THE THEORETICAL DEVELOPMENT, VALIDATION AND PRACTICAL IMPLEMENTATION OF AN X–RAY VIEWING TOOL FOR THE ASSESSMENT FOR ARTHROPLASTY IN TERMINAL KNEE OSTEOARTHRITIS

by

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A thesis submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy

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Johannesburg, November 2022

DECLARATION

I, Christiaan Rudolf Oosthuizen, declare that this thesis is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy in the branch of Orthopaedic Surgery at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

…………………………

(Signature of candidate)

7th day of November 2022 at Johannesburg

STUDENT AND CO-AUTHORS DECLARATION

Declaration: Student's contribution to articles and agreement of co-authors

I, Christiaan Rudolf Oosthuizen, student number 1830796, declare that this Thesis is my own work and that I contributed adequately towards research findings published in the articles stated below which are included in my Thesis.

Signature of Student ………………………………………… **Date**: 7 November 2022

Name of Primary Supervisor: Prof Sebastian Magobotha

Signature of Primary Supervisor ………………………………… **Date**: 7 November 2022

Agreement by co-authors: By signing this declaration, the co-authors listed below agree to the use of the articles by the student as part of his Thesis. In cases where the student is not the 1st author of a published article, the primary supervisor must explain (under comments) why the student is entitled to use the paper for his/her degree purposes.

Article 1:

Title: The Knee Osteoarthritis Grading System for Arthroplasty.

The Journal of Arthroplasty, 2019, 34 (3), 450-455.

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6th author	Gareth G. Jones		18/08/2018
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8th author	Innocent Maposa		30/09/2018
9th author	Hemant Pandit		23/08/2018

Comments by primary supervisor:

It is clearly illustrated in this article that the authors found the knee osteoarthritis grading system a useful tool in assessing the type of arthroplasty implant to use in osteoarthritis of the knee.

Article 2:

Title: The patient results and satisfaction of knee arthroplasty in a validated grading system. International Orthopaedics, 2019, 43 (12), 2747-2755.

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Comments by primary supervisor:

This article illustrates that when KOGS is used as a Tool for UKA, the patients Oxford Knee Scores were higher because it was the right implant for the condition of the knee deterioration.

Article 3:

Title: Impact of correctable mediolateral tibiofemoral subluxation on unicompartmental knee arthroplasty implant survival in patients with anteromedial osteoarthritis**.**

South African Orthopaedic Journal, 2021, 20 (4), 196-201.

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<u>Comments by primary supervisor</u>:

This article demonstrates that KOGS can differentiate clearly between different grades of Osteoarthritis with clear and predictable outcomes in implant survival and revision surgery.

ABSTRACT

Purpose of the thesis:
The essence of this submission is to present a validated tool to improve the identification of the suitable recipient for unicompartmental knee arthroplasty (UKA) and thereby facilitate the improvement of the clinical assessment and use of the UKA.

The study completed a peer-reviewed validation of the new X-ray based "Knee Osteoarthritis Grading System" (KOGS) to facilitate the accuracy/appropriateness of the arthroplasty implant required in knee surgery whether it is total knee arthroplasty (TKA) or UKA. Three studies evaluated different aspects of the system and this forms part of new empirical data that should help to facilitate the use of less invasive procedures for Kellgren and Lawrence grade 4 osteoarthritis (OA) in the tri-compartmental knee joint.

The first publication validated the KOGS as suitable to distinguish the different degenerative stages in need of a UKA (72% was selected from the cohort of KOGS Grades 1 and 2 knees) or a TKA (22.5% was selected from the cohort of KOGS Grades 3 and 4 knees).

The second publication selected the arthroplasty required and treatment implemented according to KOGS, and obtained at least the same, if not better results for the specific implants published in the literature with the distribution of TKA at 26%, medial-UKA at 59%, lateral-UKA at 13% and patellofemoral arthroplasty at 2%. The revision of TKA and UKA was no worse than the distribution in the literature with ipsilateral degeneration the most common failure mode in the UKA.

The third publication verified the authenticity of KOGS Grade 2 as a more severe degeneration with a relative 'instability' in the knee, with poorer results recorded for a unicompartmental knee implant in relation to the KOGS Grade 1, deemed to be more 'stable'. In this study, the short prospective study (P) followed a similar pattern to the retrospective larger study (R).

Further advantages of this empirical study are:
1. Recognising the different stages of pathology according to the KOGS classification, allowing empirical data accumulation.

2. The implant identification of the pathological stage is now possible e.g., UKA *versus* Bi-UKA, bicompartmental or TKA from the different stages of degeneration (different implants are used for a specific stage). Further subsets of degeneration are identifiable, relative to known results in UKA and TKA e.g., isolated single compartment OA in KOGS Grade 1 with an intact Anterior Cruciate Ligament (ACL) compared with isolated single compartment OA with ACL reconstructed knees (KOGS Grade 3A).

3. Various methods of clinical assessment and patient-reported outcome scores (PROMS) of the deteriorating KOGS Grades can be compared with different implants and as such, identify the optimal implant for a specific grade of degeneration (e.g., KOGS Grade 1 UKA *versus* Grade 1 TKA or Grade 4A Bi-UKA *versus* TKA).

DEDICATION

To the Oosthuizen family!

PRESENTATIONS ARISING FROM THE THESIS

1. Global Oxford Masters Symposium, 24–25 September 2012; Oxford, England:
   a) An X-ray score system to evaluate/qualify the knee for the suitability of a Partial Knee Replacement (PKR) or a Total Knee Replacement (TKR).
2. Amplitude International Hip and Knee Symposium, 13 April 2015; Cape Town, South Africa:
   a) Treatment options for early osteoarthritis of the knee.
3. The Partial Knee Meeting 2016, 17–18 March 2016; Knokke, Belgium:
   a) Comparison of Cemented and Uncemented Partial Knee Arthroplasty (PKA) results.
   b) Comparison between published X-Ray Knee Instability and Degenerative Score (X-KIDS) and new Knee Arthroplasty Grading System (KAGS).
   c) Constitutional Knee Wear Patterns and Incidence for Partial Knee Replacement.
4. 13th Meeting of the Combined Orthopaedic Associations 2016 (COMOC), 11–15 April 2016; Cape Town, South Africa:
   a) The results of the Cementless Partial Knee Arthroplasty (PKA) and ACL reconstructions.
   b) Comparison between the published "X-Ray Knee Instability and Degenerative Score (X-KIDS)" and the new "Knee Arthroplasty Grading System (KAGS)".
   c) Comparison of Cemented with Uncemented Partial Knee Arthroplasty (PKA) results.
   d) Constitutional Knee Wear patterns and incidence for Partial Knee replacement.
5. i-Decide 2016 Symposium (Stryker), 21–23 July 2016; Pretoria, South Africa:
   a) Assessment as to suitability for a UNI.
6. Amplitude International Knee Symposium, 22–24 September 2016; Lyon, France:
   a) Assessment of focal knee osteoarthritis for arthroplasty.
7. Oxford Partial Knee 40 Year Symposium, 26–27 September 2016; Oxfordshire, United Kingdom:
   a) The Knee Osteoarthritis Grading System.
8. Knee (Sports Medicine and Arthroplasty) and Hip Symposium, 27–29 October 2016; Cape Town, South Africa:
   a) The Knee OA Grading system (KOGS) as a Guide to Arthroplasty.
9. 18th EFORT Congress 2017 (European Federation of National Associations of Orthopaedics and Traumatology), 31 May – 2 June 2017; Vienna, Austria:

a) The Knee Osteoarthritis Grading System (KOGS).

10. The Partial Knee Meeting 2018, 25–26 January 2018; Bruges, Belgium:

a) Comparison of cemented and cementless Unicompartmental Knee Arthroplasty.

11. Life Healthcare Central Region CPD, 19 May 2018; Johannesburg, South Africa:

a) The Knee Osteoarthritis Grading System (KOGS) for arthroplasty.

12. 64th SAOA Congress 2018 (South African Orthopaedic Association), 3–6 September 2018; Pretoria, South Africa:

a) Wear Patterns of Medial and Lateral Compartments in the Knee.

b) The Results of Anterior Cruciate Ligament (ACL) Reconstruction and Unicompartmental Knee Arthroplasty (UKA).

c) Validation of KOGS (Knee Osteoarthritis Grading System).

13. Recon Instructional Course & Recon Interactions Meeting (Zimmer Biomet), 31 October – 2 November 2018; Cape Town, South Africa:

a) Interactive X-ray case discussion.

b) Avoiding early complications (and when to revise a PKA).

14. EKS Arthroplasty Conference 2019 (European Knee Society), 2–3 May 2019; Valencia, Spain:

a) Validation of KOGS (Knee Osteoarthritis Grading System).

b) The Results of Anterior Cruciate Ligament (ACL) Reconstruction and Unicompartmental Knee Arthroplasty (UKA).

c) Wear Patterns of Medial and Lateral Compartments in the Knee.

15. Annual conference of Tissue Repair and Regeneration, 29–30 November 2019; Zhejiang Chinese Medical University, Hangzhou, China:

a) Moving From Total to Unicompartmental Knee Arthroplasty: A Precursor to Tissue Repair & Regeneration of Arthritic Conditions of the Knee.

16. 66th Congress of the SAOA (South African Orthopaedic Association), 20–22 November 2020; Cape Town, South Africa:

a) Impact of correctable mediolateral femorotibial subluxation on implant survival in patients with anteromedial Osteoarthritis.

PUBLICATIONS AND BOOK ARISING FROM THE THESIS

1. Oosthuizen CR, Burger S, Vermaak DP, Goldschmidt P, Spangenberg R. The X-Ray Knee Instability and Degenerative Score (X-KIDS) to determine the preference for a partial or a total knee arthroplasty (PKA/TKA). SA Orthopaedic Journal. 2015;14(3):61-69.
2. Hamilton TW, Pandit HG, Lombardi AV, Adams JB, Oosthuizen CR, Clavé A, Dodd CA, Berend KR, Murray DW. Radiological Decision Aid to determine suitability for medial unicompartmental knee arthroplasty: development and preliminary validation. Bone Joint J. 2016 Oct;98-B(10 Supple B):3-10.
3. Campi S, Pandit HG, Oosthuizen CR. The Oxford Medial Unicompartmental Knee Arthroplasty: The South African Experience. J Arthroplasty. 2018 Jun;33(6):1727-1731.
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5. Oosthuizen CR, Van Der Straeten C, Maposa I, Snyckers CH, Vermaak DP, Magobotha S. The patient results and satisfaction of knee arthroplasty in a validated grading system. Int Orthop. 2019 Dec;43(12):2747-2755.
6. Oosthuizen CR, Maposa I, Magobotha S, Pandit H. Impact of correctable mediolateral tibiofemoral subluxation on unicompartmental knee arthroplasty implant survival in patients with anteromedial osteoarthritis. SA Orthop J. 2021;20(4):196-201.
7. Oosthuizen CR. The UKA (Knee Osteoarthritis Grading System). Textbook South Africa: Reach Publishers, 2020. ISBN 978-0-620-85273-9.

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- The Oosthuizen family

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NOMENCLATURE

AC1	First-order Agreement
ACL	Anterior Cruciate Ligament
AMOA	Anteromedial Osteoarthritis
AP	Anteroposterior
AVN	Avascular Necrosis
CPAK	Coronal Plane Alignment of the Knee
CT	Computed Tomography
FB	Fixed Bearing
FDA	Food and Drug Administration
FFD	Fixed Flexion Deformity
FJS	Forgotten Joint Score
HKA	Hip-knee-ankle
IQR	Interquartile Range
JLCA	Joint Line Conversion Angle
JSN	Joint Space Narrowing
K&L	Kellgren and Lawrence
KA	Kinematic Alignment
KOGS	Knee Osteoarthritis Grading System
MB	Mobile Bearing
MCL	Medial Collateral Ligament

MRI	Magnetic Resonance Imaging
NJR	National Joint Registry
NZJR	New Zealand Joint Registry
OA	Osteoarthritis
OKS	Oxford Knee Score
PA	Posteroanterior
PCL	Posterior Cruciate Ligament
PFA	Patellofemoral Joint Arthroplasty
PFJ	Patellofemoral Joint
PKA	Partial Knee Arthroplasty
PROMS	Patient-reported Outcome Scores
RA	Rheumatoid Arthritis
ROM	Range of Motion
TFJ	Tibiofemoral Joint
TKA	Total Knee Arthroplasty
UK	United Kingdom
UKA	Unicompartmental Knee Arthroplasty
USA	United States of America
WOMAC	Western Ontario and McMaster Universities Arthritis Index
X-KIDS	X-Ray Knee Instability and Degenerative Score

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1 INTRODUCTION

The degenerative knee presents to the clinician at a symptomatic stage with patient variance depending on symptomatology, deformity, and functional impairment. In the National review of adult elective orthopaedic services in England (2015) [1], a revealing statement is made about the real value of orthopaedic procedures: "It is clear that one of the reasons for the rising demand for orthopaedic procedures is the significant life enhancing impact of the procedures. It is the swift return for patients to good or enhanced function and to work and normal family life, which makes orthopaedics such a high demand service. It is this financial benefit to the economy, of re-enabling people, that should be remembered when considering the cost and scale of the provision".

The research by Mohammad [2] of over 8,000 medial Oxford unicompartmental knee arthroplasty (UKA) procedures interpreted that: "Very good outcomes were achieved by both designer and non-designer surgeons. The patient-reported outcome scores (PROMS), medical complication rate, and non-revision re-operation rate were better than those found in meta-analyses and publications for total knee arthroplasty (TKA), but the revision rate was higher [3]. However, if failure is considered to be all re-operations and not just revisions, then the failure rate of UKA was less than that of TKA".

The registries reflect hard data with survival as the endpoint, not distinguishing the misguided use of the UKA for unsuitable indications. This was researched by Kennedy *et al.* [4] and their assessment was quite revealing on data from 2006 – 2010, determining that only 20% of those revised had initial correct indications for UKA, with one-third presenting with unsuitable osteoarthritis (OA) for arthroplasty i.e., not "Kellgren and Lawrence" (K&L) grade 4 [5]. Furthermore, two-thirds were revised inappropriately for undiagnosed causes of pain.

The authors evaluating the New Zealand Joint Registry (NZJR) published "The lifetime revision risk" [6] and came to the conclusion that the risk of failure was higher in the younger UKA-group (46 – 50 years; 40.4%) and decreased sequentially to the oldest (86 – 90 years; 3.7%) with aseptic loosening the primary cause (and in females twice as prevalent as males) [6]. The incidence of sepsis was only 4% of all UKA revisions and 27% of the TKA with males dominating this category according to Tay *et al.* [6].

This study from 1999 to 2019 with 13,481 cases [6], follows a previous assessment from Tay *et al*. coming to the same conclusion of the UKA revision tendency [7].

Goodfellow [8] with his NZJR data analysis of the initial report [9] found that, despite more excellent clinical outcomes and results, the UKA was revised more often than similar presenting TKA's.

Kazarian *et al.* [10] in a Markov study concluded that surgical treatment using the UKA is more beneficial and cost-effective than non-surgical treatment of the affected knee suitable for an arthroplasty.

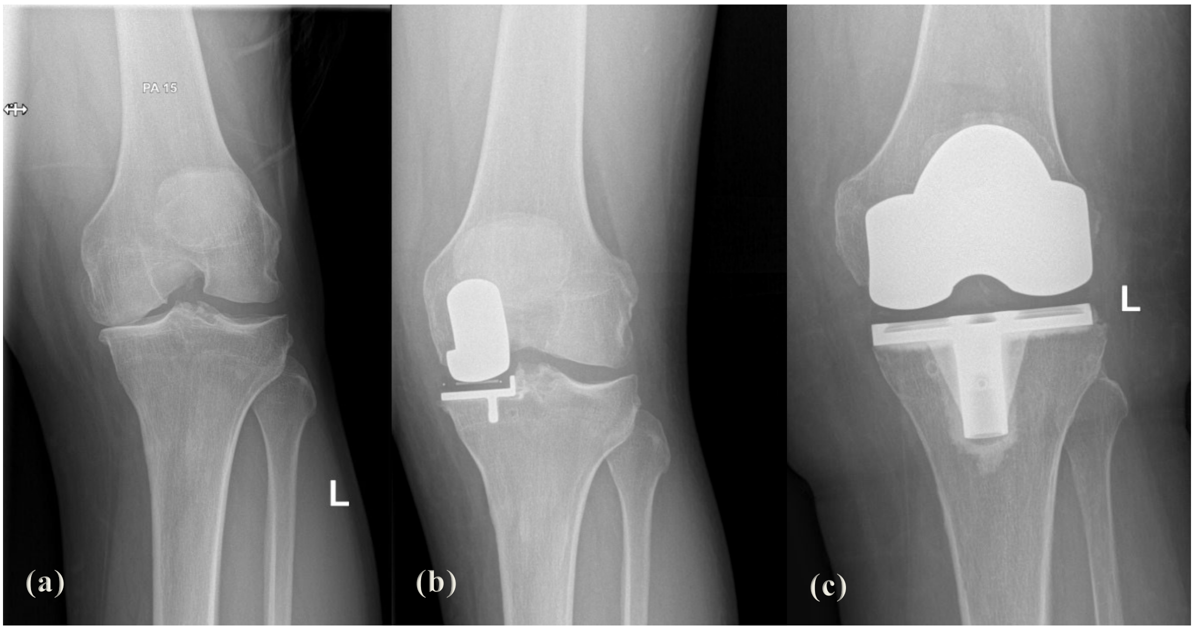

Figure 1.1: Anteromedial Osteoarthritis in the knee (a) treated with Unicompartmental Knee Arthroplasty (b) and Total Knee Arthroplasty (c) in the radiographs.

The indications for a UKA and a TKA differ markedly, although they can overlap. The decision to use a specific prosthesis should be clinically evaluated.

One of the major shortcomings in the use of the UKA is a specific tool to determine the most suitable and specific implant required. This can be achieved by grading accessible and cost-effective specialised knee X-rays with a validated grading system supporting the selection of the most suitable implant for the degenerative knee pathology.

The essence of this thesis is to present a validated tool that can facilitate the improvement of

the clinical assessment and advance the use of the UKA.
The methodology of the “Knee Osteoarthritis Grading System” (KOGS) was based on the specified X-rays, observation of in-situ wear patterns, development of the “X-ray Knee Instability and Degenerative Score” (X-KIDS) [11] and the “Radiological Decision Aid” [12].

1.1 Epidemiology of Degenerative Knee Osteoarthritis

Degenerative knee OA is a dominant health driver with a major increase in expenditure in health sectors with the lifetime cost expenditure being $140,300 and eventual TKA in 54% of all OA knees [13]. This will increase to 70% of all OA knees having a TKA with the indications of arthroplasty increasing from a K&L [5] grade 3 or 4 to a symptomatic joint grade 2 with less structural damage (The increase of knee arthroplasty is estimated to be more than 650% in the next 15 years).
Globally it is estimated that the UKA usage is about 10% [14]. In a macro study from the literature of 88 studies with 10,081,952 participants, “The Global Disease Study”, the prevalence of knee OA is 22% (over 40 years of age) and the “incidence of knee OA was 203 per 10,000 person-years” [15].

The UKA is effectively being under-utilised in the treatment of degenerative OA despite the prevalence of suitable recipients requiring a knee arthroplasty in the National Health Service in 47,6% of patients [16].

1.2 The TKA

The total knee replacement has been accepted for the last 40 years as the remedy for single compartment as well as tri-compartmental degeneration with minimal restriction in selection criteria.

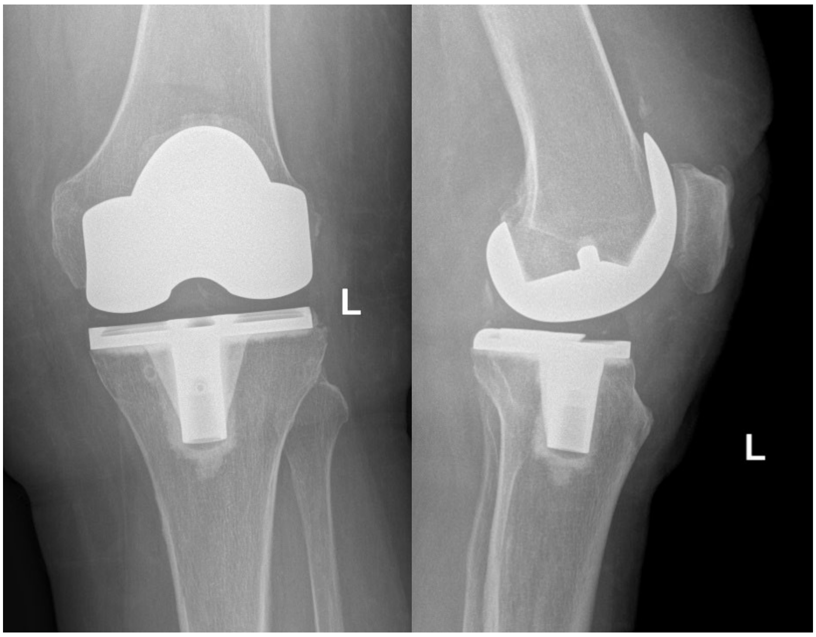

Figure 1.2: Postoperative Anteroposterior and Lateral X-ray views of the knee.
Total knee replacement in constitutional alignment.

1.2.1 Indications

The knee presenting with OA can be suitable for a TKA without boundaries in application as the indications can be justified for any knee condition with degenerative changes as seen on the X-rays. This is a major concern as K&L [5] grades 2 and 3 become acceptable for such invasive surgery, as there is no system that can evaluate the X-rays to discern the options that are probably appropriate.

The lack of defined indications and the use of the TKA as the appropriate implant is being questioned by various authors in recent times due to the poor functional outcomes achieved with current implants. Escobar *et al.* [17] developed a TKA appropriateness algorithm based on:

• Pain
• Function
• Physical examination
• Radiographic signs of OA
• History of prior knee surgeries

This algorithm selects at least 20% of TKA procedures investigated to be inappropriate [17]. Dan Riddle [18] adapted the algorithm for TKA in the United States of America (USA) and assessed 34% of the TKA procedures to be inappropriate.

The improvement after surgery of the Western Ontario and McMaster Universities Arthritis Index (WOMAC) in the inappropriate group was only 2.3 points *versus* 19.8 in the rest of the cohort in a follow-up study [19]. This is partly due to the ill-defined indications for a TKA without a reliable grading system of degeneration as a complimentary guide to the indications for arthroplasty.

The TKA implant evolved using different surgical techniques to facilitate results that are acceptable in functionality and alignment with resection of at least the anterior cruciate ligament (ACL) with measured resection, ligament balancing and 'kinematic alignment' (KA) procedures. The TKA requires removal of the distal femoral cartilage with chamfer cuts as well as a tibia chondral and meniscal cartilage removal at an accepted neutral cut of 90° on the long axis of the tibial surface. This changes the majority of the patients' native kinematics to facilitate an 'acceptable and functional' implant position.

The development of condition-specific patient-prompted studies (PROMS) indicate poor acceptance and functional results of the TKA in more than 20% – 30% of recipients [20] concurring with the contention from Bellemans [21].

1.2.2 Results

The results of TKA obtained with the 'condition-specific' PROMS illuminated the difference between the functional ability the patient experiences and the survival rate that has been the prominent foundation feature for promoting the TKA ahead of the UKA.

The awareness of individuality, associated with normal function for the individual patient, is becoming more relevant as the patient demands better function from arthroplasty.

This dissatisfaction is being addressed by improving surgical techniques to better placement and alignment, according to criteria pre-determined by the surgeon and assisted by robotic science.

Survival results for TKA is acceptable at 93% over 20 years and is higher than the UKA but with a higher permanent pain factor, with two times increase of venous thromboembolism, myocardial infarct, and deep infection. There is at least a three times higher incidence of a stroke, a four times higher risk of death in the first 30 days (and 15% higher for 8 years thereafter) and a functional deficit not assessed by the survival rate assessment criteria of the TKA [22].

The UKA revision rate to a TKA is higher than a TKA/TKA revision rate but the latter revision is exponentially more severe and complex, with poor results and a higher death rate according to Liddle [23-24].

The ‘Hinge’ TKA has a mortality rate of 10% after 2 years and is still regarded not to be a failure, but changing a bearing due to impingement, or a dislocation, is regarded as a failure with the UKA.

The prevalence of chronic pain (pain persisting longer than 3 to 6 months) in TKA is more than 20% of all procedures associated with utilitarian limitations, associated pain-related distress, depression, and social confinement according to a review study by Wylde [25]. This incidence is more than 10% in the study of Beswick *et al.* [26] with no author achieving less than 6% with permanent knee pain.

The UKA produces better outcomes according to the meta-analysis and review study by Santoso *et al.* [27] and has a 0.7% incidence of permanent pain.

Acceptance of the ipsilateral UKA/patellofemoral joint arthroplasty (PFA) option as an acceptable treatment rather than a TKA can contribute to reduce the high morbidity of the TKA revision [28].

1.2.3 Surgical Technique Innovations

In general, the TKA interventionists use John Insall’s description [29] of mechanical axis, so-called neutral alignment, as the ‘gold standard’; the alignment created does not fit all patients. Anatomical alignment for TKA was originally described by Hungerford and Krackow [30] to recreate the anatomic joint line where the overall joint line is set at 3° varus to the mechanical tibial axis. The reconstruction with these two-dimensional methods in knee arthroplasty is not always the reconstruction of the constitutional alignment, but the surgeon’s decision on alignment.

Howell [31] patented and published the “Kinematic Alignment” (KA) technique in 2005 to restore normal alignment by using three kinematic axes; the transverse axis of the femur (the tibia flexes and extends around this axis); the transverse axis on the femur (the patella flexes and extends around this axis); and the longitudinal axis of the tibia (perpendicular to the joint line) for internal and external tibia rotation. The axes are either parallel to the joint line or rotate perpendicular to the joint line and is endeavoured to be maintained during the surgical procedure [32] with results published in 2013 showing a low re-operation rate of 1.4%. No catastrophic failures were found [32].

