examination of patellofemoral pressure of UC vs. PS TKA	PS prosthesis design reduces the patellofemoral peak and mean pressure in comparison with UC

TKA, total knee arthroplasty; UC, ultra-congruent; LCS, low contact stress; CR, cruciate retaining; AP, antero-posterior; PS, postero-stabilized; RP, rotating platform; ROM, range of motion; PCL, posterior cruciate ligament.

lateral and antero-posterior stability, as well as ROM between the inserts (40). Massin *et al.*, in their kinematic analysis, observed a lower antero-posterior translation and femorotibial rotation with UC inserts, without any differences in terms of ROM compared to standard PS implants. However, the authors underlined some kind of posterior impingement in absence of physiologic rollback using an UC inserts (42).

The retrospective studies comparing UC TKA with standard PS or CR models (19,29,35,41,43,46,47) analyzed a big number of variables, trying to assess the superiority of one design *vs.* another. Implants survivorship, ROM, clinical scores (mostly Modified Hospital for Special Surgery Knee Score), radiologic results, patient satisfaction scores, incidence of adverse events, revision and complication rates were the most studied outcomes. However, none of those studies demonstrated significative differences regarding the analyzed variables, showing comparable outcomes between the inserts (19,29,35,41,43,46,47).

Conversely, two studies were able to detect some significant differences between UC and standard inserts. Recently Machhindra *et al.* retrospectively reviewed 281 TKAs, concluding about a slight reduced ROM reached with UC models and an interesting different recovery pattern. The UC TKAs reached the improvement peak of all variables studied at one year after surgery and then remained stable, while PS TKAs had a constant improvement for 2 years after surgery (44).

A smaller cohort of 50 FB CR TKAs was evaluated by Daniilidis *et al.*, who compared a highly conforming insert with the standard flat one. The authors demonstrated that either the congruent or flat inserts cannot restore a physiological kinematic movement, resulting both in an amount of abnormal anterior-posterior translation. In the same study the authors concluded that the high congruency of one group of insert may increase the metal/bone interface stresses, potentially reducing implant survival rates (37).

Heyse *et al.* focused on patello-femoral pain using different inserts, concluding that higher patello-femoral peak pressure and mean contact pressure can be achieved in UC TKA compared with CR implants (48).

Nowadays the only study that directly compared the CR and PS models of UC MB TKA interestingly found that the preservation of PCL was not helpful in improving kinematics and clinical outcomes. No differences in terms of ROM, functional scores and radiographic results were noted. However, the observation of less physiological kinematics, including more varus rotation and anterior

dislocation of the femoral component preserving the PCL, leads to the recommendation of using posterior stabilized UC inserts (45).

Table 1 summarizes the existing literature on UC inserts.

Conclusions

UC inserts were recently introduced basically to avoid the cam-mechanism wear and femoral intercondylar bone sacrifice related to PS inserts. Few literature regarding both kinematic and clinical outcomes of UC inserts is available. Clinical, functional and radiological outcomes, as well as kinematic findings are similar between UC MB and standard PS MB inserts at short to mid-term follow-up. However, those studies are characterized by small samples of patients and short follow-up: further studies are needed to confirm their findings. Considering that UC inserts were recently introduced as an alternative to PS inserts, the lack of studies comparing PS and CR UC inserts is not surprising. At our best knowledge, only one study directly compared CR and PS UC inserts, with no differences in radiological or clinical short-term outcomes. However, a less physiological kinematic was found in CR UC compared to PS UC inserts, including more varus rotation and anterior dislocation of the femoral component.

In conclusion there are few evidences on PS UC inserts, which may be a good alternative to standard PS implants, reducing the problems related to the cam-mechanism wear or breakage, and to the bone losses due to the intercondylar box. There are no clear advantages of preserving the PCL in UC inserts in terms of clinical outcomes, but less favorable kinematic was demonstrated, leading those authors to recommend PS UC instead of CR UC inserts.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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