Outcomes of Patellofemoral Joint Arthroplasties Compared to Total Knee Arthroplasties

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Abstract

Patellofemoral joint arthroplasty (PFA) and total knee arthroplasty (TKA) are established treatment options for patients with isolated patellofemoral osteoarthritis. PFA is considered a small, bone-preserving procedure that maintains native knee kinematics through preservation of the cruciate ligaments. Due to its historically high revision rates, which have been reported as high as 35%, surgeons have been cautious in adopting PFA. This may explain why PFAs still account for 1% in most national joint registries worldwide.

A comparison of matched patients undergoing PFA and TKA was performed using data from the National Joint Registry for England and Wales. Complications, revision reasons, and patient-reported outcome measures were analysed. While TKA patients were more likely to experience complications within 30 days, they were less likely to undergo revision surgery. Gender differences in revision risk and reasons for revision were evaluated across different age groups. To further understand the factors influencing revision rates, the impact of surgical experience was also examined.

Although there was a statistically significant difference in Oxford Knee Score and EQ-5D-3L outcomes, with TKA faring better, the difference did not reach the minimal clinical difference when taken as 5 and 0.085, respectively. For further comparison, differences in function were examined to delineate functional differences between the two procedures. A 10-year follow up of an international randomised controlled trial was conducted to assess differences in activity levels and gait analysis patterns between PFA and TKA in patients with isolated patellofemoral osteoarthritis.

Although limited by a small sample size, PFA patients demonstrated higher total physical activity time per week, though this did not reach statistical significance. Gait analysis revealed a more physiological pattern in PFA patients, likely reflecting the preservation of normal knee kinematics. However, further work is needed to establish if there is an objective difference in activity levels in the short term.

Acknowledgements

I would like to express my deepest gratitude to my supervisors, Mr Liddle and Professor Cobb, for entrusting me with this opportunity and for their invaluable mentorship, wisdom, and belief in my abilities. True mentorship is not measured by the amount of time spent, but by the quality of guidance and inspiration imparted, for that, I will remain sincerely grateful.

I am also deeply thankful to Mr Logishetty for introducing me to the MSk Lab. Your leadership, encouragement, and the positive environment you have always fostered have been truly inspiring and something I will always look up to.

I am profoundly indebted to those who have funded and supported this work. I have been fortunate to receive support from two charities, Orthopaedic Research UK (OR UK) and the International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine (ISAKOS). I am grateful for the faith they have shown in both this project and my ability to complete it. I would also like to express my sincere thanks to the organisations that have awarded me travelling research fellowships, including the Alex Simpson Smith Travelling Fellowship, the Royal Society of Medicine Trauma and Orthopaedic William Bodey Fellowship, the Imperial College Global Fellows Fund and the Imperial College Dean Internship Award.

Finally, my heartfelt gratitude goes to my husband, Matthew, for his unwavering belief in me and for being the most positive person I know, smiling every day and bringing light into every challenge. Thank you for being my constant source of support and optimism. My deepest thanks also go to my parents, to my father, for giving me the courage to dream and the determination to achieve, and to my mother, for instilling in me the gift of precision and organisation. Lastly, to the friends I have made throughout this journey, both medical and non-medical, local and international, thank you for helping me grow, learn, and become a better person. This journey has been truly remarkable and one I have genuinely enjoyed.

Statement of originality

I, Martinique Vella Baldacchino hereby declare that the work presented in this thesis is the result of my own original research. All sources of information, ideas, and data derived from the work of others have been fully acknowledged and appropriately referenced. This thesis has not been submitted, either in whole or in part, for any other degree or qualification at this or any other institution.

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To my family

Preface

My academic research journey began several years ago when I was offered a DPhil during my core surgical training, at Balliol College, University of Oxford. At the same time, I was offered my current Specialist Registrar training post and an academic registrar training post in the north of England. As the DPhil project was linked to specific funding arrangements, I ultimately chose to pursue clinical training in London while continuing to develop my research interests independently alongside surgical training. Subsequently, I visited the MSk Lab, where discussions emerged regarding research into patellofemoral osteoarthritis. Given my longstanding interest in partial compartment osteoarthritis and knee arthroplasty, this represented an exciting opportunity to pursue a higher degree within a highly supportive academic environment.

At the start, I often questioned whether I truly belonged within academic research, a feeling I later recognised as imposter syndrome. Over time, however, my confidence and research skills developed substantially through both successes and setbacks. Early unsuccessful grant applications became valuable learning experiences that ultimately contributed to securing competitive research funding and developing academic independence.

An important piece of advice from a senior colleague was to make the most of the opportunities available during the PhD, particularly through travel and international collaboration. This encouraged me to actively seek collaborations with leading international centres and researchers.

This led to my first visit to Marseille, where I undertook collaborative work at the Institut du Mouvement et de l'Appareil Locomoteur (IML), focusing on trochlear dysplasia. During this

period, I had the opportunity to work alongside Professor Argensön and Professor Ollivier, as well as visit Professor Dejour in Lyon at the Lyon School of Knee Surgery. These experiences provided invaluable insight into international approaches to patellofemoral pathology and knee preservation surgery.

Subsequently, discussions arising from local journal club meetings prompted me to look into alternative means for evaluating patient outcomes following arthroplasty, particularly through objective physical activity assessment. This ultimately led to collaboration with investigators involved in a previously published randomised controlled trial in Denmark.

To support this work, I attended the International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine (ISAKOS) meeting in Boston, where I became an active member and successfully secured the ISAKOS New Researcher Grant. This funding supported the consumables required for the project and enabled a month-long research visit to Denmark, where I worked alongside Danish PhD student Dr Julie Heegaard. I remain extremely grateful for her help, particularly with translation.

The work presented within this thesis reflects not only the clinical questions explored, but also a personal journey of academic development, collaboration, resilience, and mentorship. Throughout this process, I have developed skills in study design, grant writing, data analysis, international collaboration, and scientific communication, all of which have fundamentally shaped my development as a clinical academic surgeon.

Grants, Fellowships, and Awards

Year	Grant / Award	Awarding Body	Details	Amount
2024	Women in ESSKA Mentorship Programme	European Society of Sports Traumatology, Knee Surgery and Arthroscopy	Fellowship supporting visit to Medalp Sportclinic, Imst, Tirol, Austria under Dr Katja Tecklenburg	£2,000
2024	Thesis Competition: First Prize	Imperial College London Department of Surgery & Cancer	Awarded first prize for thesis presentation competition	£250
2024	Sir Alex Simpson Smith Travelling Fellowship	Royal College of Surgeons of England	Two-week fellowship at Aspetar Orthopaedic and Sports Medicine Hospital, Doha, Qatar, under Mr Alan Getgood	£2,500
2024	Sir William Bodey Travelling Fellowship	Royal Society of Medicine	Two-month fellowship at Groote Schuur Hospital, Cape Town, South Africa, under Professor Held and Professor Laubscher	£2,500
2023	Dean's Award	Imperial College London	Award supporting doctoral research activities	£5,000
2024	New Researcher Grant	International Society of Arthroscopy, Knee Surgery and	Funding supporting physical activity outcome research collaboration in	£20,000

		Orthopaedic Sports Medicine	Denmark	
2022	Early Career Research Fellowship	Orthopaedic Research UK	Research fellowship supporting the current PhD programme	£110,000
2022	Research Fellowship for 2023	British Association for Surgery of the Knee	Research fellowship supporting patellofemoral arthroplasty research programme	£5,000

Publications Arising from this Thesis

1. Vella-Baldacchino M, Bottle A, Cobb J, Liddle AD.
   Patient-reported outcomes following patellofemoral and total knee replacement: an analysis of the 6–18 months postoperative period from the National Joint Registry.
   Acta Orthop. 2026;97:42–49.
2. Vella-Baldacchino M, Heegaard J, Snorrason S, et al.
   Equivocal Physical Activity Outcomes 10 Years After Patellofemoral vs Total Knee Replacement: Follow-Up of a Previously Reported Randomised Controlled Trial in Isolated Patellofemoral Joint Osteoarthritis.
   J ISAKOS. 2025.
3. Vella-Baldacchino M, Bottle A, Cobb J, Liddle AD.
   Outcomes of patellofemoral joint arthroplasty compared with total knee arthroplasty for osteoarthritis: a population-based cohort study using data from the National Joint Registry and Hospital Episode Statistics for England.
   Bone Joint J. 2025;107-B(5):514–521.
4. Vella-Baldacchino M, Chughtai D, Kow J, Carr C, Coyle A, Farrow-Foster A, Russell J, Liddle AD.
   Outcomes of patellofemoral joint arthroplasty: a systematic review of revision timelines and complication rates.
   J Orthop Surg Res. 2025;20(1):289.
5. Vella-Baldacchino M, Davies AR, Bottle A, Cobb J, Liddle AD.
   Association Between Surgeon Volume and Patient Outcomes After Elective Patellofemoral Arthroplasty: A Population-Based Cohort Study Using Data from the National Joint Registry and Hospital Episode Statistics for England.
   J Bone Joint Surg Am. 2025.

6. Vella-Baldacchino M, Webb J, Selvarajh B, Chatha S, Davies A, Karia M, Cobb J, Liddle A.
Should we recommend patellofemoral arthroplasties? A systematic review.
Bone & Joint Open. Accepted for publication.

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Chapter 1. Introduction

1.1 Background

Isolated patellofemoral osteoarthritis affects up to 18-24% of symptomatic patients with knee pain, it disproportionately affects women and is a major cause of disability (1–3). Patellofemoral joint arthroplasty (PFA) and total knee arthroplasty (TKA) have both been advocated for patellofemoral joint osteoarthritis(4–7).

PFA is a smaller operation and confers advantages including restoration of normal kinematics (primarily due to preservation of the cruciate ligaments), improved post-operative function, faster post-operative recovery, decreased risk in blood loss and conservation of bone, which is particularly important in young, active patients who may go on to need a TKA later in life (8–14).

After the first PFA was developed in 1955, it was plagued with unpredictable revision rates between 42% to 88%(15,16). However, recently there has been a resurgence of interest in this procedure following several modifications to the design and surgical techniques which have led to better long-term outcomes(15–17).

The broad aim of this thesis is to:

- Delineate the failure of PFA in national data using multiple metrics and compare it to the failure rate of TKA.
- To determine risk factors affecting the revision rate of PFA such as patient and surgical factors.
- To compare differences between PFA and TKA using patient-reported outcome scores.

- To determine differences between PFA and TKA using objective outcomes.

1.2 Patellofemoral joint osteoarthritis

Loss of cartilage of the patella and the trochlear groove causes patellofemoral joint osteoarthritis (18). The articular cartilage of the patella is thicker, softer, and more permeable than any other human articular cartilage (19,20).

As with other articular cartilage, the patella cartilage consists of a fluid and solid phase composed of collagen and glycosaminoglycans (20,21). When a load is applied onto the articular cartilage, the fluid redistributes itself within the solid matrix (21). The pressure within the fluid is largely responsible for the cushioning effect of the articular cartilage (18). When the articular surfaces are damaged, the fluid pressure within the fluid phase is reduced, which causes higher stresses on collagen fibres and increased vulnerability, leading to a higher risk of breakdown (18).

1.3 Biomechanics

The patellofemoral joint acts as a lever that transmits the force of the quadriceps muscle to the lower leg (22). As seen in Figure 1, the quadriceps muscles move the patella upwards, while the patella tendon pulls it downward, generating a resultant force causing compression of the patella, the joint reactive force(23). When these forces are disproportionately large or unevenly distributed across both sides of the patella, the resulting load will eventually produce patellofemoral joint osteoarthritis.

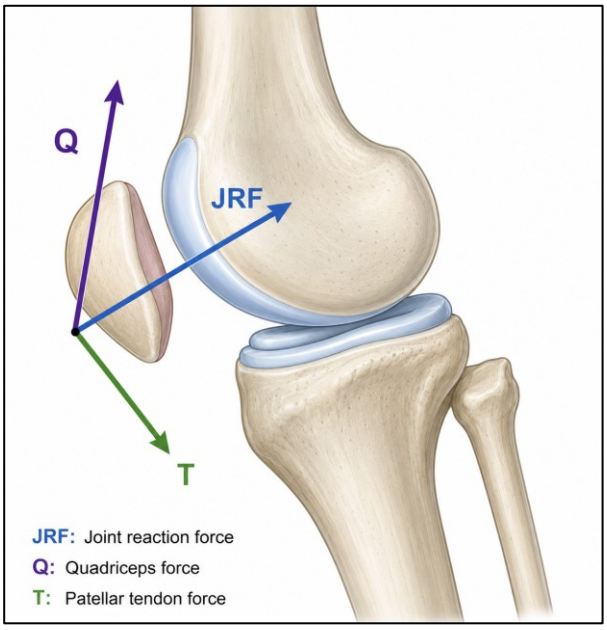


Figure 1: Schematic representation of forces acting along the patellofemoral joint

The lowest forces transmitted from the quadriceps to the patella ligament are lowest at 35°, however, at 45° the patella is engaged in the femoral trochlea maintaining its contact area during knee flexion arc, as flexion reaches a maximum of 90°, the patellofemoral joint shows maximum contact area(22,24).

The lateralising force on the patella is caused by the quadriceps angle (Q-angle) which is the resultant force of all forces acting on the patella which may cause patella subluxation(25). It is resisted by the medial force applied by the vastus medialis oblique (VMO) and ligamentous medial patellofemoral ligament (MPFL) structures and trochlea(25,26). The lateral patella facet contact area is 70%, while the medial facet contributes 30%, indicating that the lateral facet absorbs most of the forces transmitted to the patellofemoral joint (22).When the patellofemoral joint is unable to adapt to overload caused by abnormal biomechanics, this causes focal areas of increased load, commonly the lateral facet of the patella resulting in patellofemoral joint osteoarthritis (PFJ OA)(25).

1.4 Aetiology

PFJ OA is closely associated with mal-alignment, laxity or trauma. The following subsection briefly describes differences in soft tissue structures, patellae and trochlea morphology which predispose patients to PFJ OA.

1.4.1 Soft tissue structures

MPFL and quadriceps

The MPFL is the primary ligamentous stabiliser of the patella which resists lateral displacement of the patella in addition to vastus medialis (27) .If the MPFL inserts in the proximal pole of the patella, the muscle vector becomes more vertical and results in a less effective dynamic stabiliser (19). The vastus lateralis provides resistance against medial translation (28). Any discrepancy between vastus medialis and vastus lateralis, such as vastus medialis weakness can result in the patella maltracking laterally causing increased PFJ pressures (26,27).

Anterior cruciate ligament (ACL) reconstruction

ACL reconstruction increases the risk of developing PFJ OA and TFJ OA by 47% and 21%, respectively (29). This is thought to be due to quadriceps weakness because of inadequate post-operative rehabilitation(29,30) . Quadriceps weakness can cause arthrogenous muscle inhibition, a reflex elicited by abnormal afferents from the damaged joint, resulting in a decreased motor drive to muscles, thereby generating less force (26,31).

1.4.2 Patella morphology

Patella alta

In alta, the patella articulates far more superior than the upper limit of the trochlea (32). Due to a 19% decrease in patellofemoral contact area, coupled with the loss of stability within the trochlea, patients are at increased risk of developing PFJ OA due to the higher shear forces and stress on the PFJ (33–36).

Patella alignment

Patella alignment depends on bone, soft tissue and muscle structures(25). The Q-angle is measured by the line through the centre of the patella to the anterior superior iliac spine (ASIS) and a second line from the tibial tuberosity to the patella centre (32). Valgus alignment is commonly associated with a Q-angle of greater than 18 degrees. This shifts the patella laterally, increasing risk of patella subluxation, dislocation and consequently PFJ OA as a result of higher forces on the patella (32). Varus mal-alignment is associated with medial tibiofemoral joint osteoarthritis (TFJ OA) and higher forces on the medial patella facet (37–39).

1.4.3 Trochlea morphology

Trochlea dysplasia

Trochlea dysplasia consists of a shallow femoral trochlea, which is no longer concave and observed in 78% of patients with isolated PFJ OA (32). Dysplasia results in decreased confinement of the patella, causing lateral tilt, lateral displacement of the patella due to lateral pull from the quadriceps as a result of the lack of a lateral bony ridge (34). Subsequently the patella may need to reengage itself into the trochlea following displacement, compressing the medial facet of the PFJ in the process (34). The decreased contact area and higher shear forces

and contact pressures between patella and trochlea predispose the patient to PFJ OA (19,32,40,41).

Direct trauma to the front of the knee will result in changes to the patella articular cartilage and this may occur with or without patella fracture and potentially predispose to the development of patellofemoral OA. However, at this time, there is no study that has determined the threshold of trauma applied to the front of the knee that is required to cause permanent damage to the patellar articular cartilage.

1.5 Symptoms and signs

Patients with patellofemoral joint osteoarthritis present with anterior knee pain, normally exacerbated on climbing stairs or rising from a chair(6). On examination, it is associated with swelling, retropatellar crepitus and pain with pressure on the patella during range of motion(6).

1.6 Imaging

Anteroposterior, skyline, and lateral radiographic projections are often used to assess the patellofemoral joint(42). A weight-bearing radiograph is generally preferred over a non-weight-bearing radiograph when assessing tibiofemoral osteoarthritis and medial facet patellofemoral joint osteoarthritis, the latter of which is best seen in 20°-30° of knee flexion(42,43).

Despite the recognised importance of skyline imaging, there remains considerable variation in radiographic technique, with no clear consensus regarding the optimal knee flexion

angle(44,45). This lack of agreement is reflected in clinical practice, where a national survey demonstrated marked variation in the use of skyline radiographs, with some surgeons obtaining multiple images at different flexion angles(44). However, Davies et al. demonstrated that radiological parameters are most reproducibly measured from skyline tangential patellar images obtained at 30° of knee flexion, with no differences detected in radiographs taken at 30° and 50° flexion(45). Furthermore, additional imaging such as magnetic resonance imaging (MRI) can also be used to detect features of patellofemoral joint osteoarthritis not visible on a radiograph, such as the presence of bone marrow lesions, cartilage defects, or osteophytes(46).

PFJ pathology is difficult to diagnose solely by examination and often requires imaging. Conventional radiography remains the gold standard as it is widely available, non-invasive and inexpensive(46).

1.7 Non-arthroplasty treatment for patellofemoral joint osteoarthritis

Currently, there are limited reports of non-surgical physical interventions specifically designed for PFJ OA (47,48). In older patients with patellofemoral joint osteoarthritis, quadriceps and hip muscles are weak, and physiotherapy targeting these muscle groups has been explored (47,48).

Open- and closed-kinetic chain quadriceps strengthening, side-lying hip abductor strengthening, and functional retraining of vasti muscles and hip abductor muscles have not been shown to have any long-term clinical benefit (48). However, quadriceps strengthening has been shown to improve the extension force but has not had any effect on patient-reported

outcomes (47). Specifically, an 8-session, 3-month multi-modal intervention consisting of exercise, patient education, physical therapy and taping targeted to the PFJ resulted in superior short-term outcomes. However, no significant differences were observed in physical function, and the treatment effects were not maintained beyond the 9-month mark(48). These findings suggest that physiotherapy interventions may improve the short-term symptoms in PFJ OA.

Patellofemoral joint osteoarthritis is sometimes the result of altered patient biomechanics, bracing and taping have been studied with the rationale of repositioning the patella medially and redistributing the forces (49). However, in persons with patellofemoral osteoarthritis, taping or bracing has not demonstrated a clinically significant difference in physical long-term function (48,50).

1.8 Rationale for TKA

The first patellofemoral arthrtoplasties developed by McKeever et al. in 1955 had mixed results(16). Several case studies have used TKA as a surgical alternative for treating isolated patellofemoral joint osteoarthritis, arguing that it is a predictable, durable and successful procedure procedure(4,6,7,51,52). Level 2 evidence from Dalury et al. [2005], Mont et al. [2002], Laskin et al. [1999], and Dejour et al. [2004] have shown that total knee arthroplasties have superior knee scores than those matched with tri-compartment osteoarthritis, associated with a greater ability to climb stairs than their matched counterparts, demonstrating that TKA is a reliable and durable procedure for alleviating pain (4,6,7,51,52). However, patients with patellofemoral osteoarthritis present with technical challenges because they often require lateral retinacular release and realignment procedures, as well as insufficient patella bone thickness, which predisposes the patella to fracture and early loosening(51,52).

1.9 Rationale for patellofemoral joint arthroplasty

Although patellofemoral arthroplasty (PFA) was first introduced in 1955, there has been a very slow general uptake of the procedure (16). It was first shadowed with unpredictable mixed results, which resulted in authors concluding that TKA was a suitable alternative for these patients(4,6,51,52). This hindered the endorsement of patellofemoral joint arthroplasty.

Complications included patella maltracking, catching and subluxation caused by designs of trochlea components and associated with poor patient satisfaction (10,53–56). However, over time, we have seen a resurgence of the procedure due to more modern designs, with the trochlea becoming more patella-friendly, better patient selection, and improved surgical technique (53–55,57,58). Advantages of PFA over TKA have included less blood loss, shorter hospital stay, preservation of bone stock and ligaments resulting in higher functional outcomes and better stair climbing abilities(6,8,11,59–63).

Despite these advantages, just like any partial knee replacement it is associated with a higher revision rate, compared to TKA, and it is reasonable to assume that surgeons prefer to maintain their low revision status by using a procedure that is less likely to require revision than partial arthroplasty, even if the patient's function may be better with the partial arthroplasty (64,65).

1.10 Development of patellofemoral joint arthroplasty

McKeever developed the first patellofemoral arthroplasty in 1955, a Vitallium prosthesis that is fixed onto the bone by a vertical screw. The large facet of the prosthesis articulated with the lateral condyle while the smaller sized facet articulates with the medial femoral condyle (16)

Lubinus (Waldemar Link, Hamburg, Germany) designed a patella endoprosthesis made of polyethylene which articulated with a cobalt-chrome alloy in the femoral side (66). Eight-year follow-up studies of the Lubinus prosthesis by Smith AM et al. showed 64% had a good or excellent result, with 19% revised to total knee arthroplasty, due to medial osteoarthritic degeneration, knee pain, patella instability, or maltracking (55,56). Tauro et al. (2001) reported that 24% of his patients had maltracking, while 18% of patients in Board et al. (2004) had the same problem(56). Such patella maltracking is thought to be caused by its trochlea design, as its obtuse radius curvature caused impingement of the trochlea prosthesis on the tibia in extension. Some tried to address this by placing the trochlea in flexion, leaving the proximal trochlea flange proud from the anterior surface cortex, contributing to patella clunking and maltracking (10).

Blazina took McKeever's design further and resurfaced the patella and femoral groove with the Type I Richards prosthesis, and this was further improved by extending the femoral groove component towards the intercondylar notch – referred to as a Type II Richards prosthesis (Smith & Nephew Richards Inc, Memphis, Tennessee). This was the start of the second-generation devices, beginning in 1990s (53,67,68). However, problems with patella maltracking and patella catching persisted in 6-12% of patients in studies which were thought to be secondary to the deep constrained trochlea groove (68–71). The trochlea underwent further modifications and became Richards III by Cartier et al. (2005), which addressed patella catching by allowing early engagement of the patella from the first degrees of flexion (72).

Further implants were designed, but are no longer in use due to high revision rates. The Autocentric (DePuy, Warsaw, IN) consisted of a cemented polyethylene (PE) patella and a cobalt-chrome femoral component (73). The most frequent reason for revision was the

progression of arthritis in the tibiofemoral joint, occurring mainly in the primary osteoarthritis etiologic group rather than dysplastic group (74).

The Low Contact Stress Total Knee System (DePuy Orthopedics, Inc., Warsaw, IN) had a metal-backed broad polyethylene patellar component rather than a dome-shaped patella. The broad surface was able to sustain high patellofemoral joint reaction forces of a flexed knee reducing the shear stresses at the bone-implant interface (75). It was elongated in its superior-inferior dimension to remain on the trochlea in flexion(75). However, the drawback of this design was that the patellar button must be changed if a total knee arthroplasty implant from another product line is used (76). This product was discontinued in 2009(61)

The femoro-patella vialla (FPV) (Wright Medical Technology, Arlington, Tennessee), had an asymmetrical trochlea with a long steep lateral slope. The patellar component had a reciprocal facetted asymmetrical design(77). These features were claimed to improve the distribution of load, allow better patellar tracking, and provide greater resistance to subluxation throughout the range of motion(77). A series reported the failure rate as 21%, due to pain or revision, but the authors still recommended patellofemoral arthroplasty as a treatment option (77)

Very few studies report on the Sigma HP (Partial Knee, DePuy, Warsaw, IN, USA) which had an overall survivorship of 92.2%. Four PFAs were revised due to osteoarthritis progression and maltracking at 4 years. Additionally, one study reports on the use of Vanguard (Biomet, Inc, Warsaw, IN). However, the results were presented in combination with other implants (78).

The Avon (Stryker Howmedica Osteonics, Mahwah, NJ) patellofemoral joint arthroplasty had a broad symmetric trochlea flange and medialised offset dome to enhance patella tracking

(68,79). However, despite several promising results, it was sometimes complicated by soft tissue irritation (68). In general, the currently published results for the Avon prosthesis were encouraging, demonstrating a 67.4% survival at 15 years and good functional outcomes (61,80). However, this has now been withdrawn.

The following section describes patellofemoral joint arthroplasties that are currently still in use. The Hermes (Ceraver, France) consists of a central domed patella, the same as total knee arthroplasty. The trochlear component was made as thin as possible to reduce the bone resection and allow lateral translation of the trochlear component reducing the load on the lateral facet(81). The trochlea is asymmetric with a higher lateral part, it also covers the anterior cortex of the femur capturing the patella within the groove at 30' of flexion(81).

Zimmer Gender Solutions PFJ (Gender Solutions PFJ, Zimmer, Warsaw, Indiana) has an asymmetric design consisting of a slightly higher lateral flange, which that enhances patellar tracking and minimises the need for lateral release during the procedure (68). The trochlea component has a proximal extension so that the patella articulates with the trochlea through the entire extension range. It is also associated with a shortened intercondylar tail tucked into the bone to avoid impingement of the proximal role of the patella as it moves into the trochlea(68). The revision rate was found to be 4% at the 2-year follow-up of knee pain and progression of osteoarthritis(82).

Similar to the FPV, the Journey PFJ (Smith & Nephew, Andover, MA) allows for an anatomical asymmetric trochlear groove, which is deepened and lateralised. Beitzel et al. (2013), which had a short 2-year follow-up, showed improved clinical scores at the end of the study(83).

HemiCAP inlay resurfacing (Arthrosurface, Inc. Franklin, MA, USA) has a stud that interlocks into the trochlea and uses a modular polyethylene component and avoids trochlear resection(84).

Kinematch (Kinamed, Inc, Camarillo, CA), is a customised trochlear prosthesis, one that does not require femoral bone resection as CT models an exact fit to the patient's trochlea, accommodating various femora shapes(85,86).

More recent designs include an asymmetric prosthesis by PFJ prosthesis (Medacta PFJ System, Medacta Intl, Castel San Pietro, Switzerland) although there have only been cadaveric published studies to date. The prosthesis comprises an extended trochlea fixed with 3 pegs, oriented in the valgus direction to decrease patellar stresses(87).

Robotic-assisted patellofemoral arthroplasty enables preoperative 3D imaging for precise surgical planning, optimising implant positioning and improving patellar tracking(76,88). This technology facilitates accurate cartilage mapping and ensures greater reproducibility in implant placement, which is critical for surgical outcomes(76). Results from small cohort studies suggest that implant survivorship can be as high as 94.4% at four years, with only one revision to total knee arthroplasty occurring due to the progression of osteoarthritis(89).

1.10.1 Design features of the patellofemoral joint arthroplasty

The optimal design of a patellofemoral arthroplasty seeks to achieve geometric congruence between the patella and trochlea, as any mismatch can lead to component malalignment. Design

variations that do not adequately address this issue may impact implant performance and longevity (68). In general, the patella button should match the trochlear shape in TKA to allow retention of the component if a PFA revision is required (76).

The trochlear geometry, such as the sagittal radius curvature, proximal extension of the trochlea flange, thickness of trochlear component, mediolateral breath, constraint of trochlea groove, intercondylar tail of the component and whether to select onlay or inlay, remain crucial in the outcomes of patellofemoral arthroplasty(10,68). For example, a narrow trochlea, such as the Lubinus, increases the risk of subluxation, while a broader trochlea such as the Avon allows freedom of patella tracking but may cause painful soft tissue impingement(10,68).

Trochleas have been described as onlay or inlay designs, and these are based on the trochlea preparation method(76). The inlay trochleas are embedded within the femoral bone, without significantly changing the femoral shape, are thinner, and have a conservative bone resection method while decreasing the risk of overstuffing (10,76). The trochlea preparation method is referred to as a trochlea resurfacing (76)

Inlay trochlea designs such as Lubinus, Richards II, Richards III and LCS, Kinamed and Autocentric arise due to the conservative bone resection method, while the designs find it difficult to be flush with the anterior femoral cortex leaving them prominent proximally causing patella snapping and maltracking(10,76). Maltracking occurs as the trochleas do not extend proximally to articulate with the patella and so the patella articulates with the natural anterior femoral surface in full extension before transitioning onto trochlea prosthesis causing catching at an initial 30 degrees(68). The trochlea rotation is determined by the native trochlea orientation, internal rotation is far more common in inlay implants, due to medialisation of the

trochlea groove which increases the Q-angle and predisposes patients to maltracking (90). Clinical performance tends to be less predictable (53,54,56,91,92). Nowadays inlay implants have been mostly abandoned and onlay implants are predominantly used worldwide.

Onlay implants are referred to as trochlea-cutting designs (76,93). They use the same anterior femoral cuts as total knee arthroplasty, replacing the anterior compartment of the knee. This makes it suitable for a large variation of trochleas such as dysplasia, as the cut eliminates this problem (76,93). The trochlear surface is removed, allowing the implant to remain flush with the femur(68). It extends more proximal allowing the patella to articulate entirely in extension, its rotation is determined by the surgeon, perpendicular to Whiteside's line and parallel to the transepicondylar axis (68). The external rotation of the femoral component reduces patellofemoral lateral shear forces (94). The newer trochlea implants are designed to prevent impingement on the ACL and the femur-tibial joint (78).

1.11 Assessing outcomes following joint arthroplasty

Patient safety, clinical effectiveness, and patient experience are outlined as the three pillars of healthcare quality, and all three drive quality improvement (95). In the mid-1980s, in the absence of any other measures, outcomes of arthroplasty were traditionally assessed using survival analysis with revision as an endpoint(95). However, nowadays, this is supplemented by describing the patient experience using patient-reported outcome measurement tools, which are complex constructs and appear to influence patient satisfaction (96,97). Additionally, patient satisfaction is not only measured by patient-reported outcomes but also by the experience of the surgical event as a whole, including any sustained adverse events (95,98). Adverse events may include and are not limited to revision and systemic complications such

as myocardial infarction, lower respiratory tract infection, or pulmonary embolism(98).

1.11.1 Implant survival

The first joint arthroplasty registry was established in Sweden in 1975, designed as an early warning system to identify underperforming implant designs by tracking implant survival (99).

1.11.1.1 Advantages of implant survival as an outcome measure

Implant survival, defined as the time interval between the date of the initial surgery and the date of the revision (100). It is widely used across arthroplasty registries due to its objective and easily measurable nature to determine the length of time an implant has been in place. It provides a clear binary outcome whether the implant remains in place or has been revised, making is straightforward to validate and compare across different populations and healthcare settings.

1.11.1.2 Limitations of implant survival as an outcome measure

Despite its utility, implant survival does have limitations, for example if a patient experiences poor outcomes but is not offered a revision or does not wish to undergo a second procedure, this will not be recorded as a revision, but rather as a success (100). Therefore, poor clinical outcomes are not always followed by revision surgery.