Bellemans [21], in this quest to restore constitutional alignment in the TKA milieu refined the assessment with their Coronal Plane Alignment of the Knee (CPAK) to define the various phenotypes that they assessed and classified with a new matrix on joint line orientation as

valgus and varus or neutral mechanical axes [33].
Their pursuit is not to restore 'neutral' alignment as defined by a neutral tibial cut in TKA but to circumvent the joint line conversion angle (JLCA) due to the pathological process, and assess pre-disease 'native' anatomy and alignment comfortable for the specific patient [21,33-35]. The surgical procedure will then implement the pre-disease position for the implant.
The correct implementation of the CPAK method of evaluation and subsequent surgery requires long-term studies to confirm the efficacy.
The concept is important and a quantum leap improvement in the TKA technique to individualise the anatomy for better placement. The problem that is not being addressed adequately is the implant that sacrifices the anatomy including ligaments.

The open review study from Lording *et al.* [36] for EFORT in 2017 is concerned that the Bellemans-suggested system [21] does not fully consider the sagittal knee alignment and rotational alignment with soft tissue balance.
The 'correct placement' of the TKA implant is driven by 'robotic' alignment techniques, creating a new industry with debateable benefit as seen in the current literature with a very large cohort of 2392 mechanical axis TKA and 2392 robotic TKA from Tompkins with a 5-year follow-up [37].
The study from Y. Kim [38] with a suitably large cohort of 975 robotic-assisted knees and 990 conventional TKA's seems to confirm that after 10 years, the robotic implant insertion does not improve survival or functional score results and does not warrant the extra cost incurred for this treatment.
The problems associated with robotic surgery is the cost and effective time in theatre [20], as the length of the procedure after 120 minutes determines the increase of infection [39] and therefore the higher probability of incurring additional revision costs.

Figure 1.3 shows the native varus alignment on the right suitable for a UKA (KOGS Grade 1). The left knee has been treated with a primary TKA and, after failure, altered to a TKA hinge. The preferred treatment could have been a medial UKA for isolated medial compartment wear on the left knee, as is found in the right knee, to restore the constitutional alignment [40].

Figure 1.3: Anteroposterior long length alignment view.

The figure shows the native varus alignment on the right suitable for a UKA (KOGS Grade 1). The left knee has been treated with a primary TKA and, after failure, altered to a TKA hinge. The preferred treatment could have been a medial UKA for isolated medial compartment wear on the left knee, as is found in the right knee, to restore the constitutional alignment. The TKA is a solution of last resort and "UKA resurfacing techniques" should be considered if the indications are met as a substantive share of CPAK or kinematic "TKA repairs" could be treated with UKA implants that would be constitutionally aligned without the need for specific alignment technology.

1.2.4 TKA Design

The new alignment techniques do not address the loss of the cruciate ligaments in a quest for normal kinematics in the TKA design, as the medial and lateral compartments must be individualised with variable thicknesses of bearing and retention of all stabilising structures e.g., the ligaments.

The development of cruciate-retaining TKA implants improves the 'TKA concept' without addressing the restoration of the native anatomy and is a measured resection of the femur and then 'implant fixed angulations' and not the natural anatomy of the native knee. The advantage of this concept is the retention of the ACL and posterior cruciate ligament (PCL) function with a 3° intra-articular varus tibia cut and plastic bearing replacement as is required in the medial and lateral compartments. The knee that is suitable for this procedure is limited and classified as KOGS Grade 3B. This is where the patella is symptomatic and arthritic with a single tibiofemoral joint (TFJ) focal lesion and KOGS Grade 4A where both TFJ's are present with OA in an intact ACL knee. The practical prevalence of this requirement is in the vicinity of 4% of all knee arthroplasty.

The only 'total' arthroplasty that can attain near normal function is the use of a Bi-UKA rather than a TKA, as the resurfacing can be individualised in each compartment with the retention of the ligaments in isometric restoration, e.g., where the inherent KA is retained.

The call is for improved non-operative treatment modalities to lower the cost, but the focus should be to improve the diagnosis and the development of a less-morbid procedure than TKA with stricter qualifications for this 'end-stage' treatment modality.

1.3 The UKA

The major reason for the enduring acceptance of the TKA as the 'gold standard' is the controversies and results surrounding the different philosophies of the partial knee development, with the UKA driven by the success of the Oxford mobile bearing (MB) implant. The fixed bearing (FB) implant was recently improved with new available materials together with improved surgical technique in association with 'robotic' developments.

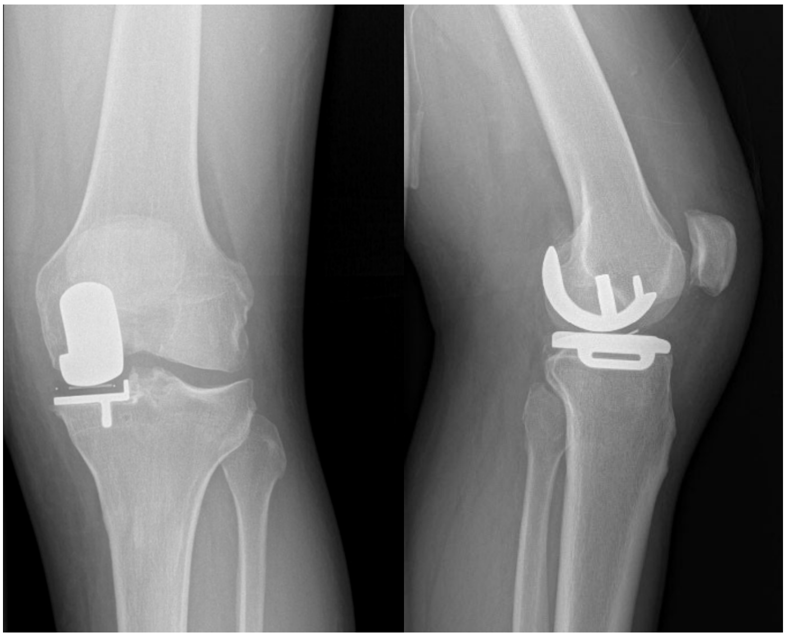

Figure 1.4: Unicompartmental knee arthroplasty with the Mobile Bearing implant.
Postoperative Anteroposterior and Lateral views of the knee.

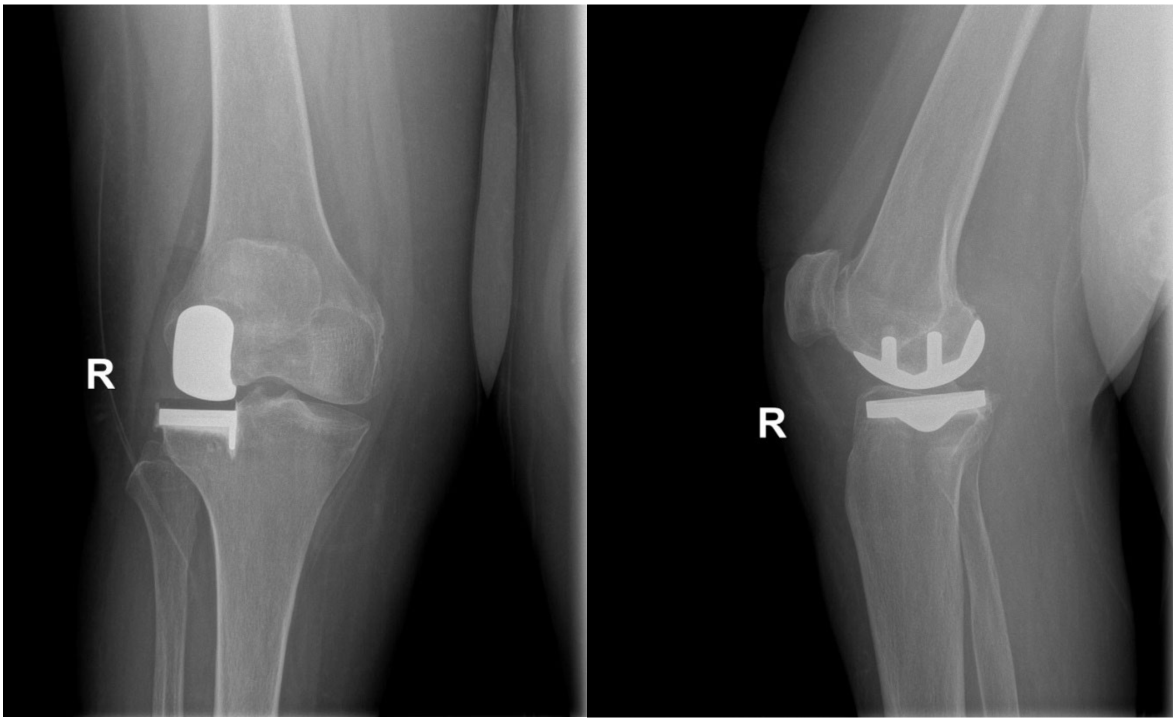

Figure 1.5: Unicompartmental knee arthroplasty with the Fixed Bearing implant.
Postoperative Anteroposterior and Lateral X-ray views of the knee.

1.3.1 Indications

A significant consensus was reached at the European Knee Society in 2019 (Valencia) as it declared the UKA the 'gold standard' for isolated knee pathology as the 10-year survival results of 96% for TKA and 94% for UKA is not significantly different and major benefits are derived for the patient with the minimal approach.

Multiple publications contradicted the findings of Kozinn and Scott [41] in their 1989 publication postulating that the UKA could be used in 2% of all patients and is thus not practical to be used. The thresholds proposed by Kozinn and Scott [41] using weight, age, activity, the state of the patellofemoral joint (PFJ) and chondrocalsinosis should not be considered as contraindications for the use of the Oxford UKA.

In the Pandit study of 1,000 prospective cases, the unnecessary contraindicated patients, in fact, did better than the "normal" indicated knees for UKA [42].

These were expanded to include isolated avascular necrosis (AVN) lesions and can be adjusted for FBs to include deficient ACLs [14,35-35].

The contraindications for the Oxford mobile option are deficient ligaments, infection and lateral facet OA or severe grooving of the patella with medial tibiofemoral disease [43].

The UKA as a treatment option had various influencing factors, including:

• An initial poor result from the publication of the Oxford Group by Goodfellow from his first 103 Oxford's in 1988 [44].

• Poor results achieved with poorly designed products and the inexperience of the surgeon was highlighted by Price [45] and Liddle [23] with great improvements over time.

• Ratification of the indications and factors influencing the implementation of the UKA, such as age, sex, young males with higher failure risk, previous pathology, expectations of the patient and the expertise of the clinician are factors to consider according to Böhler *et al.* [46].

• The reproducibility of the surgical technique and the cost (the overall costs are almost always lower due to early discharge, less need for rehabilitation and less risk of major complications) [45-49].

• The different registry results [50] and the limitation of each variant (mobile and fixed) elevated the surgical barrier for frequent implementation of the device.

• The inexperienced process of postoperative assessment; the progress of healing and understanding the long-term 'pathological' X-ray appearance (e.g., misinterpretation of 'physiological' radiolucency) [50].

• The ease of revising the UKA lowers the threshold for revision with even less pain than a similar TKA [8].

• The TKA is the accepted treatment solution for complications, although the ipsilateral OA progression can be salvaged with a better functioning UKA (discussion by Justin Cobb at Bruges 2018 Partial Knee Meeting, ‘Resisting Register’s pressure’) [51].
• Complications associated with the UKA, e.g., dislocation, loosening and/or wear of the FB-design and promoting the FB as a short-term solution due to erosive wear [52].
• The UKA is in a much better position to deal with ethnic idiosyncrasies, e.g., smaller implants and hyperflexion requirements in normal life where a chair is a luxury or not needed, e.g., in the central Asian areas.

1.3.2 Results

The National Joint Registry (NJR) for the United Kingdom (UK) reports a higher revision rate for UKA at 3.2 times that of TKA [53-55]. Even with PROMS, there is no advantage to doing the UKA according to the registries [53-55]. This is further complicated by the high-volume UKA surgeons, with an increased revision rate being classified as outliers in the UUK and were cautioned to improve their arthroplasty results despite instituting the more conservative and functional arthroplasty available (personal communication with Justin Cobb).
The data from the NZJR indicates that UKAs have fewer poor results than TKAs and more excellent clinical outcomes but get revised more often as concluded by Goodfellow in his critique of this data analysis [8]. The NZJR results indicate that UKA revisions are higher and predominantly due to loosening, whereas the TKA dominates at 27% due to sepsis *versus* 4% in the UKA-group [6].
“The most striking difference in revision rates occurs in patients who have a worse score postoperatively than preoperatively” – an Oxford Knee Score (OKS) less than 20 [8].
Patients in these categories have a 10% chance of being revised if they had a TKA and a much greater chance of being revised (60%) if they had a UKA [24]. Therefore, the revision rate of the UKA in registries is three times higher than TKA with a low revision barrier in UKA, as TKA with similar OKS (see Appendix G) is revised in 10% of cases where it is virtually 100% in the UKA. The TKA/TKA revision is exponentially more severe and complex than UKA to TKA, with poor results and a higher death rate according to Liddle [23-24].
The indication is that factors that are independent of outcome, increases the revision rate by five times, and with increased utilisation and education, the revision rate could be minimised [4,24].

1.3.3 Discussion about age

The elderly are prime candidates for the less morbid UKA although there is the current tendency to administer the 'final solution', a TKA, to prevent further procedures [56].

The exponential rise of utilisation in the younger age group of 50-59 years is disconcerting, as the disproportionate increase cannot be attributed to an increase of population or obesity, but more likely to extended indications.

Moreover, many studies have demonstrated that 25% of patients with a TKA are not satisfied with the condition specific result [57-58].

Long-term results recently published in 2018 by Kim *et al.* [59], concluded the UKA as a useful procedure for patients under 60 years of age despite the complications (dislocation (7.5%), loosening (2.5%) and of lateral progression (0.8%) usually associated with increased activity. The projection for primary and revision knee surgery as shown by Kurtz [60] confirms a large quantitative increase of arthroplasty from 2005 to 2030 with dire cost consequences, especially as the NZJR indicates that 27% of the TKA revisions are due to sepsis [6].

1.3.4 Developments

The long-standing conflict between the two different UKA philosophy proponents, MB, and FB, has been set aside to focus on the need to convince the orthopaedic surgeon and the public of the major improvements attained in recent years.

Substantially, the UKA is a resurfacing technique with two different solutions developed: the FB implant as a polyradial metal femoral prosthesis and a flat polyethylene tibia e.g., the St Georg Sled (1969) and the Marmor (1972); and secondly the spherical MB design by Goodfellow and O'Connor in 1978.

The hybrid development of a fixed and mobile bearing option on one tibia plateau is near completion and could solve the dislocation issue of the MB and the wear problem of the FB with a re-tread solution.

The resurfacing with the Oxford MB philosophy is more precise in tolerance but without the femoral anatomy replication. The implant simulates the femoral rotation of the distal condyle achieving a kinematic centre of rotation with a mobile congruent bearing on a flat surface of the tibia. Due to the spherical nature and precise isometric placement, the MB accumulates less volumetric wear from the bearing surfaces and is more forgiving to surgical error with longer survival terms [34-35].

The tibia in FB is a near-flat surface with eventual erosion of the bearing at the kinematic rotation point on the joint-line articulation surface. The FB developments are concentrated on replicating the femoral condyle anatomy as best possible with newer patient-specific computed tomography-based (CT) implants to prevent edge-loading with robotic technology being beneficial.

The principle of both philosophies is to maintain the ligaments at anatomical length to facilitate isometric balance in flexion and extension as a replication of function and alignment, therefore the restoration of normal kinematics.

The ultimate position that the TKA kinematic alignment [21,31-32] is trying to replicate is inherent in the MB design and to a lesser degree in the FB, as it is more difficult to attain.

Genetic 'abnormal kinematics' can be the cause of the enhanced varus or valgus wear.

On average this pathological cause of malfunction took 66 years in males and 65 years in females to become suitable for surgery and can hardly be improved by surgeon 'rationality' in knee arthroplasty.

The CPAK-TKA concept is the closest replication of constitutional KA of the various phenotypes as described by MacDessi [33,61] and most likely a technical improvement on Howell [31-32]. The data indicates that there are 9 specific groups of knees with varus alignment contributing 31%, neutral alignment 54% and valgus aligned knees 13%.

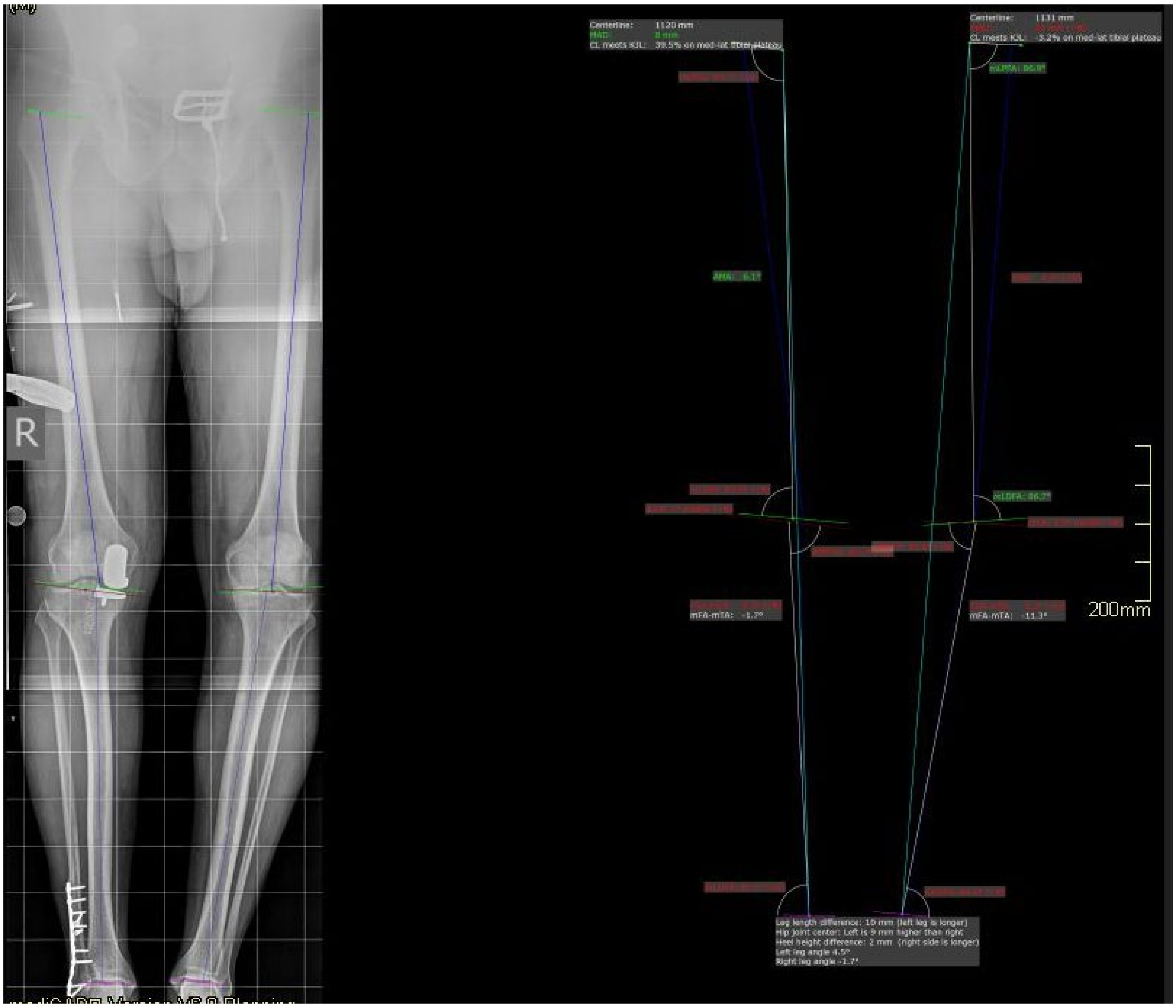

Figure 1.6: Hip-knee-ankle view.

Varus deformity confirmed with reduction in constitutional alignment as seen below.

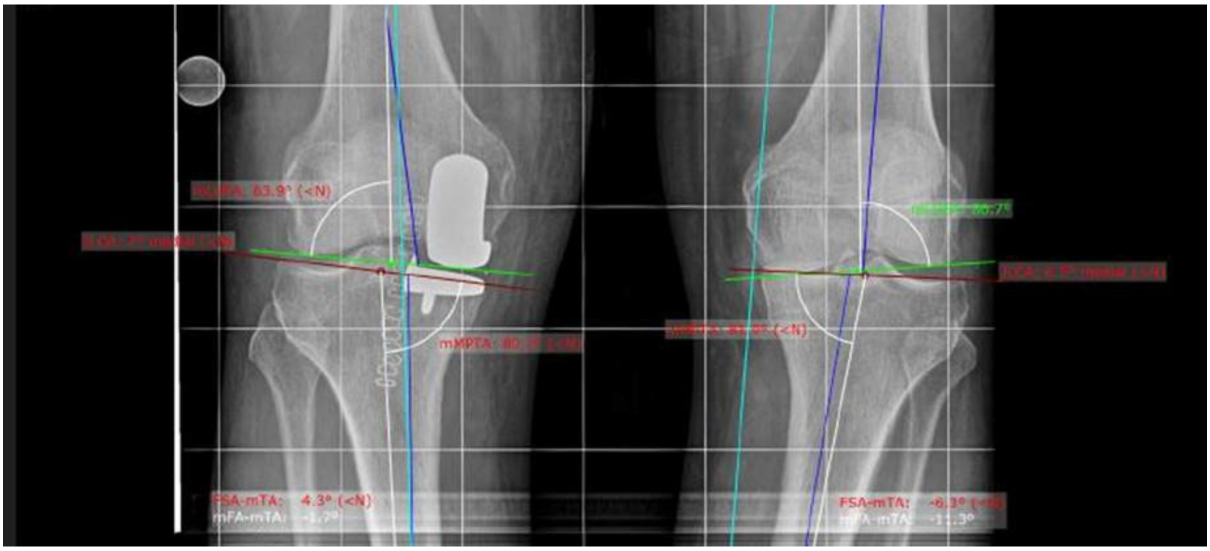

Figure 1.7: X-rays of varus coronal plane alignment in unicompartmental knee

arthroplasty.

The measured difference of the varus seen in the left knee was reduced within 1° of the constitutional alignment as measured.

It is likely that the CPAK matrix classification can benefit the identification of the 'outlier UKA' with a higher incidence of failure.

These knees could be identified by the classification and can require adaptation of surgery in FB as seen by the results of Plancher [62] who did a study to see the benefit of 'correct' placement of the implant.

It is unwise in the UKA to adapt the kinematics with bony cuts or ligament releases to facilitate 'normal' kinematics perceived by the surgeon. This is rarely necessary unless abnormal anatomy is identified and being corrected.

The MB surgical technique was simplified with the 'Microplasty' insertion technique, developed by the Oxford-group. The dislocation of the bearing was a frequent complication prior to this technique and is now less than 1%.

The insertion technique of the FB concept leans itself to the 'robotic' developments, as the femoral component requires precise insertion to prevent edge loading on a 90° neutral tibial implant. Currently the FB is taught to be inserted 'loose' as the precise tolerance of the MB technique cannot be replicated with normal instrumentation.

1.3.5 Barriers

There are multiple barriers to the use of the UKA with peer group pressure, inadequate training, fear of ipsilateral progression, fear of a dislocating bearing and a daunting learning curve.

The 'influence' of the PFJ OA is a common excuse to do a TKA rather than a UKA [63] with a real impact far beyond what the pathology deserves. This was evaluated by Hamilton in his research with no contraindication in most knees with degeneration unless lateral facet OA of the PFJ is present in a medial UKA or severe grooving of the PFJ [63].

Further problems are associated with the overload of TKA procedures required in teaching hospitals where the indications for a TKA is less restrictive and could be implemented and necessary in K&L grade 2 – 3 [5], resulting in trainees being less exposed to UKA.

This assessment from Kennedy [4] exposed the high incidence of failure due to the lack of adherence to the indications proposed by the Oxford-group [34-35] of having bone-on-bone contact (K&L grade 4 [5]).

The cornerstone of the KOGS in the assessment for arthroplasty is bone-on-bone degeneration i.e., full thickness wear in at least one compartment considered to be a K&L grade 4 [5] to obtain the optimal recipient and prevent the use of UKA without the correct indication.

1.3.6 Outcomes

The major advantage of the UKA is minimal invasion, retention of ligaments and maintenance of the native constitutional alignment and kinematics without any ligament balancing or 'neutralising' of the tibial cut.

The confluence of the UKA technology, correct indications and surgical improvement has led to the "forgotten joint score" (FJS) evaluation by Zuiderbaan in 2017 [64] and corroborated by Gill in 2021 [65] comparing the TKA *versus* UKA, with the UKA significantly better in performance than the TKA.

From a biomechanical point of view, the main characteristics of the medial and lateral compartments are different. The medial compartment is subject to high loads, with limited translation of the articular surface point of contact in the horizontal plane, whereas these displacements are more important with much smaller loads in the lateral compartment [66].

In his 2006 study, Weidow [67] demonstrated that a focal compartmental lesion accelerated wear in the ipsilateral compartment, and it is common sense to prevent further damage with the restoration of balance and stability with a minimal invasive solution like a UKA.

The spherical mobile design accommodates unique anatomical features to individual patients e.g., recurvatum and excessive varus knees in CPAK 1 phenotype [33,61].

The results of the UKA have improved with less blood loss, less risk of transfusion, improved gait restoration function as well as fewer re-admissions after surgery [68].

The UK NJR of 2016 indicated better OKS for UKA but 2.1 times the revision rate of the TKA [69].

Current literature comparing the UKA to the TKA indicates similar effectiveness with similar outcomes over 5 years with higher patient approval and cost-effectiveness in the UKA group than in the TKA [22].