Additionally, revision decisions are influenced by factors such as patient age, surgical expertise, or the type of implant(101). Younger patients are more likely to undergo revision surgery while surgeons who perform many partial knee replacement surgeries are less likely to recommend revision surgery(101). Perhaps due to their experience, high volume partial knee

replacement surgeons are less easily persuaded than beginners to undertake a conversion to TKA, since it may be unnecessary or ineffective. For instance, experience with unicompartmental knee arthroplasty has shown that pain often improves spontaneously in the first post-operative year, and sometimes even later, particularly if there is no mechanical explanation for it, and that conversion to a TKA does not reliably relieve the pain (101)

Ultimately, reasons for revision may vary depending on the underlying cause. Revisions due to complications such as infection which can have a substantial impact on a patient's quality of life(102). Meanwhile, revisions caused by osteoarthritis progression in other compartments, a common reason for revision in partial knee arthroplasty may reflect patients' high levels of activity and excellent quality of life (17).

Therefore a higher revision rate does not inherently indicate poor implant performance as some revisions improve patients quality of life such as those for osteoarthritis progression. Conversely, implants with lower revision rates may still pose significant clinical challenges such as infection, which can severely impact patient outcomes.

1.11.1.3 Challenges in comparing different types of arthroplasty surgery

The limitations of implant survival become pronounced when comparing different types of replacements due to inherent differences in their revision thresholds and failure modes. For instance, patellofemoral arthroplasties, also a partial knee arthroplasty, are more likely to be revised to a TKA as a more definitive solution, secondary to progression of tibiofemoral osteoarthritis (101,103,104). Notably, despite this being classed a revision, it is often performed in a manner similar to a primary TKA as it typically does not require the use of augments or stems (105) . More recently, robotic assistance has been utilised to help address some of the

technical challenges associated with conversion procedures, with no difficulties being reported with bone cuts or knee balancing following removal of the PFA components(106). Nevertheless, outcomes following revision of PFA to TKA may still be inferior to those observed following primary TKA, with higher reported complication and revision rates, although these remain lower than those associated with revision TKA procedures (106,107). Ultimately, a revised PFA to a TKA is not identical to a primary TKA. Meanwhile, a surgeon is less likely to revise a TKA as it is technically more difficult and hazardous (101). Due to these discrepancies it is at times challenging to make direct comparisons based solely on survival statistics.

While implant survival remains an essential outcome measure for identifying poorly performing implants, it must be complemented by other outcomes such as patient-reported outcomes to provide a more comprehensive evaluation of implant success. These additional measures are discussed in further detail below.

1.11.2 Patient-reported outcomes in joint arthroplasty

Patient satisfaction with a joint replacement is not only determined by implant longevity (100). Patient-cantered care has become increasingly prevalent in surgical treatment, replacing a traditional paternalistic approach (108). To avoid bias, Darzi proposed incorporating patient-reported outcomes which are questionnaires completed by patients(109). These would replace clinical scoring systems administered by clinical care teams (100,101).

Despite portraying a patient's experience following surgery, they are limited by a lack of robust evidence regarding the most reliable patient-reported outcomes that should be used due to

significant floor and ceiling effects(101,110). Furthermore, it is more labour-intensive and expensive to collect responses than survivorship data(100,101). Ultimately, patient-reported outcomes assess the patient's perspective of health, illness, and the effects of health care interventions, coupled with this and implant survival, improves our understanding of the efficacy of a treatment intervention(111).

1.11.3 Adverse events in joint arthroplasty

A patient may suffer adverse events that may lead to physical harm, death, or disease as a result of the index admission(112). Healthcare is moving towards increased awareness of patient safety. However, in the event of adverse events, the standard of care is less likely to meet patient safety expectations (112,113). A majority of adverse events occur within 30 days following surgery, while comorbidities (e.g. for those aged over 70 years) and duration of operation are risk factors for adverse events (113,114).

Surgeons require informed consent from patients before performing any surgery, which includes discussion of risks and benefits (115). This should also include discussions on adverse events such as regional complications following arthroplasty, which is well documented in the literature, in addition to systemic medical complications, which are less well described (115). The most affected body systems following systemic medical complications are the cardiovascular, respiratory, and genitourinary systems, with venous thromboembolism being the single most frequent complication (115). Complication rates in patellofemoral arthroplasty have been reported in terms of regional complications but in terms of systemic complications, these have not yet been published in the literature. Chapter 3 of this thesis seeks to identify the risk of developing adverse events following patellofemoral arthroplasty surgery.

1.12.1 Sources of evidence in joint arthroplasty

Typically, the orthopaedic outcomes described in Section 1.11 are measured using observational or experimental studies (116). Surgery is expensive and associated with considerable morbidity, increased risk of complications attributed to the surgical intervention, and excess mortality. Thus, seeking high-level evidence to support surgery is imperative (116). Observational studies include cohort studies, case series, or arthroplasty registry studies. Experimental studies are randomised controlled trials.

1.12.1.1 Randomised controlled trials

These are considered to be the gold standard of study design whereby the treatment or placebo can be randomly assigned (117). The design of randomised controlled trials makes them more likely to minimise selection bias and reduce confounding because they account for both known and unknown risks and their implications for health outcomes. Therefore, they are also more likely to be balanced (116). However, it is expensive to run these studies, and it can sometimes be difficult to maintain blinding procedures for surgeons and patients (118). Additionally, strict inclusion and exclusion criteria limit validity in other populations. Study sizes must be large to observe rare complications such as death which drives up costs and may make it difficult to retain a high recruiting rate (119). Randomised studies, however, are valuable because they enable researchers to make more precise conclusions from treatment without bias (119).

1.12.1.2 Observational studies

In cohort studies, patient outcomes are measured repeatedly after surgery. However, selection bias often occurs because patients are selected based on their characteristics and exposure to

the surgical treatment (118) . These studies are costly as they typically need to run for several years to observe a sufficient number of occurrences of potentially rare outcomes.

Case-control studies offer a more efficient alternative to cohort studies. In these studies, individuals are selected based on an exposure or intervention, where patients with a certain outcome (cases) are compared with a subset of individuals who did not develop the outcome (controls) (120). As the intervention or exposure is not randomised, confounding by indication is likely to exist. Any observed effect of the intervention on the outcome may be due to these pre-existing differences rather than the actual intervention itself. Therefore, it is crucial to apply methods that address confounding. These methods include traditional regression adjustment methods to account for baseline differences(121). However, more advanced statistical techniques, such as propensity score-based approaches, have become increasingly popular for reducing confounding effects (116).

A propensity score is defined as the probability of receiving a particular treatment (versus the control) based on measured baseline covariates (122). A key property of the propensity score is that it acts as a balancing score, ensuring that within a subgroup of individuals with the same propensity score, the distribution of baseline characteristics is similar between treated and control groups (123). By comparing outcomes among individuals with similar propensity scores, the effects of confounding can be minimised, improving the validity of treatment effect estimates. There are several approaches for using propensity scores to adjust for confounding, including matching and inverse probability of treatment weighting.

In propensity score matching, the propensity score represents the probability of an individual receiving a specific treatment based on observed baseline characteristics; this score is typically

estimated using logistic regression(124). Various matching methods can be employed, including nearest-neighbour matching and caliper matching. Once matched, outcomes between the treated and control groups are compared to estimate the treatment effect while reducing confounding.

Inverse probability of treatment weighting assigns each individual a weight based on their propensity score: treated individuals are weighted by 1/propensity score, while untreated individuals are weighted by 1/(1-propensity score) (125). This approach creates a pseudo-population in which confounders are more evenly distributed, allowing for unbiased estimation of treatment effects using standard statistical tests.

Ultimately propensity score matching and inverse probability of treatment weighting methods both aim to balance confounders across treatment groups and generally lead to similar study conclusions(126). Inverse probability treatment weighting retains all eligible patients in the analysis, making it useful in studies with limited sample sizes (126)

In this thesis, inverse probability of treatment weighting is used to account for confounding, improving comparability between treatment groups and approximating the conditions of a randomised controlled trial.

1.12.1.3 National Joint Registries

The Swedish Knee Arthroplasty Register was established in 1975, followed by the Swedish Hip Arthroplasty Register in 1979(127). Since then, numerous arthroplasty registries have been developed worldwide. The largest of these is the National Joint Registry (NJR), which covers

England, Wales, Northern Ireland, the Isle of Man, and Guernsey. The NJR was created in October 2002, with data collection commencing in 2003(128). Submission of data became mandatory for all National Health Service trusts in 2010, leading to compliance rates exceeding 95%(129)

The benefits of arthroplasty registries are well recognised, particularly in improving patient outcomes and maintaining high standards of care. In fact, the NJR was originally established in response to concerns regarding the unexpectedly high failure rates of certain cemented total hip arthroplasties in 2001(129,130) . Since then, the value of registries has been well recognised. They are large electronic patient databases prospectively collecting information, playing a crucial role in identifying implants with higher-than-expected revision rates and monitoring surgical performance, allowing for timely intervention and quality improvement(131).

However, despite the extensive data a joint registry provides, the data remains observational in nature and is subject to inherent limitations, such as selection biases; for instance, a surgeon may prefer certain procedures over others, and variations in surgical skill levels may influence the type of implant used(132). Nevertheless, with appropriate methodological approaches, these limitations can be mitigated. Despite these limitations, registries have the merit of reporting the actual results of vast numbers of surgical procedures carried out across a diverse range of hospitals, surgeons, and patients, making the data extremely powerful for identifying trends and early signs of problems related to certain implants or implant classes, as observed with cemented hips in the United Kingdom(127,130–133). This allows for timely interventions, such as issuing safety alerts, withdrawing problematic implants from the market, or modifying surgical techniques. Ultimately, this may influence clinical decision-making and policy

development.

1.13 Factors influencing outcomes following patellofemoral joint arthroplasty

Factors affecting the success of patellofemoral joint arthroplasty surgery can be broadly divided into three main categories: surgical, patient and implant factors. This section gives a brief introduction to all three.

1.13.1 Surgical factors

Patellofemoral joint replacement surgery requires the surgeon to be experienced in managing patellofemoral alignment, as a substantial proportion of patients present with instability or mal-alignment(134). Additionally, the surgeon should be aware of other patellofemoral presentations that may present as differential diagnoses to patellofemoral joint osteoarthritis, including tendinitis, synovitis, patellofemoral instability, and mal-alignment (134). A high risk of revision exists with any partial knee replacement, hence the need for competency in the ability to perform a revision(65).

Previous studies have shown that frequently performing surgeries fosters better technical skills and improved patient management, resulting in a lower mortality rate and complications(135). The relationship between surgeon volume and outcome is important since very few multi-centre trials discuss the influence of provider expertise on outcomes, including low-volume and high-volume surgeons together can lead to misleading conclusions (136).

Having a clear understanding of the volume-outcome relationship between surgeons might have a significant impact on the design of surgical training(135). The correlation between surgical volume and better outcomes in the field of orthopaedics has been studied in numerous studies but has not as yet been explored in the field of patellofemoral joint arthroplasty surgery (136–139).

1.13.2 Patient factors

1.13.2.1 Age

Younger patients are more likely to develop patellofemoral joint osteoarthritis (3). Patients who undergo partial knee replacements have a longer life expectancy(17). A PFA is most effective in patients aged 40 to 60 (140,141). Addressing these symptoms early returns patients to higher levels of activity(79,142). PFA patients have returned to activities such as downhill skiing, ballet, cycling, hiking, manual labour, police work, tennis, and aerobic exercise(79,143,144). However, higher levels of activity may influence the prosthesis' longevity due to the acceleration of osteoarthritis in other compartments (145).

1.13.2.2 Obesity

The most common reason for the revision of patellofemoral joint replacement is progression of tibiofemoral osteoarthritis. Obesity (30 kg/m^2) has been associated with the acceleration of osteoarthritis in other compartments and therefore been seen as a relative contraindication to patellofemoral joint replacement surgery (146). Despite similar functional outcomes to non-obese patients, Marulo et al. (2022) reported a failure rate of 20% in the obese group compared to 4.2% in the non-obese group(147)

1.13.2.3 Gender

Gender has been thought to affect outcomes in patellofemoral joint replacement surgery, with younger men doing worse (148). Although, in arthroplasty surgery, females are less likely to have a revision as compared to their male counterparts(149).

1.13.2.4 Socioeconomic factors

Those who smoked, were unemployed, or who pre-operatively used opioids and/or anti-depressants were found to have a worse post-operative improvement in function (150). Although this is not new as these psychosocial elements have been reviewed in orthopaedic literature and assessed the influence of such factors on the outcomes of arthroplasties(151,152).

1.13.2.5 Trochlea dysplasia

Patients with trochlea dysplasia are predisposed to patellofemoral joint osteoarthritis, but are less likely to develop progression of tibiofemoral joint osteoarthrosis once offered a patellofemoral joint replacement(153). Nichol et al. (2018) reported no revisions in 11 knees with trochlear dysplasia treated with PFA, as compared with five revisions for progressive arthritis in 30 knees without trochlear dysplasia (154). Middleton et al. (2018) reviewed 103 implants and found that the lowest revision rates were in those with dysplasia (with or without previous dislocation)(155).

1.13.3 Implant factors

A detailed overview of the design of patellofemoral joint arthroplasties is given in Section 1.10.

As described, there are two types of implants, onlay and inlay. Most inlay implants have been phased out nowadays as they have been associated with a higher revision rate compared to their onlay counterparts(156). Positioning the implant in the correct position is one of the main key components of the surgery as externally rotating this too much may cause maltracking. The ability to control the external rotation is offered with the onlay design. However, without enough surgical experience, this may affect outcomes. More recently, there has been one case series investigating the use of robotic technology and have shown better outcomes suggesting it could be a useful surgical aid for less experienced surgeons (157,158)

1.14 Scope and structure of thesis

The aim of this thesis is to compare failure rates in PFA and TKA and identify modifiable factors that could improve the revision rate of PFA.

The objectives of this thesis are to:

1. Compare revision rates and adverse outcomes between matched PFA and TKA patients.
2. Assess the impact of surgical volume on implant revision.
3. Compare patient-reported outcomes between PFA and TKA.
4. Evaluate objective functional outcomes, including activity levels and gait differences, through a randomised controlled trial.

In order to address these aims and objectives, the thesis is structured as follows:

- Chapter 4 compares revision rates and adverse outcomes between matched PFA and TKA patients. Adverse outcomes include lower respiratory tract infections, urinary tract infections, wound infections, cerebrovascular accidents, myocardial infarctions, deep vein thrombosis/pulmonary embolism, or death within 30 days. This represents the largest comparative analysis to date.
- Chapter 5 examines the effect of surgical volume on implant revision.
- Chapter 6 compares patient-reported outcomes between both procedures.
- Chapters 7 and 8 present findings from a randomised controlled trial conducted in Denmark, evaluating objective functional outcomes, including activity levels and gait differences, between PFA and TKA

Together, these chapters provide a comprehensive analysis of failure rates and functional outcomes in PFA and TKA, offering valuable insights to inform clinical decision-making and improve patient outcomes.

Chapter 2 Outcomes of patellofemoral joint arthroplasty

Author Contribution, Funding, and Dissemination

I conducted an extensive review of the literature to understand common complications, survivorship, patient selection, and outcomes associated with patellofemoral arthroplasty. This work formed the foundation for the subsequent research chapters within this thesis. I independently conducted the systematic review presented in Chapter 2, including development of the review protocol (PROSPERO CRD42020182597 and CRD42024595301), literature search strategy, screening of studies, data extraction, quality assessment, data analysis, and manuscript preparation. This work resulted in two publications, both of which are presented within this chapter.

Publications

Vella-Baldacchino M, Webb J, Selvarajah B, Chatha S, Davies A, Cobb JP, Liddle AD. Should we recommend patellofemoral arthroplasties to patients? Bone Jt Open. 2023 Dec 15;4(12):948-956. doi: 10.1302/2633-1462.412.BJO-2023-0100.R1. PMID: 38096897; PMCID: PMC10721344.

Vella-Baldacchino M, Chughtai D, Kow J, Carr C, Coyle A, Farrow-Foster A, Russell J, Liddle AD. Outcomes of patellofemoral joint arthroplasty: a systematic review of revision timelines and complication rates. J Orthop Surg Res. 2025 Mar 17;20(1):289. doi: 10.1186/s13018-025-05592-8. PMID: 40098204; PMCID: PMC11917147.

Chapter 2 Outcomes of patellofemoral joint arthroplasty

2.1. Introduction

Patellofemoral joint arthroplasties account for only 1% of all major joint registries worldwide, but several case series comparing PFA and TKA have been published since the McKeever implant was designed in 1955(16). To date, there has only been one registry study published based on the Australian Orthopaedic Association Joint Replacement Registry(159). This chapter presents a systematic review of the published literature relating to patellofemoral arthroplasty, with particular focus on implant survivorship and local complications following surgery. The aim was to evaluate the available evidence regarding outcomes of PFA and identify factors associated with failure and revision.

2.2 Search strategy

An initial literature search was performed in October 2021 and repeated in November 2023. Table 1 describes the EMBASE search strategy used in both cases. Studies were selected for further screening based on their titles, and the abstracts of the selected studies were read.

A total of 1,015 studies were retrieved, 249 of which were read in full and indexed. From this library, 21 long-term survival studies of PFA are presented in Section 2.2.1 and all studies comparing PFA to TKA are presented thereafter in Section 2.2.4.

Set	Search Statement
1.	(patellofemoral adj2 replace*).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword heading word, floating subheading word, candidate term word]
2.	(patellofemoral adj2 arthroplast*).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword heading word, floating subheading word, candidate term word]
3.	*patella prosthesis/
4.	(patellofemoral adj2 replace*).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword heading word, floating subheading word, candidate term word]
5.	(patellofemoral adj2 arthroplast*).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword heading word, floating subheading word, candidate term word]
6.	1 or 2 or 3 or 4 or 5
7.	patellofemoral osteoarthritis.mp.
8.	patellofemoral osteoarthritis.mp.
9.	patellofemoral arthritis.mp.
10.	patellofemoral arthritis.mp.
11.	7 or 8 or 9 or 10
12.	(replace* or arthroplast*).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword heading word, floating subheading word, candidate term word]
13.	11 and 12
14.	6 or 13

Figure 2: Search strategy used in EMBASE

2.2.1 Survival studies of PFA

All 21 survival studies of PFAs are summarised below Table 1. Studies included adult patients >18 years of age who underwent a patellofemoral joint arthroplasty for degenerative osteoarthritis. The mean or median survival for each prosthesis was recorded at 5, 10, and 15 years. If data was collected at any other time point, the closest time point was taken. Those with less than 4 years of data were excluded. As seen in Table 1, penultimate column, in addition to reporting overall survival, some studies also reported reasons for revision or complications. The studies included were non-randomised interventions, the studies were classified into overall low, medium, and high based on the ROBINS-I risk-of-bias assessment protocol.

Table 1. Survival studies of patellofemoral joint arthroplasty.

Study ID	***Number of knees included***	***Number of knees at final follow-up***	***Final follow-up***	***Implant***	***% Male of original pts***	***Average Age***	***Survival %***	***Survival given at***	**Outcomes reported**	***Robins-I***
Ackroyd et al. 2007	109	83	*5 Years (5-8)*	Avon	11.76 (10/85)	68 (46-86)	95.8 (91.8-99.8)	5 Years	Complications +Survival	Critical +Critical
Rammohan et al. 2019	103	102	*6 Years (2-11)*	Journey	31.64 (25/79)	58 (42-78)	94.3 (88.4-100)	7 Years	Complications +Survival	Critical +Critical
Leadbetter et al. 2009	79	79	*3 Years (2-6)*	Avon	25.71 (18/70)	58 (34-77)	Not reported	N/A	Complications	Critical
Imhoff et al. 2019	37	24	*5 Years (2-5)*	HemiCAP	68.57 (24/35)**	49 (22-79)	83	5 Years	Complications	Serious
Middleton et al. 2018	103	103	*6 Years (3-14)*	Avon	34.95 (36/103)	60 (34-82)	89 86	5 Years 10 Years	Complications	Critical
Wang et al. 2023	46	28	*24 Years (19-30)*	YLQ	13.16 (5/38)	55 (36-73)	83.6 76.8 59.4	15 Years 20 Years 25 Years	Complications	Critical
Clement et al. 2019	54	54	*10 Years (8-15)*	Avon	9.26 (5/54)	62 (Not reported)	94.2 (90.4-98.1) 92.3 (87.1-97.5)	5 Years 10 Years	Complications +Survival	Critical +Critical
Metcalfe et al. 2018	558	390	*18 Years*** (2-18)*	Avon	18.41 (79/249)	59 (25-92)	77.3 (72.4-81.7) 67.4(57.1-74.3)	10 Years 15 Year	Complications +Survival	Critical +Serious
Hoogervorst et al. 2015	33	28	*6 Years (2-18)*	Richards' II	20.83 (5/24)	47 (32-81)	73 (57-93)	10 Years	Complications +Survival	Critical +Critical
Akhbari et al. 2015	61	55	*5 Years (1-10)*	Avon	10.71 (5/56)	66.1 (Not reported)	96.2 (85.7-99.0) 88.9 (71.8-96.0)	5 Years 10 Years	Complications +Survival	Critical +Critical
Ahearn et al. 2016	101	90	*7 Years (5-9)*	Journey	19.80 (20/101)	60 (26-86)	88 (78-92)	7 Years	Complications +Critical	Critical +

									Survival	
van Jonbergen et al. 2010	185	181	*13 Years (2-30)*	Richards' II	37.58 (59/157)	52 (Not reported)	84 (78-90) 69 (59-79)	10 Years 20 Years	Complications + Survival	Critical + Moderate
Odumenya et al. 2010	67	50	*5 Years (2-10)*	Avon	28.13 (9/32)****	66 (42-88)	95.7 (87.8-100) 89.3 (72.9-100)	5 Years 8 Years	Complications + Survival	Critical + Critical
Osarumwense et al. 2017	52	49	*3 Years (2-5)*	Zimmer	25.00 (9/36)****	59 (39-80)	95.6	5 Years	Complications	Critical
Romagnoli and Marullo 2017	108	105	*6 Years (3-8)*	Zimmer	18.82 (16/85)	68 (39-88)	95.2	6 Years	Complications	Critical
Bohu et al. 2019	74	70	*8 Years (2-20)*	Hermes	18.75 (12/64)	60 (31-82)	85.7	8 Years	Complications	Critical
deDeugd et al. 2017	75	75	*3 Years (2-10)*	Avon	12.00 (9/75)	51 (36-81)	94.7	5 Years	Complications	Critical
Ramos et al. 2016	157	157	*7 Years (7-7)*	Avon or Vanguard PF	26 (Not reported)	Not reported	Not reported	N/a	Complications	No Information
Henrigou et al. 2014	85	70	*12 Years (10-16)*	Hermes	46.67 (28/60)	71 (Not reported)	Not reported*	N/a	Complications	Critical
Konan and Haddad 2016	51	48	*7 Years (5-11)*	Avon	61.7 (29/47)	57 (37-69)	96.1	11 Years	Complications	Critical
Mont et al. 2012	43	43	*7 Years (4-8)*	Avon	21.62 (8/37)	49 (27-67)	95 82	5 Years 7 Years	Complications	Critical

**only reports M:F knees at 2 year follow up

*** study only reports final follow up time, not average

Patellofemoral joint arthroplasty survival estimates at 5, 10, 15 and 20 years were pooled into forest plots using sample size and confidence intervals (Figure 3-Figure 6). Each study was weighted according to its standard error, calculated from published confidence intervals.

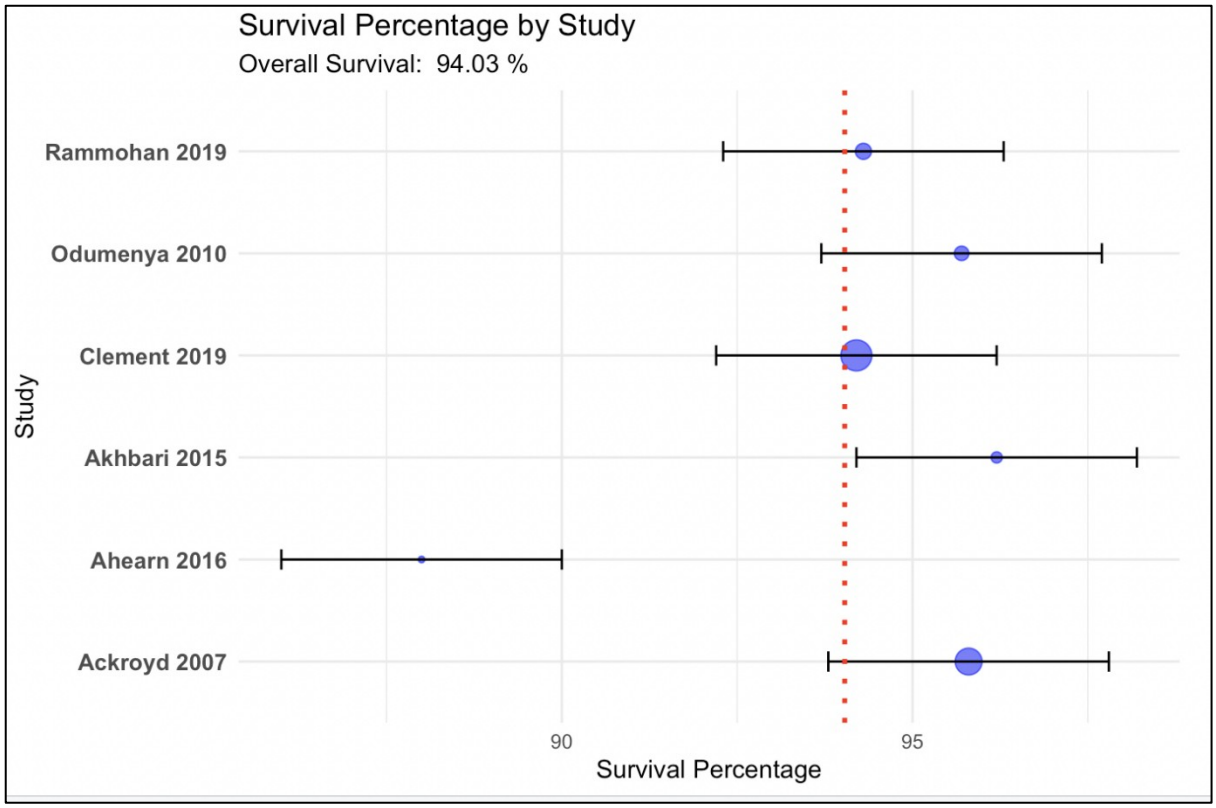


Figure 3. Pooled 5-year survival results from case series.

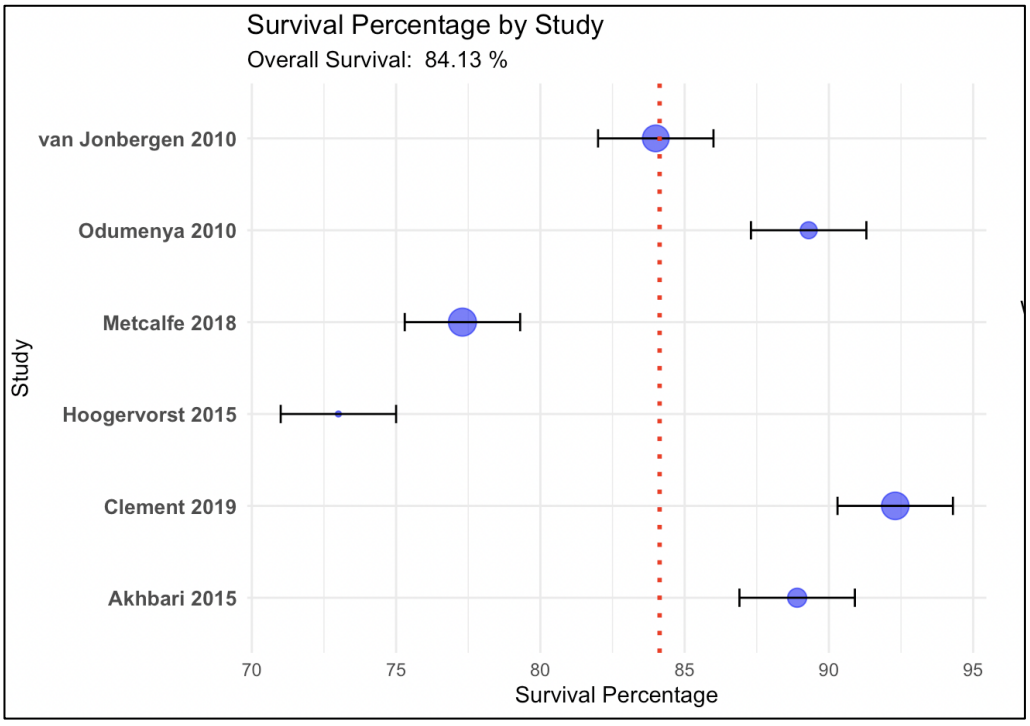


Figure 4. Pooled 10-year survival results from case series.

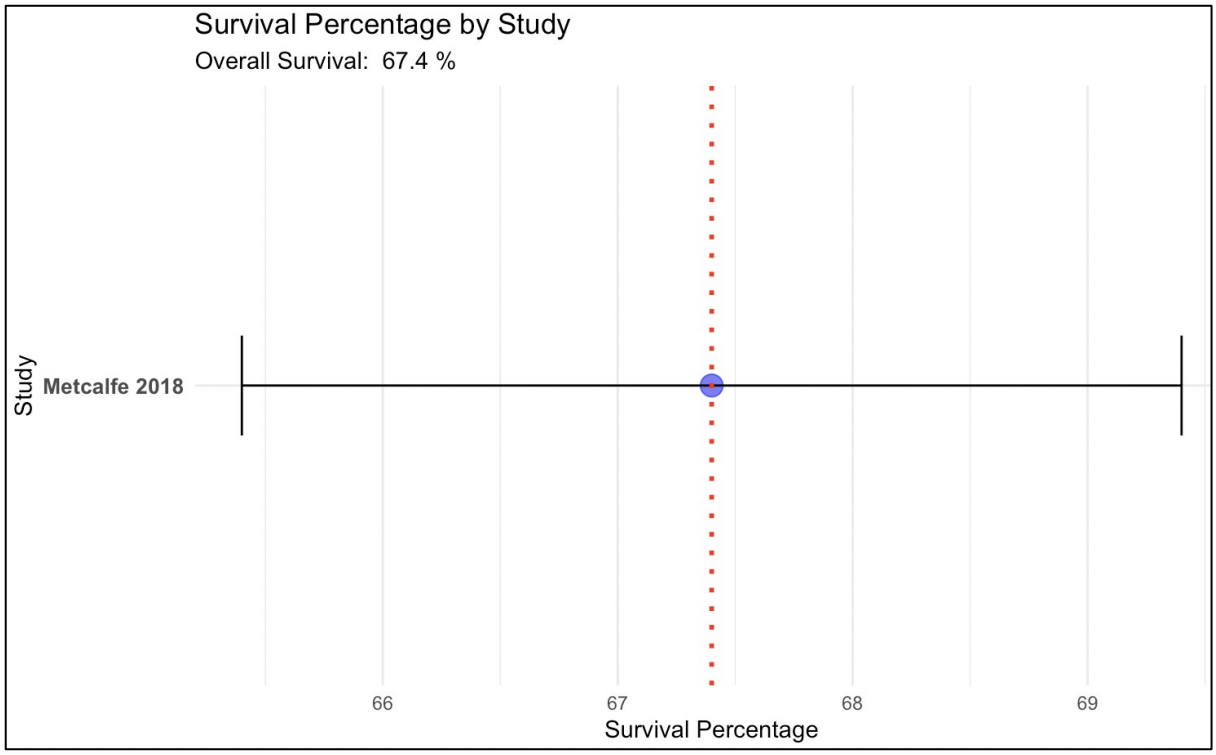


Figure 5. Pooled 15-year survival results from case series.