Multiple studies indicate the benefit of minimal invasive surgery with less morbidity with the UKA and better functional outcomes [70-72], as did a systematic review and meta-analysis by Wilson in 2019 [73] confirming the superior results for the UKA but with higher revision rates.

1.3.7 Function

The UKA improves functional restoration with a reliable long-term outcome to complement the physiological age and the patients' preference. UKA is the least destructive restoration of the anatomy, thereby restoring the constitutional kinematic pattern and proprioception at an earlier focal stage of degeneration (K&L grade 4 [5]) before secondary damage occurs.

In a study by Ischii [74], he indicated that in any kind of TKA there is significant reduction of the quadriceps function compared to aged-matched controls and it deteriorates over time unless specifically maintained.

This is the primary reason to retain function with anatomy-sparing procedures that maintain normal proprioception of the realigned knee. Jones and Cobb [75] from the UK and Seeger and Clarius [76] from Germany are proponents of the partial knee philosophy and especially interested in gait analysis after arthroplasty and the damage done with the removal of the ACL. They confirm in their studies the deficit caused by changing the TFJ offset in the accepted TKA practice. This creates an objective functional deficit in the TKA, with the UKA gait proven to be more physiological with a better cadence and higher top walking speed.

This is further seen in the quicker return to sporting activities as well as better postoperative knee scores as evaluated by different authors such as Dr JC Ho [77]. In the Naal cohort [78], the rate of return to sporting activities achieved after 18 months was 95%. Most of their patients stated that the UKA surgery had maintained or improved their ability to participate in sports or recreational activities and they scored higher in the OKS – SF36, than normal age-related scores. Pietschmann [79] also reported that many of their patients (80.1%) returned to their sporting level of activity after UKA surgery.

Isaac [80] demonstrated that the UKA resulted in better dynamic proprioception than TKA.

In a prospective study in Edinburgh by Scott [81] of 289 TKA patients, of whom 261 (90%) worked before the procedure in active employment at the time of undergoing TKA, only 105 (40%) went back to work and, of these, 34% returned to their same jobs after a mean of 13.5 weeks. The conclusion is that the under 50-year-old patients invariably go back to work and between 50- and 60-year-old patients, only half returned to work. In this regard, the under 60-year-old patients with UKA perform much better, according to the literature, in activity levels after the surgery, according to Walker *et al.* studies in Heidelberg [82-83].

Further evidence from Waldstein [84] indicated the 'activity return rate' to be between 87% and 98% of patients in 2972 UKAs. Witjes in Sports Medicine 2016 [85] compared UKA with the TKA in returning to sporting activity following UKA and TKA, with the conclusion that UKA attains the better result.

In the younger age group, the dissatisfaction rate of a TKA is 25% according to the study from Edinburgh (Scott *et al.*) [57], with K&L grades 1 and 2 OA [5], poor preoperative OKS, complications and multiple operations contributing to the high dissatisfaction rate. The dissatisfaction rate improved to 14% for patients over the age of 80 when the functional requirement is less [57].

When the knee joint complies with the indications for a UKA intervention, there is no convincing evidence in the literature to substantiate delaying the procedure. With timeous interventions like the UKA to restore balance and alignment in the knee, the ipsilateral progression of OA can be reduced as assessed by Kang [86] in his study on patient-specific implants that reduced the contact stresses in the lateral compartment. Furthermore, the ipsilateral osteophytes in the healthy compartment are not predictors of reduced cartilage volume or wear, even with the most severe degree of osteophytes [87]. The increased motion in the ipsilateral compartment with focal pathology will also be reduced with the restoration of the constitutional kinematic pattern as evaluated by Weidow [67].

1.3.8 Complications and "revision"

The results of the UKA are blemished by the acceptance of a bearing dislocation by the arthroplasty community as an event of revision despite the remedy of replacing this with a thicker or same bearing when the cause of the dislocation was remedied without disturbing the bone implant interface. This creates an advantage for the TKA in survival results, not considering the qualitative, where the salvage TKA procedure becomes the 'gold standard' as a matter of course.

A prospective study of 1,000 knees published in 2011 by Pandit [42] indicated a survival of the Oxford implant of 96% after 10 years with survival even greater, at 99.8% when the implant was not removed and preferably treated with an ipsilateral implant.

This highlighted the problem of "revision" in UKA and the deemed poor results in the acceptance of ipsilateral progression as a failure despite the option of not removing the implant and treating the ipsilateral lesion with a UKA.

The development of the classification of partial knee combinations to record and facilitate a staged approach to the OA knee treatment by Garner [88] will contribute to a positive view of ipsilateral OA treatment with UKA and complements the vision of a less invasive and staged tri-compartmental approach [89].

There are three distinct problems associated with the UKA as a viable alternative to the TKA and our study aim is to address one of the major obstacles; the identification of the correct knee pathology for UKA and TKA as evaluated on X-ray.

Problem 1: Radiological Identification of the suitable knee for a UKA or a TKA:

A common theme of resistance to the less invasive UKA is that the suitable knee is seldom seen and therefore does not warrant the education or application to identify the selection despite the classifications of K&L [5] and Ahlbäck [90].

Keyes *et al.* [91] examined 200 knees and reflected that the Ahlbäck classification [90] represented the anatomical nature of medial gonarthrosis as seen on X-ray.

The general view that the knee OA progression is certain to develop in the ipsilateral side despite a balanced insertion of a UKA was not supported in a 10-year survival study by Weale *et al.* [92], as the mechanical properties of the knee elements are restored. With the normal ligaments retained, isolated medial wear is a focal disease and does not progress to the other compartments if anatomically restored [16].

A major obstacle of this accepted treatment approach is the unreliable identification of the variety of degenerative stages of the tri-compartmental degenerative knee [93].

Problem 2: Learning curve and Surgical volume:

Despite the majority clinician attitude, the UKA replicates the native constitutional alignment with the obvious advantages already relayed. The learning curve is steep as the use in the beginners' hand is complicated due to negative peer group pressure, higher failure rate, treatment seen as temporary and the inability to select the correct knee with an empirical tool.

The problematic lack of education and relative infrequent use of the implants is leading to high failure rates especially in teaching institutions where more terminal degenerative knees can be found. This is further amplified by the work from Kennedy [4] indicating poor selection of recipients for a UKA and subsequent failures.

The NZJR 2010 [94] found a surgeon performing fewer than 12 UKA's per annum has a higher revision rate than those performing more than 12.

Liddle *et al.* [95] found that surgeons performing at least 20% UKA's in their knee arthroplasty practices have the same revision rate as that of their TKA group. The reliability and reproducibility of the surgical techniques of insertion have been widely criticised in that it

compromised the survival results.
The major negative influence of osteophytes in the ipsilateral compartment and PFJ is a common excuse for the TKA default usage.

Problem 3: Development of new prosthetic innovations:
There has been resistance from the ‘old school’ who prefers and are adept to implant TKA as well as the orthopaedic corporations driving new TKA enhancing technology with new window-dressing concepts.
The lack of investment to enhance the UKA concept is largely due to the reluctance from the orthopaedic community to sanction the UKA technology.

2 RESEARCH AIM

To introduce a novel Knee OA Grading System that enables an Orthopaedic Surgeon to identify the severity of the degeneration in the knee and reach an informed decision on whether a TKA or UKA would be most suitable for each patient.

This study addresses the problem of selection with an X-ray based OA grading system as a tool for improved identification of the ‘stage of degeneration’ to assist the surgeon in implementing the preferred arthroplasty procedure for the degeneration diagnosed. The assessment guides the surgical decision when arthroplasty is considered and distinguishes between the need for a UKA or TKA.

Using a grading system allows comparative research to evaluate the results of similarly graded degenerative knees being treated with different types of implants.
The system supplements a good clinical examination, adherence to previous indications and contraindications as proposed by the Oxford school of thought [34-35].
The ultimate philosophy is to reconstitute native knee function using the normal anatomy as the reference and recovering constitutional alignment and therefore good clinical outcomes [34-35,95-96].

The objectives to reach this aim:

a) Publication 1 (see Chapter 3): To develop and validate the novel deteriorative degenerative knee OA grading system.

b) Publication 2 (see Chapter 4): To implement the validated grading system at multi-centre orthopaedic practices and compare the clinical results of KOGS graded knee deterioration with patient satisfaction data and implant survivorship with the completion of a PROMS questionnaire; the OKS (see Appendix G).

c) Publication 3 (see Chapter 5): To evaluate the difference in outcomes of the classification categories/groups from the grading system.

3 GRADING SYSTEM DEVELOPMENT AND LITERATURE REVIEW

3.1 The New Study: The Knee Osteoarthritis Grading System (KOGS) for Arthroplasty

There is no grading system classifying the knee degeneration for arthroplasty that includes the PFJ. The KOGS was developed from the X-KIDS [11] to be more intuitive, with the advantage of recognising the PFJ as part of the arthroplasty cascade.

The current grading systems used to evaluate knee degeneration was proposed by K&L [5] in 1957 and Ahlbäck [90] in 1968 and reviewed by Keyes *et al.* [91] in 1992, confirming the medial compartment degenerative progression as illustrated by Ahlbäck [90]. These studies have been accepted since their publications as the basis for developing visual correlated treatment regimens for knee OA from conservative to arthroplasty. These classifications are currently used to determine the appropriateness for specific treatment options.
Altman *et al.* [97] indicated that the best method to assess OA of the knee is with an anteroposterior (AP) weight-bearing radiograph, which assesses narrowing, osteophytes and sclerosis in the medial and lateral compartments and delivers the greatest sensitivity. He further classified the knee degeneration according to the cause in Idiopathic, Primary and Secondary groups covering all joints without a focus on the knee joint [98]. This was further improved by the posteroanterior (PA) Rosenberg/Lyon Schuss view assessment of the TFJ degeneration [99].

3.1.1 The Constitutional TFJ wear pathology

• Background:

Knee degeneration is progressive if not treated at the right stage of development and it shows a repetitive and progressive pattern in the constitutionally aligned knee. The pathology can be mapped by evaluating the wear pattern on the tibia plateau surface and correlating wear to the X-ray appearance. This pattern has a natural progression due to repetitive constitutional knee kinematics e.g., in the medial compartment.

• Progression of Constitutional Medial Wear:

Medial UKA is suitable for degeneration of a stable knee (intact ligaments) or with the reconstruction of ligamentous stability. The medial TFJ wears predominantly central-medially, comprising isolated anterior and medial wear or, in advanced cases, as an indeterminate 'deep dish' encroaching on the posterior third of the surface as the ACL weakens [34-35,100-101]. The medial compartment process of degeneration without ligamentous insufficiency was evaluated by dividing the harvested plateau in UKA into three zones: anterior, middle, and posterior, as did the first authors who identified the anteromedial wear pattern suitable for UKA [102].

This is the natural deterioration progression found by the author over years of observation and is not applicable to every knee, but a projected process to understand the mechanical effect of the deteriorating evolvement [40]:

a) Isolated wear on medial or anteromedial area.

b) Early varus without subluxation depending on loss of cartilage thickness.

c) Progressive varus with larger defect and secondary osteophyte formation in the medial, lateral, and patellofemoral compartments.

d) Subluxation without ligamentous instability due to progressive wear defects.

e) Lateral tibia spinous process impingement onto the lateral femoral condyle.

f) Loss of extension due to anterior, posterior, and intercondylar osteophytes. The osteophytes anterior to the ACL and in the intercondylar notch will cause extension loss/fixed flexion deformity (FFD).

g) Large medial wear defects will cause 'pseudo-laxity' with osteophytes contributing to the eventual ACL function loss and subsequent posterior wear on the tibial plateau with eventual tri-compartmental degeneration.

h) With increasing subluxation, the ACL signs of disruption are seen on the X-rays with rounding of the spiky spinous processes due to the instability.

i) The PFJ and the lateral compartment deteriorates with further impingement of the tibial spine onto the femoral condyle [40,100].

j) With severe degeneration the knee 'stabilises' due to large defects with restriction of motion and massive osteophyte formation.

• Progression of Constitutional Lateral Wear:

The lateral degeneration process seems to cause the ACL rupture at a later stage, as there is less 'instability; with subluxation (medial TFJ is less lax with less rollback) and only with severe and increasing valgus, medial collateral ligament (MCL) instability develops with rigidity of the lateral ligamentous structures. Range of Motion (ROM) is initially maintained and progressive wear with loss of extension is relatively mild.

This is the also the natural deterioration progression found by the author [40]:

a) Isolated wear causes increasing valgus.

b) Progressive wear causes more external rotation of tibia.

c) Medial compartment is maintained for longer with the degeneration progression.

d) The ACL fails less often with progression in severe deformity.

Lateral compartment degeneration is similar to the medial compartment but in reverse, where the wear is predominantly central and posterior on the tibial plateau.

3.1.2 The X-ray Method of KOGS

• Sequences:

1. Standing AP [97,103] and Lateral [91,104] with patella skyline [105-107].
2. Rosenberg view/Lyon Schuss 15° (medial TFJ) [99], 45° (lateral TFJ) [108-110].
3. Stress views in 20° of flexion [34-35,111-112] confirm the stress views as the best for evaluating the contralateral compartment for wear and confirming the correctable varus wear with intact MCL.

Figure 1.8: The X-ray sequence views for the "Knee Osteoarthritis Grading System". *(a) Standing Anteroposterior view; (b) Lateral view; (c) Patella skyline; (d) Rosenberg view 15°; (e) & (f) Stress views.*

Standard X-rays are cost-effective and suitable for OA of the knee [113-115]. The standard X-ray is still the most accessible, user-friendly, and reliable system for general use, and is Food and Drug Administration (FDA) approved in arthroplasty [113-115]. This is accepted by the Oxford Group as the 'gold standard' for arthroplasty assessment as similarly published by the American Academy of Orthopaedic Surgeons comparing standard X-rays with the findings of Magnetic Resonance Imaging (MRI) [114].

The MRI is a too sensitive and more detailed evaluation of cartilage degeneration, but less pragmatic compared to standard radiography [115]. A plain radiograph (or even MRI scan) with typical bone-on-bone changes in an isolated compartment and presence of osteophytes in the other compartments, without evidence of joint space narrowing (JSN), is often diagnosed by radiologists (or rheumatologists) as ‘tri-compartmental OA’, but evidence suggests that, despite the possible early OA defects, it does not convert to early UKA failure (OA progression) [116].

Adelani [114] concludes in his research publication that MRI is not the most suitable examination as a therapeutic gauge when the joint space is less than 50% of normal (the category that progressively becomes suitable for arthroplasty). For the surgeon it is economically unfeasible to incorporate MRI, with limited funds available in the treatment algorithm of knee OA. This is further compromised by the diverse interpretation from radiologists with little or no clinical experience. The development of an accurate Artificial Intelligence Application for routine evaluation of X-ray parameters can further enhance the value of simple X-rays and compensate for the MRI cost and sensitivity problem.

There is room for the MRI when severe pain without the requisite bone contact between the femur and tibia need further assessment as to the possible cause of this pain, as part of the work-up before an arthroplasty is offered. The differential diagnosis must be completed, e.g., severe pain and inability to walk due to posterior root injury to the meniscus, bone contusion or infection, etc. Finally, despite the abnormal findings on an MRI, it does not always correlate with the outcome achieved when implementing a UKA [117]. This indeed makes life difficult for the treating orthopaedic surgeon, as patient and General Practitioner might be convinced that the only treatment option is a TKA, which is not necessarily the case. As it is apparent, this is, in part, due to the limitations of existing classification systems and partly due to the historical inherent bias against the UKA. Early intervention in OA without bone-on-bone wear does have poorer results [118-119].

The limitation of the MRI is its sensitivity with a megaphone effect on decision making and not practical for accessible use.

The use of long-standing views – hip-knee-ankle (HKA), is not included in the series of required X-rays due to the extra cost not adding to the decision for a UKA or TKA.

This is undoubtedly required when performing a constitutional kinematic reproducing procedure like that prescribed by Bellemans [21] and MacDessi [33,61].

The goal of the CPAK philosophy is for the replication of the constitutional alignment by classifying the nine different phenotypes of presentations and then to surgically replicate the alignment.

In the event of deciding against a UKA, the specific X-ray views e.g., long-standing views, should be considered, depending on the philosophy and surgical technique that is going to be implemented.

3.2 Existing Grading Systems

3.2.1 Kellgren and Lawrence System (K&L) 1957

The K&L system [5] is a method on a routine AP view of classifying the severity of knee OA using five grades, 0 – 4:

- **Grade 0:** no radiographic features of OA are present
- **Grade 1:** doubtful JSN and possible osteophytic lipping
- **Grade 2:** definite osteophytes and possible JSN on AP weight-bearing radiograph
- **Grade 3:** multiple osteophytes, definite JSN, sclerosis, possible bony deformity
- **Grade 4:** large osteophytes, marked JSN, severe sclerosis and definite bony deformity.

3.2.2 Ahlbäck Classification System 1968

The Ahlbäck classification system [90] estimates the severity of OA of the knee joint in patients with chronic knee pain using five grades, 1 – 5:

- **Grade 1:** joint space narrowing (less than 3 mm)
- **Grade 2:** joint space obliteration
- **Grade 3:** minor bone attrition (0 – 5 mm)
- **Grade 4:** moderate bone attrition (5 – 10 mm)
- **Grade 5:** severe bone attrition (more than 10 mm).

The above-mentioned classifications [5,90] evaluate the severity of TFJ degeneration by X-ray. They do differ in grading as the latter is graded with a painful joint that progresses from K&L grade 3 [5].

The limitation of the system in knee surgery is that it is applicable to all joints without indicating a possible treatment in the knee.

3.2.3 The X-Ray Knee Instability and Degenerative Score (X-KIDS) 2015

The X-KIDS system (Oosthuizen *et al.*) [11] was developed incorporating K&L grade 4 [5] as a starting point as well as researching a scoring method defining the extent of degeneration with 'weighted points' attributed to features commonly found with OA in the knee. This system identifies features (narrowing, osteophytes and subluxation) to improve the evaluation of factors that indicate degeneration and influence the surgeon when he decides on a specific prosthesis. An important shortcoming of the Score [11] is that it does not recognise the PFJ degeneration.

The experience and publication of the X-KIDS was the catalyst for the eventual KOGS, as the system was laborious to learn and complicated without including the patella. This was addressed and validated with a much improved and simple grading system indicating the severity of the degeneration by grade progression.

3.2.4 Radiological Decision Aid to determine the suitability for medial compartmental knee arthroplasty 2016

The publication of the "Radiological Decision Aid" in The Bone and Joint Journal [12] was inspired by the proposal and publication of the X-KIDS [11] to improve the identification of the medial compartment degeneration that was suitable for a UKA. This is only medial compartment specific and did not include the lateral compartment or the PFJ. The existing systems indicate wear but unfortunately, they do not confirm the tri-compartmental status with important shortcomings such as the X-KIDS [11], nor does it recognise the PFJ degeneration.

The limitation is that it does not evaluate the lateral compartment or severe isolated PFJ degeneration without TFJ involvement.

The noted current X-ray systems cannot grade the tri-compartmental degeneration of the knee and therefore cannot give a holistic view – at a glance, on all three compartments to facilitate a decision for implant selection.

The system is still subject to intra-articular findings not seen on the routine X-rays due to inadequate views or developing pathology like infection or AVN.

CHAPTER 2: RESEARCH METHODS

1 METHODS

To achieve each of the objectives, different methods were required. The implementation of these methods formulated around the publication of three peer-reviewed research papers.

The theoretical development of the KOGS was primarily due to the inability to find a system whereby, at a glance, an indication of the possible implant requirement could be made.
The wear pattern of every patient was noted, photographed and the corresponding X-rays evaluated.
This was then correlated with the Oxford indications for surgery as well as the literature from K&L [5], Ahlbäck [90], Keyes [91] and other salient publications like Rosenberg [99] and Goodfellow *et al.* [34-35].
The first system developed was a scoring system published in 2015, the X-KIDS [11] and this was followed by the further publication of "The Radiological Decision Aid" in 2016 [12].
This evolvement of KOGS is from existing grading systems, the evaluation of the anatomical pathology and the variety of implants currently available. These associations led to the eventual idea of a tri-compartmental system with progressive deteriorating evidence in the knee to represent arthroplasty surgery and complement new implant technologies.
The nature of the grading is in a progressive degeneration with more intricate arthroplasty solutions that could be possible as the grading deteriorates.
The results of the KOGS can be compared for different implants e.g., UKA *versus* TKA for KOGS Grade 1 knees.

The "KOGS" grading system, if applied correctly, will allow an increased use of the UKA as the primary treatment with the TKA as a salvage procedure:
• KOGS Grade 1: stable degenerative changes in one compartment.
Treatment options: UKA medial or lateral (MB or FB) or PFA.
• KOGS Grade 2: deteriorating condition due to progressive wear and weakening of the ACL, compared to KOGS Grade 1, with relatively unstable subluxation that is reducible.
Treatment options: UKA medial or lateral (MB or FB).

• KOGS Grade 3A: degenerative changes in one compartment and with ACL not functional, ruptured or already replaced, there is a higher risk for further deterioration (there are two elements of knee stability affected).

Treatment options: UKA medial or lateral (MB or FB) with ACL reconstruction.

• KOGS Grade 3B: one TFJ and PFJ degeneration, two compartments involved with deteriorating knee (two elements affected).

Treatment options: UKA medial or lateral + PFA.

• KOGS Grade 4A: Both TFJs are involved with intact ligaments.

Treatment options: suitable for Bi-UKA or cruciate retaining TKA.

• KOGS Grade 4B: Terminal bi-compartmental OA knee with ACL or other ligament injury.

Treatment option: suitable for TKA.

1.1 Development and validation of the Knee Osteoarthritis Grading System (KOGS) – Publication 1 (see Chapter 3)

The development and validation of the KOGS was a retrospective study of patients' records and X-rays. A cohort of 330 consecutive patients that received either UKA or TKA from the private orthopaedic surgery practice during January 2016 to October 2017 were included according to the selection criteria indicated below at Section 2 (Selection Criteria). The cohort was derived from patients presenting with terminal degenerative changes, deemed suitable for knee arthroplasty.

There was no attempt to obtain a specific trait in this assessment but only to obtain professional opinions from knee surgeons familiar with UKA and TKA treatment options on a large cohort (330) of X-ray sequences. Their preference and skill were compared to the KOGS decision that they subsequently evaluated in a scrambled fashion of the same cohort.

• X-ray:

The prescribed sequence of X-rays was adequate to investigate the different tibial plateau wear patterns and the PFJ as assessed in the literature and concluded in the first publication as well as with the tibial wear pattern assessments.

The sets of preoperative knee X-ray sequences from the cohort of the 330 consecutive patients (anonymised) were provided to seven experienced orthopaedic surgeons as "Assessment A" (see Appendix H) to assess and evaluate. All seven experts performed UKA and TKA surgeries as part of their arthroplasty experience, with a spread of at least 20% UKA as the basis for participation. The assessment by the experts of the 330 cases was based on their experience as users of UKA and TKA and their interpretation of their individual preference.

The experienced knee surgeon (individual evaluator) indicated whether a given patient is suitable for the implementation of a UKA or a TKA according to their normal routine based on the X-ray assessment of cohort "A". For "Assessment B" (see Appendix I), the same sets of X-rays were scrambled and provided to the same evaluators as cohort "B" with the specific instructions, the KOGS (see Appendix J), to grade the degeneration in the knee accordingly. To establish inter-rater reliability, the results of "Assessment A" (cohort A) would then be compared to the results of "Assessment B" (cohort B) for each evaluator, to assess the level of concordance between their recommended type of knee arthroplasty and the KOGS. Construct validity of these results were compared with the surgical choice made by the surgeon (based on intraoperative findings) to establish the type of knee arthroplasty a patient was offered.

• Data Analysis:

As there are no similar studies in literature, expert statistical help and opinion was used with the assistance of Dr Innocent Maposa from the Faculty of Health Sciences, Health Sciences Research Office at the University of the Witwatersrand. The sample sizes, data and statistical analysis were different for each objective.

The study did not target any trait or require any specific sample size, although it was suggested to be more than a 100, as the validation was based on the professional evaluation of the presented cohort of X-ray appearances.

Statistical analysis was performed using STATA version 14 [120]. Assessments from the evaluators were analysed for compliance based on the assessment method used. Concordance and agreement methods were used in this study to assess the level of concordance of the seven evaluators between the A and B Cohorts for each evaluator and against the actual arthroplasty implemented. Concordance analysis is needed to establish the validity of a new diagnostic measuring or rating technique or to demonstrate the near equivalence of multiple measuring or rating techniques [121]. The generalised Cohen's kappa coefficient for nominal measurements was used as well as Gwet's first-order agreement (AC1) coefficient [122]. Strength of agreement between the assessors was rated as per the value of kappa coefficient (poor: <0.00, slight: 0.00-0.2, fair: 0.21-0.4, moderate: 0.41-0.6, substantial: 0.61-0.8, and almost perfect: 0.81-100) [123].

However, Cohen's kappa has some weaknesses, that is, it is susceptible to trait prevalence and to balance these, Gwet's AC1 coefficient was implemented. The latter is usually very stable in the presence of trait prevalence [124]. The agreement, kappa and Gwet's AC1 coefficient results were interpreted according to benchmarks developed by Landis and Koch [125] and recommended by Viera and Garrett [123] and Wongpakaran *et al.* [124].

The outcome measures were:

- To assess whether the recognition of isolated compartmental pathology is achievable with the implementation of the KOGS
- To validate the novel KOGS classification as a suitable, reliable, and accurate tool when assessing an individual patient to undergo UKA or TKA.

1.2 Implementation of the KOGS – Publication 2 (see Chapter 4)

The implementation of the validated grading system was a retrospective study of patient records, clinical results, and X-rays. A total of 1177 consecutive knees were gathered from three different multi-orthopaedic surgery practices, surgically treated with the recommended knee arthroplasty (UKA, PFA or TKA) from a good clinical examination by the respective orthopaedic surgeon and categorised by KOGS. The results of the data were evaluated according to each type of surgery performed, the incidence of major complications, the functional OKS, and the KOGS category.

- Data Analysis:

Patients categorised by KOGS and treated with the favoured implant (UKA, PFA or TKA) from different institutions were gathered to compare the clinical results with patient satisfaction data and implant survivorship. Survival analysis methods (such as the Kaplan-Meier survival curves and log-rank test) were utilised to assess the KOGS grading selection, the effect of time on major complications and implant survival probabilities by surgery option (based on the KOGS grading criteria) between patients' characteristics.

The outcome measure was:

• To evaluate the results of the supportive diagnostic tool (KOGS), thereby confirming that there are no significant differences in the survivorship prospect of patients that receive UKA and those that receive TKA based on the criteria.

1.3 Evaluation of the KOGS – Publication 3 (see Chapter 5)

The evaluation of the difference in the outcomes of two categories/groups from KOGS was a retrospective and prospective comparative study of patient records and X-rays.

The retrospective study consisted of 436 consecutive patients that received UKA from May 2012 to October 2017. The prospective study consisted of 272 cases of patients diagnosed with anteromedial osteoarthritis (AMOA) that received UKA from November 2017 to May 2020. The patients were assessed with KOGS and grouped accordingly:

• Group 1 (KOGS Grade 1): patients diagnosed with AMOA without mediolateral subluxation or

• Group 2 (KOGS Grade 2): patients diagnosed with AMOA with mediolateral subluxation.

The results, implant survival and patient satisfaction were compared between the two groups.

• Data Analysis:

436 knees were used for the retrospective study, and for the prospective study, 272 knees were used to compare KOGS Grades 1 and 2. Survival analysis methods (Kaplan-Meier and log-rank test) were utilised to compare implant survival between the KOGS Grades (1 and 2) and the cohorts (R and P). Associations between categorical variables were evaluated using Chi-square ($\chi 2$) or Fisher's exact tests, as appropriate. Continuous variables were summarised and presented as mean and range, or as median and interquartile range (IQR). A student's T-test for normally distributed data or the Mann-Whitney U-test for non-normally distributed data was used to compare group differences in continuous variables. The multivariable Cox proportional hazards model was used to determine risk factors for time to revision.

The outcome measure was:

• To compare and evaluate the outcomes of UKA between the two groups/grades as categorised by KOGS.

2 SELECTION CRITERIA

For Publication 1 (see Chapter 3) as well as Publication 3 (see Chapter 5), all the evaluated patients were sourced from consecutive treated patients for arthroplasty in the private practice of Dr CR Oosthuizen.

Publication 2 (see Chapter 4), the evaluated patients were sourced from all the authors in their private practices as indicated in the publication.

The selection criteria are applicable to the full cohort of all three publications.

2.1 Inclusion criteria

- Patients attending the Orthopaedic outpatients with knee pathology.
- Patients older than 18 years.
- A full complement of X-ray views must be available (i.e., Standing AP and Lateral with patella skyline; Rosenberg view/Lyon Schuss [99] 15° medial TFJ, 45° lateral TFJ and Stress views in 20° of flexion).
- At least one of the three compartmental joints in the knee should have bone-on-bone contact (K&L grade 4 [5]).
- The 'unaffected' (healthy) weight-bearing TFJ compartment must be more than 5mm in width and parallel (congruent) to the opposing joint surfaces on the stress view.

2.2 Exclusion criteria

- Patients with incomplete records and X-rays.
- Patient-specific considerations or preferences.
- Patients with excessive deformities.
- Patients with clinical findings such as AVN or Rheumatoid Arthritis (RA).
- Clinically assessed disruption of ligaments.
- Contraindications as proposed by the Oxford school of thought [34-35].

CHAPTER 3: PUBLICATION 1 – THE KNEE OSTEOARTHRITIS GRADING SYSTEM FOR ARTHROPLASTY

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Statement of Contributions of Joint Authorship

Oosthuizen C.R.: 55% (Candidate)
Conceptualisation of original idea, conducted the research, writing and compilation of the manuscript

Takahashi T.: 5% (Research Colleague)
Participated in the research as the cohort investigator and co-author of manuscript

Rogan M.: 5% (Research Colleague)
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Pandit H.G.: 10% (Research Colleague)

Assisted with data analysis, interpretation of results, reviewing the manuscript and co-author of manuscript

The Knee
Osteoarthritis Gradin

Chapter 3 is an exact copy of Publication 1 referred to above.

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Primary Arthroplasty

The Knee Osteoarthritis Grading System for Arthroplasty

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ABSTRACT

Background: The aim of this study is to validate the Knee Osteoarthritis Grading System (KOGS) of progressive osteoarthritic degeneration for the tri-compartmental knee. This system defines the site and severity of osteoarthritis to determine a specific knee arthroplasty.

Methods: The radiographic sequence for KOGS includes standing coronal (anteroposterior), lateral, 30° skyline patella, 15° and 45° Rosenberg and stress views in 20° of flexion. Cohen's kappa and related agreement statistical methods were used to assess the level of concordance of the 7 evaluators between A and B cohorts for each evaluator and also against the actual arthroplasty used. Sensitivity and specificity was also assessed for the KOGS in identifying true partial knee arthroplasties (PKAs) and total knee arthroplasties (TKAs) as decided from the cohort A evaluations.

Results: From a cohort of 330 patients who were included in the study, 71 (22.5%) underwent a TKA procedure, 258 (78.2%) a PKA, and 1 (0.3%) was neither a TKA nor PKA. KOGS was able to identify true PKAs (sensitivity) in the range of 92.2%-98.5% across all the different evaluators. The KOGS method was able to identify a PKA or a TKA with an accuracy ranging from 92% to 98.8% across all different evaluators. The surgical results after 20 months are at least comparable with the expected average in the academic literature.

Conclusion: The KOGS classification provides a reliable and accurate tool to assess suitability of an individual patient for undergoing PKA or TKA.

An osteoarthritic (OA) knee patient usually presents to the clinician with varying symptoms including pain, stiffness, instability, and difficulties in activities of daily living. In patients with significant symptoms, the decision of whether to offer a knee arthroplasty is dependent on confirmation of bone-on-bone arthritis in the affected knee [1]. Assessment before the

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implementation of a specific type of knee arthroplasty (KA) includes the history, clinical presentation, special investigations, patient's preference, and surgeon's skill in different available options.

Typically, primary OA tends to start in one compartment and with time progresses to be tri-compartmental. In cases with single compartment disease, partial (or unicompartmental) knee arthroplasty (PKA) provides significant advantages over total knee arthroplasty (TKA). These include better function, reduced morbidity and mortality, and more natural feel of the replaced knee [2]. Although excellent results following PKA are seen in appropriate patients, there is significant variability in outcomes and globally higher revision rates of PKA are observed when compared to TKA. The reasons for this higher revision rate are multi-factorial and include variation in patient selection, surgical technique, as well as differing thresholds for revision of PKA, compared to TKA [3].

At present, guidelines for patient selection for PKA are, at best, based on medium-term data with no externally validated method of patient selection in existence. This is reflected by the variability in current PKA utilization ranging between 0% and 60% of all primary knee arthroplasties [4].

A clinician's decision to consider a PKA is based on his/her interpretation of the pathoanatomy of the knee arthritis which is usually reached by careful examination of radiographs. The radiographs need to assess severity and extent of knee OA in individual tibiofemoral and patellofemoral compartments and also indicate integrity of cruciate and collateral ligaments. This will help the clinician make an informed decision as to the type of KA that will be optimal to an individual patient and whether any supplementary procedure is needed.

Traditional X-ray grading systems such as Ahlbäck classification [5], Kellgren-Lawrence grading [6], and Osteoarthritis Research Society International [7] do not take radiographic signs into account for a single joint compartment in their classification of OA. They typically assess weight-bearing anteroposterior (AP) and lateral radiograph of the affected knee and comment on the status of joint space, presence and severity of osteophytes, and other salient features to diagnose knee OA. Although widely used, these systems are inadequate to classify the tri-compartmental knee degeneration and cannot give an indication of the need for PKA or TKA. To overcome this limitation, additional radiographs and/or atlas-based scoring systems have been developed. These typically include weight-bearing radiographs of a flexed knee and/or varus-valgus stress views. X-KIDS (X-ray Knee Instability and Degenerative Score) [8] and Decision Aid [9] are 2 such systems.

X-KIDS [8] assessment is based on 6 radiographic views (standing AP, lateral, standing Posteroanterior (PA) in 15° flexion, standing PA in 45° flexion, and varus and valgus stress views in 20° flexion). Knees are scored for narrowing, osteophytes, and subluxation in both the coronal and sagittal plane. Overall, the knee could receive a maximum of 10 points with a score of 3 or 4 indicating PKA to be the treatment of choice, 5 indicating that PKA may be appropriate pending clinical findings and surgical correlation, and a score of greater than 5 indicating that TKA is indicated. In an internal validation study, Oosthuizen et al [8] reported X-KIDS to be 92% accurate at determining the optimum treatment option in 336 knees. This system does not address the patella-femoral joint (PFJ) and includes presence of osteophytes as a predictor. Therefore, it does not help in assessing the suitability for a PFJ arthroplasty and presence of osteophytes has been shown to be unrelated to the long-term success of a PKA [10]. Decision Aid [9], an atlas-based system, was developed and validated by Hamilton et al. It consists of 5 sections, each assessing one of the 5 criteria, with radiographic view and exemplar radiographs provided that demonstrates when the criteria are met, as well as exemplar radiographs that demonstrate when the criteria are not met. It has been validated but only for medial PKA.

The Knee Osteoarthritis Grading System (KOGS), a radiological grading system (Figure 1) of degenerative arthritis of the knee, was developed to provide the clinician with a comprehensive system which is easy to use and has the ability to evaluate all 3 compartments of the knee to aid the surgeon's decision on the type and timing of knee arthroplasty. The system complements clinical evaluation as a tool to improve surgical decision. Patients with severe enough symptoms to consider a KA have 6 radiographs taken of the affected knee with no involvement by the clinician: AP standing, lateral, 30° skyline view, PA 15° (medial OA) and PA 45° (lateral OA) flexion views, and stress views in 20° flexion. The proviso for considering a joint arthroplasty is that at least one compartment has bone-on-bone contact (Kellgren and Lawrence grade 4). In addition to assess functional integrity of a tibiofemoral (TF) compartment, it must be more than 5 mm in width and parallel to the opposing joint surfaces on the stress view. When a stress view causes an increased joint line convergence angle (>2°), the "stress wedge deformity" in the ipsilateral compartment, it indicates ligamentous instability or more wear in the healthy compartment than anticipated [11].

The grading system consists of 4 deteriorative grades with a variety of possible treatment options to be implemented.

Grade 1 is an isolated medial, lateral TF or PFJ OA with ligament stability and 2 functionally intact compartments.

Grade 2 is a deteriorating isolated lesion with ligament stability and a correctible coronal subluxation.

Grade 3 (2 pathologies) includes an isolated medial or lateral TF OA and concomitant pathology such as anterior cruciate ligament deficiency (3A) or grooving of PFJ or patellectomy (3B).

Grade 4A includes cases of bi-compartmental TF OA without concomitant ligament instability and 4B with ligament instability.

Both Grade 1 and 2 affected joints are suitable for a partial KA, while Grade 3 and 4 are suitable for a TKA.

The overall objective of the study is to validate KOGS as a reliable determinant of pathology and suitability for a PKA by using a structured deteriorative radiological assessment in combination with an atlas-based Decision Aid. The primary aim of this study is to establish inter-rater reliability of a new Decision Aid aimed at assisting the clinician in choosing PKA as a possible treatment option for an individual patient presenting with symptomatic knee OA. It also aims to confirm the face validity of the tool and establish short-term outcomes of PKA in patients who underwent the intervention based on the KOGS algorithm.

Materials and Methods

The X-ray sequence was produced as a routine requirement at a single radiological facility. Ethical approval was obtained from an institutional review board and all patients provided informed consent for inclusion in the study. A cohort of 330 complete X-ray sets was included.

To establish face validity, these radiographs were independently assessed by 7 experienced orthopedic surgeons from Europe and South Africa with the aim of establishing whether a given patient is suitable for a PKA or a TKA. Patients were followed up to establish the incidence of short-term failures.

A cohort of 330 X-ray sequences (cohort "A") were evaluated for the implementation of a PKA or TKA by 7 experienced knee surgeon evaluators; the same cohort was scrambled into cohort "B" and evaluated according to KOGS and compared with the A and B results of the individual surgeons.

The evaluators were selected based on their expertise in the field. Each evaluator assessed the radiographs and opined on whether the patient was suitable to undergo a KA and if so whether they would recommend a PKA or a TKA based on the X-ray assessment (cohort A). This was considered as the gold standard for that particular assessor. To establish content validity of KOGS, the same observers were provided with the KOGS atlas with the same set of radiographs in a random fashion, after an interval of 4 weeks. Based solely on the KOGS, the observers were asked to opine the suitability of the patient for PKA or TKA or no joint arthroplasty (cohort B). To establish construct validity, these results were compared with the surgical choice made by the surgeon (based on intra-operative findings) to ascertain the type of KA a patient was offered.

Statistical analysis was performed using STATA 14 [12]. All the assessments from the 7 evaluators were analyzed for agreement based on the assessment method used. Concordance and agreement methods were used in this study. Concordance analysis is needed to establish the validity of a new diagnostic measuring or rating technique or to demonstrate the near-equivalence of multiple measuring or rating techniques [13]. The generalized Cohen's kappa coefficient for nominal measurements was used as well as Gwet's first-order agreement coefficient (AC1) [14]. Cohen's kappa is used to show the degree to which different measuring or rating techniques agree with each other and takes into account the expected agreement that is purely by chance [13]. Strength of agreement between assessors is rated as per the value of kappa coefficient (poor: <0.00, slight: 0.00-0.2, fair: 0.21-0.4, moderate: 0.41-0.6, substantial: 061-0.8, and almost perfect: 0.81-1.00) [15]. However, Cohen's kappa has some weaknesses, that is, it is susceptible to trait prevalence and to balance these Gwet's AC1 coefficient was implemented. The latter is usually very stable in the presence of trait prevalence [16]. The agreement, kappa and Gwet's AC1 coefficient results were interpreted according to benchmarks developed by Landis and Koch [17] and recommended by Viera and Garrett [15] and Wongpakaran et al [16].

Results

From a cohort of 330 patients who were included in the study, 71 (22.5%) underwent a TKA procedure, 258 (78.2%) a PKA, and 1 (0.3%) was neither a TKA nor PKA. Of those undergoing a PKA, 205 underwent medial, 49 lateral, and 4 patellofemoral arthroplasties. The mean follow-up after the index procedure was 20 months (range 19-24). None of the patients were lost to follow-up. Seven patients experienced complications, 5 in the medial PKA group—3 for medial-bearing dislocation and 2 for subsidence—and 2 in the TKA group underwent further surgery (1 TKA for dislocation and 1 for patella fracture).

Table 1 assesses the agreement between the actual arthroplasty performed on the patients and the 2 assessment procedures, that is, the X-ray method (radiography assessment) and the KOGS. Each evaluator's assessment based on these 2 approaches is contrasted to what procedure the patient actually received. For the X-ray method, the percentage agreement with the procedure that was actually performed was 84% or higher for all assessors. Cohen's kappa was 0.56-0.68. Gwet's AC1 was 0.83-0.88 (Table 2). Cohen's kappa indicates a fair agreement, while Gwet's AC1 coefficient indicates an almost perfect agreement among the 7 assessors in their evaluations. For the KOGS method, the percentage agreement with the procedure that was actually performed was 84% or higher for all assessors. Cohen's kappa was 0.56-0.68. Gwet's AC1 was 0.84-0.87. Cohen's kappa indicates a fair agreement, while Gwet's AC1 coefficient indicates an almost perfect agreement among the 7 assessors in their evaluations.

Table 2 shows the inter-assessor concordance or agreement in the implementation of the X-ray procedure and then the KOGS for

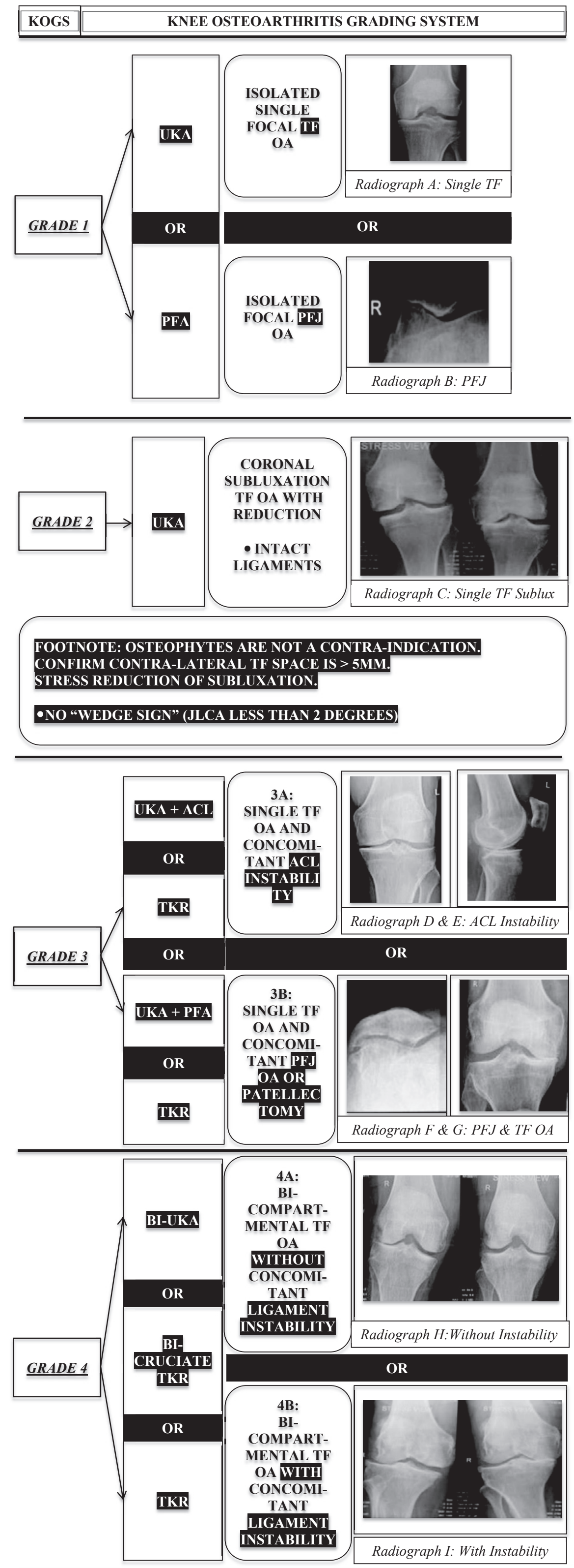

Fig. 1. KOGS flowchart with radiographs. UKA, Unicompartmental knee arthroplasty; PFA, Patellofemoral arthroplasty; BI-UKA, Bi-Unicompartmental knee arthroplasty; TF, Tibiofemoral; OA, Osteoarthritis; PFJ, Patella-femoral joint; JLCA, Joint line convergence angle; ACL, Anterior cruciate ligament..

the 330 patients. Inter-assessor agreement was examined using the Cohen's kappa and Gwet's AC1 coefficient for the results of X-ray and KOGS evaluations. Percentage agreement between the 7

Table 1
X-Ray and KOGS Raters' Agreement With the Type of Knee Arthroplasty Performed.

Rater	X-Ray (Cohort A)			KOGS (Cohort B)		
	Percent Agreement	Gwet's AC1	Cohen's Kappa	Percent Agreement	Gwet's AC1	Cohen's Kappa
#1	0.870 [0.833-0.906]	0.844 [0.799-0.890]	0.608 [0.504-0.716]	0.870 [0.834-0.906]	0.841 [0.795-0.887]	0.639 [0.541-0.737]
#2	0.861 [0.824-0.898]	0.834 [0.788-0.880]	0.563 [0.452-0.674]	0.842 [0.803-0.881]	0.808 [0.758-0.858]	0.557 [0.453-0.661]
#3	0.897 [0.864-0.930]	0.877 [0.837-0.917]	0.683 [0.584-0.782]	0.894 [0.861-0.927]	0.873 [0.832-0.914]	0.682 [0.585-0.779]
#4	0.888 [0.854-0.922]	0.868 [0.827-0.909]	0.627 [0.519-0.735]	0.864 [0.830-0.901]	0.837 [0.791-0.883]	0.590 [0.483-0.697]
#5	0.864 [0.827-0.901]	0.832 [0.785-0.879]	0.644 [0.550-0.738]	0.870 [0.834-0.906]	0.839 [0.793-0.885]	0.659 [0.566-0.752]
#6	0.876 [0.840-0.912]	0.852 [0.808-0.896]	0.618 [0.515-0.721]	0.879 [0.844-0.914]	0.855 [0.811-0.899]	0.630 [0.526-0.734]
#7	0.894 [0.861-0.827]	0.876 [0.836-0.916]	0.646 [0.540-0.752]	0.864 [0.827-0.901]	0.838 [0.792-0.884]	0.577 [0.467-0.687]

Figures in brackets represent 95% confidence intervals.
KOGS, Knee Osteoarthritis Grading System.

evaluators on the X-ray method for the 330 patients (cohort A) was 86.6% with a confidence interval of 84.5-88.7 suggesting an almost perfect agreement. Cohen's kappa was 56.6% [CI 49.9-63.3]. Gwet's AC1 was 84.1% [CI 81.4-86.8]. Cohen's kappa indicates a fair to almost perfect agreement, while Gwet's AC1 coefficient indicates an almost perfect inter-assessor agreement among the 7 assessors in their evaluations.

Table 3 shows the intra-assessor agreement for the 2 evaluation methods, that is, the X-ray and the KOGS methods. Percentage agreement between the 2 cohorts for the same assessor ranged from 88.5% to 99.5% suggesting an almost perfect agreement. Cohen's kappa was 62.3%-95.2%, while Gwet's AC1 was 86.4%-98.2% (Table 3). Cohen's kappa indicates a fair to almost perfect agreement, while Gwet's AC1 coefficient indicates an almost perfect intra-assessor agreement for each of the 7 assessors in their evaluations.

KOGS was able to identify true PKAs (sensitivity) based on X-ray method in the range of 92.2%-98.5% across all the different evaluators. The KOGS method was able to identify a PKA or a TKA with an accuracy ranging from 92% to 98.8% across all different evaluators (Table 4).

Discussion

This study validates KOGS and confirms its suitability in being used as a reliable tool for assessing suitability of a patient to undergo a PKA or a TKA. It also confirms high sensitivity and accuracy of KOGS as a diagnostic tool. The strengths of the study are the size of the cohort of required X-rays, the comparison of the experienced PKA and TKA surgeons' own assessment to a subsequent scrambled cohort KOGS evaluation with the actual implemented KA. The lower values achieved in Table 2, where the actual implemented procedures are compared with the rating, are partly due to the surgical decisions taken on clinical grounds, for example, excessive valgus, undiagnosed anterior cruciate ligament deficiency, patients preference, or even the surgical decision that does not relate to the X-ray grading.

Key prerequisite for a KA in patients with significant OA symptoms is the presence of full-thickness cartilage loss in at least one compartment of the knee. However, partial thickness cartilage loss is seen in over a quarter of secondary care consultations for OA that have failed non-operative treatment [18,19]. In most cases, the pain and functional scores of these patients are the same as, if not worse than, patients with more advanced structural changes. However, if a KA is offered to such patients not only the improvement in symptoms is significantly less and unreliable but also the revision rates are significantly higher [1,20–22].

Escobar et al [23] developed a TKA appropriateness algorithm based on pain, function, physical examination, radiographic signs of OA, and history of prior knee surgeries. Based on this algorithm, at least 20% of TKA are judged inappropriate. Riddle et al [24] adapted the appropriateness algorithm of TKA in the United States and found 34% of the TKA to be inappropriate. In a follow-up publication, the improvement after surgery in the inappropriate group was only 2.3 Western Ontario and McMaster Universities Osteoarthritis Index points versus 19.8 in the rest of the cohort [25]. This is, in part, due to the ill-defined indications for a TKA without a reliable grading system of degeneration as a guide regarding indications for arthroplasty.

Magnetic resonance imaging (MRI) provides a more accurate evaluation of cartilage degeneration compared to standard radiography. However, the standard X-ray is still the most accessible, user-friendly, cost-effective, and reliable system for general uses and is FDA approved in arthroplasty [26]. The research publication from Adelani confirms MRI as not the most suitable examination as therapeutic indicator when the joint space is less than 50% of normal [27]. Furthermore, treating surgeons often have limited funds to incorporate MRI in the treatment algorithm of knee OA and generally relies on the varied interpretation from the radiologist with no clinical experience. MRI sensitivity in establishing patient suitability for a PKA remains a problem. An abnormal finding on MRI does not always correlate with the outcome of a PKA. Hurst et al [28] have demonstrated no difference in clinical outcomes following PKA in knees with MRI contraindications to PKA compared with those without questioning the clinical relevance of MRI findings.

It is important to develop a valid and user-friendly system for adequate pre-operative diagnosis of bone on bone focal compartmental knee degeneration. It will help in patient selection as well as

Table 2
Inter-Rater Agreement for X-Ray and KOGS for All 7 Raters.

	Percent Agreement	Gwet's AC1	Cohen/Conger's Kappa
X-ray	0.866 [0.845-0.887]	0.841 [0.814-0.868]	0.566 [0.499-0.633]
KOGS	0.845 [0.821-0.869]	0.812 [0.781-0.843]	0.553 [0.491-0.616]

Figures in brackets represent 95% confidence intervals.
KOGS, Knee Osteoarthritis Grading System.

Table 3
Intra-Rater Agreement Coefficients for the 2 Methods.