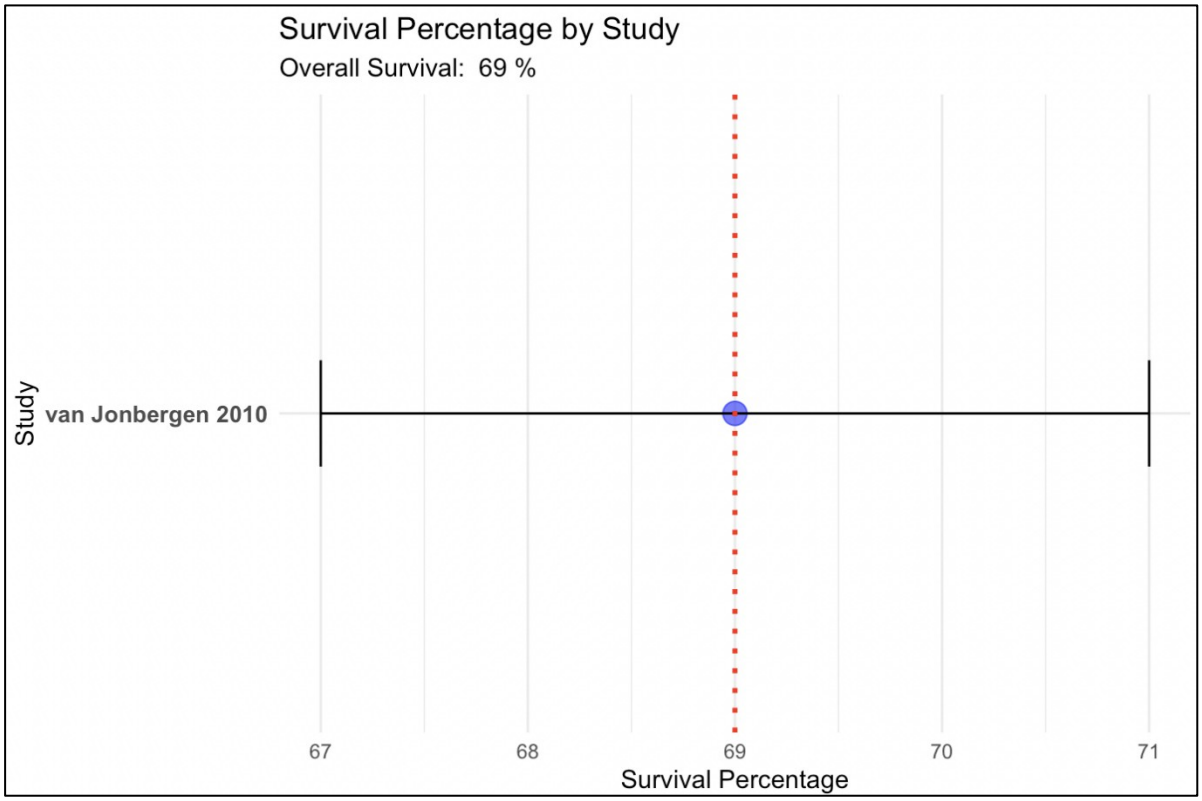


Figure 6. Pooled 20-year survival results from case series.

The most commonly used implant was Avon, followed by Richards II. Avon had the longest duration of studies reporting on the survival of patellofemoral joint arthroplasties, with a maximum of 20 years (160). The risk of revision in a unicompartmental knee replacement increases with time, with the overall survival decreasing from 94.45% at 5 years to 69% at 20 years (Figure 3-Figure 6).

Table 2 shows the reasons for revision in each study and further illustrated in a bar chart Figure 7. The most common reason for the revision was the progression of osteoarthritis followed by pain. Unlike TKAs, where the commonest reasons for revision are infection or aseptic loosening, this is not common in patellofemoral joint arthroplasties (161). Reasons for higher risk of osteoarthritis progression have been thought to be secondary to higher returns to physical activity, failure to address lower leg alignment pre-operatively, and obesity(11,12,162). Progression of osteoarthritis in another knee compartment is not related to the implant but is considered to be an advanced stage of osteoarthritis disease(163). Therefore, perhaps a revision of a patellofemoral joint arthroplasty should not be considered a failure of the procedure; as wear of the PFA implant is rarely a cause for failure.

Table 2. Reasons for revision of patellofemoral joint arthroplasties.

Paper Author	***Year***	***Knees***	***Prosthesis***	***Revisions total***	***Revision reason***
Leadbetter	2009	79	Avon	5	Progression of OA (4) Instability (1)
Ackroyd	2007	83	Avon	4	Progression of OA (4)
Rammohan	2019	103	Journey	4	Patellar maltracking (1) Persistent pain (1) Progression of OA (2)
Imhoff	2019	35	Hemicap	6	Pain (5) Allergy leading to progressive synovitis (1)
Middelton	2018	103	Avon	10	Progression of OA (9) Trochlear malpositioning (1)

Wang	2023	28	YLQ prosthesis	14	Progression of OA (11)* Polyethylene wear (1)
Clement	2019	54	Avon	5	Progression of OA (2) Pain (2) Fracture (1)
Metcalfe	2018	483	Avon	105	Progression of OA (61) Pain (12) Femoral loosening (7) Button wear (6) Mal-alignment/ mal-sizing (2) Avascular necrosis (2) Unknown (18)
Hoogervorst	2015	28	Richards' II	12	Progression of OA (5) Infection (1) Pain (3) Instability (3)
Akhbari	2015	55	Avon	4	Progression of OA (3) Patella maltracking (1)
van Jonbergen	2010	181	Richards' II	41	Progression of OA (23) Patella maltracking (10) Loosening (4) Wear (4)
Odumenya	2010	50	Avon	3	Progression of OA (2) Unknown (1)
Ahearn	2016	90	Journey	12	Progression of OA (8) Pain (1) Maltracking (1) Infection (1) Broken trochlear component (1)
Osarumwense	2017	49	Zimmer Gender Solutions	2	Progression of OA (2)
Romagnoli	2017	105	Zimmer Gender Solutions	3	Progression of OA (1) Fall (1) Wrong Indication (1)
Bohu	2019	70	Hermes	15	Progression of OA (9) Pain (2) Malposition (1) Cementing issue (1) Unknown (2)
deDeugd	2017	75	Avon	4	Unknown (4)
Ramos	2016	157	Avon or Vanguard PF	3	Pain or Progression of OA (3)
Henrigou	2014	70	Hermes	3	Progression of OA (3)
Konan	2016	48	Avon	2	Progression of OA (1) Pain (1)
Mont	2012	43	Avon	5	Aseptic reasons (5)

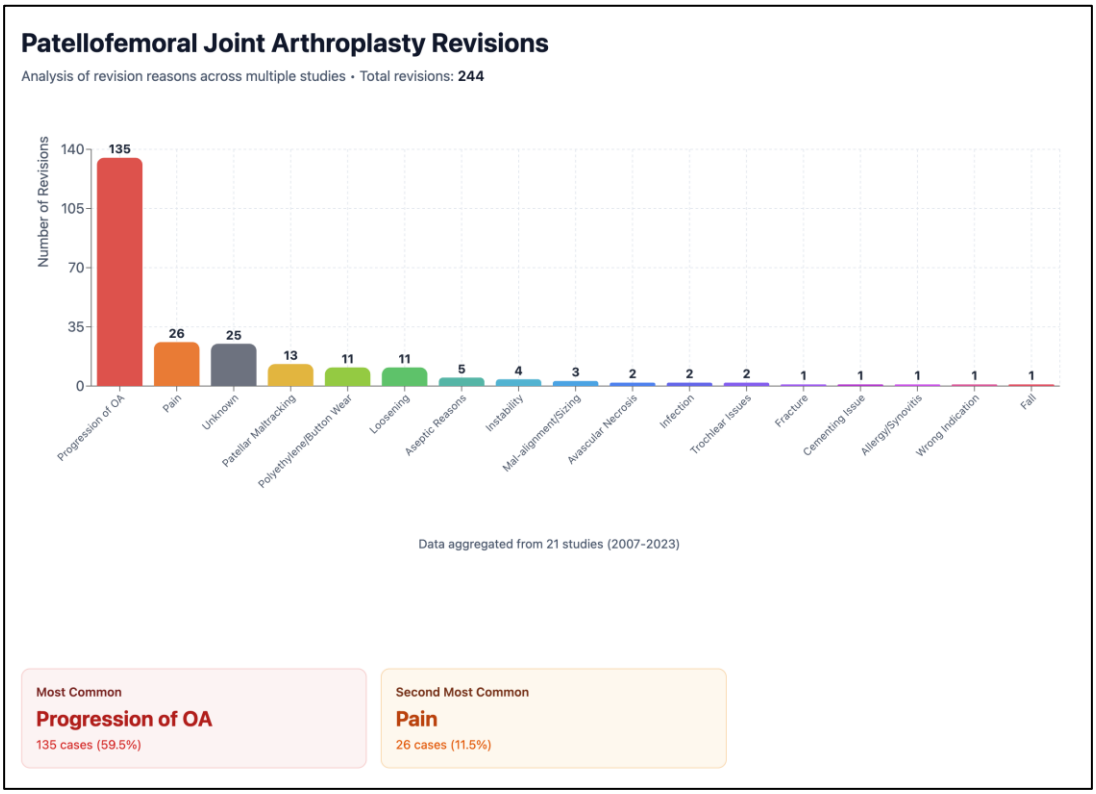


Figure 7: Bar chart illustrating the reasons for revision across the studies

In terms of local complications following patellofemoral joint arthroplasties, the commonest complication reported was pain Table 3. The studies do not investigate the cause of the pain however, post-operative pain following PFA surgery may be inferred from previous studies demonstrating that the patellofemoral joint requires congruency to allow smooth flexion-extension movement (164,165). Without the right surgical experience, the patellofemoral component may be overstuffed and, as a result of the inability to restore the rotational alignment of the trochlea, may cause maltracking and pain (164,165)

Table 3. Overall summary of local complications following patellofemoral joint arthroplasties.

Complication	*Patients %*	*Paper*
Haematoma	0.97	Rammohan 2019
Patella Fracture	0.97	Rammohan 2019
Wound Infection	1.94	Rammohan 2019
	3.57	Wang 2023
Maltracking	0.97	Rammohan 2019
Post-operative Hemarthrosis	2.41	Ackroyd 2007
Synovitis	1.20	Ackroyd 2007
	2.86	Imhoff 2019
Delayed Wound Healing	2.41	Ackroyd 2007
Pain	6.33	Leadbetter 2009
	14.29	Imhoff 2019
Arthrofibrosis/MUA	1.27	Leadbetter 2009
	1.20	Ackroyd 2007
	2.91	Rammohan 2019
	2.91	Middleton 2018
	3.57	Wang 2023
Tibial Tubercle Fracture	1.27	Leadbetter 2009

All published case series with over four years of survival data have been combined into this section. However, registries have the advantage of looking at larger pools of data representing a larger number of patients and surgeons with varying levels of experience. Case series, on the other hand, publish results from selected units and surgeons who have a particular interest in the procedure, resulting in a selection bias. The following section summarises the outcomes of patellofemoral joint arthroplasties from national joint registries around the world.

2.2.3 PFA in registries

The United Kingdom (UK) National Joint Registry, Swedish Joint Registry, and Australian Joint Registry give accurate, in-depth reports of the number of patellofemoral joint

arthroplasties inserted, including the number of revisions. These were used to determine survival outcomes.

Overall survival data could only be included from international joint registries that publish their data in publicly available annual scientific reports. Five international joint registries were screened. However, only those from the UK, Sweden, and Australia were used. The American and New Zealand registries were excluded due to the lack of specific survival data for this overview.

Figure 8-Figure 11 show overall survival at 5, 10, and 20 years for the specific registries. A forest plot is presented in Figure 12 and was used to obtain an overall picture of the results from the case series in Section 2.2 and those from the joint registries. Registries show similar results to case studies, with overall lower survival rates in the first 10 years and higher survival rates after 15 years relative to case series. However, their confidence levels overlap, which indicates that the differences are not significant (166).

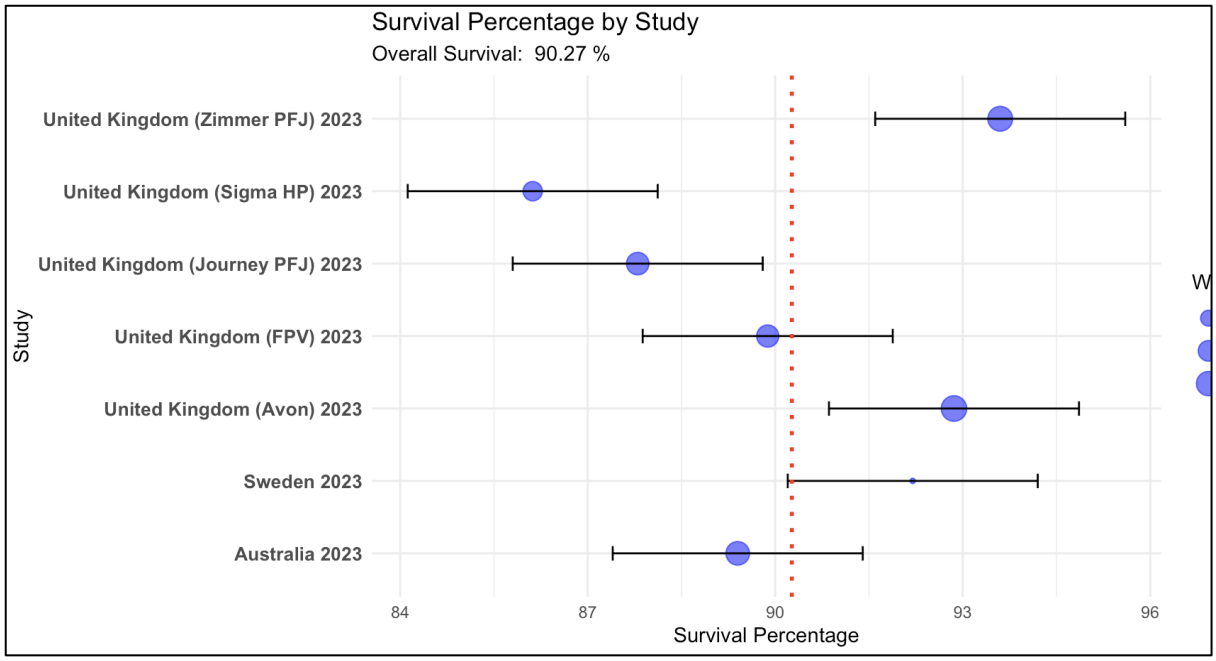


Figure 8. The overall 5-year survival of patellofemoral joint arthroplasties included from all national joint registries.

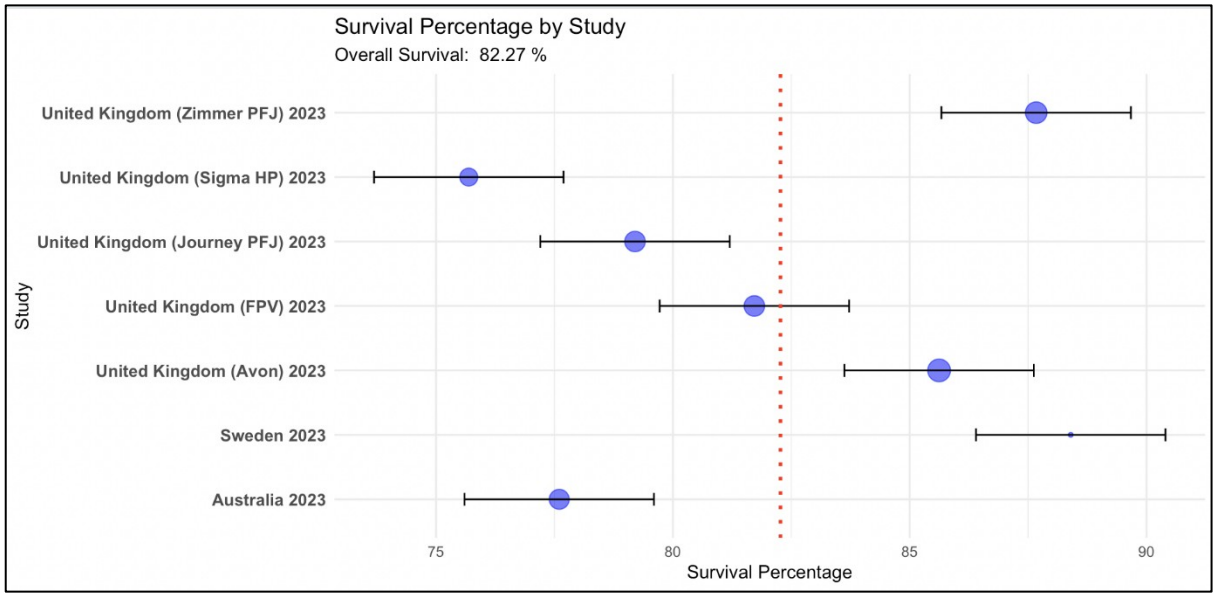


Figure 9. Overall 10-year survival of patellofemoral joint arthroplasties included from all national joint registries.

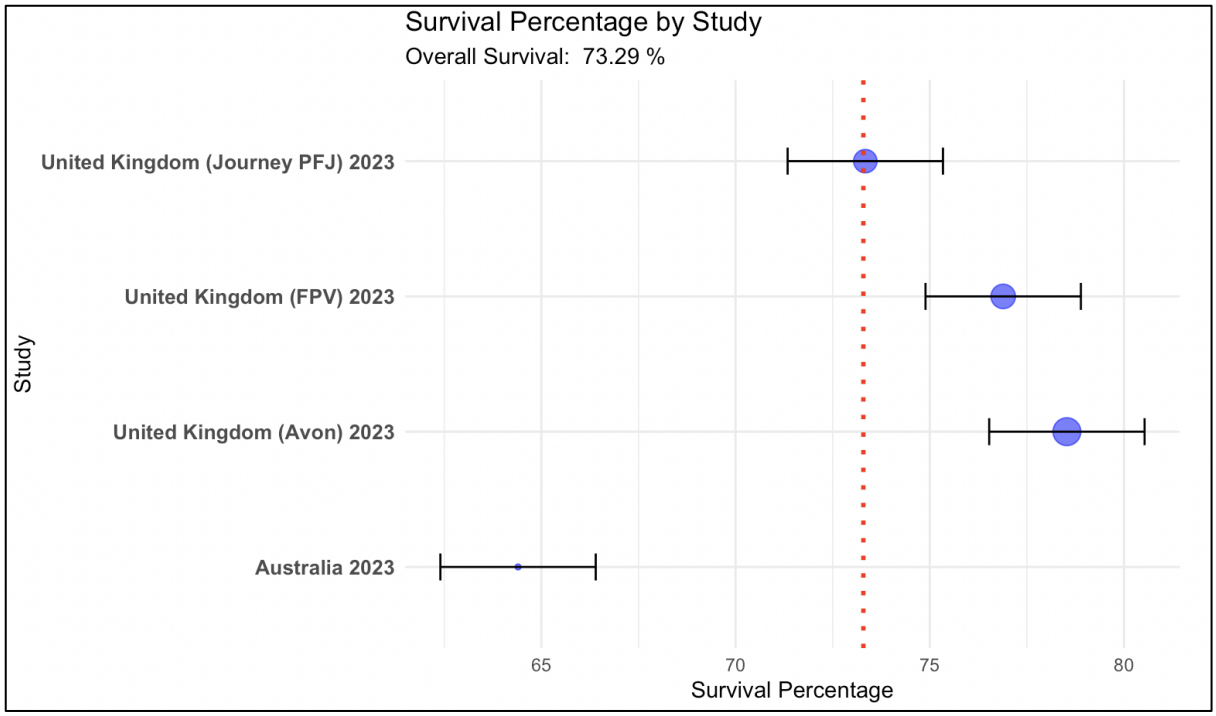


Figure 10. Overall 15-year survival of patellofemoral joint arthroplasties included from all national joint registries. Overall 15-year survival of patellofemoral joint arthroplasties included from all national joint registries.

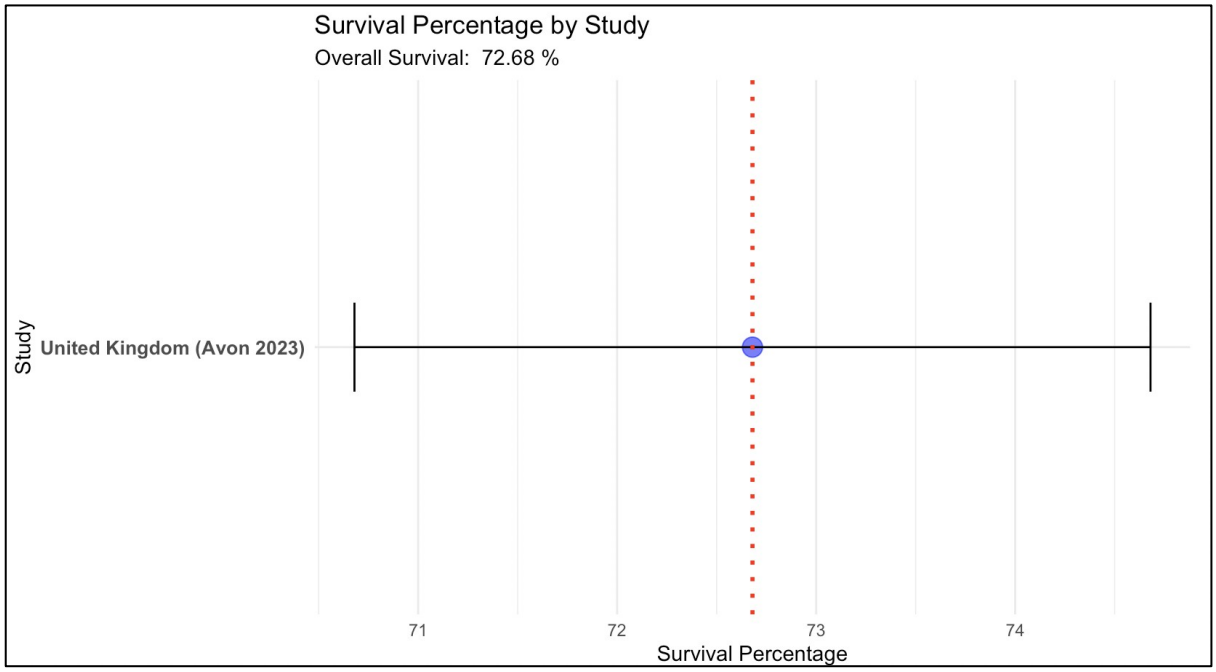


Figure 11. Overall 20-year survival of patellofemoral joint arthroplasties included from all national joint registries.

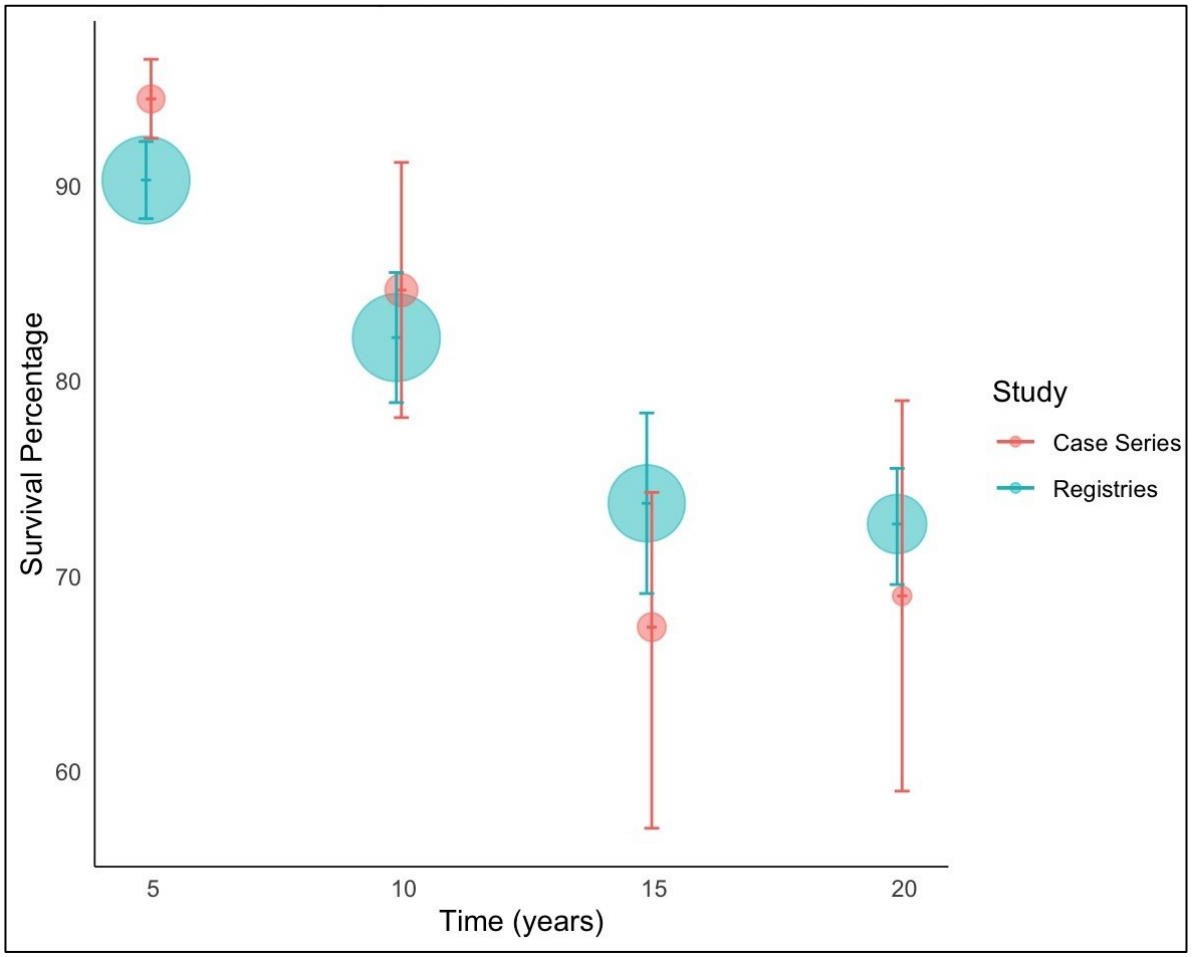


Figure 12. Survival percentage of patellofemoral joint arthroplasties over time.

As seen in Figure 12 , the patellofemoral joint arthroplasty survival rate decreases from 90% at five years to around 70-80% at 20 years, this result differs significantly from the first generation of patellofemoral arthroplasties designed before the 1990s. The revision rates were as high as 35-47% within 2 years, leading scientists to recommend stopping such surgeries due to the unforgiving natures of prostheses (56). Overall, surgical design and understanding have improved substantially over the years and it is now a recognised treatment option for patellofemoral joint osteoarthritis (156).

2.2.4 Comparative studies of patellofemoral joint arthroplasty and total knee arthroplasty

Using the same search strategy outlined in 1.8.1, 9 studies are detailed below, comprising four randomised controlled trials and five cohort studies comparing outcomes of TKAs with patellofemoral joint arthroplasties in patients with isolated patellofemoral joint osteoarthritis. This section describes differences in patient-reported outcomes, complications and 5-year and 10-year survival rates.

2.2.4.1 Randomised controlled trials

Four randomised controlled trials looked at patient-reported outcome scores, which in the longer term showed no difference in Oxford Knee Score (OKS) or patient-reported outcome scores looking at knee function (KOOS-Physical function, WOMAC, UCLA, Tegner and KOOS)(59,167–169). Two of these are from the same author on the same cohort of patients, but reported at different time points. (59,167–169).

Odumenya et al. (2011) and Joseph et al. (2020) reported outcomes from the same randomised controlled trial cohort at different stages of follow-up(59,169). The trial included 64 patients, with UCLA Activity scores favouring PFA, p = 0.05 at 1 year follow up . The minimum clinically important difference was set for WOMAC, which was 8 points based on 12% of the absolute value for WOMAC function. However, no statistically significant differences were observed in WOMAC function scores or other secondary outcome measures, including WOMAC domains (WOMAC Pain, WOMAC Stiffness), American Knee Society Score (AKSS), EQ-5D, EQ5D-VAS and OKS. Complication rates were comparable between groups, with four superficial surgical site infections reported in the PFA group versus five in the TKA

group. Longer-term follow-up at 2 and 5 years similarly demonstrated no statistically or clinically significant differences in WOMAC, UCLA, OKS, AKSS, EQ-5D or EQ-VAS outcomes, and no differences in revision rates were identified.

Odgaard et al. (2018) included 100 patients who reported outcomes at 2 and 6 years post-operatively(167,168). In the first 6 months, there were improvements from baseline for KOOS pain, SF-36 physical functioning, and OKS. The minimum clinically important difference for OKS was set at 5, 8 to 10 for KOOS and 6-7 for SF-36. However, in the long term, there was no difference in terms of patient-reported outcomes, length of stay, revisions, reoperations, or complications at 6 years. These findings show that most of the early advantages of PFA were no longer observed by 6 years. At 5 years, the range of movement had decreased less in patients who had undergone PFA compared to those who had undergone TKA (-4° versus -11°, mean difference 7° [95% CI 1° to 13°]; p = 0.02), however, it is unknown whether this difference has any clinical significance.

2.2.4.2 Cohort studies

Five cohort studies compared patellofemoral joint arthroplasties to TKAs. A study by Perrone et al. (2018) in the Netherlands examined 19 patients who had undergone PFA and 36 patients who underwent TKA (170). There was no significant difference between the two groups with regard to patient-reported outcomes in terms of the pain subsection of the OKS, the KOOS-Physical Function, or the Kujala score. However, the authors found that PFA patients were younger and their mean post-operative OKS was lower than their TKA counterparts, 29.5 (range 9–47; standard deviation (SD) 10.5) as compared to 40.4 (range 22–48; SD 8.2) (p = 0.003) (170). The authors hypothesised that this may be due to the age discrepancy, where PFA

patients are younger than TKA patients and therefore, their expectations are higher.

A designer series of the AVON PFA included 54 patellofemoral arthroplasties and propensity-matched them to a group of 54 patients who had a TKA for patellofemoral joint osteoarthritis(9). Again, there was no significant difference in patient-reported outcomes cores in terms of OKS or SF-12. There was also no statistical difference in the rate of survival at the end of the 10-year follow-up.

In the American study by Dahm et al. (2010), between 23 PFA and 22 TKA at the end of 2 years, the authors found a difference in the mean post-operative KSS function and Tegner scores, which averaged 4.3 (range 3 to 6) in the PFA group and 2.6 (range 2 to 3) in the TKA group(8). In fact, 87% of patients returned to walking compared to 81% of TKA patients. Additionally, 15-30% of PFA patients returned to swimming or running, but only 5% of TKA patients took up swimming, and none returned to running (8). PFA patients had a reduced blood loss compared to TKA $p=0.03$ and a shorter length of stay with a mean inpatient stay of 3.3 days as compared to 4.4 days $p=0.001$(8).

In the Canadian study, Kamioski et al. (2019) looked at 23 PFA patients and propensity-matched to a cohort of 23 TKA patients based on age, sex, body mass index, and laterality(171). Differences were observed in the first year within the KOOS pain, activity of daily living and sports and recreation, WOMAC pain, WOMAC function, and total overall WOMAC score in the first year (171). At 2 years, there was no significant difference. Moreover, at either time point, there was no difference in Tegner or UCLA scores.

Researchers at the Avon Design Center reviewed 37 patients undergoing PFA and 41

undergoing TKA. At the end of three years, Foote et al. (2009) demonstrated that there was no statistically significant difference arising between the different cohorts in the post-operative knee score (OKS p = 0.497, or WOMAC p = 0.993)(172). As a result, only 8% of those who had a PFA felt their ability to work was significantly improved, compared to 37% in the TKA group, suggesting that PFA was unfavourable in comparison to TKA (p=0.0049)(172). No significant differences were observed in post-operative knee scores between the cohorts despite the observed difference in return to work. This indicates that patient-reported outcome scores do not reflect those patients who return to work or the rate at which they return to work.

2.3 Assessment of evidence

A risk-of-bias assessment using ROB-2 for randomised controlled trials and ROBINS-I for non-randomised interventions are presented in the following Table 4 (173,174). The studies were then classified into overall low, medium, and high, based on the scoring protocol of the instruments.

Table 4. Cochrane risk-of-bias tool for randomised controlled trials (ROB-2).

Study ID	Study design	Follow-up (years)	Sample size	Inclusion criteria	Mean Age (**SD** or range)	Gender of participants at final follow-up (M:F)	Mean BMI (SD)	Outcome measures	Implants used	Risk-of-bias
RCT studies										
Fredborg et al. 2020 (39)	RCT	1	100	Radiologically bone-on-bone contact on tangential view of patellofemoral joint and preserved joint lines on a posteroanterior (PA) weight-bearing view of the knee.	PFA 64 **(8.6)** TKA 64.4 (**9.3)**	PFA 11:39 TKA 12:38	PFA 28(**4.7**) TKA 27.8 (**4.1)**	PROMS: EQ-5D SF-6D Complications Duration of surgical procedure Length of stay Use of primary care resources	PFA: Avon (Stryker Orthopaedics, Manwah, New Jersey, USA) TKA: PFC SigmA fixed bearing CR implant ((DEpuy synthes, Rsynham, Massachusetts, USA)	LOW
Joseph et al. 2020 (38)	RCT	5	64	Pragmatic approach, Skeletally mature with severe	PFA 64.7 (**10.5)** TKA 64.4 **(12.8)**	12:48	PFA 28.9 (6.7) TKA 29.2 (4.2)	PROMS: WOMAC, OKS, AKSS, UCLA, EQ-5D-3L, EQ-	PFA: Avon (Styker, Mahwah, New Jersey, USA)	SOME CONCERNS

				isolated patellofemoral arthritis deemed suitable for a PFA by surgeons.				VAS.	FPV (Wright Medical Technology, Arlington, Tennessee, USA) Zimmer (Zimmer Biomet, Warsaw, Indiana, USA) TKA: NexGen (Zimmer Biomet) Vanguard (Zimmer Biomet) Triathlon (Stryker) Medial Pivo (MicroPort Orthopaedics, Arlington, Tennessee, USA)	
Odgaard et al. 2018 (40)	RCT	2	100	Debilitating symptoms of pfj oa where conservative management had	64 (**8.9**)	23:77	Not published	PROMS: SF-36, OKS, KOOS, Physical examination (ROM, swelling),	PFA: Avon (Stryker Orthopaedics, Manwah, New Jersey, USA) TKA:	SOME CONCERNS

				failed Clinical examination indicating isolated pf oa. Radiographic examination including tangential radiographs showing bony contact in the patellofemoral joint and preserved tibiofemoral joint lines.				reoperations and serious adverse events - death, revision, deep infection, revision.	PFC SigmA fixed bearing CR implant (Depuy synthes, Rsynham, Massachusetts, USA)	
Odgaard et al. 2022 (168)	RCT	6	100	Debilitating symptoms of pfj oa where conservative management had	64 (**8.9**)	42:47	Not published	PROMS: SF-36, OKS, KOOS.	PFA: Avon (Stryker Orthopaedics, Manwah, New Jersey, USA) TKA:	SOME CONCERNS

				failed Clinical examination indicating isolated pf oa. Radiographic examination including tangential radiographs showing bony contact in the patellofemoral joint and preserved tibiofemoral joint lines.					PFC SigmA fixed bearing CR implant (Depuy synthes, Rsynham, Massachusetts, USA)	

Cohort studies										
Kamikovski et al. 2019 (34)	Cohort study - Retrospective	5.3	42	Propensity-matched based on age, gender, BMI, side Younger than 55	50.4 (**2.9)**	PFA 20:3 TKA 19:4	PFA 28.5 (5.6), TKA 28.2 (5.8)	PROMS; KOOS, WOMAC, UCLA, Tegner activity scale.	Avon PFA (Stryker Howmedica Osteonics, Mahwah, NJ) Gender Solutions PFJ (Zimmer Bomet, Warsaw, IN)	Serious
Perrone et al. 2018 (35)	Cohort study - Retrospective	2.7	50	Consecutive PFA patients, randomly selected 60 patients undergoing TKA.	PFA 52.4(10.6) TKA 72.9 (10.2)	PFA 5:13 TKA 12:19	PFA 27.9(4.4), TKA 30.2 (3.7)	PROMS; OKS, KOOS-PS, Kujala score.	Gender Solutions PFJ (Zimmer Bomet, Warsaw, IN) TKA: NexGen LPS (Zimmer Biomet, Warsaw, USA)	
Dahm et al. 2010 (11)	Cohort study - Retrospective	2.4	45 knees	Isolated Patellofemoral arthritis Kellegren Lawrence score < 2 at tibiofemoral joint Iwano score >2 at patellofemoral joint.	PFA 60 (39-81) TKA 69 (44-83)	Not published	PFA 30; TKA 30	PROMS; KSS, TAegner activity, UCLA Trochlear dysplasia assessed using Dejour Classification method Patella position assed	PFA Avon PFA (Stryker Howmedica Osteonics, Mahwah, NJ) TKA (Zimmer, Warsaw, Indiana; or SIGMA, Depuy Orthopaedics , Inc., Johnson & Johnson,	Serious

								using the Insall-Slavati Index Blood loss Hospital stay Functional outcomes (ROM) Complications	Warsaw, Indiana)	
Clement et al. 2019 (37)	Cohort study - Retrospective	9.2	108	Severe symptomatic OA of the patellofemoral joint with complete loss of joint space, refractory to conservative management Propensity score matching based on age at time of surgery, gender, comorbidities, severity of	PFA 62.4 (**11.3),** TKA 64 (**10.8)**	PFA 5:49, TKA 8:46	Not recorded	PROMS: OKS, SF- 12	PFA: Avon TKA: Triathlon, Kinematic , Stryker	Moderate

				radiological involvement, pre-operative functional scores.						
Foote et al. 2010 (36)	Retrospective consecutive cohort study	36 months	109	Patients included from hospital records.	PFA 52.2 (40 – 59), TKA 54.1 (44 – 59)	28:50	Not recorded	PROMS; OKS, WOMAC Return to work (time from operation to return to fork, performing normal duties) Patients subjective opinion on their ability to return to work.	PFA: Avon , TKA : Rota glide plus	Serious

2.4 Conclusions

TKA and PFA are viable options for patients with patellofemoral joint osteoarthritis. Studies have shown superiority in patients with PFA in the KOOS pain, SF-36 physical functioning, OKS, and UCLA Activity domains from 6 months to 1 year (59,167). Following this period, the results of both surgical treatments were equivocal. Results are limited to short-term randomised controlled trials and cohort studies that represent centres with a high level of expertise that are prone to selection bias. To adjust for baseline differences between the groups, more extensive research studies are needed that use multiple clear endpoints, such as survival, death, complications, and patient-reported outcome measures (PROMs), as well as other objective outcomes, such as gait analysis.

Chapter 3. Data sources

Author contribution, funding and dissemination

I applied to the Royal College of Surgeons National Joint Registry Research (RCS2020/20) for access to registry data and registered the project with Imperial College London. I was responsible for coordinating the project including data governance processes, data cleaning, dataset linkage and subsequent data analyses. To support this work I attended several courses relating to data cleaning in Stata (16.1, StataCorp LLC, College Station, TX) and courses relating to Hospital Episode Statistics dataset (175).

Chapter 3. Data sources

3.1 Introduction

There were three main datasets used during this study, these were the National Joint Registry for England and Wales, Hospital Episode Statistics and Patient-Reported Outcome Measures. This chapter describes the data processing and cleaning process, with the completed dataset being used in the following sections. Each chapter contains a detailed description of the methods used to conduct the statistical analyses. Throughout most of this thesis, statistical analysis was performed using Stata (16.1, StataCorp LLC, College Station, TX) (175).

Chapters 6 and 7 incorporate additional datasets, including data from an international randomised controlled trial conducted across multiple institutions in Denmark. Further details regarding this dataset and its integration into the analysis are provided within the respective chapters.

3.2 National Joint Registry for England and Wales

3.2.1 Background

Following the high rate of early failure of the femoral components of the 3M Capital Cemented Hip System, the Royal College of Surgeons of England produced a report which, amongst other recommendations, proposed the development of a national joint registry along the lines of that present in Sweden since 1975 (127,176,177). Its purpose was to capture data on hip and knee replacements, allowing for rapid patient identification, implant monitoring, and identifying affected patients if necessary (176,177).

Whilst the National Joint Registry initially covered patients operated upon in England and Wales, it has broadened its geographical reach to include Northern Ireland in 2013 and the Isle of Man in 2015 (177). Data on arthroplasty procedures performed in Scotland remain outside of the scope of the National Joint Registry, and a separate Scottish Arthroplasty Project collects data on these cases.

3.2.2 Data collection

Data collection in the National Joint Registry has been mandatory since 2011. It is the largest orthopaedic registry in the world, holding up to 3.7 million records (177). To ensure accurate data capture, users submit data using structured forms developed by the National Joint Registry, referred to as minimum data set forms (178). To ensure the quality of the data, the registry data is compared with the data extracted from the local hospital administration system, and any discrepancies are reported to the hospital (179). Implementation of the process has resulted in up to 97% data completion with several other units achieving a 100% capture of the data (180).

Within the National Joint Registry dataset, each joint replacement procedure performed on a patient is represented by an assigned unique National Joint Registry number. This entry captures essential information recorded in the National Joint Registry minimum data set forms, including procedure type and implant details (178). The National Joint Registry updates this dataset on a quarterly basis to incorporate new procedures and any revisions, ensuring that the most current status of each implant is accurately reflected.

To enhance the National Joint Registry data with additional clinical and administrative details, it is routinely linked with the Hospital Episode Statistics dataset. This linkage is conducted by NEC Software Solutions following formal data requests submitted directly to the National Joint

Registry(181). To protect patient confidentiality, both datasets are anonymised using a pseudo-Hospital Episode Statistics number, a unique, de-identified identifier present in both National Joint Registry and Hospital Episode Statistics(181,182). This enables secure and accurate matching of patient records across datasets without revealing identifiable patient information.

3.2.3 Data extraction

The data for this project was requested and approved by the National Joint Registry Committee and accessed via the official data access portal following approval (183).

3.2.3.1 Data cleaning

The dataset was imported into Stata as a comma-delimited text file. To facilitate data analysis, variables recorded in string format were transformed into indicator variables to facilitate their inclusion in statistical analysis. Indicator variables included gender (male or female), indication for surgery (osteoarthritis, rheumatoid arthritis, inflammatory arthritis, avascular necrosis, trauma, infection), type of thromboprophylaxis (aspirin, low molecular weight heparin, warfarin, pentasaccharide, direct thrombin inhibitor, factor 10a inhibitor), Anaesthesiologists' (ASA) classification of physical health, unit type (National Health Service (NHS) or private) and use of computer-aided surgery.

Using the National Joint Registry, indications for revision were recorded as binary unique variables. To address those surgeries with more than one reason for revision, a new variable was created using the diagnosis hierarchy used by the Australian Orthopaedic Association National Joint Replacement Registry (103) This was used to determine the most important reason for knee replacement revision.

The implant identification numbers were cross-checked with the category of joint replacement in order to ensure the type of surgery (patellofemoral joint replacement, total knee arthroplasty, complex total knee arthroplasty and unicompartmental knee arthroplasty) was recorded accurately. The identification of complex knee arthroplasty was cross-validated by identifying cases that involved the use of tibial wedges, femoral wedges, or extension stems. Cases meeting these criteria were confirmed as complex total knee arthroplasty. For this analysis, complex TKAs and unicompartmental knee replacements were dropped. only primary TKAs and patellofemoral joint arthroplasties were retained as shown in Table 5.

Table 5. Summary of patellofemoral joint arthroplasties and TKAs contained in the National Joint Registry dataset.

		PFA	TKA
N		15,287	1,114,647
Mean age (range)		**59.3 (22-98)**	**70.1 (18-102)**
Gender (male, n, %)		3,543 (23.2)	475,586 (42.7)
Mean BMI		**18.7**	**20.6**
ASA classification of physical health (n, %)	**1**	3,909 (25.6)	116,030 (10.4)
	2	10,098 (66.0)	807,570 (72.5)
	3	1,280 (8.4)	191,047 (17.1)
Unit type (n, %)	**National Health Service**	11,625 (76.0)	972,109 (87.2)
	Private	3,299 (21.6)	117,192 (10.5)
Indication (n, %)	**Osteoarthritis**	14,827 (97.0)	1,079,880 (96.9)
Year of surgery (n,%)	**2003**	146 (0.0)	11,849 (0.9)
	2004	292 (0.0)	23,439 (1.8)
	2005	466 (0.0)	35,216 (2.7)
	2006	565 (0.0)	41,110 (3.2)
	2007	926 (0.1)	55,121 (4.3)
	2008	1,044 (0.1)	60,759 (4.7)
	2009	1,067 (0.1)	62,680 (4.9)
	2010	1,110 (0.1)	65,771 (5.1)
	2011	1,156 (0.1)	68,408 (5.3)
	2012	1,073 (0.1)	71,662 (5.6)
	2013	957 (0.1)	72,344 (5.6)
	2014	985 (0.1)	80,705 (6.3)
	2015	1,058 (0.1)	83,477 (6.5)
	2016	1,057 (0.1)	86,560 (6.7)

2017	1,104 (0.1)	87,190 (6.7)
2018	888 (0.1)	82,569 (6.4)
2019	934 (0.1)	85,108 (6.6)
2020	459 (0.0)	40,676 (3.2)

3.3 Hospital Episode Statistics

3.3.1 Background and data collection

The Hospital Episode Statistics database was developed in 1987 which collects patient data such as patient details (age, sex), clinical details (primary diagnosis, secondary diagnosis, operative procedures), administrative details (such as hospital name, consultant) and admission details (emergency or elective) (184).

Coding schemes for diagnoses using the International Classification of Diseases 10th Revision (ICD-10) and Office of Population, Censuses and Surveys, Classification of Surgical Operations and Procedures (OPCS) for operative procedures are undertaken by professional coders at the trust using discharge summaries and clinical notes (185–187).

Each financial year, data are sent from both NHS providers and the independent sector. The recorded data are submitted to the Hospital Episode Statistics database using pre-arranged datasets. Records belonging to the same patients are then appended to the historical data (184).

In the Hospital Episode Statistics, data are organised into individual rows, each representing a hospitalisation event, referred to as a spell(188). A spell denotes the entire period of an inpatient stay, from admission to discharge (188). Within each spell, there may be one or more episodes. An episode is defined as a continuous period of care under one consultant within a single healthcare provider, during which the patient occupies a hospital bed (188).. This hierarchical structure enables detailed tracking of patient care throughout their hospital stay.

3.3.2 Data extraction

The National Joint Registry and Hospital Episode Statistics are linked through a centralised service by the Health and Social Care Information Centre (HSCIC) linkage service using patient identifiers to identify matched patients(187,189). Each Hospital Episode Statistic (HES) record within the HES dataset was supplied with a National Joint Registry identifier to allow matching (190).

3.3.3 Data cleaning

For each admission into hospital, patients' official primary and secondary diagnoses were separated into separate variables using ICD-10, as described in Section 3.3.1. These diagnoses were to be used in prospective analyses. Appendix A shows the list of ICD-10 codes utilised for this process.

Furthermore, for each patient using their HES identifier, the Charlson Comorbidity Index (CCI) and a recalibration of the CCI with England-calibrated weights for the International Classification of Disease and Tenth Revision (ICD-10) codes were calculated (191,192).

3.3.4 Data linkage

The author linked the HES dataset to the National Joint Registry (NJR) dataset into one dataset. The NJR identifier, laterality, gender, and date of surgery were used to ensure the data fields belonged to the same patient. This was done in a stepwise process, as shown in Table 6, using the 'append' and 'merge' in Stata (16.1, StataCorp LLC, College Station, TX) (175).

Table 6. Approach to linking NJR Dataset to HES dataset.

Step	Name of data set	Details	Number of observations
1	*Dataset 1*	Unique value appearing once in the HES database	959798
2	*Duplicates*	HES number appears more than once separated into a dataset duplicates. On further inspection of duplicates, some rows contain the same NJR identifier but a different HES number or same NJR identifier and same HES number.	11173
3	*Dataset 2*	Identifying those with the same NJR identifier and same HES number within duplicates to create Dataset 2	8475
4	*Dataset 2*	NJR data linked to Dataset 2 using NJR identifier, gender, laterality, and operation date. Duplicates are subsequently removed (same NJR identifier and same HES number occurring more than once)	3703
5	*Interim*	Loading duplicates dataset, Identifying those with the same NJR identifier but different HES number	2698
6	*Dataset 3*	NJR data loaded and linked to Interim using NJR identifier, gender, laterality and operation date.	1507
6	*Dataset 3*	Unique values retained saved as Dataset 3 duplicates saved as separate Dataset 4	1051
7	*Dataset 4*	Dataset 4 loaded. As these are all duplicates.	456
8	*Dataset 4*	The first record with the same data is kept.	226
9	*Dataset 5*	All HES datasets appended (Dataset 1-4)	964778
10	NJR *dataset*	NJR Dataset loaded	1288343
11	*Final dataset*	Dataset 5 matched with the NJR dataset	
		Unmatched values	320023
		Matched values and kept for research analysis	968320

Patellofemoral joint and TKA patients recorded in the NJR were cross-checked with the respected implant details provided by the NJR, to ensure appropriate coding.

3.4 Patient reported outcome measures (PROMs)

3.4.1 Background and data collection

As of 2009, patients receiving arthroplasty surgery are invited to report on their health status without the interpretation of medical health professionals, this is referred to as patient reported outcomes(193). Generic and specific PROMs questionnaires are completed by patients, and their perspectives are translated into objective numerical data (194,195). This includes assessing patients' quality of life and degree of functioning before surgery and at the six-month post-operative period (193). The hospital provider securely transfers the completed PROMs to accredited suppliers, such as NEC Software Solutions, which are responsible for collating the data (193). The completed forms are electronically scanned and patient NHS numbers are traced to enable linkage with pre-operative PROMs data and the HES dataset (193). The data are then securely linked and pseudonymised using a common pseudo-HES identifier, ensuring patient confidentiality (193). The final dataset is subsequently stored and managed by NHS Digital(196).

The OKS and the EQ5D-3L are the two PROMs used in this thesis. The OKS is a 12-item patient-reported outcome measure specifically developed to assess pain and functional outcomes following total knee replacement surgery(197). It is a brief, valid, and reliable tool that provides a single score reflecting the severity of a patient's knee symptoms and functional limitations (197).

The OKS was originally introduced in 1998 which was designed to be simple and accessible, particularly for clinicians and researchers with limited experience using PROMs (197). In its initial format, each of the 12 questions was scored from 1 to 5, with lower scores indicating better outcomes. The scores were then summed to produce a total ranging from 12 (best outcome) to 60 (worst outcome). However, due to reported confusion in the interpretation of the scale, the scoring method was revised (198). The current recommended scoring approach assigns values from 0 to 4 for each item, with higher scores indicating better outcomes (198). This results in a total score ranging from 0 (worst outcome) to 48 (best outcome). For consistency and clarity, this revised method is now widely adopted in clinical research and practice. A simple conversion formula is available for studies using the original scale, by subtracting the total score from 60 to convert it to the 0–48 current scale (198).

The UK version of the EQ5D-3L is a measure of health-related quality of life which generates a numerical score of 1 which is considered full health and 0 which equates to death (199). Negative scores are also possible, ranging from -0.594 to 1 which means worse than death. In its name, the '5D' system describes health states using five dimensions: mobility, self-care, usual activities, pain/discomfort, and anxiety/depression(200). Each dimension includes three levels of problems, corresponding to no, moderate, and extreme problems in the pain/discomfort and anxiety/depression dimensions, as well as none, some, and inability to in mobility, usual activities, and self-care dimensions (200,201). Information on how the dataset was extracted, cleaned and linked is provided in the sections below.

3.4.2 Data extraction

National PROMs is separate to the NJR database (193). The corresponding HES number in the PROMs dataset is linked to the HES identifier in the NJR data (196,202).

3.4.3 Data cleaning and linkage

The PROMs dataset comprised the individual scores from each of the 12 questions that make up the OKS. The total score was calculated by summing the scores from all questions. If one or two questions of the OKS were missing values, this was supplemented with the mean value representing all of the other responses (198). In the case of more than two questions remaining unanswered, the total score was left uncalculated (198). While the total EQ5D-3L was provided by the PROMs dataset, the components of EQ5D-3L were also provided. Therefore, a second total EQ5D-3L variable was calculated using the English value sets (203).

As discussed in Table 6, step 2, if observations within the variables, including HES identifiers, NJR identifiers, pre-operative total OKS, post-operative total OKS, total pre-operative EQ5D-3L or total post-operative EQ5D-3L, as well as the date of completion of the questionnaire and the date when the questionnaire was received, were duplicates *(defined as having identical values to other observations in the dataset)*, these were removed.

The operation date variable from the HES-NJR dataset formulated in Section 3.3.4 was linked to the PROMs data records using the -joinby- function. The results from this step may be seen in step 4, Table 7. Those without PROMs data were removed, as shown in step 5, Table 7. In the absence of a date at which the PROMs post-operative questionnaire was completed and received, the data were discarded (steps 6-7, Table 7). Using the -joinby- function, the remaining data was joined to the HES-NJR dataset, resulting in the PROMs-HES-NJR dataset

which will be used in the analysis.

Table 7. Approach to linking NJR - HES dataset to PROMs dataset.

Step	Description	Number of observations
1	Total number of observations in PROMs dataset.	577,346
2	Identification of duplicates in terms of HES identifiers, NJR identifiers, pre-operative total OKS, post-operative total OKS, total pre-operative EQ5D-3L, total post-operative EQ5D-3L, date of completion of the questionnaire and the date when the questionnaire was received.	1,312
3	Total number of observations in PROMs dataset following duplicate removal in Step 2.	576,034
4	Operation date variable from HES-NJR dataset linked to the PROMs dataset using the NJR identifier.	
	A. HES-NJR dataset without any available PROMs.	833,762
	B. PROMs dataset without linked NJR identifier.	114,946
	C. HES-NJR dataset with PROMs.	461,130
5	Observations available after dropping those without PROMS data (4A).	576,076
6	Total number of dropped data if dates when questionnaire received and completed missing.	208,659
7	Official PROMS dataset.	367,417
8	Official PROMs dataset (step 7) joined to HES–NJR dataset using NJR identifier. The slight increase in total (367,487) is due to duplicate NJR identifiers representing multiple PROMs submissions on different dates; these were retained to preserve all available data. This results in the PROMS-HES-NJR dataset.	367,487

A range of statistical methods was employed across the various analyses conducted in this thesis. These methods are described in detail in the respective analytical chapters.

Chapter 4. Comparison of adverse outcomes of patellofemoral joint arthroplasties compared to TKAs

Author Contribution, Funding, and Dissemination

I used the cleaned datasets developed in the preceding chapter and restructured the data further in preparation for the analyses in this chapter. I led the statistical analysis and interpretation of findings

I also sought statistical guidance from Professor Paul Dickman and Professor Paul Lambert who form part of the biostatistics group at the Karolinska Institute.

Publications

Vella-Baldacchino M, Bottle A, Cobb J, Liddle AD. Outcomes of patellofemoral joint arthroplasty compared with total knee arthroplasty for osteoarthritis : a population-based cohort study using data from the National Joint Registry and Hospital Episode Statistics for England. Bone Joint J. 2025 May 1;107-B(5):514-521. doi: 10.1302/0301-620X.107B5.BJJ-2024-1273.R2. PMID: 40306698.

Presentations

- Oral presentation at The British Association for Surgery of the Knee (BASK): *Patellofemoral Joint Replacements: Should you offer this as a treatment option to your patients*

Chapter 4. Comparison of adverse outcomes of patellofemoral joint arthroplasties compared to TKAs

4.1 Introduction

Patellofemoral joint osteoarthritis can be treated with either a PFA or TKA but most patients with isolated patellofemoral joint osteoarthritis receive a TKA. The reasons for this may include familiarity of surgeons with TKA: on average, surgeons who perform both TKA and PFA perform 52 TKAs and only 3.7 PFAs per year, and over 70% of lower limb arthroplasty surgeons do not perform any PFAs (4,51,204,205). Alternatively, surgeons may be dissuaded from performing PFA as they are not convinced of the benefits of PFA over TKA, or due to the higher documented revision rate of PFA. Due to the five-fold higher revision rate associated with partial knee arthroplasty, it is reasonable that surgeons would prefer to maintain a low revision rate status through a procedure that is less likely to require revision (64,65).

Two randomised controlled trials have examined six years of patient-reported outcomes, post-operative complications, and revisions in small cohorts of less than 100 patients (59,167,168). These studies were powered with patient reported outcome measures as a primary outcome measure and as a result, the study sample size was not large enough to detect a difference in revision rates between the two procedures. Furthermore, the studies were conducted in centres with specialised surgeons with an interest in patellofemoral arthroplasty surgery, therefore the results cannot be generalised. Registry data which is observational data do represent national practice but are susceptible to selection bias and confounding factors which may influence treatment.

In spite of the difference in rate of revision between the two procedures, PFA has potential advantages over TKA including being less invasive, sparing normal bone, joint surfaces and ligaments (in particular, the anterior cruciate ligament) and may be associated with a higher rate of return to work and sport (10,32,104,206,207). Other partial knee replacements have demonstrated a better safety profile compared to TKA together with faster rates of recovery and fewer early complications (208). Despite the high revision risk, PFA surgery should not be dismissed without assessing and understanding the causes of revision.

The aim of this chapter is to undertake a comprehensive comparison of the rates of adverse outcomes after TKA and PFA, using a large dataset from the NJR for England and Wales, together with linked datasets from the HES and PROMs databases. Multiple outcomes will be studied, including complications, reoperations, death, revision and PROMs. The revision profile of the two procedures will be explored in terms of differences over time, differences in terms of patient factors (such as gender and age) and reasons for revision. To address the problem of confounding by indication, patients have been adjusted using inverse probability of treatment weighting which has been described in Section 4.2.5.1

4.2 Methods

4.2.1 Data sources

The study used the combined dataset consisting of the NJR and HES datasets (2.3.4). Chapter 3 describes the process of cleaning and linking the data. In cases where data was provided by more than one source, the NJR was considered to be the most reliable. Listed below are the variables that were used in each dataset.

Table 8. Sources of data. Asterisks denote that the preferred sources of data are available from more than one source.

NJR	HES
Procedure type*	Procedure type
Operation date	
Gender*	Gender
ASA physical status classification system	
Anaesthesia type	
Grade of primary surgeon	
	Ethnicity
	Comorbidities using the ICD-10 codes listed in Appendix A
	Index of multiple deprivation
Thromboprophylaxis	
Computer surgery	
Provider	
Age*	Age
	Conditions and reoperations using the ICD-10 codes listed in Appendix A
Revision details	
Age of death	Date of death

In terms of comorbidities, the CCI and the recalibrated English Comorbidity Index (ECI) were calculated(192).

4.2.2 Exposures

The analysis included only adults aged 18 or over who had a primary TKA or PFA.

4.2.3 Outcomes

4.2.3.1 Perioperative complications and length of stay

In the study, I decided to analyse the risks of myocardial infarction, lower respiratory tract infection, urinary tract infection, stroke, delirium, deep vein thrombosis, wound infection, and death after a patellofemoral arthroplasty were compared with those of a TKA. As a result, a 30-day safety profile was created for both procedures, this is similar to other studies looking at the complication profile of various arthroplasties(208–210). Additionally, the length of stay was compared.

4.2.3.2 Survival comparison

Revision rates for TKAs and patellofemoral joint arthroplasties were compared. The overall survival of a patellofemoral arthroplasty was compared to a TKA over time. The rate of revision of PFA was compared to that of TKA over a ten year time span both overall and by gender and age.

In addition, a 3-year age-standardised 10-year survival for both genders for a PFA and TKA was plotted. If more than one reason for revision was given, they were ranked according to the hierarchy previously defined by the Australian Orthopaedic Association National Joint Replacement Registry to determine the most important cause for revision (103)

4.2.4 Confounders

The NJR contains data on confounders, which include, gender, age, American Society of Anesthesiologists (ASA) physical status classification system, index of multiple deprivation, grade of operating surgeon, unit type (public/private hospital), computer-aided surgery, comorbidities determined using the CCI and recalibration of the CCI with England-calibrated weights (192). By utilising 37 indicators, the index of multiple deprivation ranks 32,844 small geographical areas in England from least deprived to most deprived (211). These indicators are grouped into seven domains: income, employment, education, health, crime, housing and services barriers, and living environment (211). For the purpose of this study, the index of multiple deprivation was grouped by national quintiles, with higher quintiles being the least deprived.

4.2.5 Statistical analysis

4.2.5.1 Propensity score: Inverse probability of treatment weighting methods

Propensity score methods are commonly employed in observational studies to reduce the effects of confounding arising from differences in baseline characteristics between treatment and control groups(212,213). The propensity score is defined as the probability of receiving a particular treatment based upon a set of observed covariates(212). These scores may then be used with matching techniques or inverse probability of treatment weighting (IPTW). Both methods use propensity scores to create comparable treatment and control groups by pairing individuals with similar characteristics (propensity scores). In matching, the unmatched individuals are excluded from the final analysis, which reduces the sample size(125). However, IPTW uses propensity scores to weight individuals according to the inverse probability of

receiving the treatment they received(125). This approach allows the majority of participants to be retained within the analysis, thereby preserving statistical power and increasing the effective sample size(212–214).

Therefore, inverse probability of treatment weighting (IPTW) methods were used to adjust patients who had a PFA and TKA due to the confounding factors listed in 3.2.4. To ensure the distribution of measured baseline covariates was similar between the treatment and control, assessments of the mean and SD of the weights were performed (214). This was reported in both graphical and tabular form. In terms of the standardised difference, more than 10% was taken to be indicative of an imbalance in covariates between treatment and control (214).

4.2.5.2 Statistical analysis of complications and length of stay

Following IPTW, both groups were compared using adjusted risk ratios to assess differences in complication rates. In terms of length of stay, logistic regression was used, with a prolonged length of stay defined as an admission of more than 4 days.

4.2.5.3 Survival analysis

A Kaplan-Meier mortality curve was plotted to compare the risk of death within the first 30 days for both procedures. A Cox regression with revision was fitted as the revision endpoint. Appendix C shows the finalised model fit following backward selection. Proportional hazards and time-varying coefficients were assessed (Appendix C). A parametric survival model was fitted using splines and degrees of freedom(215). This model was compared to the Cox regression model. This model was used to model the overall survival of a PFA implant compared to a TKA implant over time.

4.3 Results

4.3.1 IPTW results

The analysis included 669,960 records, which included 662,141 TKAs and 7,819 PFAs. Patient demographics are presented in Table 9 and Figure 13 illustrate the quality of adjustment using IPTW.