Rater	Percent Agreement	Gwet's AC1	Cohen/Conger's Kappa
#1	0.952 [0.929-0.975]	0.941 [0.913-0.969]	0.863 [0.798-0.928]
#2	0.897 [0.864-0.930]	0.877 [0.836-0.918]	0.690 [0.599-0.781]
#3	0.985 [0.972-0.998]	0.982 [0.966-0.998]	0.952 [0.910-0.994]
#4	0.915 [0.885-0.945]	0.901 [0.865-0.937]	0.703 [0.601-0.805]
#5	0.894 [0.861-0.927]	0.866 [0.823-0.909]	0.743 [0.663-0.823]
#6	0.885 [0.851-0.919]	0.864 [0.822-0.906]	0.623 [0.517-0.729]
#7	0.927 [0.899-0.955]	0.916 [0.883-0.949]	0.733 [0.632-0.834]

Figures in brackets represent 95% confidence intervals.

Table 4
Sensitivity-Specificity Analysis for KOGS on PKAs.

Assessor	Sensitivity	Specificity	Accuracy
#1	93.9%	100%	95.1%
#2	92.2%	100%	93.4%
#3	92.5%	88.9%	92.0%
#4	98.5%	100%	98.8%
#5	92.8%	81.7%	89.6%
#6	93.3%	84.8%	92.1%
#7	94.6%	87.0%	93.6%

KOGS, Knee Osteoarthritis Grading System; PKA, partial knee arthroplasty.

ensuring that optimal treatment is offered to an individual patient which is evidence based rather than empirical. KOGS can improve the selection of knee OA for smaller and more functional arthroplasty options rather than the tendency to default to a TKA even when isolated focal degeneration is found. The system is a tri-compartmental improvement of the X-KIDS [8] and the Decision Aid [9] as it takes into account the PFJ as well as the status of the ligaments. The KOGS can be used to compare the results of comparable and different stages of degeneration with the various modalities of treatment implemented. The strength of the KOGS includes its accessibility as a tool to differentiate the selection of PKA, general applicability in every-day orthopedic practice, its user-friendliness and cost-effectiveness when compared to MRI while avoiding excessive radiation associated with CT scans.

Independent assessment by 7 raters provides external validation and confirms the generalizability of this tool. Relatively short-term follow up, single surgeon series, and small numbers for patella-femoral arthroplasty are potential weaknesses of this study. The mean follow-up of 20 months is short but it gives a clear indication of success or failure of a PKA. It has been shown that if Oxford PKA is functioning well in the short-term, then the long-term outcome is likely to be satisfactory [29]. The previous long-term studies of the Oxford PKA demonstrated that the failures tended to occur early rather than late. Technical errors and/or patient selection related errors tend to manifest themselves early and long-term problems are rare because of the resistance of the device to wear [30–32]. We therefore believe that this follow-up period including complications encountered provides additional useful information to this study. Although the numbers of cases undergoing isolated PF arthroplasty are small in this series, the lead author primarily used KOGS in these cases to assess tibiofemoral compartments. Indeed, it has been previously shown that early progression of the disease due to under-diagnosed TF OA is the primary reason for high revision rates noted in some series of PFJ arthroplasty [33].

Conclusions

With the correct KOGS sequence and quality of accessible “routine X-rays,” the identification of isolated pathology is achievable by newly introduced or experienced surgeons and routinely available with high sensitivity, specificity, and accuracy. The KOGS is the first tri-compartmental grading that can compare different implant implementations with the pre-operative OA status.

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CHAPTER 4: PUBLICATION 2 – THE PATIENT RESULTS AND SATISFACTION OF KNEE ARTHROPLASTY IN A VALIDATED GRADING SYSTEM

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Statement of Contributions of Joint Authorship

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Van Der Straeten C.: 5% (Research Colleague)
Assisted with interpretation of results, reviewing the manuscript and co-author of manuscript

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The patient results
and satisfaction of kn

Chapter 4 is an exact copy of Publication 2 referred to above.

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ORIGINAL PAPER

The patient results and satisfaction of knee arthroplasty in a validated grading system

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Abstract

Introduction The validated Knee Osteoarthritis Grading System (KOGS) was implemented and clinical results were compared with patient satisfaction data and implant survivorship in a multi-centre study with surgeons familiar with unicompartmental knee arthroplasty (UKA), patellofemoral arthroplasty (PFA) and total knee arthroplasty (TKA).

This is also the first study to evaluate the prevalence of UKA and TKA in consecutive osteoarthritis (OA) knee arthroplasties assessed by this system..

Method A consecutive cohort of knees was gathered at three different institutions as categorized by KOGS and surgically treated with the recommended implant unless clinical reasons or patient preference precluded such an option.

One thousand one hundred seventy-seven consecutive knees were evaluated including 311 TKA (26%), 695 medial UKA (59%), 154 lateral UKA (13%) and 17 PFA (2%) and the results of the categories evaluated with the Oxford Knee Score (OKS) and the complications reflected in the different categories.

Results The failure rate of the UKA (3.5%) or TKA (1.6%) is not higher than accepted results in the literature and the difference in complications is negligible between the UKA (72%) and TKA (26%) cohorts.

Revision of a UKA to a TKA as an endpoint was 0.58% with ipsilateral progression at 0.8% over a period of five to 84 months (mean follow-up of 36 months) despite the 'excessive' proportion of UKA in this cohort.

The Oxford Score improvement is significant in TKA and UKA and contributes to the acceptable outcomes (The OKS for TKA improved from 20 pre-operatively to 36 post-operatively and the UKA improved from 22 pre-operatively to 39 post-operatively).

Conclusion KOGS achieves acceptable early survival and functional results when implemented and is a suitable tool for identifying the preferred implant as was validated.

Keywords X-ray · Osteoarthritis · Grading · Knee · Arthroplasty · Replacement

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Introduction

The osteoarthritic (OA) knee presents to the clinician due to pain, function loss or deformity and in the process of degeneration requiring the appropriate clinical evaluation, activity level, range of motion (ROM), special investigations and discussion of the patient's expectations.

The patient morphotype is unique, with the wear pattern the key to the kinematic pathological process, culminating in a particular solution that is currently predominantly a total knee arthroplasty (TKA) irrespective of the wear pattern and without native kinematic restoration.

The institutionalized neglect advocated by surgeons until eventual TKA leads to poor patient and social acceptance as demonstrated in the publication by Kazarian et al. [1] and a 'staged approach' for the deteriorating knee can be beneficial. On balance, the unicompartmental knee arthroplasty (UKA) identification and surgical experience has been a barrier to the orthopaedic surgeon performing the procedure, as there are distinct problems associated with the selection, the technique and the different implants.

The ability to identify and implant an appropriate arthroplasty is essential in the surgeon's practice, with the Kellgren and Lawrence (K&L) in 1957 [2] and the modification by Ahlbäck in 1968. The K&L is inaccurate when applied to the tricompartmental knee, as the varying degrees of deteriorating pathology of the three different compartments are not assimilated in one comprehensive system.

The utilization rates of a specific knee arthroplasty vary greatly and there is no clear consensus regarding the implementation of a specific arthroplasty in the evolution of degenerative knee disease whether focal or tricompartmental [3] with the commensurate unavailability of a comparable accounting of the variable severity and distribution of OA in the use of arthroplasty.

The research publication from Adelani confirms that magnetic resonance imaging (MRI) is not the most suitable examination as a therapeutic indicator when the joint space is less than 50% of normal (in the category that progressively becomes suitable for arthroplasty) [4]. Furthermore, treating surgeons often have limited funds to incorporate MRI in the treatment algorithm of knee OA and generally also rely on the varied interpretation of a radiologist with little or no clinical experience. MRI cost and sensitivity remains a problem although the MRI is required with pain and function loss without the necessary X-ray confirmation of bone-on-bone degeneration.

Current TKA status

The TKA has been accepted for the past 40 years as the panacea solution for single compartment degeneration as well as tricompartmental degeneration and is used in 90% of all knee arthroplasty. It has been established as a successful treatment of end-stage knee OA achieving pain relief, improvement of function and quality of life with very good to excellent implant longevity up to 91–96.8% at 20–25 years [5]. This leads to better survival results of TKA but includes a substantial percentage of dissatisfied patients with functional impairment in whom a TKA may not have been appropriate in the beginning [6, 7].

The rate of major complications of patients undergoing a TKA is higher than UKA as researched by Liddle [8], and even computer-assisted surgery has not improved the results compared with conventional instrumentation as studied by D'Amato [9].

Chronic pain (persisting in excess of 3 to 6 months) after TKA is prevalent in about 20% of all TKA procedures associated with functional limitations (25%), pain-related distress, depression and social isolation according to a review study by Wylde [10].

The recently improved function-based outcome assessments highlighted the relative inadequacy of the TKA with the UKA becoming a more functional alternative as evaluated in the meta-analysis from Migliorini [11] and a further study by Lons (INOR), Dec. 2017 indicated the large metal surface of TKA generates a significant detrimental elevation of chrome, cobalt and titanium one year after implantation which can lead to allergy, hypersensitivity etc. [12].

Current UKA status

A prospective study with different evaluation methods such as "Forgotten Joint Score (FJS), the short form of the Knee Injury and Osteoarthritis Outcome Score (KOOS PS), EuroQOL Five Dimensions Questionnaire (EQ-5D), and the Knee Society Score (KSS)" has shown that in arthroplasty surgery, the UKA patients are less aware of their prosthesis than TKA from as early as two weeks post-operatively to 12 months [13].

The progression of OA to the ipsilateral compartments (the most common mode of failure beyond 10 years) is generally no more than 2.5% over 15 years in the study of Pandit of over 1000 mobile UKA [14].

Willis-Owen, in his study of more than 41,000 knee arthroplasties, indicated that at least 47.6% of knee OA is suitable for UKA [15]. The 2018 National Joint Registry report (United Kingdom) indicates the utilization of TKA at 89.5% and the UKA at 9.4% [16].

The drive to identify the suitable knee for a UKA is increasing and a recent watershed publication in the Journal of Bone and Joint Surgery 2018 by Kazarian et al. [1] indicates the cost-effectiveness of the UKA as a treatment modality and "found that unicompartmental knee arthroplasty was universally the best treatment option for focal knee arthritis from 40 until the age of 87." This study included the results of reliable registries that indicated UKA's have more excellent and fewer poor results than TKA's, but are revised more often, as identified by Goodfellow [17].

The Open Review Article by Rodríguez-Merchán and Gómez-Cardero in 2018, details an overview of the current indications, technical issues and results of the UKA [18].

This is not a comparative study of any specific procedure for OA although the results are literature conforming. The UKA is a favourable procedure as studied by Won-Joon Cho et al. [19] and Kim in 2019 [20] confirming a better short-term functional outcome and return to recreational and sporting activities than high tibial osteotomy in medial OA.

The UKA results will be enhanced by further developments where the same system can be used for medial and lateral OA together with the option of a mobile and fixed-bearing as studied by Saragaglia, confirming excellent results [21].

The research aim is to evaluate the results of KOGS determined arthroplasty procedures in a cohort of 1177 knees.

Materials and methods

The KOGS

The *Knee Osteoarthritis Grading System (KOGS)* is a dynamic radiological tool for progressing degenerative tricompartmental OA of the knee, validated and published in The Journal of Arthroplasty (JOA) in March 2019 by Oosthuizen et al. [22].

The system is *initiated* with bony contact in one compartment, a K&L grade 4 classification, and identifies the isolated wear lesion whether in the tibiofemoral (TF) or patellofemoral (PF) joints. With the specified X-ray views, the specific type of implant can be considered according to the grading achieved. A recent study in INOR confirmed that the complete obliteration (K&L grade IV) of the joint renders better results in TKA than a joint space of more than 2 mm (K&L grade III) [23]. This has also been proven in the UKA studies and is a pillar of the KOGS.

"KOGS was able to identify true Partial Knee Arthroplasty (PKAs) (sensitivity) based on X-ray method in the range of 92.2% to 98.5% across all the different evaluators. This method was able to identify a PKA or a TKA with an accuracy ranging from 89.6% to 98.8% across all different evaluators. Percentage agreement between the two cohorts for the same assessor ranged from 88.5% to 99.5%, suggesting an almost perfect agreement" [22].

This grading developed from the "X-ray Knee Instability and Degenerative Score" (X-KIDS) [24] and the decision aid (DA) for medial wear [25]. However, these methods did not evaluate the knee as a tricompartmental joint but focused on the weight bearing TF joints as several authors proclaimed the PF joint having little influence on the outcome of the medial UKA [26].

Full thickness PF joint degeneration is seldom a contraindication for UKA [27] but grooving of the lateral facet in the isolated medial and lateral TF OA was considered to be a contraindication or an indication for patellofemoral arthroplasty (PFA) or TKA. The existence of PF degeneration in TKA had no detrimental effect on TKA surgery when the PF joint was not resurfaced even in Outerbridge grade IV according to Guo-Chun Zha [28], a similar approach is therefore taken in the UKA in this study.

Isolated PF joint OA with intact TF joints can be treated with a PFA. This is a less invasive procedure with similar or better results, as recently published, than a TKA [29].

The clinical indications for surgery were based on the publication and experience of the Oxford Group as KOGS is not a standalone decision maker and complements the clinical evaluation, minimizes the possibility of ipsilateral progression and improves the evaluation of the knees that are suitable for a UKA and TKA.

Three surgeons in different locations assessed the outcomes of KOGS evaluated procedures in their practices. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee (University of the Witwatersrand [WITS] with Clearance Certificate Nos. M1704111 and M1704112) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

The specific KOGS X-ray sequence was implemented as a routine requirement for every patient at the radiological facility of the various hospitals with no involvement by the clinicians (Fig. 1).

The X-ray sequence method is based on standard preoperative X-rays and includes the following:

1. Anteroposterior (AP) and lateral knee views and a 30° skyline patella view
2. 15° (medial OA) and 45° (lateral OA) Rosenberg/Lyon views
3. Stress views in 20° of flexion

The inclusion proviso in this assessment for arthroplasty is that all the X-rays are available. At least one of the tricompartmental joints should be a K&L grade 4 and has bone-on-bone contact [30]. The results were evaluated based on the incidence of major complications and the functional Oxford Scores [23] (Tables 1 and 2).

A synopsis of the KOGS is included as an Appendix to this publication and in the JOA March 2019 publication [22].

Results

There are no significant differences (log-rank P value = 0.160) in the survivorship probabilities between patients that receive partial knee arthroplasty and those that receive total knee arthroplasty based on the KOGS grading criteria (as a supportive diagnosis measure) (Table 2)

There is no statistical difference between the complication rates of the PKA vs. TKA.

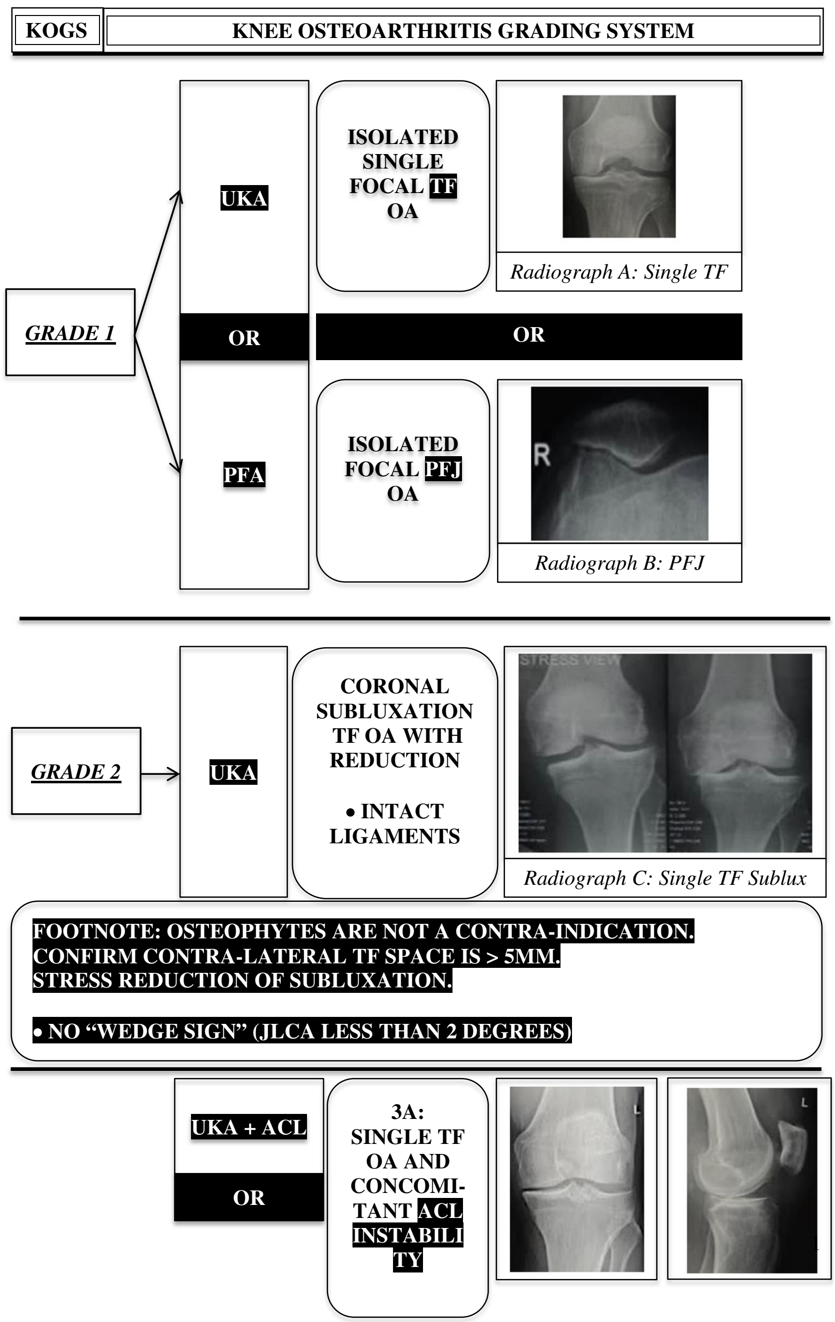


Fig. 1 KOGS flowchart with radiographs

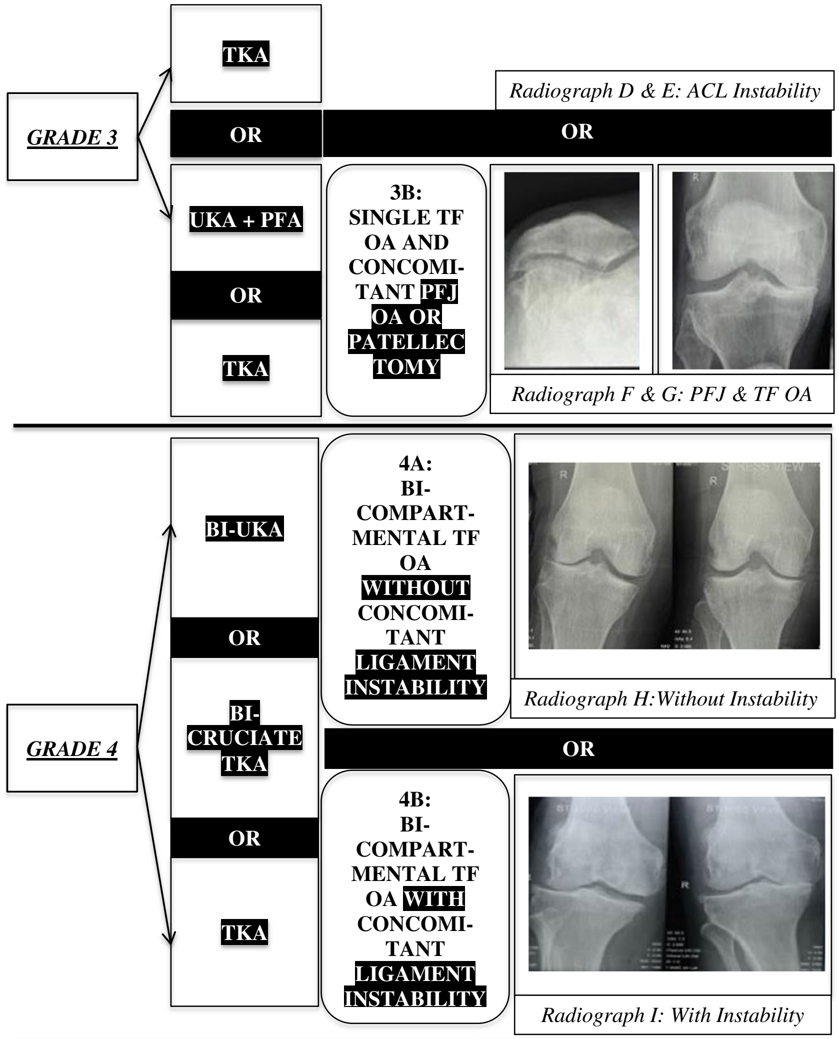


Fig. 1 continued.

- There are no significant differences in the survival probabilities between patients that receive their surgical option based on a KOGS grading assessment of 1, 2, 3 or 4 (log-rank P value = 0.156) and those who experience major complications (Fig. 2).

Patients who smoke are at a significantly higher risk of experiencing major complications compared with those who do not smoke (log-rank P value < 0.001).

The KOGS could identify the arthroplasty required and when implemented, there are no statistical differences in the failure rate of the different categories.

The higher failure rate of 6.2% is seen in grade 2 (comprising 12.3% [145 cases] of the total cohort), compared with the 2.6% in grade 1 and the 3% in grade 4 [Table 2].

The functional data (OKS and ROM) of the PKA performs better than the TKA and also indicates that the more severely affected KOGS grade 3 and grade 4 (usually TKA's) do not achieve the same improvement as the grade 1 and grade 2's (usually PKA's) (Table 1).

When the PKA revision endpoint is determined by a revision to a TKA, the incidence is 0.58% (major complications are 3% of the full cohort) with smokers having an increased complication rate in the complete cohort (Smokers' major complication rate is at 11% with non-smokers at 2.2%) (Tables 2 and 3).

Discussion

The implementation of the UKA is between 8 and 10% worldwide, with a major stumbling block being the reliable identification of the focal lesion and the variety of degenerative stages of the tricompartmental knee. Although the statistical survival assessment of the UKA compared with the TKA can

Table 1 KOGS selection, demographics, and Oxford Knee Scores

	PKA $n = 849$ (72%)	TKA $n = 311$ (26%)	PFA $n = 17$ (2%)
KOGS grading			
KOGS grade 1	671 (79.0)	32 (10.3)	17 (100)
KOGS grade 2	134 (15.8)	11 (3.5)	0
KOGS grade 3	37 (4.4)	106 (34.1)	0
KOGS grade 4	7 (0.8)	162 (52.1)	0
Gender			
Female	419 (49.4)	213 (68.5)	13 (76.5)
Male	430 (50.6)	98 (31.5)	4 (23.5)
Mean age (SD)	64.4 (9.20)	65.4 (10.58)	64.9 (10.81)
Median time to major complication [IQR]	28.6 [15.64–46.35]	29.19 [16.79–42.21]	36.68 [19.88–57.85]
Oxford Knee Score (OKS) averages			
Pre-operative	22	20	19
6-week post-operative	34	33	32
3-month post-operative	37	36	36
Most recent	39	36	–

improve significantly if progression of degeneration is not penalized (primary implant did not fail or was revised from its bony attachment), the improvement in ipsilateral compartment assessment (stress and Rosenberg views) will prevent some implant failure due to progression. Although this study has a relatively short mean post-operative period, it has been shown that if the UKA is functioning well in the short term, the long-term outcome is likely to be satisfactory.

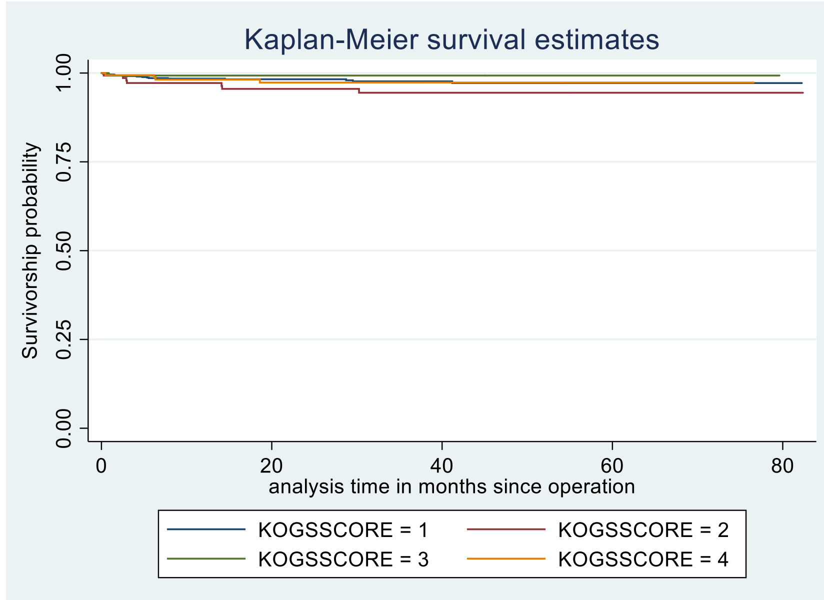
The system categorizes the deficient anterior cruciate ligament and focal TF lesion in grade 3A and allows comparative results with the isolated focal lesion in grades 1 and 2. The use of a fixed or mobile-bearing in this category seems to be irrelevant in the short term as studied by Tecame et al. [31].

The cost-effectiveness study of Kazarian [1] and Wilson in BMJ 2019 [32] are watershed publications for the suitability

Table 2 Complications in the various categories (demographic, KOGS grading, surgery type, etc. for UKA and TKA)

Characteristic	Type of complication: Major $n = 35$ (2.9%)	None and minor $n = 1142$ (97.1%)	P value
Age at operation	62.3 (1.510)	64.8 (0.287)	0.247
Time since operation (median)	4.8 (1.47–14.17)	29.19 (16.43–45.49)	0.467
KOGS grading			
KOGS grading 1	19 (2.6%)	701 (97.4%)	
KOGS grading 2	9 (6.2%)	136 (93.8%)	
KOGS grading 3	2 (1.4%)	141 (98.6%)	
KOGS grading 4	5 (3%)	164 (97%)	0.246
Surgery type			
PKA + PFA ($n = 866$)	30 (3.5%)	836 (96.5%)	
TKA ($n = 311$)	5 (1.6%)	306 (98.4%)	0.063
Smoking			
Yes	11 (11%)	100 (8.5%)	
No	24 (2.2%)	1077 (91.5%)	

Fig. 2 KOGS grading and effect on time to major complication



of the partial knee surgical treatment for focal knee OA and coupled with better identification techniques e.g. KOGS [22], X-KIDS [24] and DA [25] will improve the implementation of the correct treatment modalities for focal OA.