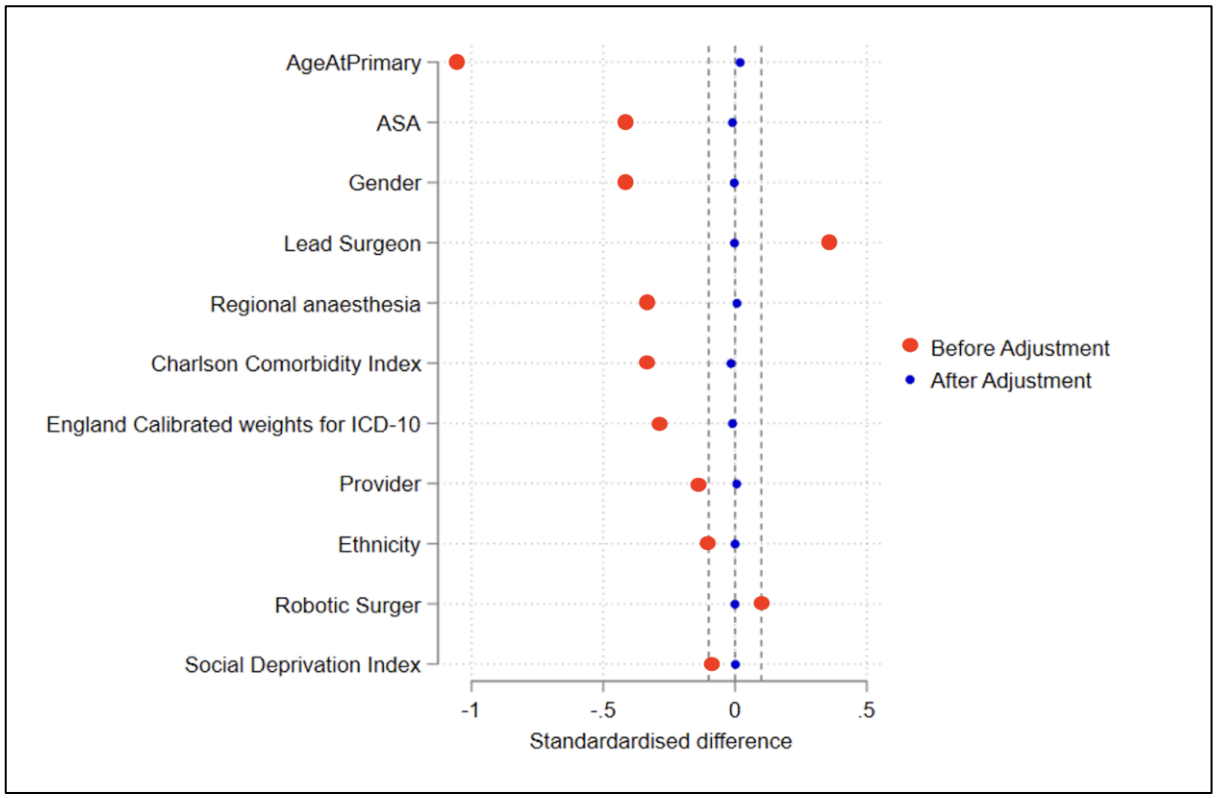


Figure 13. Graphical representation of inverse proportional treatment weighting - after adjustment.

Table 9. Baseline characteristics of patients before and after IPTW adjustment.

	BEFORE ADJUSTMENT					**AFTER ADJUSTMENT**				
	TKA N=848,508		PFA N=10,001		Standardised mean difference	TKA N=662,141		PFA N=7,819		Standardised mean difference
	Mean weight	Number and (%)	Mean weights	Number and (%)		Mean weight	Percent (%)	Mean weights	Percent (%)	
Patient age	**70.3**		**59**		**-1.06**	**58.79**		**58.99**		**0.02**
Gender	**0.43**		**0.23**		**-0.42**	**0.24**		**0.23**		**-0.00**
Female		487,035 (57)		7,680 (76.8)			38		38	
Male		361,465 (43)		2,321 (23)			12		12	
ASA †	**2.09**		**1.87**		**-0.42**	**1.87**		**1.87**		**-0.01**
ASA-1		79,121 (9)		2,281 (23)			11		11	
ASA- 2		614,219 (72)		6,794 (68)			34		34	
ASA- 3		155,168 (18)		926 (9)			0.05		0.05	
Ethnicity	**1.15**		**1.27**		**-0.10**	**1.15**		**1.15**		**-0.01**
White		693,429 (82)		8,513 (85)			48		48	
Black Caribbean		4,343 (1)		36 (0)			0.2		0.2	
Black African		2,817 (0)		17			0.1		0.1	
Black Other		1,293 (0)		11			0.06		0.06	
Indian		17,627 (2)		86 (1)			0.01		0.01	
Pakistani		6,379 (1)		22 (0)			0.00		0.00	
Bangladeshi		529 (0)		1 (0)			0.006		0.006	
Chinese		535 (0)		1 (0)			0.006		0.006	
Mixed Race		2,065 (0)		25 (0)			0.1		0.1	
Other Asian		7,789 (1)		65 (1)			0.4		0.4	
Social deprivation index	**3.27**		**3.14**		**-0.09**	**3.14**		**3.14**		**0.00**

1st - Most deprived		126,129 (15)		1764 (18)			10.1		10.1	
2nd		81,874 (10)		999 (10)			5.9		5.9	
3rd		185,787 (22)		2,090 (21)			11.7		11.7	
4th		194,145 (23)		2,074 (21)			11.5		11.5	
5th - Least Deprived)		178,478 (21)		1,982 (20)			10.8		10.8	
Regional anaesthesia	**0.73**		**0.56**		**-0.35**	**0.56**		**0.56**		**0.01**
Regional anaesthesia		617, 094 (73)		5,542 (55)			28.8		28	
Absence of regional anaesthesia		231,414 (27)		4,459 (45)			22.0		22.9	
Provider	**0.20**		**0.15**		**-0.13**	**0.15**		**0.15**		**0.01**
NHS		661, 945 (78)		8,303 (83)			42.7		43.6	
Private		186, 563 (22)		1,698 (17)			7.4		7.4	
Lead surgeon	**0.78**		**0.91**		**0.35**	**0.91**		**0.91**		**-0.01**
Consultant lead		669,381 (79)		9,094 (91)			45.4		45.3	
Non-consultant lead		179,127 (21)		907 (9)			0.05		0.05	
Robotic surgery	**0.01**		**0.03**		**0.09**	**0.03**		**0.03**		**-0.01**
Computer-aided		11,876 (1)		257 (3)			48.8			48.7
Absence of computer - aided		836,632 (99)		9,744 (97)			1.3			1.3
CCI	**0.66**		**0.42**		**-0.33**	**0.43**		**0.42**		**-0.02**
None		448,685 (53)		6,774 (68)			32.9		33.4	

Mild		288,128 (34)		2,592 (26)			13.8		13.3	
Moderate		81,086 (10)		479 (5)			2.6		2.5	
Severe		30,609 (4)		156 (2)			0.9		0.8	
Recalibration of the CCI with England-calibrated weights	2.51		1.55		-0.29	**1.58**		**1.55**		**-0.01**

† *ASA – American Society of Anaesthesiologists physical status*

4.3.1.2 Analysis of complications

The likelihood of complications among patients undergoing PFA procedures was significantly lower compared to TKA. This includes a lower respiratory tract infection (RR 0.65, P<0.05), deep vein thrombosis/pulmonary embolism (RR 0.35, P<0.05), urine tract infection (RR 0.59, P<0.05), wound infection (RR 0.73, P<0.05) and death within 30 days (RR 0.36, P<0.05) from the surgical procedure compared to a TKA, PFA patients had a lower mortality risk (99.8%) in the first 6 months relative to TKA patients (99.7%), as shown in Figure 14.

There were no differences between the procedures with regard to myocardial infarction risk. Compared with TKA patients, PFA patients were more likely to experience cerebrovascular events (RR 1.69, p=0.05). In Figure 15 and Table 10, risk ratios are presented as graphics and absolute risk differences are presented as tables.

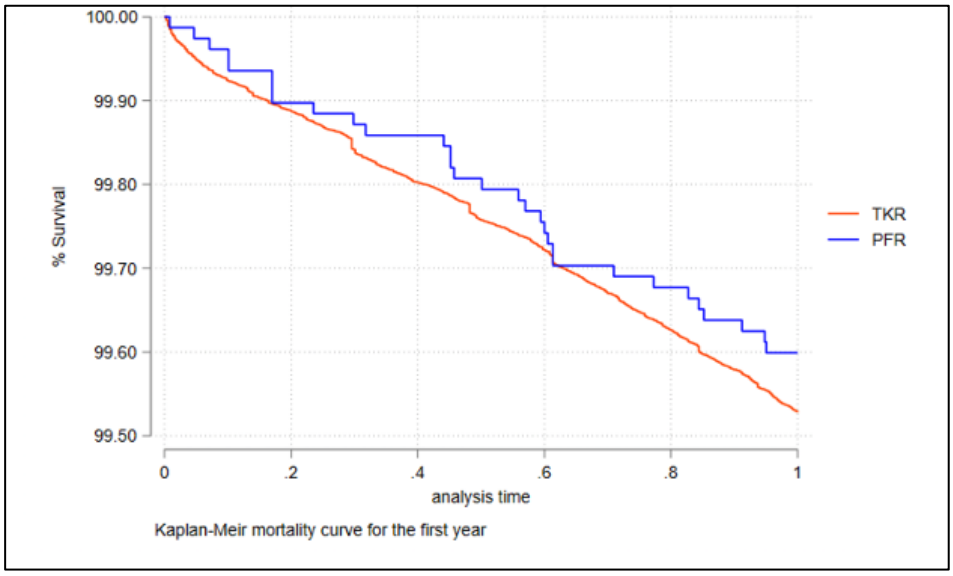


Figure 14. Kaplan-Meier survival estimates for the first year.

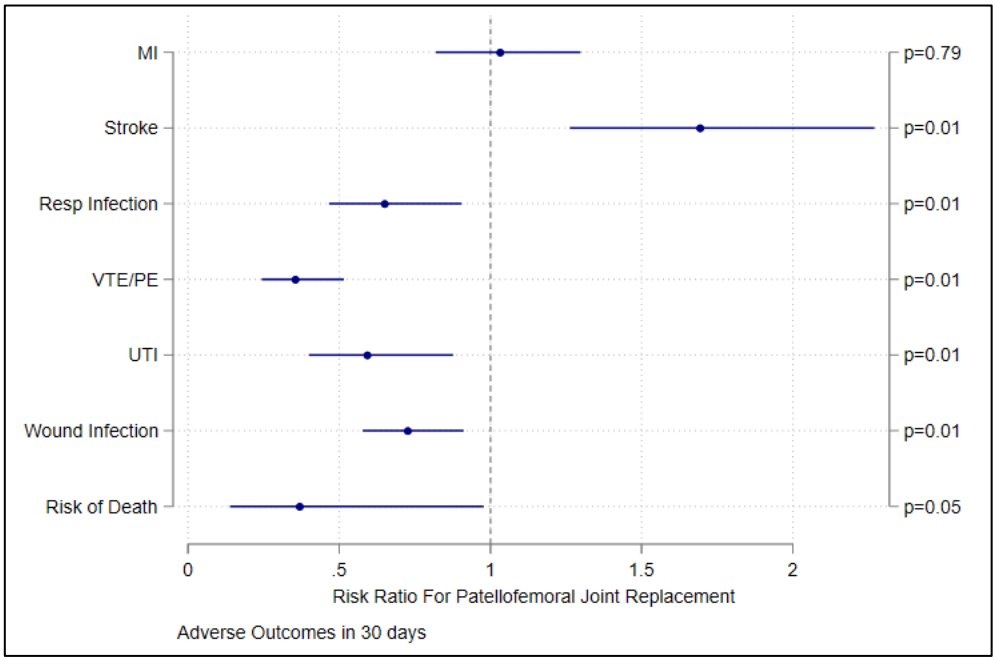


Figure 15. Risk ratio safety profile forest plot comparing PFAs and TKAs.

Table 10. Absolute risk and risk differences between PFAs and TKAs.

Variable	*Absolute risk: TKA (%)*	*Absolute risk: PFA (%)*	*Absolute risk difference (% points)*
Myocardial infarction (MI)	0.91	0.94	0.03
Stroke	0.4	0.6	0.2
Lower respiratory tract infection	0.7	0.4	0.3
Deep vein thrombosis/pulmonary embolism (VTE/PE)	1.0	0.3	0.7
Urinary tract infection (UTI)	0.5	0.3	0.2
Wound infection	1.3	1.0	0.3
Death	0.09	0.03	0.06

The exploratory analysis investigating why PFA patients were more likely to sustain a cerebrovascular event within the first 30 days compared to TKA patients revealed a few key findings. Initially, it was observed that PFA patients were slightly more likely to receive a general anaesthetic than TKA patients (OR 1.05, P<0.05, CI 1.00–1.10). Furthermore, after adjusting for factors such as age, comorbidities, hypertension, ethnicity, and social deprivation, the likelihood of PFA patients having a stroke remained higher (OR 1.72, P<0.05, CI 1.23–2.35). There was no difference in the type of thromboembolic prophylaxis given (OR 1.13, CI 0.88–1.44, P<0.05) and patients were more likely to have a shorter length of stay, OR 1.51, CI 1.43–1.59, P<0.05.

4.3.2 Survival analysis

4.3.2.1 Survival analysis: Hazard ratio over time

At ten years, the overall rate of survival for TKA was 95% and the rate for PFA was 85%. Over this time period there was a statistically significant higher rate of revision for PFA than for TKA (HR 2.45 (95% CI 2.16 to 2.78); p = 0.015).

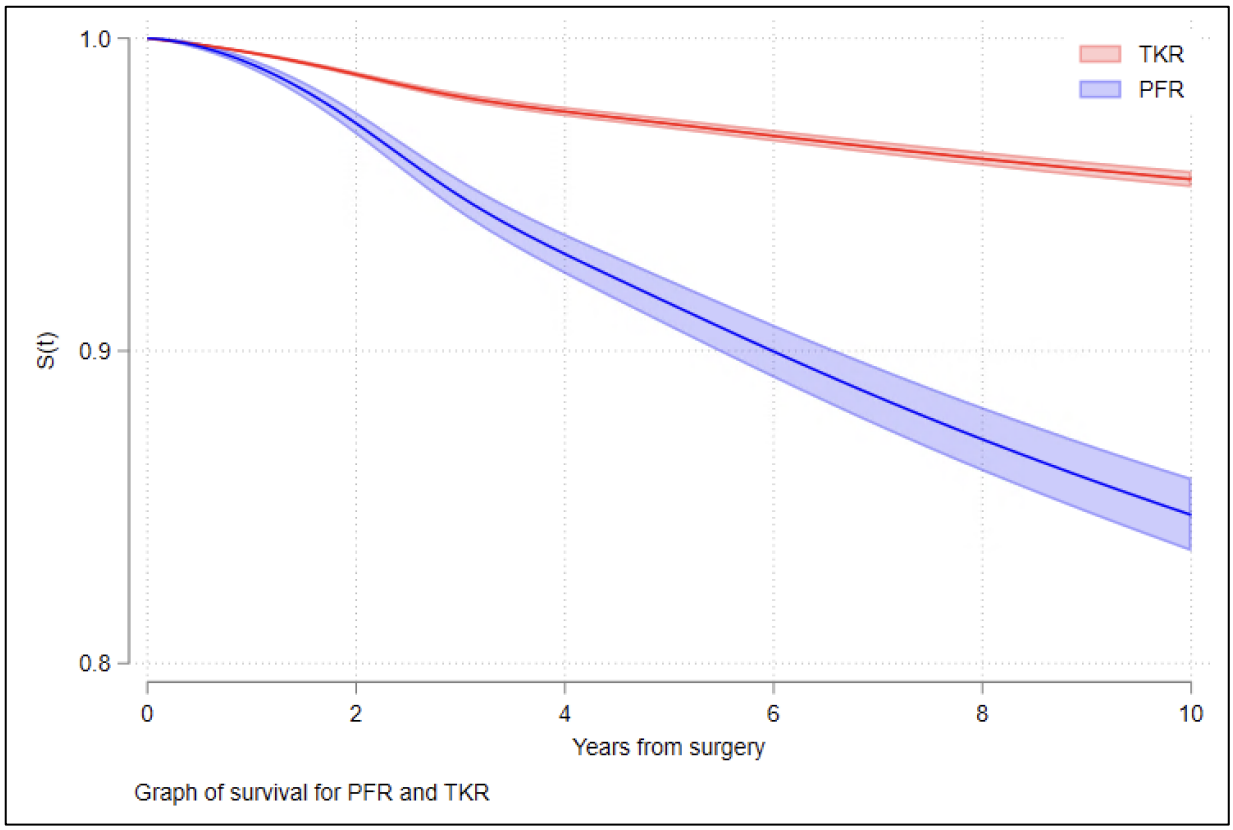


Figure 16. Survival of PFA compared to TKA over 10 years.

In both procedures (Figure 17) revision rates varied over time, with patellofemoral arthroplasties having a hazard function of 2.50 per 100 person-years at 2.5 years, compared to 0.75 per 100 person-years for TKAs at the same time. In comparison to TKAs, patellofemoral arthroplasties had a 1.33 hazard (CI 1.14–1.55) per 100 person-years at 10 years, but total patellofemoral arthroplasties had a 0.32 hazard (CI 1.33–1.55).

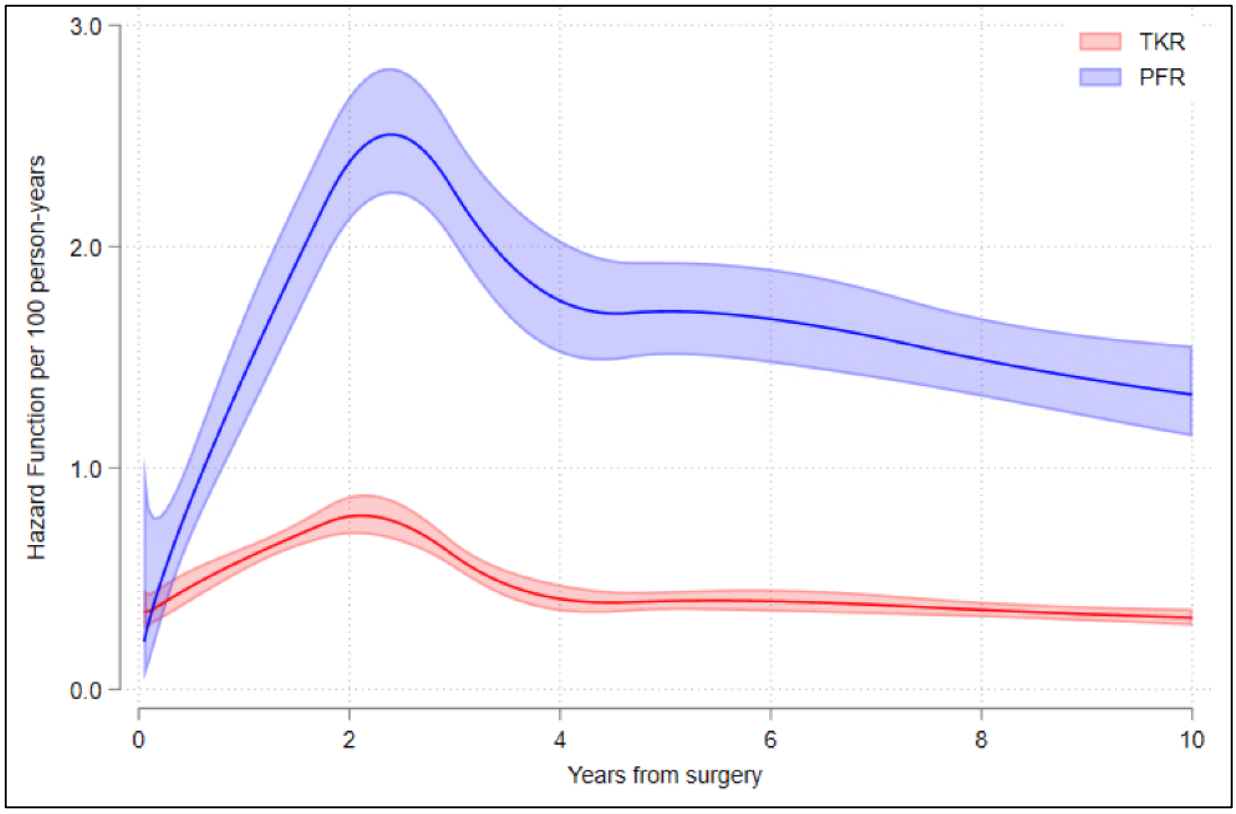


Figure 17. Hazard Function per 100 person-years for TKA and PFA. Shown are revisions per person-years over a 10-year follow-up.

4.3.2.1.1 Survival analysis: Reasons for revision

As both procedures followed the same trajectory, peaking at the 2.5 year mark and plateauing beyond this time point. Therefore, the reasons for revision were analysed during these respective time periods (before and after 2.5 years). In both TKA and PFA, the reason for revision varied between the early post-operative period and later time points. Prior to 2.5 years, pain was the most common reason for revision of PFA (8%), whilst infection was the most common reason for revision of TKA (16%). Beyond 2.5 years, PFAs were commonly revised due to progressive arthritis (33%), followed by pain (9%), and aseptic loosening (8%). In contrast, the most commonly reported revision reasons for TKA after 2.5 years were aseptic loosening (15%), infection (9%), and instability (5%).

Reason for revision	TKA n/N (%)	PFA n/N (%)
Infection	2527/15360 (16.45%)	13/1069 (1.22%)
Malalignment	614/15360 (4.00%)	30/1069 (2.81%)
Incorrect Sizing	1/15360 (0.01%)	0/1069 (0.00%)
Aseptic Loosening	1059/15360 (6.89%)	22/1069 (2.06%)
Lysis	42/15360 (0.27%)	3/1069 (0.28%)
Polywear	67/15360 (0.44%)	12/1069 (1.12%)
Implant Fracture/Comp	60/15360 (0.39%)	4/1069 (0.37%)
Dislocation/Subluxation	968/15360 (6.30%)	29/1069 (2.71%)
Periprosthetic Fracture	165/15360 (1.07%)	2/1069 (0.19%)
Progressive arthritis	456/15360 (2.97%)	71/1069 (6.64%)
Stiffness	488/15360 (3.18%)	10/1069 (0.94%)
Pain	563/15360 (3.67%)	85/1069 (7.95%)

Table 11 Reasons for revision in TKA and PFA stratified by revision occurring within 2.5 years from primary surgery. Values are presented as n/N (%), where N represents the total number of revised implants in this dataset

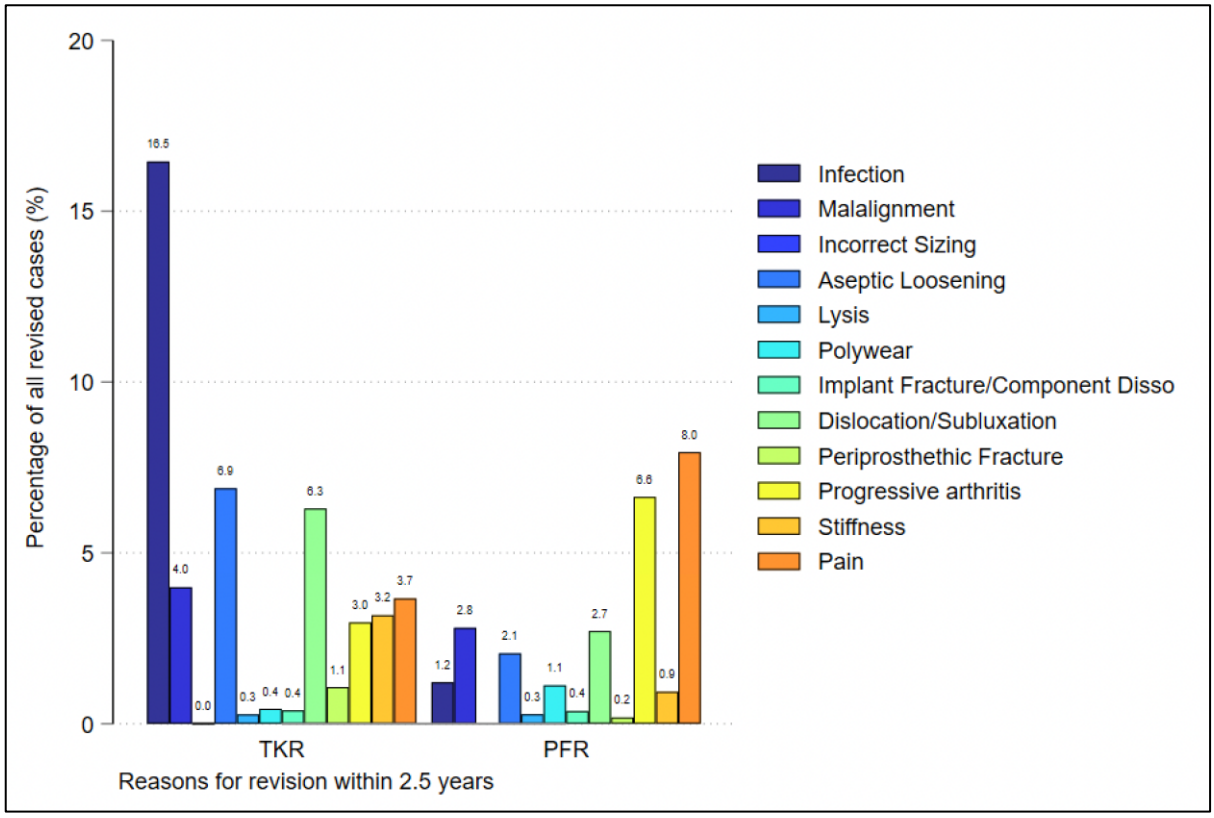


Figure 18 Reasons for revision comparing TKAs and PFAs within 2.5 years of the index procedure

Table 12 Reasons for revision in TKA and PFA stratified by revision occurring after 2.5 years from primary surgery. Values are presented as n/N (%), where N represents the total number of revised implants in this dataset

Reason for revision	TKA n/N (%)	PFA n/N (%)
Infection	1450/15360 (9.44%)	15/1069 (1.40%)
Malalignment	600/15360 (3.91%)	30/1069 (2.81%)
Aseptic Loosening	2345/15360 (15.27%)	82/1069 (7.67%)
Lysis	91/15360 (0.59%)	6/1069 (0.56%)
Polywear	206/15360 (1.34%)	36/1069 (3.37%)
Implant Fracture/Comp	52/15360 (0.34%)	11/1069 (1.03%)
Dislocation/Subluxation	828/15360 (5.39%)	28/1069 (2.62%)
Periprosthetic Fracture	354/15360 (2.30%)	5/1069 (0.47%)
Progressive arthritis	614/15360 (4.00%)	349/1069 (32.65%)
Stiffness	284/15360 (1.85%)	7/1069 (0.65%)
Pain	522/15360 (3.40%)	98/1069 (9.17%)

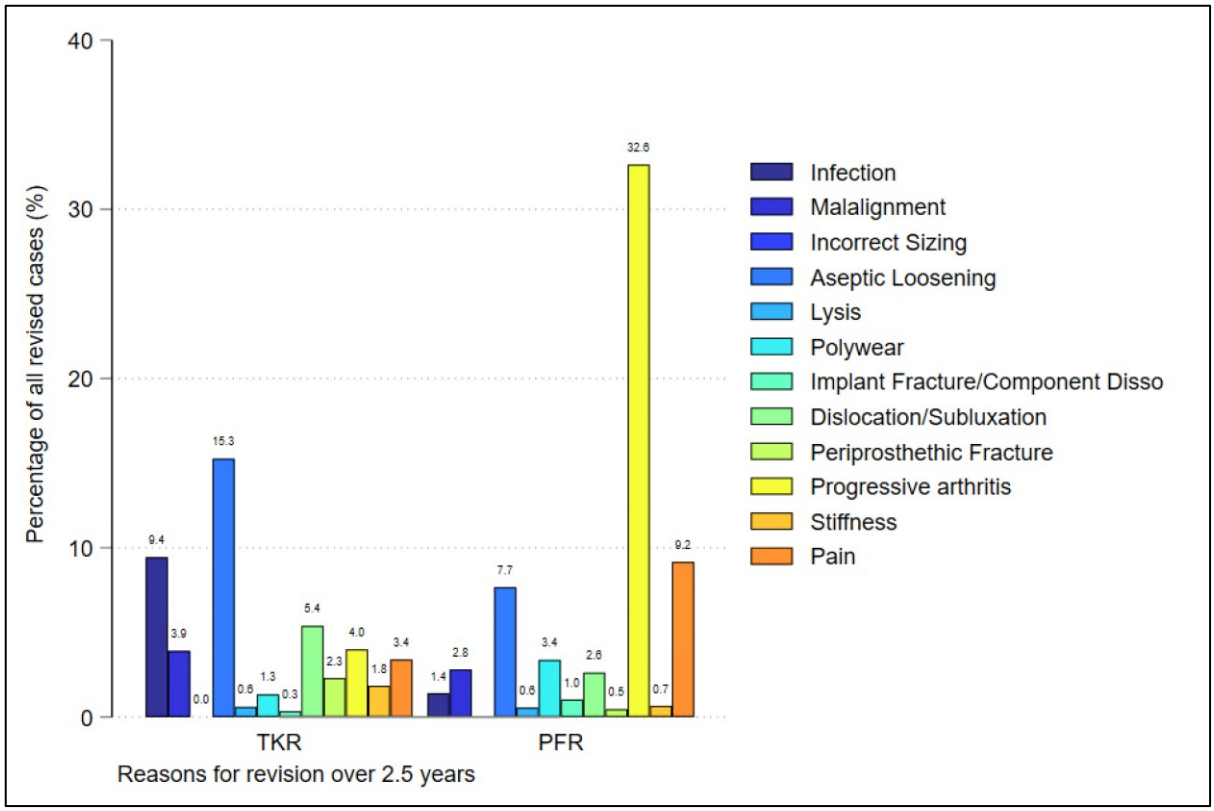


Figure 19 Revision for revision comparing TKAs and PFAs over 2.5 years after the index procedure.

Factors associated with the progression of osteoarthritis in PFA were explored. As seen from, Table 15 progressive arthritis was by far the commonest reason for revision of PFA following 2.5 years. Osteoarthritis progression was more common in women(OR 0.64, CI 0.45–0.92, P<0.05) and in people with obesity(OR 2.31, CI 1.28–4.15, P<0.05). Age at surgery, index of multiple deprivation and history of patellar disorders had no effect on risk of revision.

Table 13. Factors associated with developing progressive osteoarthritis when PFA revised beyond the 2.5-year mark

Factor	Odds Ratio, CI	P-value
Male	0.65 (0.45–0.92)	0.01
Obesity	2.31 (1.28–4.16)	0.01
Social deprivation index	1.03 (0.93–1.14)	0.58
History of patella disorders	0.94 (0.43–2.08)	0.89
Age per year	1.00 (0.98–1.01)	0.60

The variable 'history of patellar disorders' was defined as present if the patient had a previously recorded diagnosis corresponding to the ICD-10 codes listed in Appendix A. These codes indicate a documented history of trochlear dysplasia, patellar instability, or patellar dislocation. It is potentially of importance as it indicates patients who have differences of trochlear morphology which may favour development of isolated patellofemoral osteoarthritis as opposed to tricompartmental arthritis(216).

4.3.2.2 Survival analysis: Hazard ratio in terms of gender and revision differences

There was a higher rate of revision for patellofemoral joint arthroplasties in males than in females. Male–to–female hazard ratios over time were plotted to illustrate the male survival disadvantage (Figure 20). The hazard ratio was 1.38 (CI 1.1 -1.60) within the first 2 years after surgery for men and was significant only within this period.