The studies by Liddle, on how to optimize the UKA outcomes, confirm the percentage usage as the key factor where the surgeon should preferably increase the percentage of UKA in his knee practice to approximately 50% to achieve a lesser revision rate than with his TKA [33].

KOGS identifies the increased percentage of knees required for UKA and selects the suitable knee with a validated system that is cost effective with minimal ipsilateral progression, 0.47%, at a mean of three years, is possible. According to the review study on lateral UKA failures by Ernstbrunner [34], the progression of OA is the most common problem in mid-term and late-term failures in mobile or fixed UKA and this can be minimized by improved selection.

The conclusions are as follows:

1. The KOGS can delineate focal pathology with minimal ipsilateral progression and implant options can be successfully implemented. Although the mean follow-up is only 36 months, it is known that failure in the UKA is predominantly early.
2. The KOGS can be used to scientifically compare the results of different stages of degeneration with the different modalities of treatment implemented.

Table 3 Major complications listed

Type of complication (35 major complications)		
	PKA (866), $n = 30$ (3.5%)	TKA (311), $n = 5$ (1.6%)
Ipsilateral pathology (OA, avascular necrosis, spontaneous chondrolysis)	7 (0.8%)	0
Avulsion of infra-patellar tendon	0	1 (0.3%)
Dislocation of bearing (lateral higher)	10 (1.2%)	2 (0.7%)
Fracture	6 (0.7%)	0
Haematoma	0	1 (0.3%)
Incarceration of patella	1 (0.1%)	0
Infection	1 (0.1%)	0
Patella fracture	0	1 (0.3%)
Subsidence	5 (0.6%)	0

3. The functional results, despite the irregular high proportion of UKA, are acceptable as seen by the OKS improvement.

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Author declarations We, the authors declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. All authors have participated in the research. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We understand that the Corresponding Author, CR Oosthuizen, is the sole contact for the Editorial process.

Compliance with ethical standards

Conflict of interest All authors declare that they received no research grants from funding agencies for this research.

Author 1 is an ad hoc paid consultant for Zimmer Biomet and Amplitude. Author 2 has received a speaker honorarium for a presentation on general aspects of Research and Innovation from Smith & Nephew.

No other interests required declaration as no benefits in any form have been received from a commercial party related directly or indirectly to the subject of this article.

Ethical approval Ethical approval was obtained from the Human Research Ethics Committee at the University of the Witwatersrand (WITS) to study the data and X-rays of the individual orthopaedic practices with Clearance Certificate Nos. M1704111 and M1704112. All procedures performed in studies involving human participants were in accordance with the ethical standards of the above named institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

Appendix. Synopsis of KOGS [22]

The grading system consists of four grades with treatment options to be implemented. Despite the specific grading achieved, there are clinical reasons which can influence the final decision for a particular prosthesis e.g. rheumatoid arthritis, clinically assessed disruption of ligaments, excessive deformities or patient-specific considerations or preferences. KOGS cannot be the only deciding factor.

Grade 1

Single TF or PF joint OA

Degeneration affects any one of the three compartments, with K&L grade 4 degeneration.

Grade 2

Single TF OA and ‘pseudolaxity’

AP view subluxation, isolated K&L grade 4 wear defects cause AP translation without ligament instability (stress X-ray restoration of JLCA < 2°).

On average, above this line would be UKA and below TKA

Grade 3

A: Single TF OA with K&L grade 4 and concomitant ACL instability with sagittal translation.

B: Single TF OA with K&L grade 4 and severe PF joint pathology or patellectomy.

Grade 4

4 A: Both TF joints are K&L grade 3 or 4 (< 5 mm space) with ligament stability.

4 B: Both TF joints

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CHAPTER 5: PUBLICATION 3 – IMPACT OF CORRECTABLE MEDIOLATERAL TIBIOFEMORAL SUBLUXATION ON UNICOMPARTMENTAL KNEE ARTHROPLASTY IMPLANT SURVIVAL IN PATIENTS WITH ANTEROMEDIAL OSTEOARTHRITIS

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Statement of Contributions of Joint Authorship

Oosthuizen C.R.: 55% (Candidate)
Conceptualisation of original idea, conducted the research, writing and compilation of the manuscript

Maposa I.: 10% (Research Colleague)
Assisted with data analysis, preparation of tables and figures, reviewing the manuscript and co-author of manuscript

Magobotha S.: 20% (Principal Supervisor)
Supervised and assisted with manuscript compilation, editing and co-author of manuscript

Pandit H.: 15% (Research Colleague)
Assisted with interpretation of results, reviewing the manuscript and co-author of manuscript

Impact of
correctable mediola

Chapter 5 is an exact copy of Publication 3 referred to above.

Impact of correctable mediolateral tibiofemoral subluxation on unicompartmental knee arthroplasty implant survival in patients with anteromedial osteoarthritis

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Abstract

Background

Medial unicompartmental knee arthroplasty (UKA) is advocated for treating symptomatic anteromedial osteoarthritis (AMOA). Correctable mediolateral tibiofemoral (TF) subluxation can be safely ignored according to the UKA enthusiasts. However, no clinical studies compare the results in AMOA patients with and without subluxation. This study reports the early prospective clinical outcomes of medial UKA in AMOA, with and without correctable mediolateral TF subluxation and the comparison to the retrospective larger patient cohort.

Methods

The results of an initial retrospective study (R) consisting of 436 consecutive UKA cases (patients treated from May 2012 to October 2017) were compared to a prospective study (P) consisting of 272 consecutive UKA cases in 248 patients with AMOA (evaluated from November 2017 to May 2020). All patients in both cohorts underwent cementless Oxford UKA and were classified into two groups: group 1 (AMOA without mediolateral subluxation) and group 2 (AMOA with mediolateral subluxation) on anteroposterior (AP) radiological knee stress views. Survival analysis methods (Kaplan–Meier and logrank test) were utilised to compare implant survival between the two groups (1 and 2) and the cohorts (R and P). The multivariable Cox proportional hazards model was used to determine risk factors for time to revision.

Results

The two cohorts, R and P, had patient groups (group 1 vs group 2) matched for age, sex, wear pattern, preoperative Oxford Knee Score and follow-up period. The overall implant survival for the P cohort that had at least 20 months of follow-up was 98%. The overall implant survival for group 1 (99%) was significantly better compared to group 2 (93%). These results are amplified in the R cohort with an average follow-up of 54 months, and with the group 1 survival at 97% and group 2 at 86%. Subsequent months of follow-up show more failures in group 2 compared to group 1. Patient-reported outcome measures (PROMs) and range of movement were similar for both groups.

Conclusion

Patients with AMOA and correctable mediolateral TF subluxation have a significantly higher risk of implant failure compared to those without subluxation. This study establishes this association, which has an important implication on patient selection, but does not confirm causality.

Level of evidence: Level 4

Keywords: unicompartmental knee arthroplasty, partial, osteoarthritis, X-ray, implant

Introduction

Medial unicompartmental knee arthroplasty (UKA) is advocated for treating symptomatic anteromedial osteoarthritis (AMOA). By definition, AMOA has bone-on-bone medial compartment osteoarthritis (OA) in the presence of intact ligaments and a functionally intact lateral tibiofemoral (TF) compartment.[1] To confirm the diagnosis of AMOA, use of varus and valgus stress radiographs in addition to weight-bearing anteroposterior (AP) and lateral radiographs is recommended.[2] These radiographs are performed with the patient lying supine and the knee under study flexed at 20°, with either manual or aided stress applied to the knee. The technique is well described elsewhere.[2] A varus stress radiograph is the most reliable radiographic method to demonstrate full thickness loss of articular cartilage (bone-on-bone contact) between the medial femoral and tibial condyles.[2,3] A valgus stress radiograph helps confirm normal thickness of articular cartilage in the lateral TF compartment and demonstrates that the intra-articular varus deformity is correctable (i.e., the medial collateral ligament is not shortened). In patients with AMOA, the wear pattern on the medial tibial plateau does not extend to the posterior margin of the tibia, and in all the cases there is intact articular cartilage on the posterior margin of the medial tibial plateau.[1,2]

In a proportion of patients with AMOA, a preoperative AP radiograph demonstrates the presence of mediolateral subluxation of the femur on the tibia. It is typically seen when there is significant loss of bone from the medial compartment (varus > 10°) and this subluxation persists with a varus stress view. The Oxford Group suggests that in such cases, if the valgus and varus stress views show complete reduction of the mediolateral subluxation, the presence of preoperative subluxation can be safely ignored.[4] If the subluxation persists, it is indicative of anterior cruciate ligament (ACL) deficiency and is therefore a contraindication for Oxford UKA (OUKA).[2] Although this has been advocated, no studies exist comparing the long-term results of OUKA in patients with correctable subluxation with those without any subluxation.

Does the subluxation on weight-bearing knee X-rays affect the results and outcome of UKA?

This single centre, single surgeon cohort study of consecutive cases has two aims: first, to present early prospective (P) results of OUKA in patients with AMOA between patients with correctable preoperative mediolateral TF subluxation and those without, from an independent centre; and second, to similarly compare the outcomes of a larger medium-term retrospective (R) AMOA cohort followed up by the same surgeon until 2020.

Methods

The prospective cohort (P) study comprised 272 consecutive AMOA knees (248 patients) treated with medial OUKA (Zimmer Biomet, Warsaw, USA) over a 31-month period from November 2017 to May 2020. The larger retrospective cohort (R), comprising 436 cases from May 2012 to October 2017, was then similarly evaluated according to the selection criteria for OUKA as per the published recommendations.[2-4] All patients underwent a standardised preoperative work-up including detailed clinical assessments and a series of radiographs as described previously.[5] Preoperative Oxford Knee Score (OKS)[6] and range of movement (ROM) was recorded. The ACL status and integrity of the lateral TF compartment were confirmed intraoperatively. If ACL was found to be friable and fragmented or absent, the patient underwent a total knee arthroplasty (TKA). In addition, the tibial wear pattern was carefully recorded using a method described by White et al.[1] The wear pattern was labelled as either anterior, or central or posterior according to the location of the deepest area of wear in relation to the AP tibial plateau dimension. All plain radiographs were assessed by an independent assessor for the presence or absence of mediolateral TF subluxation and patients were grouped accordingly into group 1 (patients with AMOA without any evidence of mediolateral subluxation on preoperative weight-bearing AP radiographs, *Figures 1 a–c*) and group 2 (patients with AMOA with presence of mediolateral subluxation on preoperative weight-bearing AP radiographs, *Figures 2 a–c*). In all cases in group 2, the mediolateral subluxation completely corrected on valgus stress view with parallel reduction of the lateral joint space thereby confirming the suitability for OUKA.

To simplify the assessment of subluxation on the AP views, it was defined as any overhang of the femoral condyle (excluding osteophytes) over the medial border of the tibia.

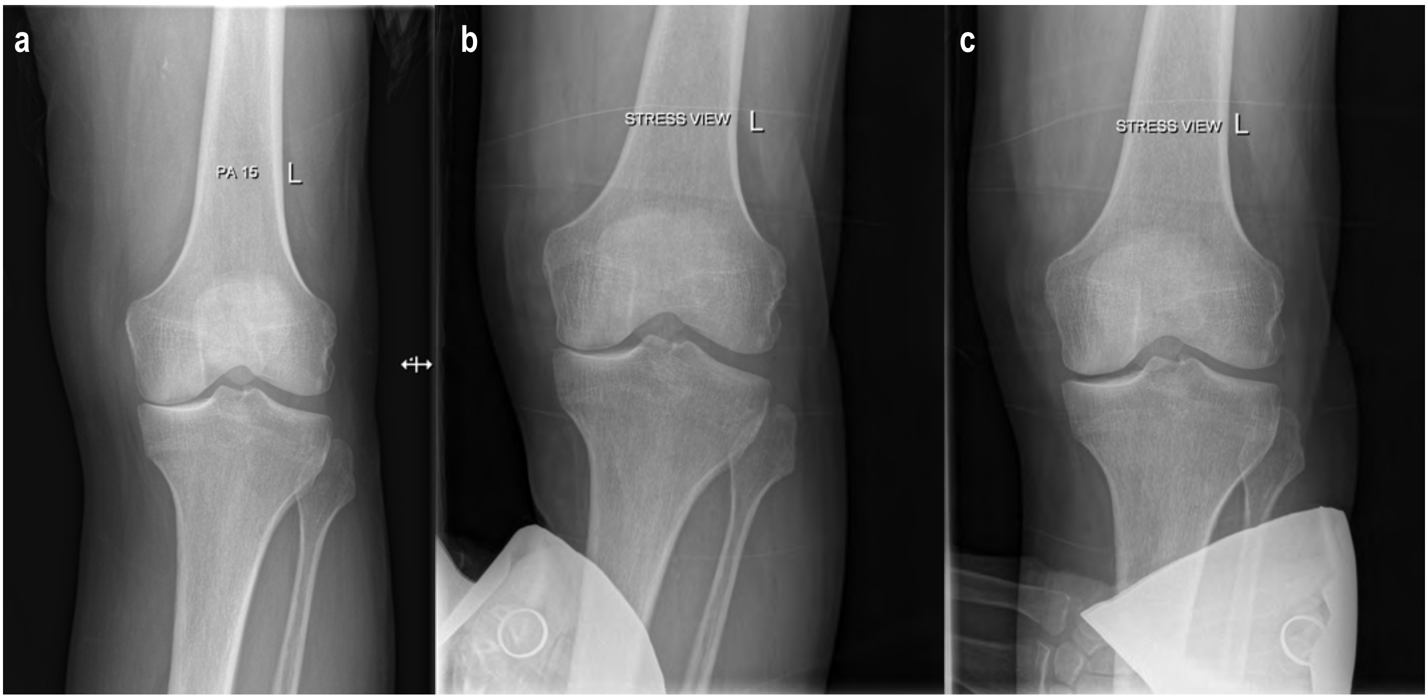

Figure 1. Group 1 preoperative radiographs. a) 15° AP; b) varus stress view; c) valgus stress view

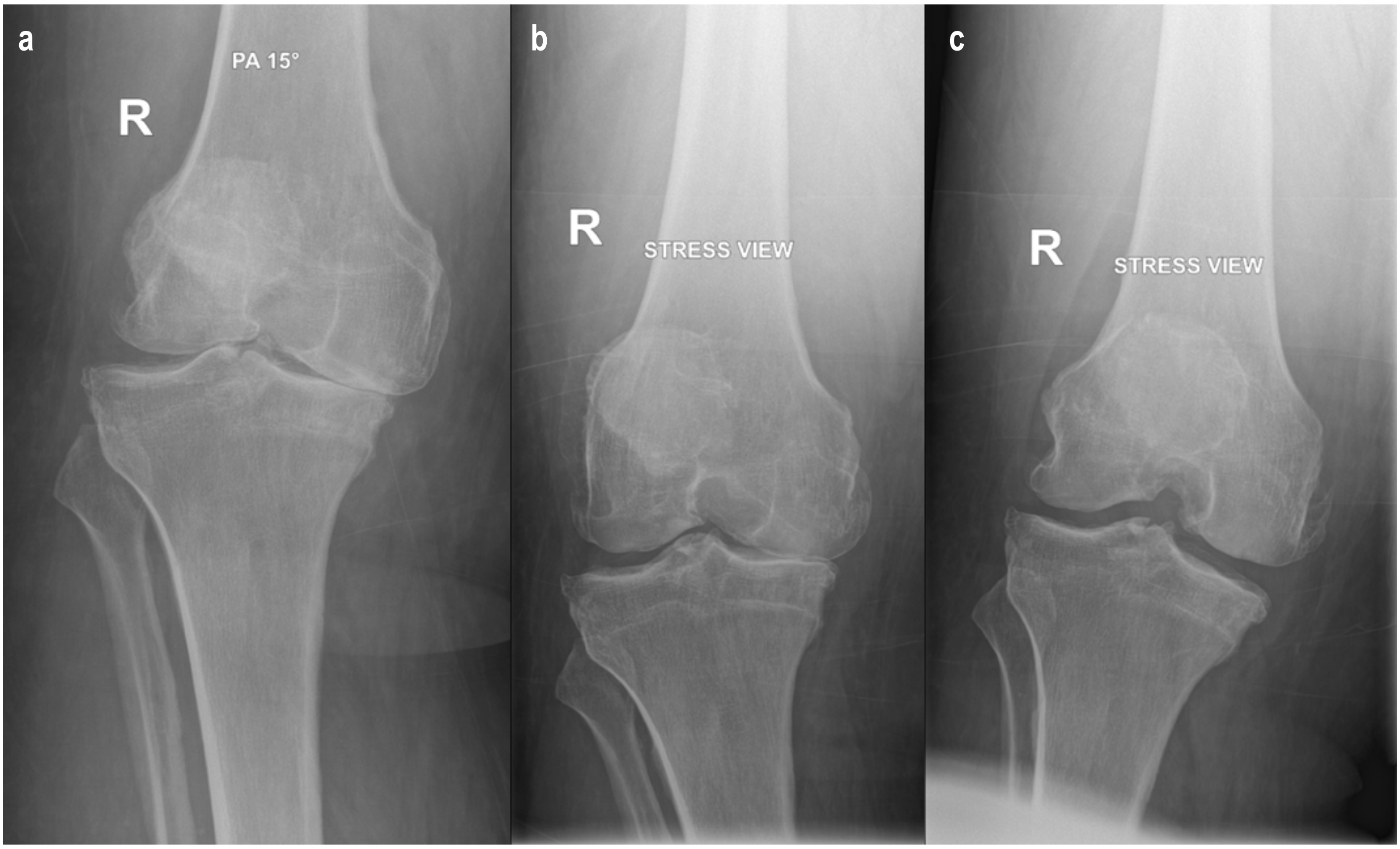

Figure 2. Group 2 preoperative radiographs. a) 15° AP; b) varus stress view; c) valgus stress view

All patients underwent a cementless medial OUKA using the recommended surgical technique with Microplasty® instrumentation with standardised postoperative management.[7] Patients were followed up at predetermined regular intervals (three months and then annually after surgery) with clinical and radiological assessment. Clinical assessment included OKS, a validated and widely used patient-reported outcome measure (PROM) and active ROM. All complications and/or further interventions on the index knee were recorded on an anonymised secure database. Any surgical intervention needed for removal or exchange of an existing implant or addition of another implant was labelled as revision.

Statistical analysis

Description of categorical variables was reported as a number and percentage. Associations between categorical variables were evaluated using chi-square (χ^2) or Fisher's exact tests as appropriate. Continuous variables were summarised and presented as mean and range, or as median and interquartile range (IQR). A student's t-test for normally distributed data or Mann-Whitney U test for non-normally distributed data was used to compare group differences in continuous variables. Survival analysis methods such as the Kaplan–Meier survival curves and logrank test were utilised to assess the patterns of implant survival between patients' characteristics. The multivariable Cox proportional hazards model was used to fit the predictive model for time to revision. A two-sided 5% significance level was used in all the statistical tests.

Results

The prospective (P) cohort of 272 knees (248 patients) included 162 (60%) men and 110 (40%) women with an average age of 64 (40–92; SD = 10) years at time of operation. The mean follow-up was 20 months (range 4–34; SD = 10). The mean postoperative OKS in the non-revised knees (at the time of last follow-up) was 43 (range 14–48; SD = 6.3), while for the revised knees it was 44 (range 26–48; SD = 5.6). The mean ROM was 0.3° (range 0–3; SD = 0.86) to 140° (range 120–150; SD = 6.2).

The retrospective (R) cohort of 436 knees (388 patients; 175 [40%] females and 261 [60%] males) had an average age of 64 years (range 42–87, SD = 8.7) at operation. The mean postoperative follow-up was 54 months. The mean postoperative OKS in the non-revised knees (at the time of last follow-up) was 44 (range 12–48, SD = 5.7), while for the revised knee it was 42 (range 22–48, SD = 8.0). The mean ROM for this cohort was 0.68° (range 0–5, SD = 1.3) to 138° (range 110–150, SD = 8.2).

The patient demographics (*Table I*), implant survival rates (*Table II*), and clinical outcomes and complications (*Table III*) for group 1 and group 2 in the respective cohorts P and R are summarised accordingly. The two groups were well matched for all relevant patient demographics as well as preoperative scores, ROM, follow-up period and tibial wear patterns.

The complications were not associated with a specific wear pattern.

Reasons for revision

In total, six knees underwent revision at a mean of 25 months (SD = 10.9; range: 8.1–33.2 months) post base year of follow-up in the P cohort. These included two for tibial subsidence, two for bearing dislocation and two for progression of arthritis in the lateral compartment. The R cohort had 23 knees that underwent revision, and these had a slightly longer duration before revisions. The detail of the complications and procedures performed are detailed in *Table III*.

The life table analysis for patients who had surgery between 2012 and 2017 (R cohort) is presented in *Table II* with the

Table I: Patient demographics and relevant preoperative data

Category	Prospective (P) cohort		Retrospective (R) cohort	
	Group 1	Group 2	Group 1	Group 2
Cases	228	44	352	84
Age in years at operation; mean (SD)	64 (9.5)	66 (11.2)	65 (8.8)	64 (8.5)
Males	64 (9.5)	64 (9.9)	65 (8.4)	63 (8.6)
Females	64 (9.6)	70 (13.0)	64 (9.3)	64 (8.4)
Tibial wear pattern:				
Anterior	51 (22%)	5 (11%)	87 (25%)	10 (12%)
Central	161 (71%)	35 (80%)	247 (70%)	67 (80%)
Posterior	16 (7%)	4 (9%)	18 (5%)	7 (8%)
Preoperative ROM; mean (from–to)	3–128°	4–129°	2–131°	3–126°
Preoperative OKS; mean (SD)	21 (8.1)	21 (10.1)	22 (8.0)	23 (8.6)

SD: standard deviation; ROM: range of movement; OKS: Oxford Knee Score

respective implant survival for group 1 and group 2. The first three years' implant survival for patients in both group 1 and 2 was 100%. The implant survival in the subsequent two years was 99% (95% confidence interval [CI]: 96.9–99.6) among those who were diagnosed without mediolateral subluxation (group 1) and 96% (95% CI: 89.2–98.8) among those with mediolateral subluxation (group 2) respectively. The difference between the two groups was statistically significant overall ($p = 0.0097$) over the follow-up period. The P cohort had only three years of follow-up and in that period, survival for group 1 was 99% (95% CI: 96–99.6) while group 2 was 93% (95% CI: 80.3–97.8). *Figure 3* shows the failure patterns in the two groups for both cohorts.

Multivariate Cox regression analysis showed that presence or absence of mediolateral subluxation was a significant independent

Table II: Life table analysis with 95% CI for implant revision for any cause in the 2012–2017 (R) cohort

Follow-up (years)	Group 1		Group 2	
	No. at start	Survival (95% CI)	No. at start	Survival (95% CI)
0–3 (base)	352	100%	84	100%
4–5	339	99% (96.9–99.6%)	83	96% (89.2–98.8%)
6–8	132	93% (88.3–96.5%)	52	80% (66.7–88.1%)

CI: confidence interval

Table III: Clinical outcomes and complications for the two groups in cohort

Category	Prospective (P) cohort		Retrospective (R) cohort	
	Group 1 (n = 228)	Group 2 (n = 44)	Group 1 (n = 352)	Group 2 (n = 84)
Follow-up period in months; mean (SD)	21 (8.8)	18 (8.4)	57 (15.9)	66 (16.0)
Postoperative ROM; mean (from–to)	0.3–140°	0–138°	1–138°	0–138°
Most recent postoperative OKS; mean (SD)	43 (6.3)	44 (5.6)	44 (5.7)	43 (8.0)
Complications needing revision surgery	3 (1%)	3 (7%)	11 (3%)	12 (14%)
Average period to implant failure in months; mean (SD)	24 (13.5)	27 (10.3)	63 (17.1)	65 (16.6)
Bearing dislocation – with revision of medial UKA (polyethylene replaced)	0	1	1	2
Bearing dislocation – with revision of medial UKA (implant replaced)	0	1	0	0
Lateral compartment OA – with revision to lateral UKA	2	0	3	3
Tibial subsidence – with revision of medial UKA (implant replaced)	1	1	1	0
Tibial subsidence – with revision of medial UKA (polyethylene replaced)	0	0	2	0
Avascular necrosis in the lateral compartment – with revision to lateral UKA	0	0	1	0
Tibia fracture – with revision to TKA	0	0	0	2
Impingement – with revision of medial UKA (implant replaced)	0	0	0	1
ACL trauma and polyethylene dislocation – with revision of medial UKA (polyethylene replaced) and ACL reconstruction	0	0	0	1
Loose prosthesis – with revision to TKA	0	0	0	1
No bone growth to attach prosthesis – with revision to TKA	0	0	1	0
Complication unknown – patients underwent revision surgery to TKA from other surgeons	0	0	2	2

SD: standard deviation; ROM: range of movement; OKS: Oxford Knee Score; UKA: unicompartmental knee arthroplasty; OA: osteoarthritis; TKA: total knee arthroplasty; ACL: anterior cruciate ligament

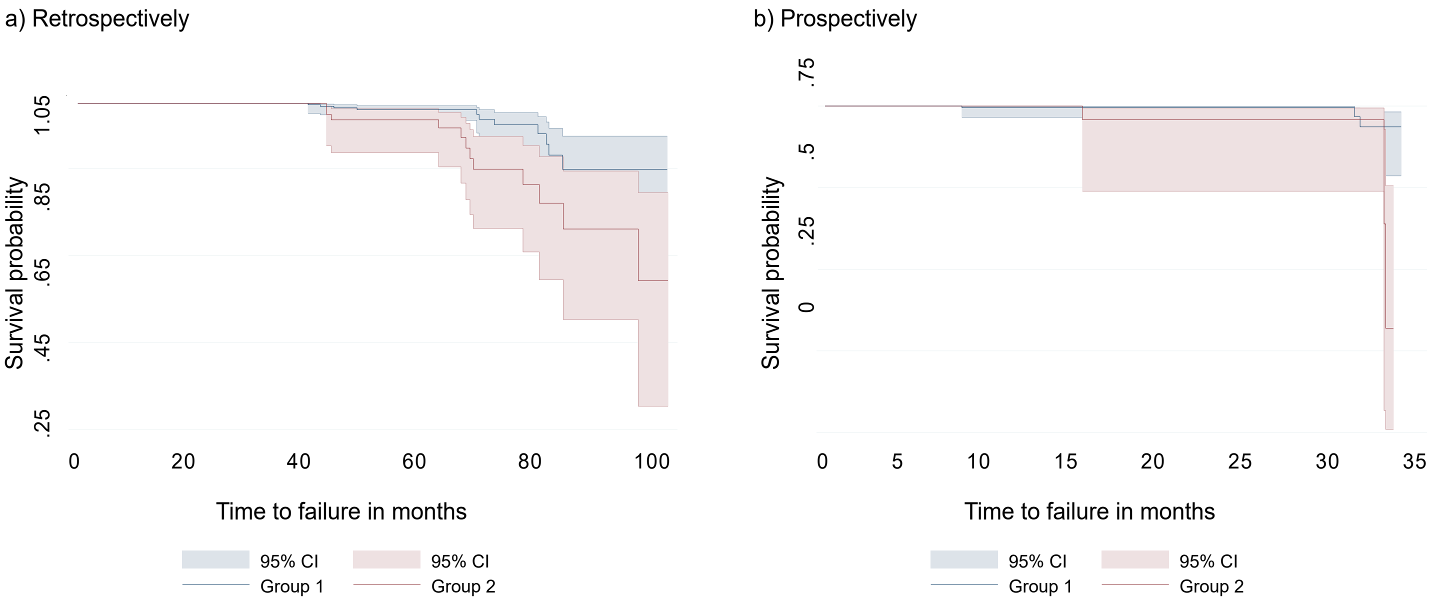

Figure 3. Surgical failure in group 1 and group 2 by the presence or absence of mediolateral subluxation on preoperative radiographs in patients followed up a) retrospectively and b) prospectively

predictor of implant failure (*Table IV*). A patient with preoperative mediolateral subluxation had, on average, a three times higher risk of surgical failure (adjusted hazard ratio [aHR] = 3.3; 95% CI: 1.4–8.7; p = 0.0170) compared to a patient without mediolateral subluxation. Age, sex and wear pattern were not significantly associated with the risk of implant failure in this cohort (*Table IV*).

Discussion

This is the first prospective study to assess the impact of preoperative correctable mediolateral subluxation on the outcomes of UKA in patients with AMOA. Although this is a short prospective study, it confirms the higher failure rate, contrary to the previous recommendations in the literature, when compared to those with AMOA without preoperative mediolateral subluxation.[4]

AMOA knee is an ideal indication for UKA. Various studies have demonstrated the clinical effectiveness and cost-savings of UKA over TKA in such patients.[8-12] In a significant proportion of patients, preoperative AP radiographs reveal the presence of mediolateral subluxation. Although the exact aetiology for such subluxation is unknown, it is believed to be associated with significant wear and/or bone loss and potentially ACL deficiency – the latter being a contraindication for mobile-bearing UKA.[4] To ascertain the suitability of such patients for UKA, it is recommended that patients should be assessed using stress views – particularly the valgus stress – and intraoperative assessment of the lateral compartment as well as ACL integrity.[5] If valgus stress and intraoperative inspection confirms suitability for UKA, patients could be safely offered a UKA. In this series, we prospectively collected data on all the patients undergoing UKA. This included careful recording of preoperative patient demographics including radiological stress views, intraoperative assessment for suitability for UKA, tibial wear patterns and regular clinical follow-up at predetermined intervals. In our cohort we noted correctable mediolateral subluxation in 27% of cases. The implant survival was significantly inferior in patients with correctable mediolateral subluxation compared to those without subluxation. There were no significant differences in demographics between the two patient groups. Although the reasons for implant failure were similar in the two patient cohorts, the frequency of bearing dislocation was significantly higher in patients with mediolateral subluxation.

The assessment of wear patterns was compared to the area of wear (*Table V*), and no association of complications with a specific wear pattern could be found.

If we assess the risk of implant revision based on the pattern of tibial wear, it is interesting to note that the risk increases when the wear pattern changes from anterior to central or posterior. The central/posterior area of wear may contribute to pseudolaxity and higher incidence of bearing dislocation. Although the centre of the deepest portion of the wear pattern was posterior to midline in none of the cases, the wear extended to the posterior margin of the medial tibial plateau. In all cases, the ACL was functionally intact

Table IV: Factors affecting time to failure in cohort: multivariable Cox regression model

Factor		Prospective (P) cohort		Retrospective (R) cohort	
		aHR (95% CI)	p-value	aHR (95% CI)	p-value
Mediolateral subluxation	Group 1 (subluxation absent)	1		1	
	Group 2 (subluxation present)	11 (1.67–66.1)	0.012	2.9 (1.25–6.86)	0.013
Sex	Female	1		1	
	Male	0.41 (0.06–2.92)	0.372	0.67 (0.29–1.54)	0.349
Wear pattern	Anterior	1		1	
	Central/posterior	0.82 (0.08–8.58)	0.869	1.12 (0.37–3.37)	0.841
Age at surgery		1.0 (0.91–1.1)	0.959	1.0 (0.56–1.05)	0.926

aHR: adjusted hazard ratio; CI: confidence interval

Table V: Patient characteristics for failed vs not failed implants

Variable		Prospective (P) cohort			Retrospective (R) cohort		
		Surgery failed, n (%)	Surgery not failed, n (%)	p-value	Surgery failed, n (%)	Surgery not failed, n (%)	p-value
Sex	Female	2 (2)	108 (98)	0.535*	11 (6)	164 (94)	0.440*
	Male	4 (3)	158 (97)		12 (5)	249 (95)	
Age in years (range)		64 (57–72)	64 (40–92)	0.865++	64 (48–76)	65 (42–87)	0.907++
Mediolateral subluxation	Group 1	3 (1.3)	225 (98.7)	0.056*	11 (3)	341 (97)	<0.001*
	Group 2	3 (6.8)	41 (93.2)		12 (14)	72 (86)	
Tibial wear pattern	Anterior	1 (2)	55 (98)	0.739*	4 (4)	93 (96)	0.925*
	Central	5 (3)	191 (97)		18 (6)	296 (94)	
	Posterior	0 (0)	20 (100)		1 (4)	24 (96)	

*chi-squared test
++ independent-samples student's t-test

(on intraoperative assessment), thereby confirming the patient's suitability for UKA as per established criteria.

This study has certain limitations. It is a single surgeon, single centre study with a short prospective element conforming to the trend seen in the larger retrospective cohort which cannot yet be generalised. The prospective cohort also had very few failures (only six) for both groups, which could increase uncertainty in the risk estimate due to limited power. However, analysis of the prospective (P) cohort is still under continuous evaluation, and will be submitted when the five-year mean has been achieved. The study confirms association (and not causality) between higher implant failures and patients with pre-existing correctable mediolateral subluxation in patients with AMOA.

The indications for surgery, surgical technique and postoperative regimen were standardised. All patients were followed up with detailed records of their clinical outcomes and complications. The follow-up is adequate and overall implant survival is similar to other reported series with the use of cementless OUKA.

Further work is needed to establish if similar findings are observed by other researchers, and attempts should be made to understand the association between smoking status, tibial wear patterns, coronal subluxation and implant failure.

Conclusion

The AMOA with anterior wear and without mediolateral subluxation is the most suitable knee for UKA. In patients with correctable preoperative mediolateral subluxation, caution must be exercised when offering a cementless UKA.

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Ethics statement

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

All procedures were in accordance with the ethical approval obtained from the Human Research Ethics Committee at the University of the Witwatersrand (Wits) with clearance certificate numbers M1704111 and M1704112. All patients provided informed consent for inclusion in the study.

Declaration

The authors declare authorship of this article and that they have followed sound scientific research practice. This research is original and does not transgress plagiarism policies.

Professor Pandit is a National Institute for Health Research (NIHR) Senior Investigator. The views expressed in this article are those of the author(s) and not necessarily those of the NIHR, or the Department of Health and Social Care.

Author contributions

CRO: Primary author, study conceptualisation, design, data collection and contribution, first draft preparation, manuscript preparation and revision, submission of final manuscript

IM: Design, data analysis, manuscript preparation and revision

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CHAPTER 6: DISCUSSION

The future of knee arthroplasty surgery is best illustrated in the publication by Garner *et al.* (2019) [88] wherein the nomenclature of 'combined' partial knee arthroplasties (PKAs) was set out to accommodate the need to classify the use of smaller procedures e.g., Bi-UKA, medial bi-compartmental arthroplasty, lateral bi-compartmental arthroplasty as well as tri-compartmental arthroplasty, formalising the partial knee solutions. This philosophy supports the TKA as the salvage procedure for knee degeneration and not the default position for all, even isolated compartmental OA, as is currently the vogue.

The first publication **(see Chapter 3)** reached the aim in validating the KOGS as a tool to differentiate the surgical options and determine the arthroplasty procedure required; UKA for KOGS Grades 1 and 2 or TKA for KOGS Grades 3 and 4, depending on the site and severity of degeneration and the ligament stability.
The first study collected sequential X-ray knee evaluations (routine visits for knee arthroplasty in the private sector) and was evaluated for arthroplasty by the co-authors relying on their own experience of assessing the X-rays for UKA or TKA. The same cohort was then randomised and the UKA or TKA identified according to the KOGS. The experienced surgeons confirmed selection by KOGS with a 92 – 98% sensitivity and accuracy like their own experienced assessment without any clinical knowledge of the patients. This validation process confirmed that KOGS renders similar selections for arthroplasty as that of the experienced surgeon when evaluating the proper X-ray sequence.
This supports the view that the 'default TKA' as a solution is selected due to factors not supported by the radiological appearance. The higher percentage of UKA assessed was also interesting as this is much higher than in their current practice when they are blinded from any clinical data. The use of KOGS amongst the seven evaluators markedly increased their distribution of UKA assessment *versus* TKA. Two evaluators had a much higher ratio of TKA than UKA (80 *versus* 20) in their practice, two on par with the evaluation (major UKA users) and three nearer to equal distribution UKA *versus* TKA (50 *versus* 50). The evaluators own experience agreed with their selection of a specific arthroplasty with the KOGS. This increase of selection was devoid of any clinical data and as it was the routine sequential distribution of a private knee practice cohort, it indicates at the very least, a much higher distribution of eligible knees for UKA (78.2% UKA, 22.5% TKA).

KOGS was able to identify true UKAs (sensitivity) based on the X-ray method in the range of 92.2 – 98.5% across all the different evaluators. The KOGS method was able to identify a UKA or a TKA with an accuracy ranging from 92 to 98.8% across all different evaluators.
KOGS can improve the selection of knee OA for smaller and more functional arthroplasty options rather than the tendency to default to a TKA even when isolated focal degeneration is found. The strength of the KOGS includes its accessibility as a tool to differentiate the selection of UKA, general applicability in every-day orthopaedic practices, its user-friendliness and cost-effectiveness.

The second publication **(see Chapter 4)** from a multi-centre study confirmed that the incidence of treating the isolated lesion with UKA will be increased dramatically with acceptable results by using the KOGS criteria. The prevalence of UKA was 72% *versus* 26% for TKA and the prescribed X-ray sequence was suitable and reproducible in any radiology department with minimal education, as these are known radiological views. The study illustrated the acceptable results KOGS achieved in a diverse multi-centre cohort that apply a 'stage specific prosthesis' leading to less invasive procedures that can lessen the known morbidity associated with the TKA and the improved ROM and function achieved by partial replacements.
There are no significant differences in the survivorship probabilities between patients that receive UKA and those that receive TKA based on the KOGS grading criteria (as a supportive diagnosis measure). There is no statistical difference between the complication rates of UKA *versus* TKA. By using KOGS, it will reduce the use of TKA in favour of UKA for isolated lesions with acceptable results comparing with published international results.
The incidence of UKA in the multi-centre knee arthroplasty cohort of the second study was greater than the current usage of any orthopaedic community, even higher than the assessment of Willis-Owen [16]. Further research can compare grade specific implantations and their different results (e.g., comparing all UKA *versus* TKA in KOGS Grade 1 etc.) and is a benefit arising from the KOGS ergo, an empirical system for degenerative knee pathology.
Analysis of the different constitutional wear patterns as seen on the tibial plateau did not affect the ultimate outcome in the second or third publication with wear being dominated in the central part of the tibial specimen on the medial and the lateral side. The evaluations confirmed the dominant anteromedial damage on the medial side and the reverse of posterolateral wear on the lateral tibial surface. Interesting to note is the seldom-found wear of the posterior third

of the medial compartment despite intact ACL ligaments, contrary to the publications of Keyes [91] and White [102]. The lateral compartment also had an incidence similar to the medial compartment of idiosyncratic wear on the anterior surface of the tibial specimen. The variety of wear must be further evaluated as it can arise due to altered kinematics, genetic variance, tibial inclination, trauma, or disease.

The results of the third publication **(see Chapter 5)** justified the KOGS preference to regard the subluxating knee (KOGS Grade 2) as a more deteriorative degree of wear than KOGS Grade 1 (‘stable’). This is the first prospective study to assess the impact of preoperative correctable mediolateral subluxation on the outcomes of UKA in patients with AMOA.

Two cohorts were assessed; Retrospective (R) and Prospective (P), both having been graded according to KOGS into Grade 1 (without subluxation) and Grade 2 (with subluxation) knees. The two cohorts matched for age, gender, wear pattern, preoperative OKS, and follow-up period. The overall implant survival for the P cohort that had at least 20 months of follow-up was 97.8%.

The overall implant survival for KOGS Grade 1 (98.7%) was significantly better compared with KOGS Grade 2 (93.2%).

These results are amplified in the R cohort with an average follow-up of 54 months and with the KOGS Grade 1 survival at 97% and KOGS Grade 2 at 86%. Subsequent months of follow-up show more failures in KOGS Grade 2 compared with KOGS Grade 1. PROMS and ROM were similar for both grades.

Multivariate Cox regression analysis showed that presence or absence of mediolateral subluxation was a significant independent predictor of implant failure. A patient with preoperative mediolateral subluxation, on average, had a three times higher risk of surgical failure compared with a patient without mediolateral subluxation. Age, gender, and wear pattern were not significantly associated with the risk of implant failure in this cohort.

The relatively small cohort of KOGS Grade 2 is more prone to failure and therefore judged a higher risk in the older patient, although the morbidity associated with a TKA may justify the risk, especially in the younger patient who could accept the risk of failure and revision to a combined procedure [28] e.g., preferably an ipsilateral arthroplasty.

The KOGS can enhance UKA use in the young patient under 60 years of age who could benefit from a staged approach of arthroplasty where the ‘final solution TKA’ is postponed and used as a salvage procedure. The ‘high incidence’ of lateral progression in UKA surgery deemed a failure in current convention and contributing to the high failure rate of the UKA can be addressed with an ipsilateral PKA, further enhancing the longevity of the knee function without revision to a TKA procedure.

The deteriorating nature of the KOGS was confirmed with the results of the third study where the KOGS Grade 2 had worse results than the isolated lesion in Grade 1, as well as with the first study where the process and results validated the basic principle. This allows the clinician to implement the UKA but informing the patient of the risk involved of lateral progression that can be addressed with an ipsilateral arthroplasty or a TKA. The treatment of isolated OA in e.g., RA (an auto-immune disease) with a patient stabilised with biologic treatment and in remission, can now be evaluated and compared with a UKA or TKA, as is the accepted standard. This study did not incorporate the clinical examination by the surgeon, and it is imperative to understand that the clinical indications and contraindications must be assessed in association with the X-ray assessment and can be used to improve the diagnostic decision.

The future of knee arthroplasty will be determined by the patient experience with minimal invasive techniques suitable for out-patient treatment or overnight care.

The TKA is a salvage procedure, even if it is inserted kinematically or according to CPAK.

The obvious solution is the development of the UKA as the primary treatment in a staged fashion when indicated with the spherical design, the biomechanical beacon of best practice and cost-effectiveness.

The MB philosophy is less prone to a ‘misplacement’ problem due to the tolerance of surgical error in the design and the simplified instrumentation.

Research of the CPAK with the FB philosophy and robotic placement to minimise the misplacement of the implant will benefit the large share of proponents in improving the results [62].

The research of these issues can be facilitated by the comparisons of pathologies by virtue of KOGS and the use of different implants.

CHAPTER 7: CONCLUSION

In the first publication **(see Chapter 3)** the objective was reached to introduce and validate a new novel grading system (KOGS) for OA knee surgery. The system identifies the higher incidence of isolated pathology suitable for UKA. The system further clarifies the selection of more severe pathology and selects the different options of arthroplasty. It can be implemented as an empirical template to compare the results of surgical and implant preference of less-severe degrees of OA with identifiable higher degrees of OA and ligamentous instability.

In the second publication **(see Chapter 4)** the categorised results achieved in a multi-surgeon and centre study are similar to that published in the literature of current UKA and TKA users. The system furthermore confirms the higher incidence of UKA as a viable option in this study when the knee pathology was assessed with the KOGS and distinguishes the results of a UKA from a TKA in the deteriorating degenerative cascade. The system is suitable for multi-centre cohort assessment for comparative studies of e.g., KOGS Grade 1 knees assessed and then with two radically different implants (UKA or TKA), a comparison of the results when utilised for the same pathology. As an example, the TKA results of ligament insufficient (KOGS Grade 4B) *versus* stable knees (KOGS Grade 4A) can be compared to combined Bi-UKA or bi-compartmental UKA as the system incorporates these different pathologies.

The third publication **(see Chapter 5)** compared the results of KOGS Grade 1 and 2 and vindicated the decision to grade the subluxating knee as an advanced and less favourable degree of OA for UKA. A longer timeframe of evaluation in the results of KOGS Grade 2 can also substantiate the need for a UKA rather than the TKA in the younger patient requiring an arthroplasty, despite the higher incidence of failure.

Summary: The KOGS as a validated tool presents the knee surgeon with practical advantages

1. The ability to improve the identification of the recipient suitable for a partial knee implant.
2. The ability to defend such a decision in court.
3. The ability to improve the decision for all implants with confidence and use a staged approach to knee arthroplasty.
4. The ability to compare the same pathology with the use of different implants (Apples-

with-apples comparison).

5. The ability to compare the results of UKA *versus* TKA without prejudice in the nature of the pathology.

6. This is the first tri-compartmental knee grading solution for arthroplasty.

Specific pathology requires further evaluation e.g., long leg X-rays, CT scanning or MRI for AVN of a condyle, as this complements the final assessment.

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APPENDIX A

ETHICS CLEARANCE CERTIFICATE NO. M1704112

R14/49 Dr Oosthuizen and Dr C Straeten

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M1704112

NAME: (Principal Investigator)	Dr Oosthuizen and Dr C Straeten
DEPARTMENT:	Orthopaedic Surgery Imperial College, London
PROJECT TITLE:	The Knee Osteoarthritis Grading System (KOGS)
DATE CONSIDERED:	05/05/2017
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Prof Sebastian Magobotha
APPROVED BY:	Professor P. Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	01/11/2017

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary on the 3rd floor, Philip Tobias Building, Parktown, University of the Witwatersrand. I/We fully understand the conditions under which I am/we are authorised to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit to the Committee. **I agree to submit a yearly progress report.** The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. In this case, the study was initially review April and will therefore be due in the month of April each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature　　　　Date 08/01/2017

APPENDIX B

ETHICS CLEARANCE CERTIFICATE NO. M1704111

R14/49 Dr CR Oosthuizen et al

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
CLEARANCE CERTIFICATE NO. M1704111

NAME: (Principal Investigator)	Dr CR Oosthuizen et al
DEPARTMENT:	School of Clinical Medicine Department of Orthopaedic Surgery Medical School
PROJECT TITLE:	Knee osteoarthritis grading system (KOGS) validation
DATE CONSIDERED:	28/04/2017
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr S Magobotha
APPROVED BY:	Professor PE Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	03/11/2017

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary on 3rd floor, Phillip V Tobias Building, Parktown, University of the Witwatersrand, Johannesburg.
I/We fully understand the conditions under which I am/we are authorised to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated from the research protocol as approved, I/we undertake to resubmit to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. in this case, the study was initially reviewed in **April** and will therefore be due in the month of **April** each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature

07/11/2017
Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

APPENDIX C

ETHICS CLEARANCE CERTIFICATE NO. M1704114

R14/49 Dr CR Oosthuizen et al

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
CLEARANCE CERTIFICATE NO. M1704114

NAME: (Principal Investigator)	Dr CR Oosthuizen et al
DEPARTMENT:	School of Clinical Medicine Department of Orthopaedic Surgery Medical School
PROJECT TITLE:	Medial unicompartmental knee replacement
DATE CONSIDERED:	28/04/2017
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr S Magobotha
APPROVED BY:	Professor PE Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	01/11/2017

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary on 3rd floor, Phillip V Tobias Building, Parktown, University of the Witwatersrand, Johannesburg.
I/We fully understand the conditions under which I am/we are authorised to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated from the research protocol as approved, I/we undertake to resubmit to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. in this case, the study was initially reviewed in **April** and will therefore be due in the month of **April** each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature

01/11/2017
Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

APPENDIX D

DATA COLLECTION SHEET FOR ETHICS CLEARANCE RECEIVED

KOGS / UKA / TKA

List of Data to be Recorded:
Code / Case Reference
Type of Surgery Performed
Diagnosis
Gender
Date of Operation
Left or Right Knee
Cartilage Loss: Medial (TF) / Lateral (TF) / PFJ
Wear Area
Smoker or Non-Smoker
Age at time of Operation
KOGS assessment by Dr Oosthuizen
KOGS assessment by independent Practitioners / Radiographers
Any Patient Preference towards Surgery
Clinical Finding influencing implant selection
BMI
PFJ Commentary
ACL Status (Normal / Without Synovium / Instability)
Mobile or Fixed Bearing Inserted
Hybrid Prosthesis Inserted
Oxford Prosthesis Inserted
Type of Complications
When did Complication occur?
Reason for Complications?
Minor or Major Complication
Complication Resolved How?
Date of Pre-Op Assessment
Range of Motion (R.O.M.) Pre-Op
Oxford Knee Score Pre-Op
Date of 6 Weeks Post-Op Assessment
Range of Motion (R.O.M.) 6 Weeks Post-Op
Oxford Knee Score 6 Weeks Post-Op
Date of 3 Months Post-Op Assessment
Range of Motion (R.O.M.) 3 Months Post-Op
Oxford Knee Score 3 Months Post-Op
Date of Most Recent Post-Op Scoring
Range of Motion (R.O.M.) Most Recent (1-5 years) Post-Op
Oxford Knee Score Most Recent (1-5 years) Post-Op
Bearing size Inserted
Tibial Prosthesis Size Inserted
Femoral Prosthesis Size Inserted
Poly Size
Patella Size
Deceased due to unrelated medical conditions? (Yes / No)
Deceased When?

	X-Ray Views: Pre-Operative
1.	AP Knee View
2.	Lateral Knee View
3.	30° Skyline Patella View
4.	15° (Medial OA) or
5.	45° (Lateral OA) Rosenberg/Lyon View
6.	Stress Views in 20° of Flexion (2 views)
	X-Ray Views: Post-Operative
1.	AP Knee View
2.	Lateral Knee View

APPENDIX E

INFORMATION SHEET PRESENTED TO PATIENT / INVITATION TO PARTICIPATE

STUDY INFORMATION DOCUMENT

Study title: The "Knee Osteoarthritis Grading System" (KOGS) / The theoretical development, validation and practical implementation of an X-ray viewing tool for the assessment for arthroplasty in terminal knee osteoarthritis

Dear Patient of Dr Oosthuizen,

Introduction:
I, Dr CR Oosthuizen, am doing research on the results of the knee replacement procedures performed in my practice. Research is a process used in seeking new knowledge. In this study I want to learn if my theoretically developed guide/tool (KOGS) will be able to assist other Orthopaedic Surgeons with their diagnosis and decision-making if knee replacement surgery is required and also the type of knee replacement that will be more suitable.
A knee replacement is a surgical procedure that replaces the damaged part/parts of the knee with an artificial part (the "prosthesis"). The most common reason for a knee replacement is deterioration of the joints because or osteoarthritis of the knee. Other possible causes include other forms of arthritis or knee injury.
Partial Knee Surgery (PKA) is a lesser invasive procedure usually required when only a part of the joint is damaged with reduced mobility and constant pain, even while resting. Total Knee Surgery (TKA) is usually necessary when all the knee joint surfaces are damaged and other forms of treatment have not been able to relieve pain. Since there is the option of a PKA or TKA (depending on severity of damage), the aim of the research is to identify if the grading tool is effective in indicating whether a patient is suitable for a PKA or TKA. The KOGS will then be introduced to other Orthopaedic Surgeons as a guide.
The research consists of the anonymous collection and analysing of your demographical data together with your pre- and postoperative x-rays (stored on a secured database). The data collected consists of the following: The type of knee surgery received; Gender; Age at the time of the operation; Smoking status: BMI; Whether any complications arose and the cause thereof; Pre-op Oxford Knee Scoring and multiple Post-op Oxford Knee Scoring (completed several times after surgery).
The benefit of this research is to compile data to educate and inform other Orthopaedic Surgeons that Partial Knee Surgery should preferably be the first option of treatment for bone-on-bone degeneration in 1 or more of the knees' compartments instead of a Total Knee Replacement (and offered to the patient as such).