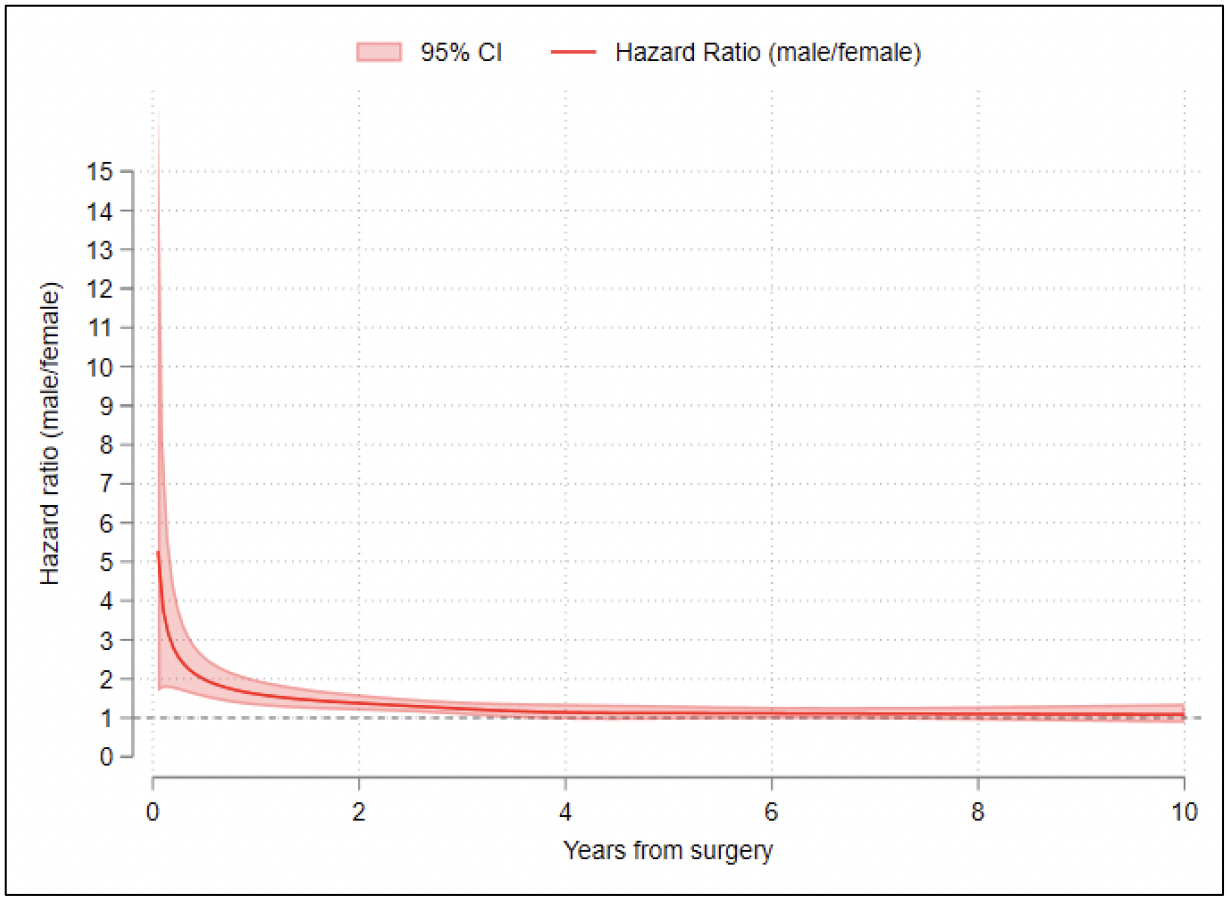


Figure 20. Patellofemoral joint arthroplasty specific hazard ratio for males compared with females by years since index surgery

Following the same trend Figure 21, males had a higher revision rate than females within the first 2 years, with a significant hazard ratio of 1.31 (CI 1.14 -1.53), but a lower hazard than patellofemoral joint arthroplasties. After 3 years, there were no significant gender differences.

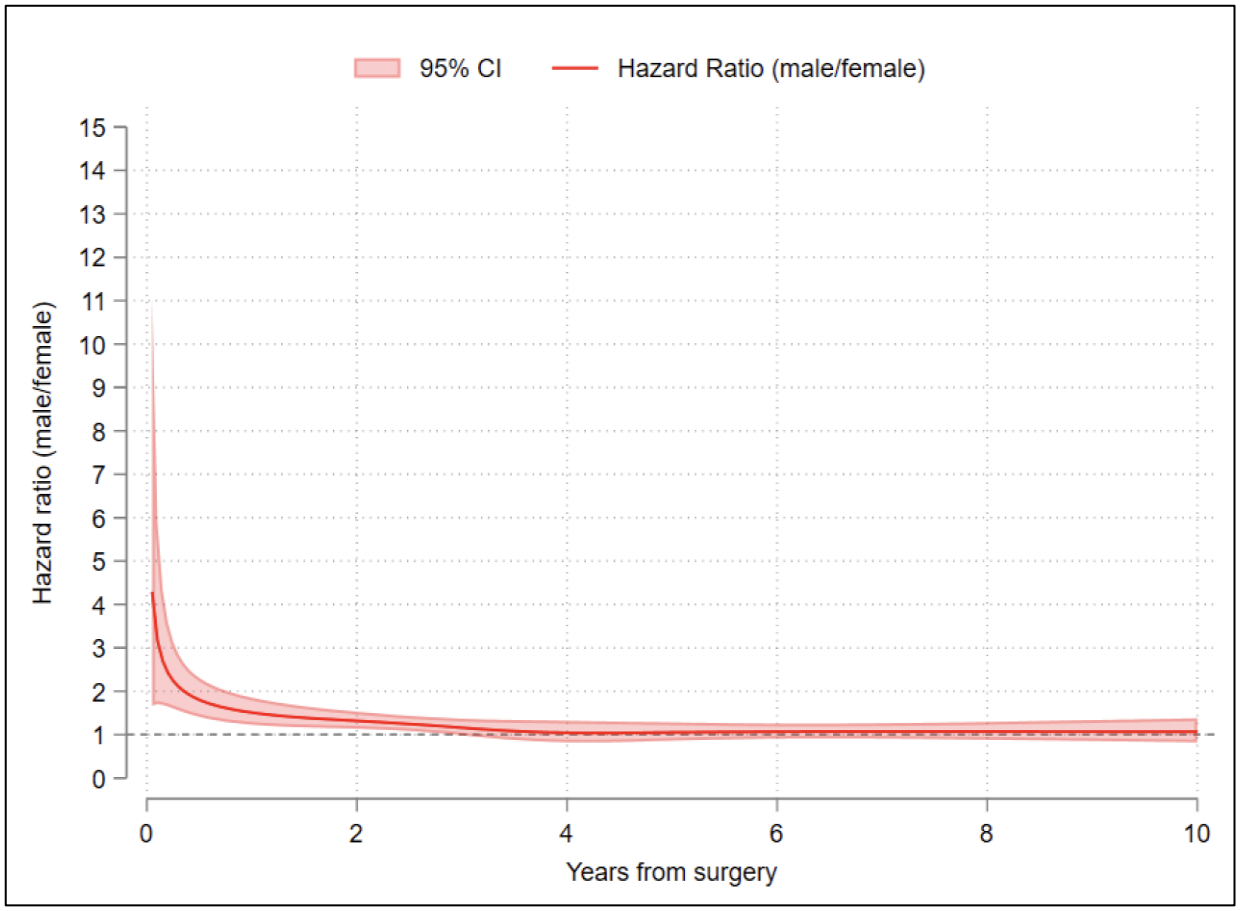


Figure 21. TKA specific hazard ratio for males compared with females by years since index surgery.

4.3.2.2.1 Survival analysis: Gender and revision differences

For both procedures, PFA and TKA, both genders failed for the same reasons, albeit at different rates before and after two years (Figure 22-Figure 25, Table 14-Table 15). Regarding PFA, revision due to pain was the most common reason within the first 2 years. In terms of TKA, infection was the most common cause of revision in the first two years, accounting for 8.5% of male revisions and 5.8% of female revisions. After two years, progressive osteoarthritis was the most common cause of revision following PFA, accounting for 28.1% of females compared to 6.8% of males. In TKAs, aseptic loosening accounted for 9.4% of female revisions and 7.7% of male revisions after two years.

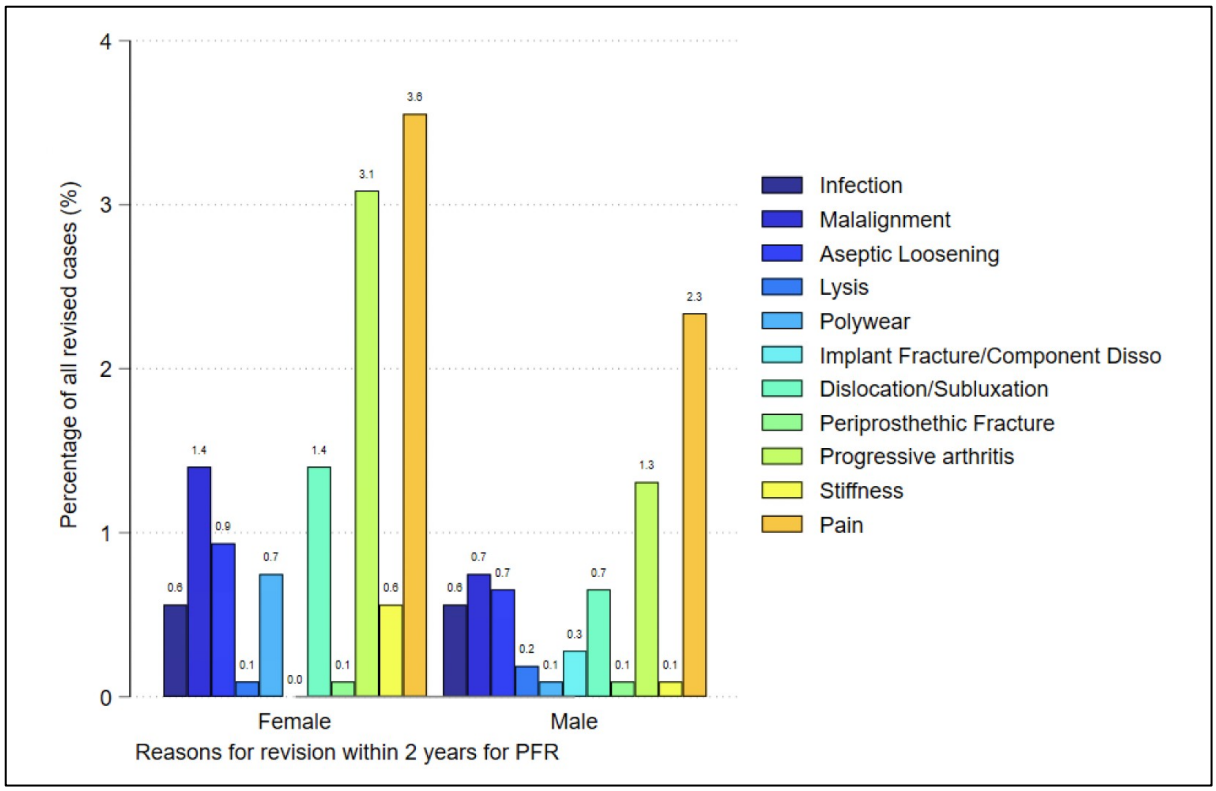


Figure 22. Reasons for revision within 2 years of patellofemoral joint arthroplasties stratified by gender.

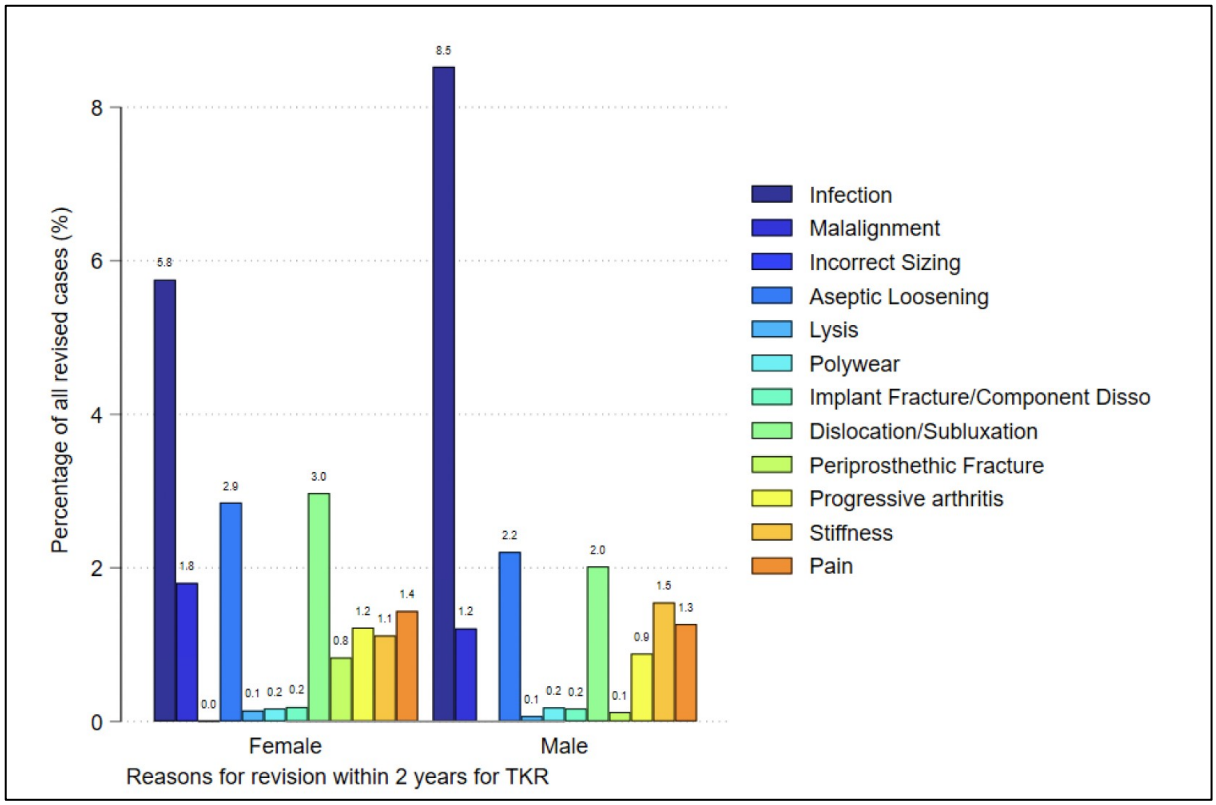


Figure 23. Reasons for revision within 2 years for total knee arthroplasties stratified by gender.

Table 14 Early revisions (within 2 years): Revision indications by gender and implant type, presented as n/N (%) of all revised TKA (N=15,360) and PFA (N=1,069).

Reason for revision	Female TKA n/N (%)	Male TKA n/N (%)	Female PFA n/N (%)	Male PFA n/N (%)
Infection	884/15360 (5.76%)	1310/15360 (8.53%)	6/1069 (0.56%)	6/1069 (0.56%)
Malalignment	277/15360 (1.80%)	186/15360 (1.21%)	15/1069 (1.40%)	8/1069 (0.75%)
Incorrect Sizing	1/15360 (0.01%)	—	0/1069 (0.00%)	—
Aseptic Loosening	438/15360 (2.85%)	339/15360 (2.21%)	10/1069 (0.94%)	7/1069 (0.65%)
Lysis	22/15360 (0.14%)	11/15360 (0.07%)	1/1069 (0.09%)	2/1069 (0.19%)
Polywear	26/15360 (0.17%)	28/15360 (0.18%)	8/1069 (0.75%)	1/1069 (0.09%)
Implant Fracture/Comp	29/15360 (0.19%)	26/15360 (0.17%)	0/1069 (0.00%)	3/1069 (0.28%)

Dislocation/Subluxation	457/15360 (2.97%)	310/15360 (2.02%)	15/1069 (1.40%)	7/1069 (0.65%)
Periprosthetic Fracture	128/15360 (0.83%)	19/15360 (0.12%)	1/1069 (0.09%)	1/1069 (0.09%)
Progressive arthritis	188/15360 (1.22%)	136/15360 (0.89%)	33/1069 (3.09%)	14/1069 (1.31%)
Stiffness	172/15360 (1.12%)	238/15360 (1.55%)	6/1069 (0.56%)	1/1069 (0.09%)
Pain	221/15360 (1.44%)	195/15360 (1.27%)	38/1069 (3.55%)	25/1069 (2.34%)

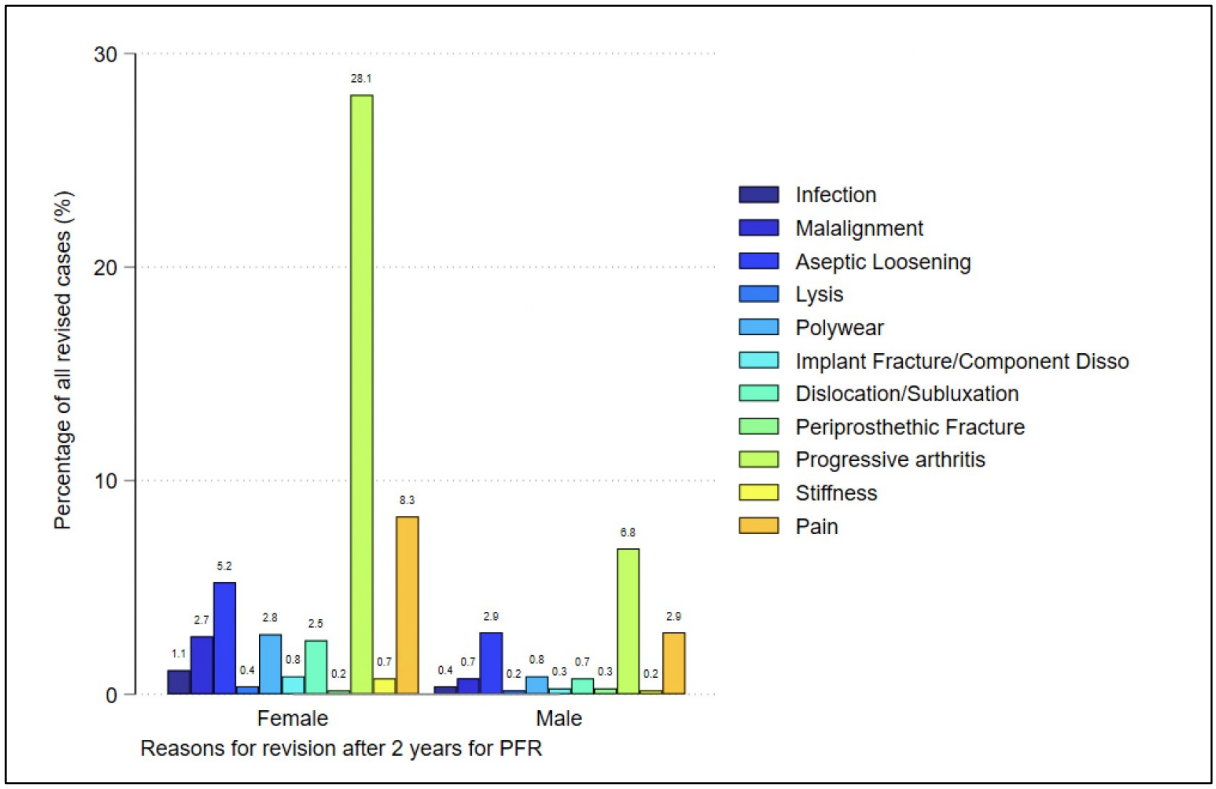


Figure 24. Reasons for revision after 2 years for patellofemoral joint arthroplasties stratified by gender.

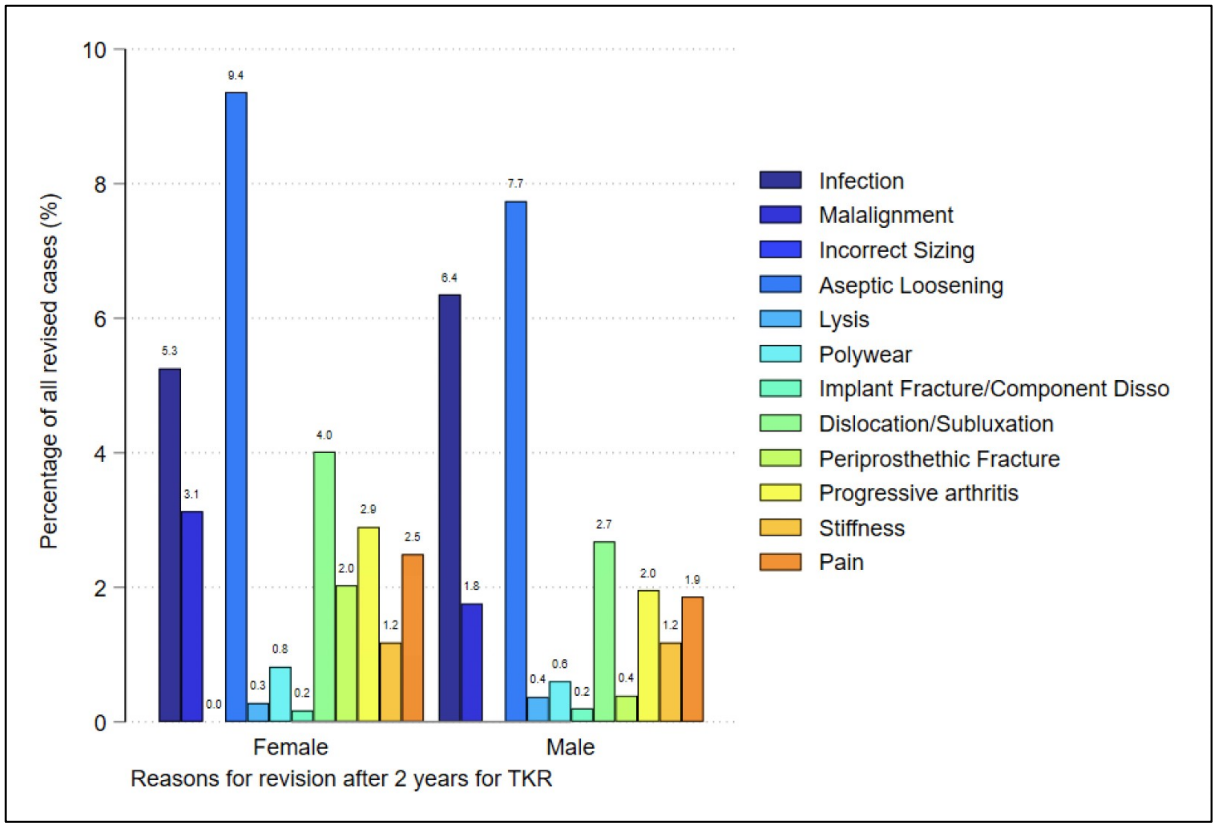


Figure 25. Reasons for revision after 2 years for TKAs, stratified by gender,

Table 15 Late revisions (after 2 years): Revision indications by gender and implant type, presented as n/N (%) of all revised TKA (N=15,360) and PFA (N=1,069).

Reason for revision	Female TKA n/N (%)	Male TKA n/N (%)	Female PFA n/N (%)	Male PFA n/N (%)
Infection	884/15360 (5.76%)	976/15360 (6.35%)	6/1069 (0.56%)	4/1069 (0.37%)
Malalignment	277/15360 (1.80%)	270/15360 (1.76%)	15/1069 (1.40%)	8/1069 (0.75%)
Incorrect Sizing	1/15360 (0.01%)	.	0/1069 (0.00%)	.
Aseptic Loosening	438/15360 (2.85%)	1189/15360 (7.74%)	10/1069 (0.94%)	31/1069 (2.90%)
Lysis	22/15360 (0.14%)	57/15360 (0.37%)	1/1069 (0.09%)	2/1069 (0.19%)
Polywear	26/15360 (0.17%)	93/15360 (0.61%)	8/1069 (0.75%)	9/1069 (0.84%)
Implant Fracture/Comp	29/15360 (0.19%)	31/15360 (0.20%)	0/1069 (0.00%)	3/1069 (0.28%)
Dislocation/Subluxation	457/15360 (2.97%)	412/15360 (2.68%)	15/1069 (1.40%)	8/1069 (0.75%)
Periprosthetic Fracture	128/15360 (0.83%)	60/15360 (0.39%)	1/1069 (0.09%)	3/1069 (0.28%)
Progressive arthritis	188/15360 (1.22%)	301/15360 (1.96%)	33/1069 (3.09%)	73/1069 (6.83%)
Stiffness	172/15360 (1.12%)	181/15360 (1.18%)	6/1069 (0.56%)	2/1069 (0.19%)
Pain	221/15360 (1.44%)	286/15360 (1.86%)	38/1069 (3.55%)	31/1069 (2.90%)

4.3.2.3 Hazard as a function of age

The effect of patient age on revision for both procedures was explored. Figure 26 and Figure 27 show, for example, a 60-year-old woman who undergoes a TKA has a 10-year revision risk of 5% which rises to 17% in a patient with the same attributes who undergoes PFA.

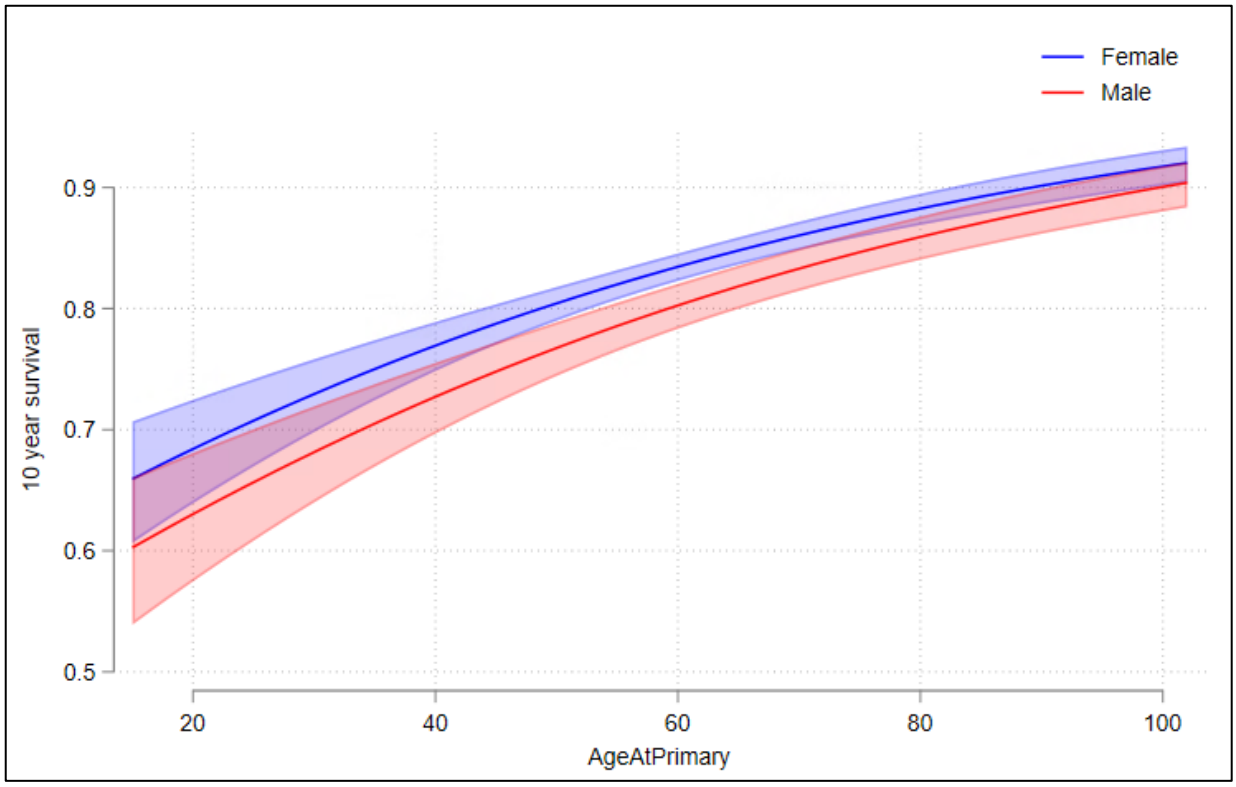


Figure 26. Survival of PFA stratified by gender as a function of patient age.

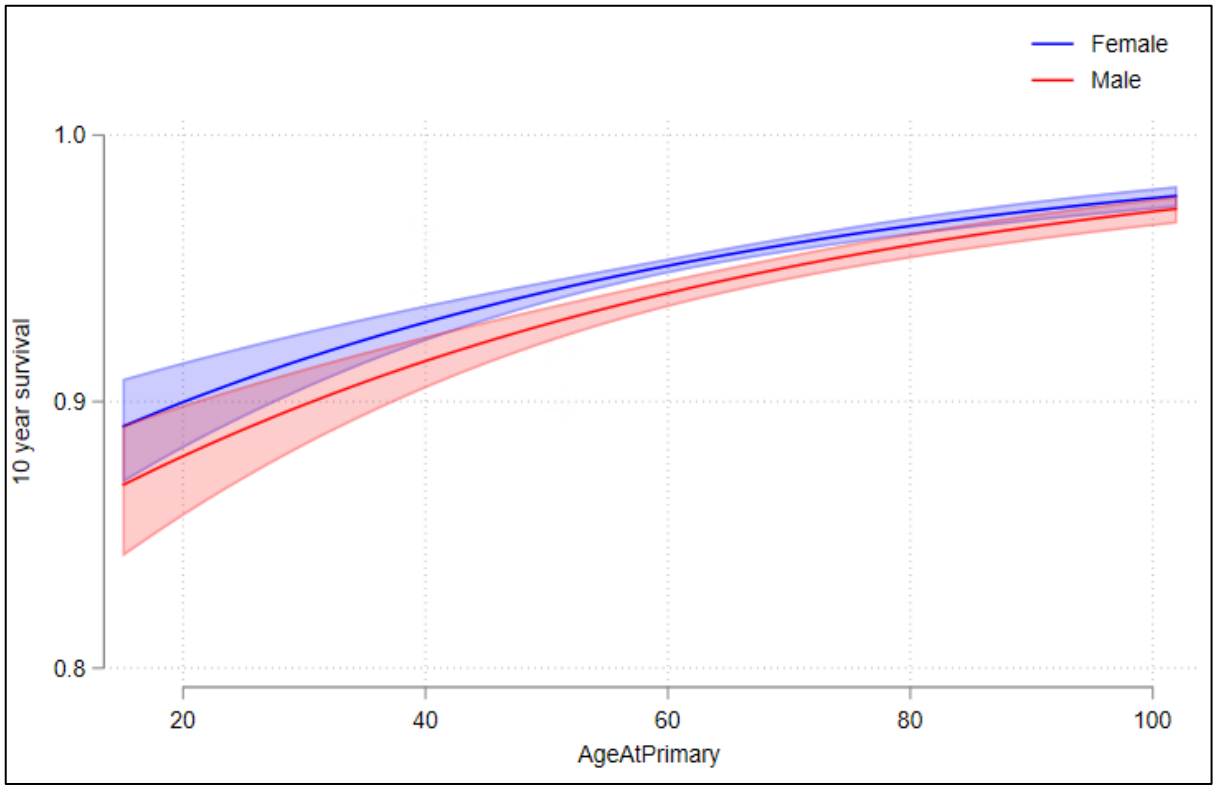


Figure 27. Survival of TKA stratified by gender as a function of patient age.

Based on age group, the top two reasons for the revision of patellofemoral joint arthroplasties are illustrated in Figure 28 with pain and progressive osteoarthritis being the most common causes of revision for ages between 31 and 79. Pain accounted for 3.6% (1/28) and stiffness for 3.6% (1/28) were the most common reasons for revisions in individuals younger than 31; meanwhile, dislocation, subluxation, pain, and progressive arthritis were more likely causes of revisions in individuals older than 80. Absolute numbers can be found in Table 16. Appendix D provides a comprehensive breakdown of revision reasons for both PFA and TKA based on age groups.