Invitation to Participate: We are asking / inviting you to take part in this research study. Should you agree to participate, kindly sign the attached consent form.

What is your involvement in the study as a Participant? This could include but would not necessarily be limited to such features as:

1. The completion of a questionnaire pre-and postoperatively as a patient of Dr Oosthuizen's that have/will receive knee surgery;
   The above questionnaire is the standard Oxford Knee Score (OKS) which may take 1-2 minutes to complete in hard copy (during your first routine follow-up consultations with Dr Oosthuizen post-surgery at 6 weeks and 12 weeks) or telephonically (at 1 year and 5 years post-surgery).
   It is a 12-item patient-reported outcome questionnaire specifically designed and developed to assess your function and pain before and after your knee replacement surgery. It is short, valid and sensitive to clinically important changes;
2. By giving consent that your anonymized demographical data and x-rays may be collected and analysed (by Dr Oosthuizen, evaluators of the grading system as well as statistical analysts);
3. Engaging in the completion of the questionnaire telephonically implies that you have consented to take part in the study;
4. No blood samples or tests will be required that does not form part of an Orthopaedic Surgeon's routine care responsibility.

Participation in the research is voluntary. Refusal to participate in the study will not result in any penalty or loss of benefits from Dr Oosthuizen as your treating Orthopaedic Surgeon. You may refuse to answer questions and you may withdraw from the study at any time.

Risks of being involved in the study: This study is a collection and interpretation of data. This research and study does not involve any treatment and/or payment other than Dr Oosthuizen's Code of Practice as an Orthopaedic Surgeon. There are no foreseeable risks, discomforts, side effects or benefits from the study itself.

Benefits of being in the study: There is no direct benefit to the Participant. The objective of the study is to improve and validate the novel grading system for Orthopaedic Surgeons to use as an assisting tool in their decision-making for a patient to receive a particular type of arthroplasty.

There are no alternative procedures or courses of treatment that might be advantageous as a Participant.

The Participant can be given pertinent information on the study while involved in the project and after the results are available upon request.

Participation is voluntary: Refusal to participate in this study will involve no penalty or loss of benefits from Dr Oosthuizen as your treating Orthopaedic Surgeon. You may refuse to answer questions or discontinue participation at any time without penalty. There is no requirement to provide a reason for withdrawing and any data collected for the study will in default be destroyed, unless the Participant specifically consents to its retention. The medical file as a patient of Dr Oosthuizen will still remain intact and confidential.

Reimbursements/Cost associated with participation: There is no cost, payment or re-imbursement associated with participation in the study. Participation will be voluntary during routine follow-up consultations with Dr Oosthuizen as your Orthopaedic Surgeon

Confidentiality: Personal information will be treated in the strictest confidence and will only be available to the Medical Practice of the Principal Investigator (PI), Dr Oosthuizen. This study is anonymous.
The only exceptions - and all of them are rare - would normally be:

1. personal information may be disclosed if required by law;
2. the Human Research Ethics Committees of the University may exceptionally require personal data to respond to a formal complaint, or for a compliance audit.

This study will not involve focus group discussions.

The results from the study will be distributed and reported anonymously in a statistical manner and will/may be published in academic papers or presented at seminars and conferences as a cohort with no individual identification. For example: "Dr Oosthuizen performed 10 Total Knee Replacements and 10 Partial Knee Replacements; 8 Males and 12 Females at an average age of 65". All data collected during the course of this study will be securely retained for ten (10) years, allowing for post-operative follow-up. Thereafter it will be destroyed accordingly.

Contact details of researcher/s: Should you require further information or need to report adverse events, please contact:
Principal Investigator: Dr CR Oosthuizen (Margaret Houman), Tel 011 794 3397, E-mail: c-c@mweb.co.za
Supervisor: Prof. Sebastian Magobotha (University of the Witwatersrand), Tel: 011 933 8000, E-mail: sebastian.magobotha1@wits.ac.za

Outputs: The results of the study will be published in relevant orthopaedic academic papers and can be accessed from the Journal Publication.

Contact details of HREC administrator and chair: This study has been approved by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand, Johannesburg ("Committee"). A principal function of this Committee is to safeguard the rights and dignity of all human subjects who agree to participate in a research project and the integrity of the research.
If you have any concern over the way the study is being conducted, please contact the Chairperson of this Committee who is Professor Clement Penny, who may be contacted on telephone number 011 717 2301, or by e-mail on Clement.Penny@wits.ac.za. The telephone numbers for the Committee secretariat are 011 717 2700/1234 and the e-mail addresses are Zanele.Ndlovu@wits.ac.za and Rhulani.Mukansi@wits.ac.za

Thank you for reading this Study Information Sheet.
Date: November 2017

APPENDIX F

PARTICIPANT CONSENT SHEET

WITS UNIVERSITY

PARTICIPANT CONSENT SHEET

The "Knee Osteoarthritis Grading System" (KOGS) / The theoretical development, validation and practical implementation of an X-ray viewing tool for the assessment for arthroplasty in terminal knee osteoarthritis

1. I have been given a Participant Information Sheet which explains the nature and processes involved in this study, which is attached hereto;
2. I was given time to read it, or had it read to me, in the language I best understand;
3. I was given time to ask any questions I wanted to and found any answers given to me to be reasonable and satisfactory;
4. I believe I fully understand why the study is being conducted and what the intended outcomes will be;
5. I understand that there will be no immediate benefit or risks to me, should I agree to participate, nor will I receive any payment; conversely, participation will not cost me anything but my time;
6. I understand that, even if I initially consent to take part in the study, I may subsequently withdraw at any time and would not be required to give any reasons; if that happened, any data collected about me for the purposes of the study would immediately be destroyed, unless I give consent for it to be retained;
7. I understand that the study consists of the anonymous details of my knee replacement surgery performed by Dr CR Oosthuizen. Details to be included for example are: Radiographs, Gender, Age, Type of Surgery Received, Smoking Status, BMI, etc;
8. I understand that I will be required to complete a questionnaire at multiple times pre-and-postoperatively (the Oxford Knee Score);
9. I have been given a range of contact details, listed below. If I require further information or become concerned about any aspect of this study I am free to speak to any of these contacts;
10. I agree to participate in the study;
11. I agree that the data gathered in this study may be stored (after it has been anonymised) – including anonymised radiographs in a specialist data centre and may be used for future research.

Contact details:

Dr CR Oosthuizen, Principal Investigator, telephone no. 011 794 3397 (Margaret Houman), or by e-mail at c-c@mweb.co.za.
Prof. Sebastian Magobotha, Supervisor, telephone no. 011 933 8000, or by e-mail at sebastian.magobotha1@wits.ac.za.
Professor CB Penny, Chairperson of the Human Research Ethics Committee (Medical) at the University of Witwatersrand, on telephone no. 011 717 2301, or by e-mail at Clement.Penny@wits.ac.za.
Ms. Z Ndlovu or Mr Rhulani Mkansi, Committee Secretariat, telephone nos.: 011 717 2700 or 1234, or by e-mail at: Zanele.Ndlovu@wits.ac.za or Rhulani.Mkansi@wits.ac.za

Name of Participant: ____
Date: ____
Place: ____

Signature: ____

Witnessed by:

Name of Witness: ____

Signature: ____
Date: ____

APPENDIX G

THE OXFORD KNEE SCORE (OKS) QUESTIONNAIRE

DR C.R. OOSTHUIZEN: PRE- AND POSTOPERATIVE QUESTIONNAIRE

Page 1 of 2

FILE NUMBER:	
DATE OF OPERATION:	
DATE FORM FILLED IN:	

MALE
FEMALE
AGE:

TOTAL KNEE REPLACEMENT		
PARTIAL KNEE REPLACEMENT:		
LATERAL DOMED	CEMENTLESS	CEMENTED
SIDE:	LEFT	RIGHT

***PLEASE MARK WITH X IN THE BLOCKS**

Question 1: How would you describe the pain you usually have in your knee?

4	None
3	Very Mild
2	Mild
1	Moderate
0	Severe

Question 2: Have you had any trouble washing and drying yourself (all over) because of your knee?

4	No trouble at all
3	Very little trouble
2	Moderate trouble
1	Extremely difficult
0	Impossible to do

Question 3: Have you had any trouble getting in and out of a car or using public transport because of your knee?

4	No trouble at all
3	Very little trouble
2	Moderate trouble
1	Extremely difficult
0	Impossible to do

Question 4: For how long are you able to walk before the pain in your knee becomes too severe?

4	More than 30 minutes
3	16 to 30 minutes
2	5 to 15 minutes
1	Around the house only
0	Not at all – severe when walking

Question 5: After a meal (eaten at a table), how painful has it been for you to stand up from a chair because of your knee?

4	No trouble at all
3	Slightly painful
2	Moderately painful
1	Very painful
0	Unbearable

Question 6: Have you been limping when walking, because of your knee?

4	Rarely / Never
3	Sometimes or only at first
2	Often, not only at first
1	Most of the time
0	All of the time

Question 7: Can you kneel down and get up again afterwards?

4	Yes, easily
3	With little difficulty
2	With moderate difficulty
1	With extreme difficulty
0	No, impossible

Question 8: Have you been troubled by pain from your knee in bed at night?	4	Not at all
	3	Only 1 or 2 nights
	2	Some nights
	1	Most nights
	0	Every night
Question 9: How much has pain from your knee interfered with your usual work? (Including housework)	4	Not at all
	3	A little bit
	2	Moderately
	1	Greatly
	0	Totally
Question 10: Have you felt that your knee might suddenly "give way" or let you down?	4	Rarely / Never
	3	Sometimes or just at first
	2	Often, not at first
	1	Most of the time
	0	All of the time
Question 11: Can you do household shopping on your own?	4	Yes, easily
	3	With little difficulty
	2	With moderate difficulty
	1	With extreme difficulty
	0	No, impossible
Question 12: Can you walk down a flight of stairs?	4	Yes, easily
	3	With little difficulty
	2	With moderate difficulty
	1	With extreme difficulty
	0	No, impossible

Question 13: Did you have any knee operation before your knee replacement. If so, what? ______________________

Question 14: Did you have any knee operation after your knee replacement? If so, what was done and by whom was the operation performed? ______________________

Question 15: Did you have any complications after your knee replacement? ______________________

Question 16: Do you smoke?	YES
	NO

Question 17: Did you come for your follow-up visit? If not, why not? ______________________

Question 18: Would you recommend this surgery to your family and friends with knee problems?	YES
	NO

APPENDIX H

PUBLICATION 1 – “COHORT A” ASSESSMENT SHEET FOR EVALUATORS

ASSESSMENT A: SURGICAL IMPLEMENTATION				DR:	
(As according to normal Routine)			(Please insert the name of the assessor above)		
X-Ray Views: Pre-Operative			**X-Ray Views: Post-Operative**		
1.	AP Knee View		1.+ 2	AP Knee View and Lateral Knee View	
2.	Lateral Knee View				
3.	30° Skyline Patella View			(Please indicate the preferred/suggested procedure to be performed after viewing the X-Rays of each case)	
4.	15° (Medial OA) or				
5.	45° (Lateral OA) Rosenberg/Lyon View				
6.	Stress Views in 20° of Flexion (2 views)		Partial Knee Arthroplasty = PKA (UKA or PFA)	Total Knee Arthroplasty = TKA	No Arthroplasty = None

X-Ray Case Reference		**Suggested Arthroplasty Procedure**		
Case Number	1	PKA	TKA	NONE
Case Number	2	PKA	TKA	NONE
Case Number	3	PKA	TKA	NONE
Case Number	4	PKA	TKA	NONE
Case Number	5	PKA	TKA	NONE
Case Number	6	PKA	TKA	NONE
Case Number	7	PKA	TKA	NONE
Case Number	8	PKA	TKA	NONE
Case Number	9	PKA	TKA	NONE
Case Number	10	PKA	TKA	NONE
Case Number	11	PKA	TKA	NONE
Case Number	12	PKA	TKA	NONE
Case Number	13	PKA	TKA	NONE
Case Number	14	PKA	TKA	NONE
Case Number	15	PKA	TKA	NONE
Case Number	16	PKA	TKA	NONE
Case Number	17	PKA	TKA	NONE
Case Number	18	PKA	TKA	NONE
Case Number	19	PKA	TKA	NONE
Case Number	20	PKA	TKA	NONE

APPENDIX I

PUBLICATION 1 – "COHORT B" ASSESSMENT SHEET FOR EVALUATORS

KNEE OSTEOARTHRITIS GRADING SYSTEM (KOGS)		DR:			
		(Please insert the name of the assessor above)			
X-Ray Views: Pre-Operative		X-Ray Views: Post-Operative			
1. AP Knee View		1. AP Knee View	2. Lateral Knee View		
2. Lateral Knee View					
3. 30° Skyline Patella View		(Please indicate the grade of focal degeneration according to the KOGS			
4. 15° (Medial OA) or		after viewing the X-Rays of each case)			
5. 45° (Lateral OA) Rosenberg/Lyon View					
6. Stress Views in 20° of Flexion (2 views)					

X-Ray Case Reference		KOGS				
Case Number	K1	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K2	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K3	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K4	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K5	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K6	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K7	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K8	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K9	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K10	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K11	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K12	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K13	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K14	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K15	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K16	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K17	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K18	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K19	Grade 1	Grade 2	Grade 3	Grade 4	No Grading
Case Number	K20	Grade 1	Grade 2	Grade 3	Grade 4	No Grading

APPENDIX J

SPECIFIC INSTRUCTIONS TO EVALUATORS FOR "COHORT B" ASSESSMENT

Dear Evaluators,

In the first cohort (PKA/TKA) I requested all to determine, with the X-rays available, which procedure is the most suitable. This is usually how we proceed in practice, as we all do not require the full sequence of X-rays as required by KOGS.

The second cohort must be graded pedantically according to the synopsis of the KOGS.

The stats will then be done.

The following preoperative X-ray views are provided to be evaluated and graded according to the KOGS for each case:

AP Knee View; Lateral Knee View; 30° Skyline Patella View; 15° (Medial) or 45° (Lateral) PA Rosenberg/Lyon View; Stress Views in 20° of Flexion (2 views).

A final synopsis of the grading system (KOGS) to help with the evaluation:
This grading is to facilitate the final type of Arthroplasty decision and Bone-on-bone is required to start the grading e.g., a TF or a grooved PFJ.
The progress of the grading is plotted to be able to finally compare similar knee pathology and the outcome achieved, whether a UKA/PFA or TKA is implemented.

The proviso for TF partial knee replacements is that one compartment should be normal. This can be assessed by standing knee AP, lateral, "Stress-view" in 20° flexion and 15° (medial) or 45° (lateral) PA (Rosenberg View). The "unaffected" (healthy) weight-bearing compartment must be more than 5mm in width and be parallel to the opposing joint surfaces on the stress view. The PFJ is assessed by a skyline view and stress views to confirm the integrity of the weight-bearing compartments (TF).

The KOGS consists of four grades:

Grade 1

An isolated bone-on-bone lesion involving any of the three compartments, despite osteophytes at other joints, which are still fully patent.
The PFJ might have OA changes, but is not grooved or dysplastic (most likely asymptomatic and not in need of an arthroplasty).

Grade 2

The lesion is isolated to the TF joints but with large lesions causing subluxation (due to the defects), on the AP views.
The ligaments are stable with reduction of the knee on the stress views, the contralateral TF is normal and reduced.

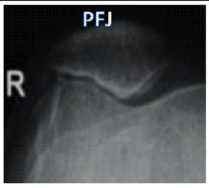
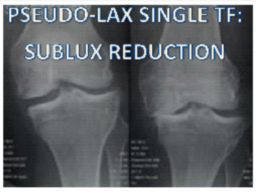
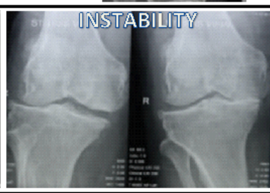
Grade 3

Two pathologies involving one TF joint and a concomitant second problem.
Single TF bone-on-bone with an ACL instability or previous surgery to the ACL.
A single TF is involved with less than 5 mm joint space and an associated grooved PFJ (Osteophytes only at the PFJ is not sufficient to do a procedure here and thus do not qualify as a Grade 3 but rather a Grade 1)
A previous patellectomy is also considered to be a "pathology" and therefore not a Grade 1 if associated with a TF bone-on-bone, but a Grade 3 .

Grade 4

Both TF joints are pathological and less than 5 mm in joint space.

Thank you for the time and effort to comply with the method analysis.

KOGS (KNEE OSTEOARTHRITIS GRADING SYSTEM)		[Can be used as a Knee Arthroplasty Guide System] (KAGS)	TREATMENT
GRADE 1 SINGLE COMP. OA TF OR PFJ	➡	SINGLE TF  OR PFJ 	PKA OR PFA
GRADE 2 SINGLE TF OA SUBLUXATION (INTACT LIGAMENTS)	➡	PSEUDO-LAX SINGLE TF: SUBLUX REDUCTION  FOOTNOTE: OSTEOPHYTES NOT A CONTRA-INDICATION. CONFIRM CONTRA-LATERAL TF SPACE > 5 MM STRESS REDUCTION OF SUBLUXATION • NO "WEDGE SIGN"	PKA
GRADE 3 SINGLE TF OA CONCOMITANT INSTABILITY SUBLUXATION OR PFJ OA / PATELLECTOMY	➡	ACL INSTABILITY  PFJ AND TF OA 	RECON. ACL + PKA OR PFA + PKA
GRADE 4 BOTH TF OA WITH OR WITHOUT LIGAMENT INSTABILITY	➡	NO INSTABILITY  INSTABILITY 	NO INSTABILITY: BI-CONDYLAR PKA, BICRUCIATE TKA INSTABILITY: TKA

APPENDIX K

THE KNEE OSTEOARTHRITIS GRADING SYSTEM (KOGS) – TREATMENT GUIDE (ATLAS)

KOGS
KNEE OSTEOARTHRITIS GRADING SYSTEM

TREATMENT GUIDE

GRADE 1

SINGLE COMPARTMENT OA →

OR

Treatment guide: **UKA OR PFA**

GRADE 2

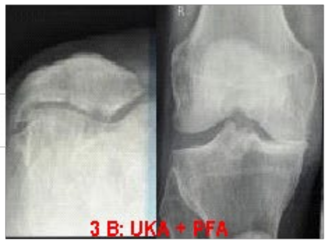
SINGLE TF + SUBLUXATION →

FOOTNOTE:
OSTEOPHYTES ARE NOT A CONTRAINDICATION.
CONFIRM CONTRALATERAL TF SPACE > 5 MM
STRESS REDUCTION OF SUBLUXATION
NO "WEDGE SIGN" (JLCA > 2°)

Treatment guide: **UKA**

GRADE 3

SINGLE TF + CONCOMITANT →



Treatment guide: **UKA OR TKA**

GRADE 4

BOTH TF →

Treatment guide: **TKA**

APPENDIX L

THE KNEE OSTEOARTHRITIS GRADING SYSTEM (KOGS) – LEGEND

KOGS

THE KNEE OSTEOARTHRITIS GRADING SYSTEM

LEGEND

The KOGS is a dynamic radiological tool for degenerative osteoarthritis (OA) of the knee.
By evaluating all three compartments, it aids the surgeon in deciding on the type and timing of knee arthroplasty (UKA – Unicompartmental Knee Arthroplasty; TKA – Total Knee Arthroplasty; or PFA – Patellofemoral Arthroplasty).
The system complements clinical evaluation as a tool to improve the surgical decision.

To improve the identification of the correct knee for a specific arthroplasty, the following need to be evaluated:

• Tibiofemoral joints (TFJ) **and**
• Patellofemoral joints (PFJ)

The inclusion proviso in this assessment for arthroplasty is that at least one of the three compartmental joints should be a Kellgren and Lawrence (K&L) grade 4 and have bone-on-bone contact. This can be assessed by standing knee Anteroposterior (AP), lateral, "Stress-view" in 20° of flexion and 15° (medial) or 45° (lateral) Posteroanterior (PA) – Rosenberg View. The "unaffected" (healthy) weight-bearing TFJ compartment must be more than 5mm in width and parallel (congruent) to the opposing joint surfaces on the stress view.

NB: When the stress view demonstrates a "wedge deformity" in the "healthy" compartment, it indicates ligamentous instability or more wear than anticipated in the healthy compartment.

The PFJ assessment uses the 30° skyline and lateral view, as well as the stress and Rosenberg views to confirm the integrity of the weight-bearing compartments when considering PFA.
The grading system consists of **four grades** with treatment options to be implemented. Despite the specific grading achieved, clinical reasons can influence the final decision for a particular prosthesis, for example rheumatoid arthritis (RA), clinically assessed disruption of ligaments, excessive deformities or patient-specific considerations or preferences. KOGS cannot be the only deciding factor. This system is based on wear patterns and constitutional wear progression.

<u>KOGS GRADE 1:</u> <u>UKA</u> OR <u>PFA</u>

SINGLE TFJ COMPARTMENT OA / SINGLE TFJ K&L GRADE 4.

(SINGLE TFJ OR PFJ)

Degeneration affects any one of the three compartments, with bone-on-bone degeneration. Osteophytes may be present in other compartments, but these retain their integrity being >5mm with a parallel joint surface required in the weight-bearing compartment.
The KOGS Grade 1 can have OA changes in the other compartments e.g., the PFJ might have OA changes but is not grooved or dysplastic and therefore remains a Grade 1 or osteophytes not affecting joint space in the ipsilateral joint remains a Grade 1.

E.g., A TFJ with bone-on-bone degeneration or less than 5mm joint space and associated, early *(non-symptomatic)* PFJ OA *(not dysplastic or grooved)*
OR
Osteophytes in TFJ's without narrowing *(Full thickness cartilage as seen on Stress-view or 15° and 45° Rosenberg View)* and grooving of the PFJ *(isolated PFJ OA)*.

<u>KOGS GRADE 2:</u> <u>UKA</u>

SINGLE TFJ COMPARTMENT OA / SINGLE TFJ K&L GRADE 4 <u>WITH</u> "PSEUDO-LAXITY" – SUBLUXATION ON AP KNEE VIEW.

(SINGLE TFJ + SUBLUX REDUCTION)

The lesion is isolated to the TFJ's but with large lesions causing subluxation (due to the defects) on the AP views. However, this is reduced by the stress views and the ligaments are stable.
The healthy ipsilateral compartment is maintained (Parallel and > 5mm) despite the presence of osteophytes.
Evaluation of subluxation is dependent on good stress and Rosenberg views with the identification seen where the tibial spines move towards the opposing lateral femoral condyle or seen with the lateral femur displaced medially to the lateral tibia.
Lateral subluxation is possible but seldom seen.

<u>KOGS GRADE 3A:</u> <u>UKA + ACL</u> OR <u>TKA</u>
<u>KOGS GRADE 3B:</u> <u>UKA + PFA</u> OR <u>TKA</u>

<u>3A:</u> SINGLE TFJ COMPARTMENT OA / SINGLE TFJ K&L GRADE 4 <u>AND</u> CONCOMITANT ANTERIOR CRUCIATE LIGAMENT (ACL) INSTABILITY.

<u>3B:</u> SINGLE TFJ COMPARTMENT OA / SINGLE TFJ K&L GRADE 4 <u>AND</u>

CONCOMITANT GROOVED PFJ OA.

Two pathologies that involve one TFJ and a concomitant second problem.

3A: UKA + ACL OR TKA
Single TFJ bone-on-bone (K&L grade 4) with an ACL instability or previous surgery to the ACL.

3B: UKA + PFA OR TKA
A single TFJ OA with a grooved PFJ is involved with less than 5mm joint space (Osteophytes only at the PFJ are not sufficient and do not qualify as a KOGS Grade 3B but rather a Grade 1).
A previous Patellectomy is also considered to be "pathology" and therefore a KOGS Grade 3B when associated with a TFJ bone-on-bone (K&L grade 4).

KOGS GRADE 4A: BICONDYLAR UKA OR BICRUCIATE RETAINING TKA
KOGS GRADE 4B: TKA

BOTH TFJ COMPARTMENTS OA

4A: BICONDYLAR UKA OR BICRUCIATE RETAINING TKA
Both TFJ's are affected with ligament stability.

4B: TKA
Both TFJ's wear and ligament instability.

These treatment recommendations depend on clinical evaluation and patient compliance with KOGS Grade 1 PFJ possibly requiring a TKA and KOGS Grade 3 knees similarly a TKA.

APPENDIX M

STUDENT'S CONTRIBUTION TO THE RESEARCH AND WRITING OF THE PUBLISHED PAPERS

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7 November 2022

Faculty of Health Sciences, University of the Witwatersrand

RE: CHRISTIAAN RUDOLF OOSTHUIZEN'S CONTRIBUTION TO THE RESEARCH AND WRITING OF THE PUBLISHED PAPER

To whom it may concern,

This letter serves to confirm that the co-authors of the published research paper have agreed to its use by Christiaan Rudolf Oosthuizen, student number 1830796, as part of his PhD thesis.

Christiaan Rudolf Oosthuizen made a substantial contribution to conducting the research study and writing the manuscript.

Yours sincerely,

....

Prof Sebastian Magobotha
Primary Supervisor

....

Christiaan Rudolf Oosthuizen
PhD Candidate

APPENDIX N

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Publication Title: The Knee Osteoarthritis Grading System for Arthroplasty

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Journal: The Journal of Arthroplasty

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The Knee Osteoarthritis Grading System for Arthroplasty

Author:
Christiaan R. Oosthuizen,Tsuneari Takahashi,Mack Rogan,Christian H. Snyckers,Duwayne P. Vermaak,Gareth G. Jones,Andrew Porteous,Innocent Maposa,Hemant Pandit

Publication: The Journal of Arthroplasty

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APPENDIX O

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Journal: International Orthopaedics

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Publication Title: Impact of correctable mediolateral tibiofemoral subluxation on unicompartmental knee arthroplasty implant survival in patients with anteromedial osteoarthritis.

Publisher: Medpharm Publications

Journal: South African Orthopaedic Journal (SAOJ)

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PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

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