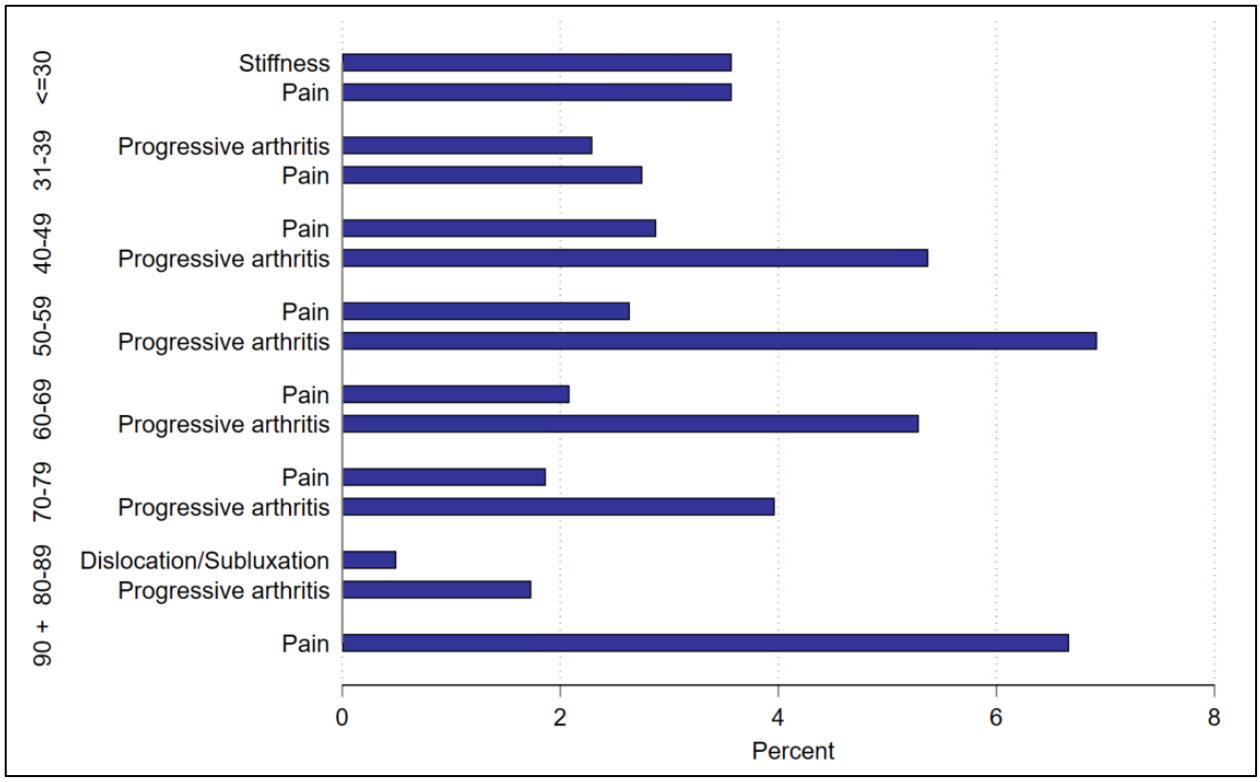


Figure 28. 10-year revision reasons for PFA as a function of age group; the denominator is the total number of PFA revisions within that age category.

Table 16 10-year revision reasons for PFA revision by age group. Values are presented as n/N (%) where N is the total number of PFA revisions within each category.

Age group	Pain n/N (%)	Progressive arthritis n/N (%)
31–39	6/218 (2.8%)	5/218 (2.3%)
40–49	45/1563 (2.9%)	84/1563 (5.4%)
50–59	64/2427 (2.6%)	168/2427 (6.9%)
60–69	41/1967 (2.1%)	104/1967 (5.3%)
70–79	24/1286 (1.9%)	51/1286 (4.0%)
80–89	—	7/404 (1.7%)
90+	1/15 (6.7%)	—

4.4 Discussion

Summary of results

In suitable patients, PFA has advantages over TKA including a lower morbidity rate, has a lower risk of wound infection, urinary tract infection, deep vein thrombosis, pulmonary embolism, and is less likely to cause death than a TKA. As evidenced by a shorter hospital stay, patellofemoral joint arthroplasties are associated with a quicker recovery. However, this should is balanced with a higher risk of revision when compared to TKA.

In this dataset, we found postoperative stroke to be more common after PFA than TKA; a difference which remained in spite of adjustment for known confounders predisposing risk factors for stroke, such as hypertension, ethnicity, and type of thromboprophylaxis (217). Stroke is a rare complication after arthroplasty, the absolute numbers were low (5,514 for TKR, 1% and 50 for PFR, 1%) and the difference may just be due to increased variation due to low event numbers. It is difficult to imagine a scientifically plausible explanation for this, given that PFA is associated with less tissue trauma and would be expected to elicit less of a stress response than TKA. Possible explanations were explored including differences in anaesthesia (with general slightly more common in PFA)(218–220). It may be that patients with patellofemoral joint osteoarthritis could be more likely to have connective tissue disorders and hence be predisposed to strokes (221). It would appear more likely, in light of the very small numbers involved, that this difference is due to chance or may be secondary to unmeasured confounding.

In both TKA and PFA, revisions were more likely within the first 2.5 years. This is similar to

findings reported by case series and national registers for all arthroplasty procedures(222). Reasons for revision differed between early and late revisions, and between TKA and PFA nad between TKA and PFA, persistent pain accounted for the greatest proportion of revisions for PFA. This was different from TKA which was more likely to be revised due to infection. Among PFA patients who required revision after 2.5 years, progressive osteoarthritis was the most common cause, which was more prevalent among females and obese individuals. It was not related to age or a history of patellofemoral disorders.

Both females and males had similar reasons for revision before and after 2.5 years. In the younger age group, defined as less than 39 years of age, PFA patients were more likely to be revised secondary to mal-alignment and aseptic loosening. For patients over the age of 40, the most common reason for revision was pain and progressive osteoarthritis.

Application to practice

The study shows that obesity is not a contraindication to PFA surgery and is safer overall than TKA. This study sheds light on the importance of thromboprophylaxis in patients undergoing PFA surgery who have an overall increased stroke risk. It has been described as technically demanding, resulting in a longer operating time and more likely to require general anaesthesia. General anaesthesia disturbs the circulator homeostasis, which may predispose patients to stroke (218–221). Additionally, untreated patellofemoral instability can lead to patellofemoral osteoarthritis, a condition caused by multiple factors, such as connective tissue disorders (221). The factors mentioned above may contribute to the increased risk of cerebrovascular events among PFA patients.

This study shows that pain is one of the commonest causes of PFA revision. The cause of post-operative pain following PFA surgery may be inferred from previous studies since the

patellofemoral joint requires congruency to allow smooth flexion-extension movement (164,165). Technical experience is, therefore, extremely important because surgical inexperience could result in an overstuffed patellofemoral component, which may result in complications such as maltracking and pain, resulting from the inability to restore the rotational alignment of the trochlea (164,165). Pre-operative long-leg radiographs are essential to assess knee alignment and address any deformities predisposing to progressive osteoarthritis in other compartments post-operatively (12).

Limitations and further work

Although patients may have had a TKA for tri-compartment osteoarthritis, the study looked at differences in procedural risk but did not look at outcomes following radiographic osteoarthritis patterns, however to date there are not papers that suggest that the risks of complications after surgery differ depending on the distribution of the osteoarthritis. The most common reason for revision in the first two years of a PFA was pain, but due to data limitations, the exact cause of pain was unable to be determined. Future research should investigate the cause of pain.

Chapter 5 Analysing the patterns of usage of patellofemoral joint arthroplasties

Author Contribution, Funding, and Dissemination

I the dataset developed previously and undertook additional data cleaning, restructuring, and statistical analysis specific to surgeon volume and outcome analysis. I led interpretation of the findings and manuscript preparation.

Publications

Vella-Baldacchino M, Davies AR, Bottle A, Cobb J, Liddle AD. Association Between Surgeon Volume and Patient Outcomes After Elective Patellofemoral Arthroplasty: A Population-Based Cohort Study Using Data from the National Joint Registry and Hospital Episode Statistics for England. J Bone Joint Surg Am. 2025 Apr 16;107(8):819-828. doi: 10.2106/JBJS.24.00703. Epub 2025 Feb 3. PMID: 39899649.

Presentations

- Poster presentation: *Association Between Surgeon Volume And Patient Outcomes After Elective Patellofemoral Joint Replacement Surgery Using Data From The National Joint Registry And Hospital Episode Statistics For England: Population Based Cohort Study* - ISAKOS Congress.

Chapter 5 Analysing the patterns of usage of patellofemoral joint arthroplasties

5.1 Introduction

In national joint registries worldwide, PFA accounts for between 1 and 1.5% of all knee arthroplasty procedures, with a revision rate several times higher than TKA (128,223–225). Historically, PFA has been associated with complications, particularly in early designs from the 1950s due to poor implant design (16,91,226). Whilst improvements to implant design and a greater understanding of indications have led to a reduction in the rate of revision of PFA, this has not resulted in a significant increase in the popularity of this procedure (10,12,61,68,227). One of the reasons for its low uptake is that it has been considered to be a technically demanding operation with varying results depending on the surgeon's experience (228–230). It is unclear to what extent surgical caseload affects PFA outcomes. In this chapter, I aimed to determine whether performing a higher volume of PFAs, reflecting greater surgical experience, improves implant survival.

This chapter has four main aims:

1. To determine the effect of surgical caseload on implant survival and identify thresholds to be considered to pertain to a high-volume or low-volume surgeon.
2. To determine the effect of surgical caseload on the risk of developing adverse outcomes and post-operative complications.
3. To determine whether surgical caseload experience affected patient selection criteria such as obesity, comorbidity status, and identification of patients with patellofemoral disorders.

4. To determine whether surgical caseload experience affected implant selection and reasons for revision.

5.2 Methods

5.2.1 Data sources

The analyses presented in this chapter are based on the combined datasets of the NJR and HES created in Chapter 3. There were a total of 15,287 patellofemoral joint arthroplasties available for analysis.

5.2.1.1 Descriptive analysis of caseload

For each year, the total number of patellofemoral joint arthroplasties performed by each consultant in each consecutive year (2003-2020) was calculated. This was defined as the yearly patellofemoral joint caseload. There were three outcomes, namely implant survival, risk of sustaining a systemic complication or local complication.

Implant survival was defined as the person time incidence rate (PTIR) which was calculated which was calculated per surgeon per year as seen in Figure 29 (231)

$$\text{PTIR} = \frac{Total\ number\ of\ revisions\ by\ a\ surgical\ consultant}{(Total\ length\ of\ survival\ of\ each\ implant\ )\ x100}$$

Figure 29. Prothesis Time incidence rate calculation

The total length of time until each prosthesis failed is defined as the total length of time until

the prosthesis was revised, the patient died, or the last date of follow-up.

5.2.1.2 Exposures and outcomes

Only one revision reason diagnosis was allowed for each revision in order to explore the reasons for the revision. If more than one reason was listed as a diagnosis, the hierarchy used by the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) was used (103). This was used to determine the important reason for patellofemoral joint arthroplasty revision.

Table 17 Diagnosis hierarchy used by the AOANJRR for determining revision reason

Rank	Diagnosis
1	Infection
2	Progression of disease
3	Aseptic Loosening
4	Pain
5	Component dissociation
6	Implant fracture
7	Femur Lysis
8	Tibia lysis
9	Polywear
10	Prosthesis Dislocation Subluxation
11	Instability

12	Malalignment
13	Periprosthetic fracture
14	Stiffness
15	Incorrect sizing

The following conditions obtained in Section 3.3.3 and listed in Appendix A were used to determine whether the patient sustained a systemic complication or local complication within the first 30 days (Table 18).

Table 18. Conditions which determined if the patient sustained a systemic or local complication

Systemic complication	**Local Complication**
- Myocardial infarction - Stroke (CVA/TIA) - Delirium - Deep vein thrombosis - Pulmonary embolism - Lower respiratory tract infection - Urinary tract infection - Patient death	- Hemarthrosis - Tibia-tuberosity fracture - Knee pain - Arthrofibrosis - Manipulation under anaesthetic - Lateral release - Wound infection

5.2.1.3 Patient factors

To examine whether patient selection differed between volume groups, patients were adjusted using IPTW methods using the Index of Multiple Deprivation (IMD) and treatment provider (NHS or private). As described in Section 4.2.5.1, IPTW meant that the two samples, those operated by high-volume surgeons and those operated on by low-volume surgeons look almost

identical for the covariates selected (i.e., IMD, treatment provider). This adjustment minimises any systemic differences between the pool of patients in high and low volume groups. This was reported in both graphical and tabular form. In terms of the standardised difference, more than 10% was taken to be indicative of an imbalance in covariates between treatment and control (214).

Following the adjustment, any difference found in patient selection between the two groups were true differences between surgical groups. The patient selection differences explored were comorbidity status, using the ASA physical status classification system, age at which the patient was operated upon, and whether the patient had pre-existing patella disorders or dislocation of the patella. Patella conditions were defined as shown in Appendix A.

5.2.1.4 Surgical factors

All of the PFAs used in this dataset are considered to be "second-generation" devices. The number of implants and type of implants used by surgeons with different caseload numbers were compared, as well as the reasons for revision.

5.2.3 Analysis

5.2.3.1 Descriptive analysis of caseload effect

To visually assess the relationship between the revision rate, defined as PTIR, and the yearly surgical caseload, a locally weighted scatterplot smoothing (LOWESS) graph was plotted. Outliers on the scatter plots were explored to determine their credibility. Once outlier analysis was complete, the nature of the relationship between caseload and PTIR was demonstrated by plotting lines LOWESS. The scatter plots are suppressed in the figures presented.

5.2.3.2 Survival analysis of caseload effect

Two linear splines were fitted corresponding to two linear segments observed, and differences in survival hazard were compared using Cox regression. The survival model selected with backward selection was assessed using Cox-Snell residuals and Akaike's Information Criterion (AIC)(232–234). The proportional hazards assumption was assessed using Schoenfeld residuals. A flexible parametric survival model using restricted cubic splines was fitted and compared with the Cox regression, comparing the hazards for similarity (215).

Additionally, high and low-volume surgeon groups were compared in terms of the number of systemic and local complications using multilevel logistic modelling. Differences in the type of implants used were compared using logistic regression.

5.2.3.3 Analysis of patient factors

The surgical caseload was divided into two groups corresponding to each spline section, representing low and high-volume surgeons. The patient characteristics in each volume group were compared using linear and logistic regression and multivariable regression was performed to determine whether the difference in patient factors between the groups explained the difference in outcomes between the groups.

5.2.3.4 Analysis of surgical factors

Using linear regression, the number of implants and types of implants used by surgeons with different caseload numbers were compared. The different reasons for revisions were graphed on a bar chart for comparison.

5.3 Results

From the 3,300 lower limb arthroplasty surgeons, 858 surgeons (26%) performed PFAs. The analysis included 15,065 records of patellofemoral arthroplasty. Based on the ECDF curve (Figure 30), the modal yearly caseload was 2 cases per year, while the median caseload (ECDF=0.5) was 5 cases per year (SD 8).

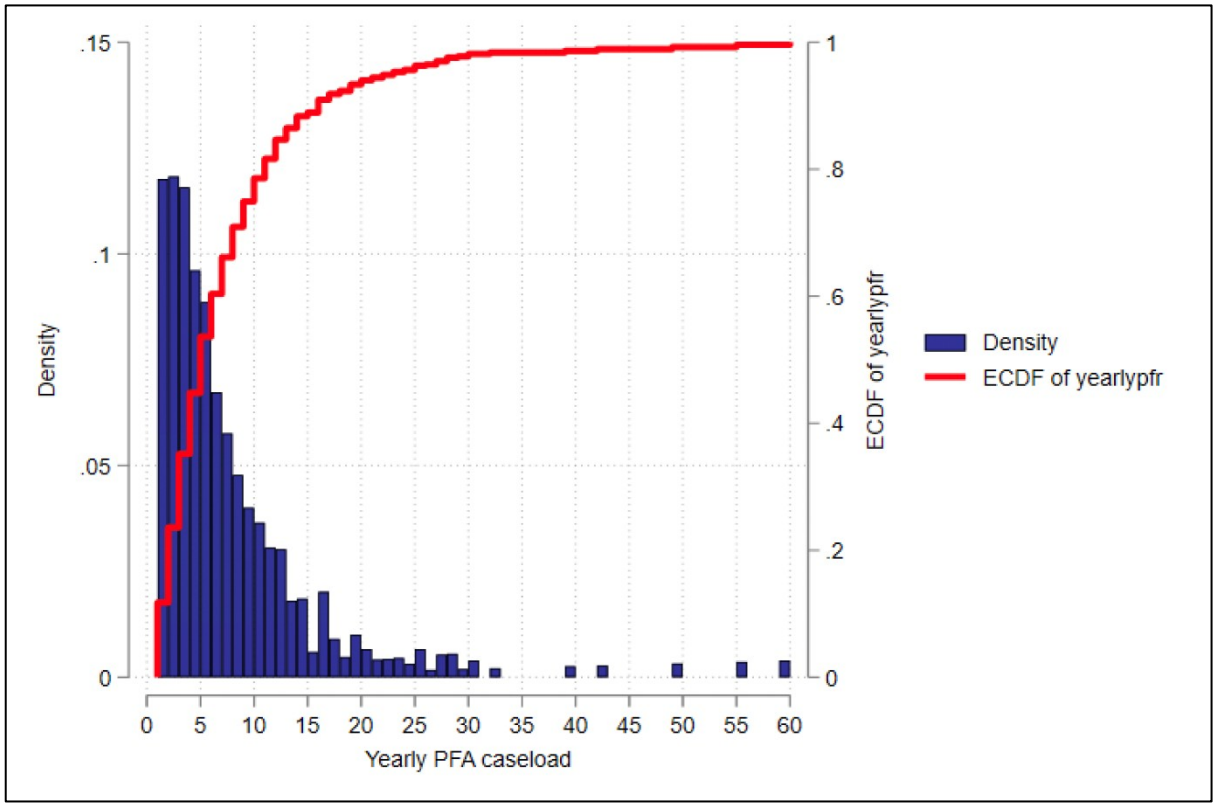


Figure 30. Estimator of the cumulative distribution function curve (ECDF) for yearly caseload.

5.3.1 Descriptive analysis of caseload effect

As shown in Figure 31, the LOWESS plot showed a non-linear relationship between PTIR and yearly caseload. As the trend decreased after five cases per year, linear splines were fitted and a knot was fitted at 5 cases per year. A high-volume surgeon was defined as one who performed five or more cases per year. A low-volume surgeon was defined as one performing less than 5 cases per year. The gradient of the curve decreased beyond the 5 yearly case point,

but there was still a statistically significant association between the caseload and the revision rate (HR 0.98 per additional case, CI 0.97-0.99, p=0.01, Figure 32, Table 19)

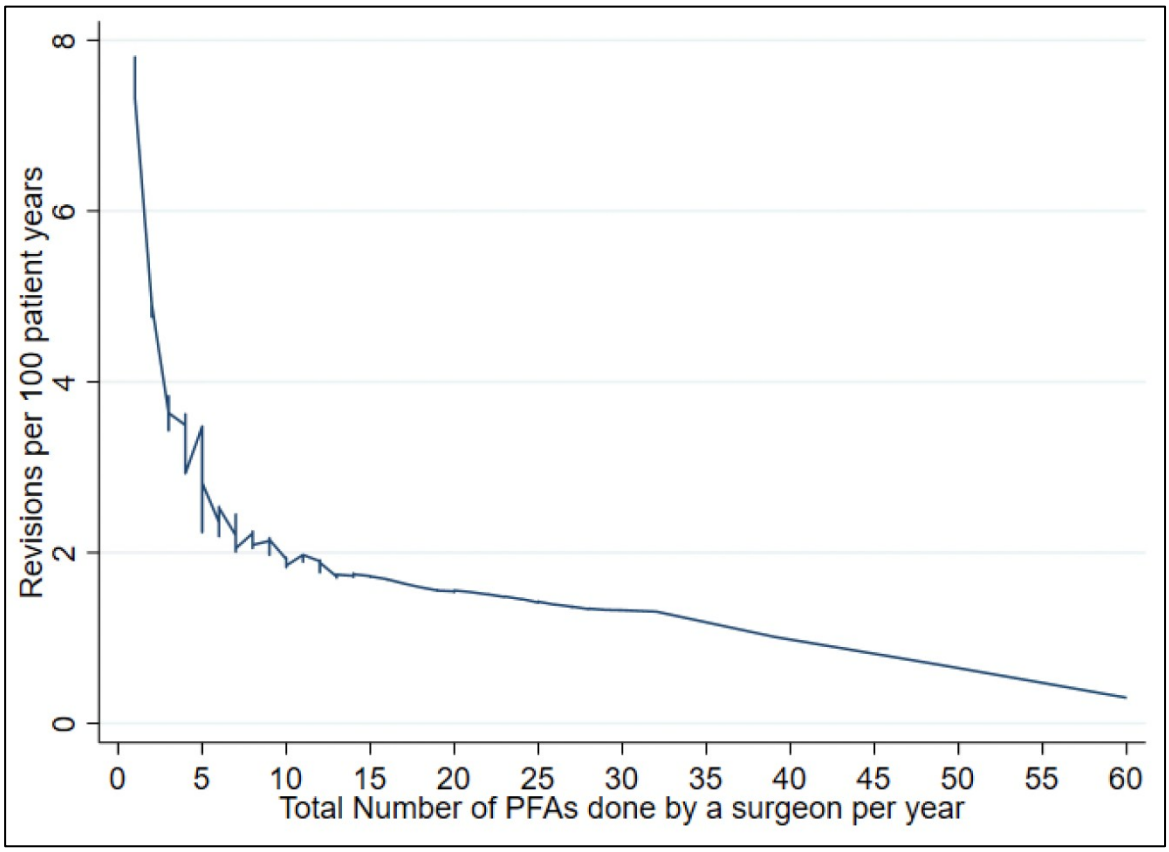


Figure 31. LOWESS plot showing a non-linear relationship between PTIR and a yearly caseload.

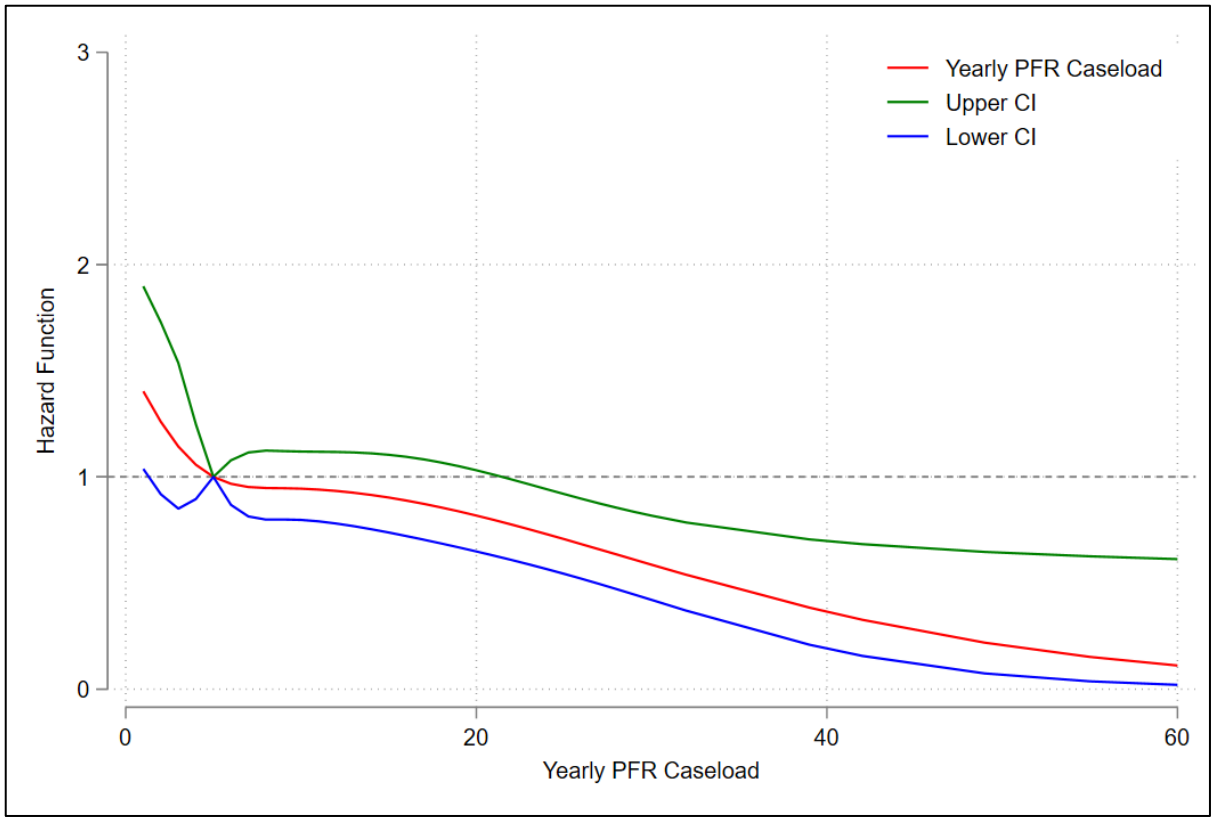


Figure 32. Hazard function vs yearly surgical experience.

Table 19. Hazard ratio for surgical revision in relation to different surgical volume groups.

Spline section	Hazard ratio	P– value	Confidence Interval
Low Volume 0-5 cases	**0.92**	**0.02**	**0.86, 0.99**
High Volume >= 5 cases	**0.98**	**0.01**	**0.97, 0.99**

4.3.1.1 Survival analysis of caseload effect

Unadjusted Kaplan-Meier curves for high and low-volume PFA were plotted and are presented in Figure 33. Gender, age and type of anaesthetic were the predictors found to influence survival and were included in the finalised model following backward selection. The decision was made using AIC and Cox-Snell residuals (

Appendix B).

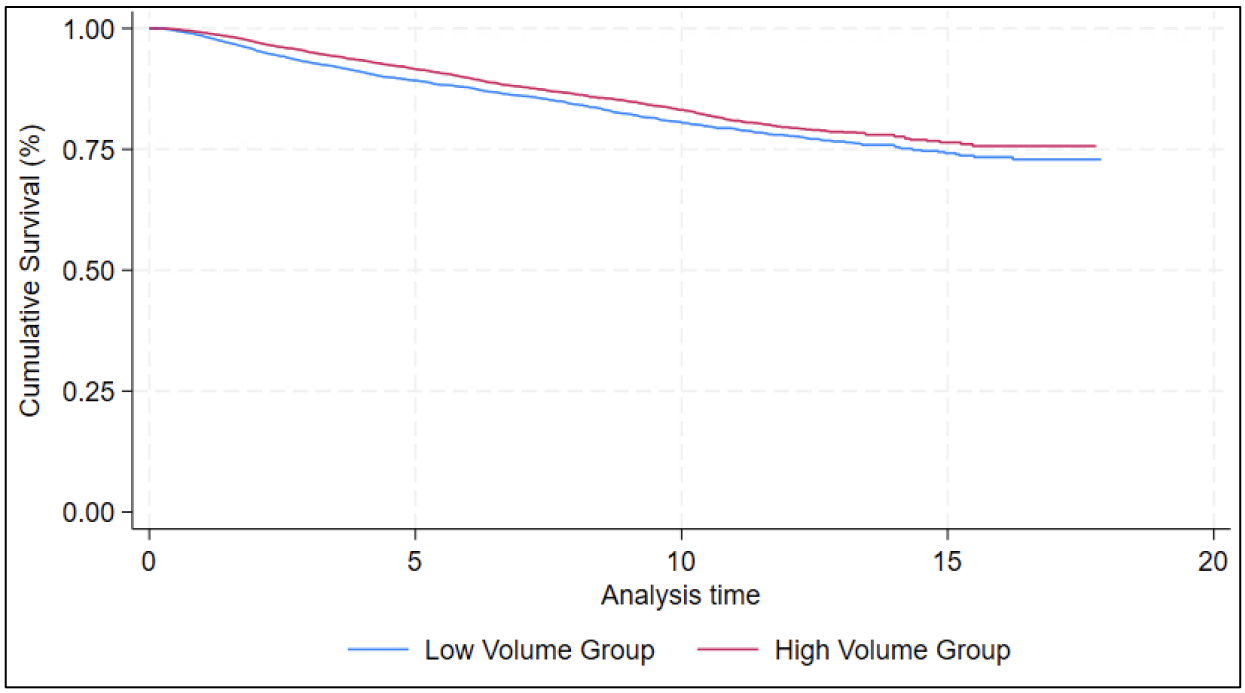


Figure 33. Survival hazards in two PFA volume groups (unadjusted for patient characteristics).

A flexible parametric survival model using restricted cubic splines was fitted to the finalised model following a review of proportional hazards using Schoenfeld residuals (

Appendix B). The overall survival with adjusted covariates is presented in the graph below.

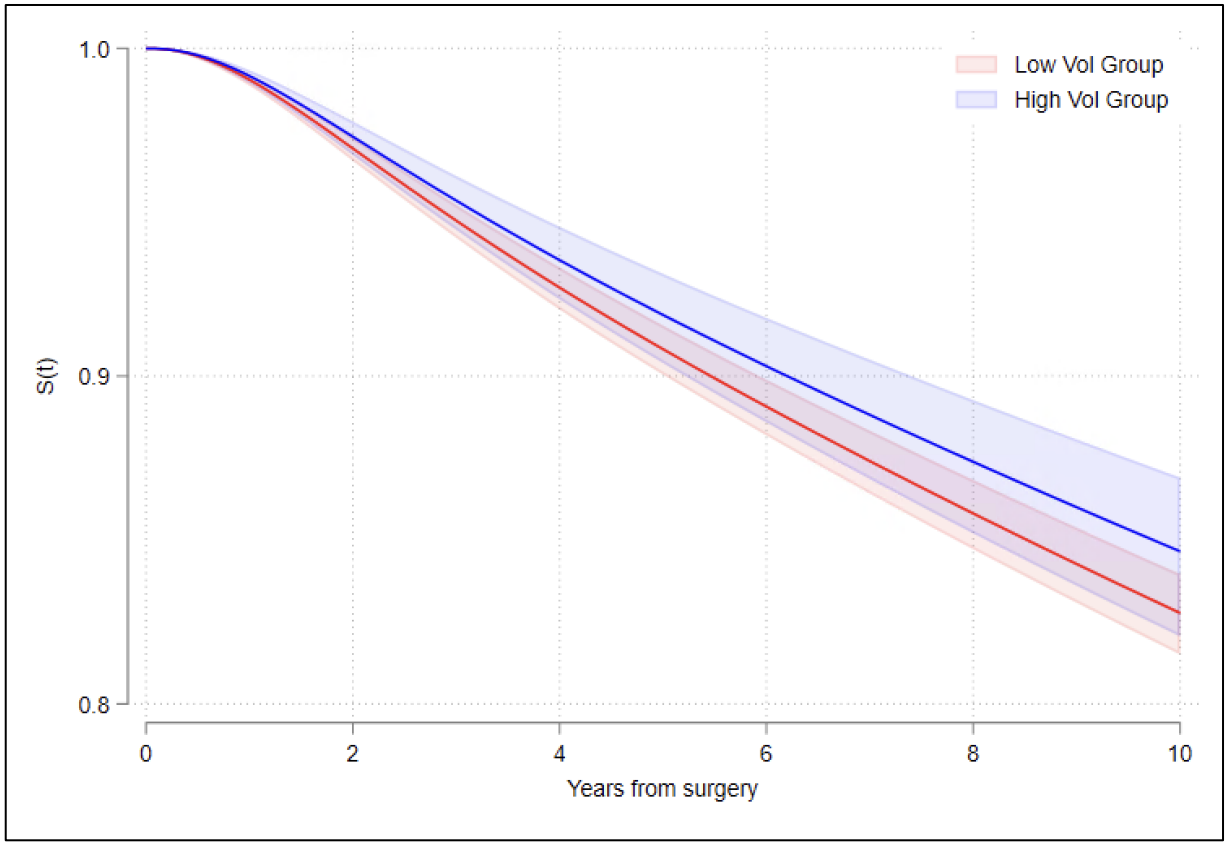


Figure 34. Survival hazards in two PFA volume groups adjusted for patient characteristics.

Patients operated on by higher-volume surgeons had a higher chance of survival (lower risk of revision) compared with lower-volume surgeons Figure 34. At 10 years, high-volume surgeons had a hazard of 1.69 (CI 1.53 – 1.87) per 100 person-years as compared to 2.00 (CI 1.81 – 2.21) per 100 person-years (Figure 35) .

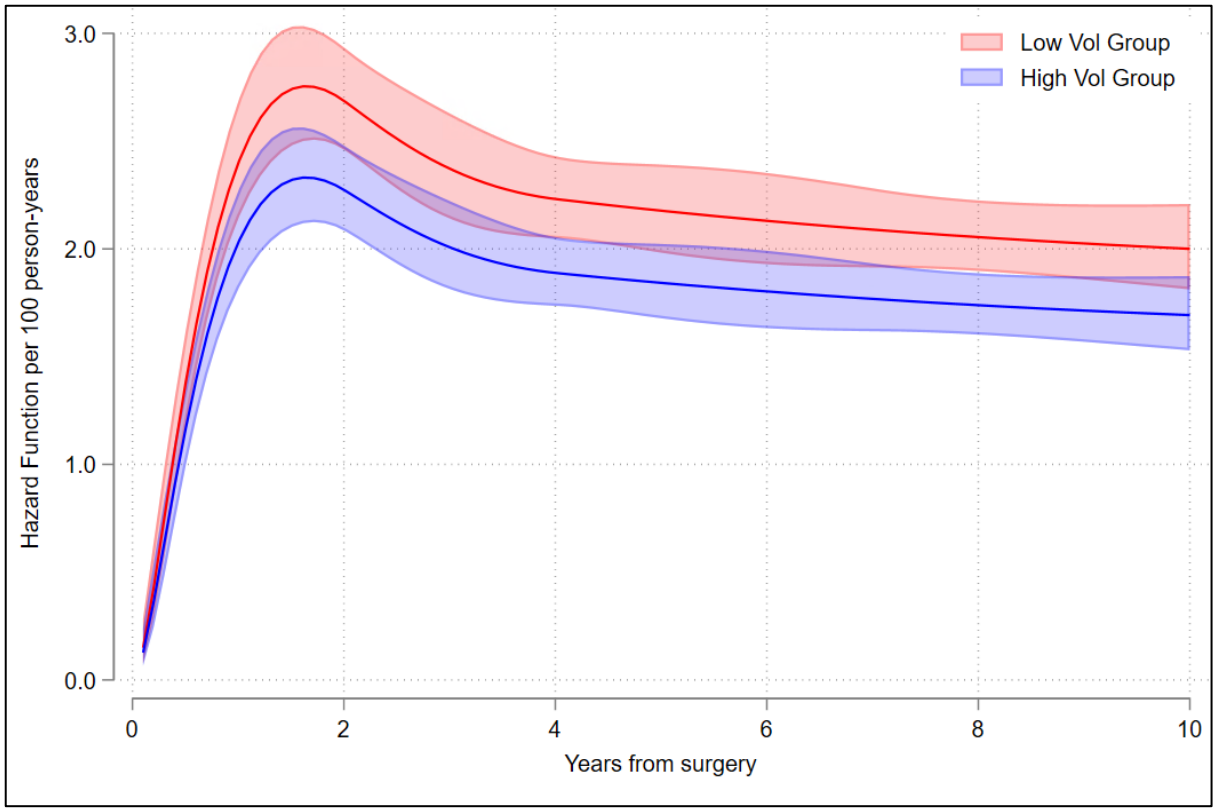


Figure 35. Caseload volume-specific hazard. Shown are revisions per person-years over a 10-year follow-up.

It can be seen in Figure 36 that 10-year revision probabilities decrease as surgical experience increases. Using the example of a surgeon with a yearly caseload of 60 patients, the revision probability is 8%, while a surgeon with an annual caseload of 2 has a revision probability of 20%.

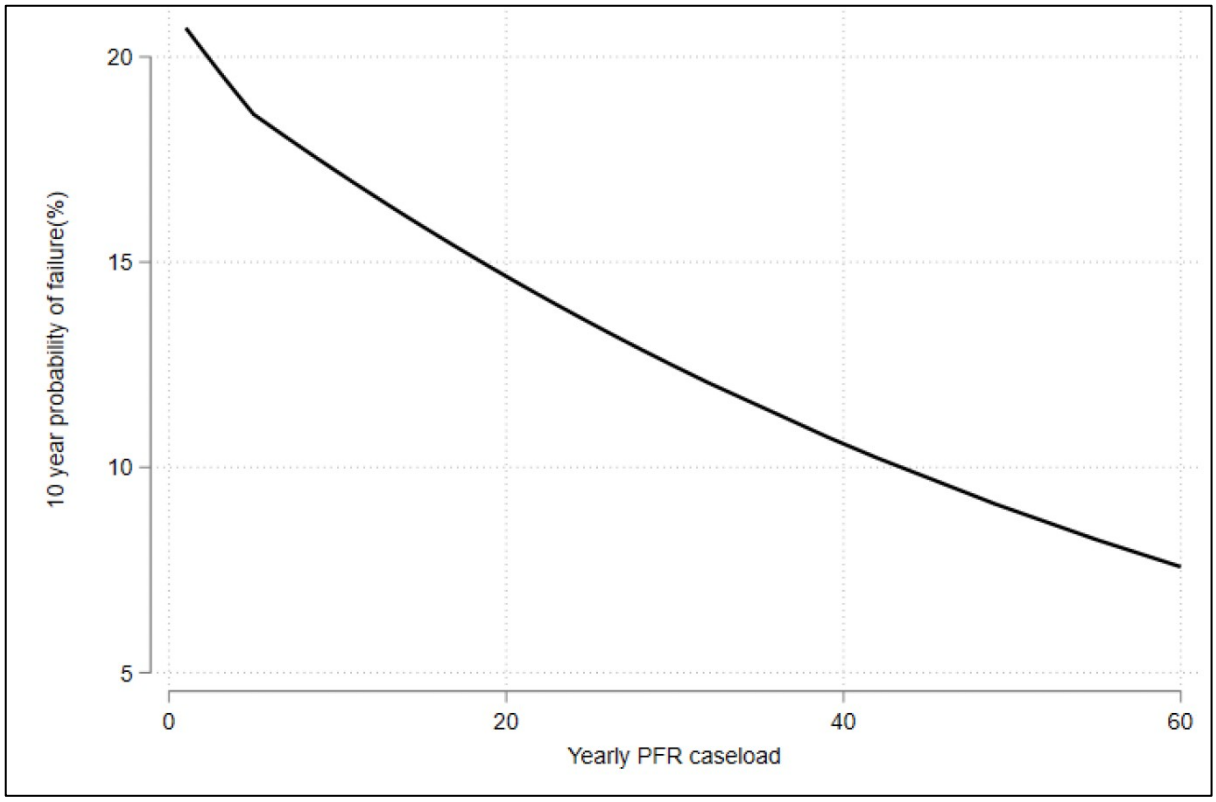


Figure 36. 10-year risk of revision as a function of yearly caseload.

5.3.1.2 Caseload effect on adverse outcomes

There was a lower risk of systemic complications among patients operated on by surgeons with a higher-case load of operations (OR 0.97, CI 0.95–0.99, P < 0.05). Surgical caseload did not affect the risk of developing complications, as seen from Table 20.

Table 20. Odds ratio of developing systemic or local complications as a function of surgical experience.

	Higher-volume surgeons Odds ratio (confidence intervals)	**Lower-volume surgeons** Odds ratio (confidence intervals)
Systemic complication	0.97 (0.95– 0.99) P = 0.02	0.97 (0.91 – 1.03) P= 0.31
Risk of local complications	1.01 (0.98– 1.04) P = 0.47	0.97 (0.87–1.09) P = 0.61

5.3.1.3 Analysis of patient factors

As a result of knot and spline fitting, Table 21 provides a descriptive summary of the differences in patient criteria between surgeons performing high and low surgical caseload.

Table 21. Patient selection characteristics as a function of high and low-volume surgeons.

Variable	Low Volume n = 6525	High Volume n=8090	p – Value
Patient age*	59.3 (11.4)	59.3 (11.8)	0.82
Yearly PFA caseload*	2.4 (1.1)	11.6 (8.8)	0.01
Gender			
Male	1038 (16)	1175 (22)	0.28
Female	3407 (84)	4063 (78)	
Type of anaesthetic			
General Anaesthetic	3610 (55)	4412 (55)	0.24
Regional Anaesthetic	2835 (55)	3604 (55)	
Modified CCI*	1.6 (2.9)	1.4 (2.7)	0.02
Provider			
NHS	3795 (58)	4213 (80)	0.01
Private	650 (42)	1025 (20)	

*Data are presented as mean (SD) for continuous measures and n (%) for categorical measures.

High and low-volume surgeons operated on similarly aged patients, with a mean age of 59.3. In order to explore differences between both volume groups in terms of the patient factors described in 4.2.1.3, the results following IPTW adjustment are found in the tables below (Table 22, Table 23, Figure 37).

Table 22. Inverse proportional treatment weighting – Pre-matching

Pre-matching	Mean in PFA	Mean in TKA	Standardised mean difference
Social deprivation	6.00	5.78	0.08
Provider	0.80	0.85	–0.14

Table 23. Inverse proportional treatment weighting, post–matching.

Post–matching	Mean in PFA	Mean in TKA	Standardised mean difference
Social deprivation	5.99	5.99	0.00
Provider	0.80	0.80	–0.00
Range of weights	1– 1	0.97 – 1.85	

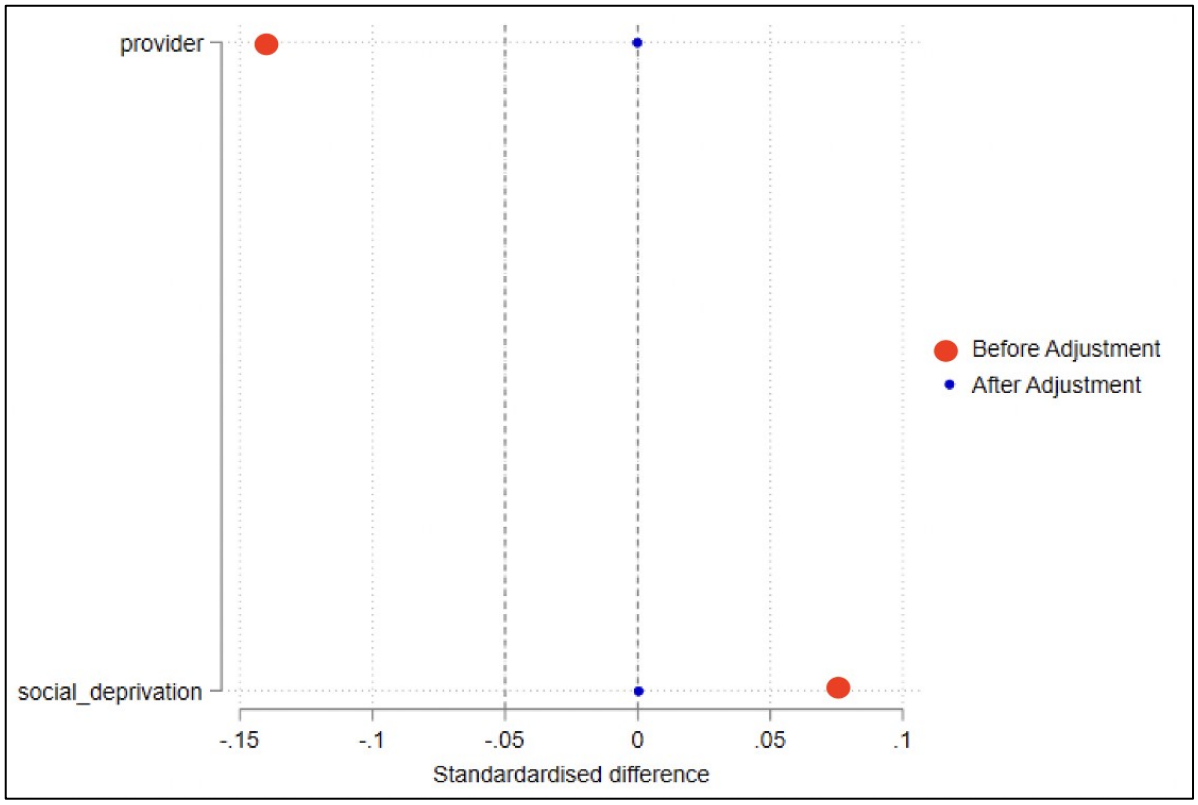


Figure 37 Graphical representation of inverse proportional treatment weighting

As seen from Figure 38, irrespective of the patient age, patients had a lower risk of revision when operated on by higher-volume surgeons.

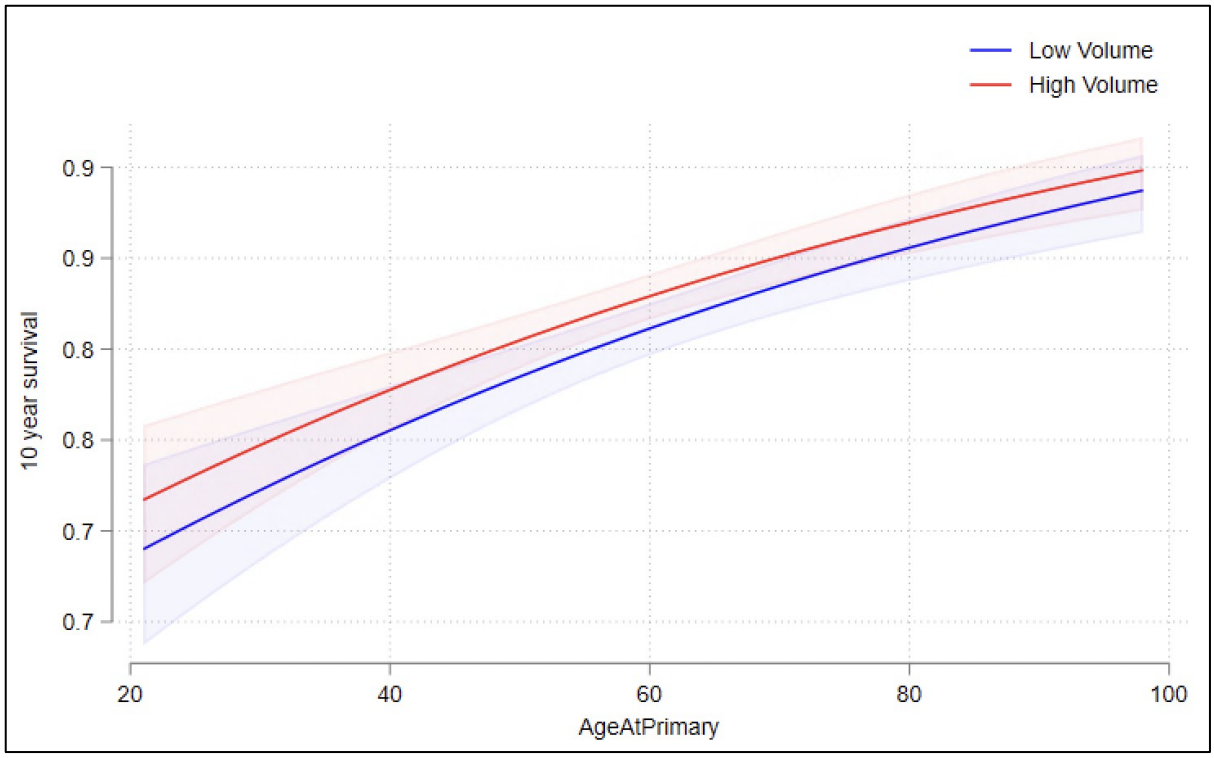


Figure 38. Patient age as a function of surgical experience.

Compared with low-volume surgeons, higher-volume surgeons operated on more obese patients (OR 1.35, CI 1.19 - 1.54, $P < 0.05$). Patients with higher-grade ASA were less likely to be operated on by high-volume surgeons (OR 0.88, CI 0.81-0.96, $P < 0.05$). Figure 39 shows that high-volume surgeons operate on healthier patients (ASA–1) 25% more often than lower-volume surgeons when surgical experience is left as a continuous variable, $P<0.05$, CI 0.23–0.25. When using the recalibrated CCI, there were no differences between volume groups.

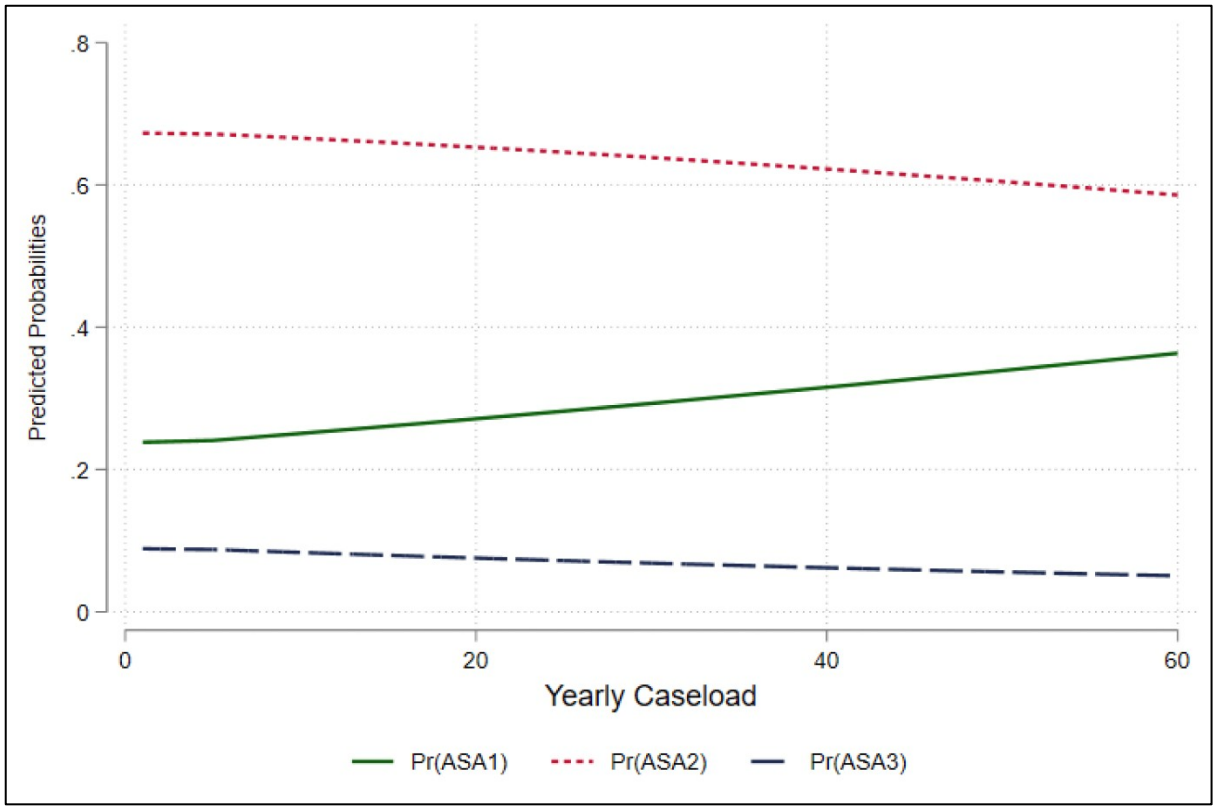


Figure 39. Predicted probabilities of patient comorbidity selection using the American Society of Anaesthesiologists (ASA) Physical Status Classification System, as a function of yearly patellofemoral replacement caseload.

Patients with a history of patella disorders were more likely to be operated on by surgeons with a higher-volume of surgical experience (OR 1.34, CI 1.09 - 1.77, $p< 0.05$), as were those who had previous patella dislocations (OR 1.82, CI 1.06 - 3.10, $p<0.05$).

5.3.1.4 Reasons for revision and surgical factors

As seen from Figure 40, the most common reason for revision was progressive arthritis regardless of the surgeon's surgical caseload experience.

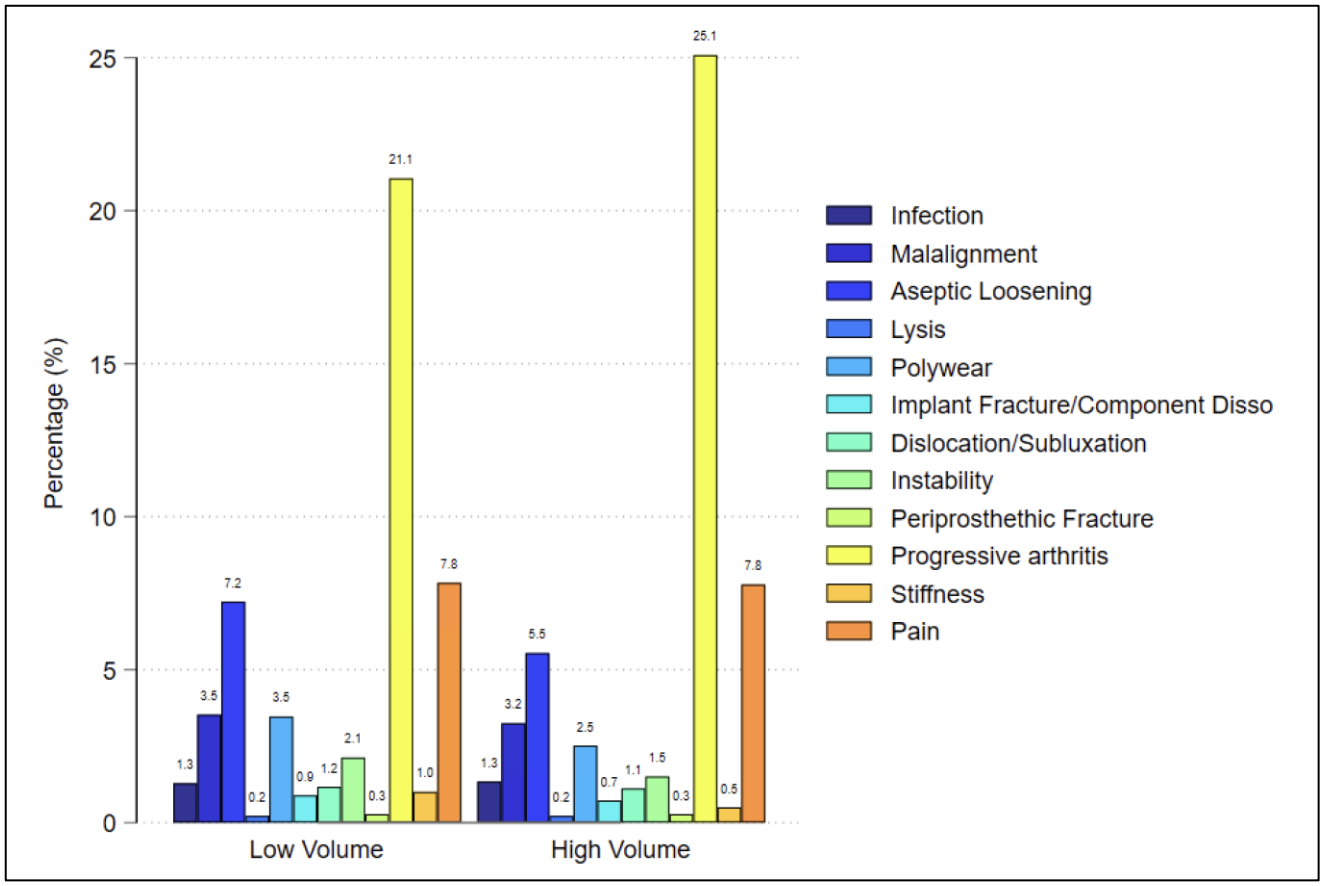


Figure 40. Reasons for revision in high and low-volume surgeon groups.

The Avon patellofemoral arthroplasty implant was the most commonly used implant by high-volume surgeons, as shown in Figure 41. Linear regression analysis revealed a positive correlation between implant number and volume group, with high-volume surgeons using more than one implant 0.54 (0.54 CI 0.44 – 0.66, P <0.05) times more frequently. It is more common to use two implants, as shown in Table 24.

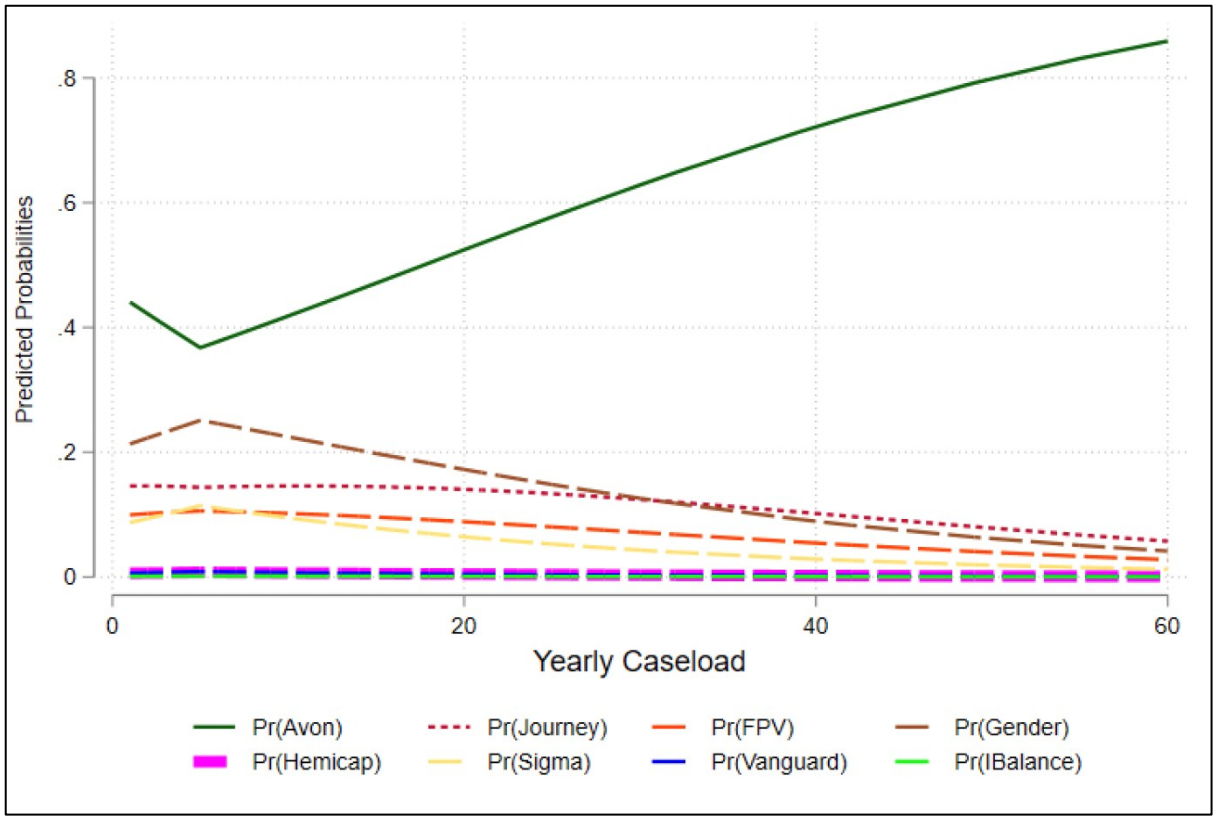


Figure 41. Predicted probabilities of implant choice as a function of yearly patellofemoral arthroplasty caseload

Table 24. Variation in implant usage as a function of case volume surgical group.

Number of different second-generation implants used during the study period	Low-volume surgeons n (%)	High-volume surgeons n (%)
1	370 (67.4)	80 (32.1)
2	141 (25.7)	114 (45.8)
3	26 (4.7)	40 (16.1)
4	11 (2.0)	13 (5.2)
5	1 (0.2)	2 (1.0)

5.4 Discussion

Summary of results

The study demonstrates a clear volume effect in patellofemoral arthroplasty, unsurprisingly similar to trends seen in TKA, UKR, and shoulder arthroplasty (139,235,236) . Surgeons performing fewer than five PFAs per year had worse outcomes, supporting the recommendation that a minimum threshold of five cases annually may be necessary to safely offer this procedure. High-volume surgeons were less likely to perform early revisions (within two years of surgery), and implant survival was improved in this group.

High-volume surgeons were associated with a lower incidence of systemic complications. While overall complication rates and reasons for revision did not significantly differ across volume groups. Surgeons with higher volumes used more implants and were less likely to undergo early revisions, defined as within two years of surgery.

Surgeons with higher caseloads were more selective in their patient population, operating more frequently on healthier individuals (lower ASA grades). In addition, high volume surgeons were more likely to be operating in the private sector, which this alone may introduce an element of selection bias, as it may attract far healthier individuals (237,238) . They were also more likely to identify patellofemoral-specific disorders, such as dislocations or patellar abnormalities, indicating a more refined diagnostic approach. Despite their selectivity, high-volume surgeons showed greater willingness to operate on obese patients, likely reflecting increased confidence and experience.

Determination of cut-off points

The LOWESS graph indicates that revision rates improve rapidly with increasing surgical volume up to approximately five cases per year, with a more gradual improvement observed beyond this threshold. Categorisation provides clinicians with a better understanding of the volume of experience they need. An alternative approach could have involved tracking the total number of cases handled by a surgeon throughout their entire practice, as suggested by Vickers et al. (239)**.** However, it was decided that tracking the number of cases per year would be more suitable for accounting for periods of a surgeon's absence, such as long-term sickness or sabbatical.

Application to practice

As the number of cases a surgeon performs per year increases, the risk of revision markedly decreases, particularly reducing the likelihood of early revision within the first two years. Surgeons offering this procedure should therefore have a strong understanding of patellofemoral pathology, including the management of patellofemoral instability. Early treatment of patellofemoral dislocations may help prevent progression to patellofemoral osteoarthritis, which has been reported in up to 25% of this patient cohort (43) . These findings further support the principle that rare and complex conditions are best managed in high-volume centres with specialist expertise, where greater experience may be associated with improved patient outcomes(240,241).

The literature has traditionally considered obesity to be a contraindication to patellofemoral joint arthroplasties, but this study demonstrates that high-volume surgeons will not exclude obese patients from this procedure(61). Regardless of surgical experience, progression of tibiofemoral osteoarthritis was the most common reason for revision. Identifying the cause of tibiofemoral osteoarthritis progression is important. Research has show that patients with trochlear dysplasia undergoing a PFA as the primary indication were least likely to demonstrate progression of tibiofemoral osteoarthritis(242) . Whilst, progression of osteoarthritis following PFA has shown that this commonly results from pre-existing bicompartmental osteoarthritis that progresses over time, however, other hypotheses such as increased postoperative activity levels has also been suggested (11,12,162)

Limitations and further work

Future research efforts should focus on continuing to evaluate the outcomes of patellofemoral joint arthroplasty. One limitation of this study is the lack of access to pre-operative and post-operative radiographs, which would have allowed confirmation of disease pattern and progression of osteoarthritis. Future research should aim to incorporate radiographic evaluation to better characterise patient selection and disease severity in patellofemoral joint arthroplasty. The surgical technique used must also be analysed to prevent problems such as patella maltracking, which is common after patellofemoral joint arthroplasty surgery (17). This will eliminate the bias that the revision could be due to poorly positioned implants.

To increase the usage of PFA surgeons, adequate training must be provided, primary care physicians should be encouraged to refer patients with such a condition, and patellofemoral joint dislocations should be addressed at a young age to avoid patellofemoral joint osteoarthritis.

Chapter 6. Comparison of patient-reported outcomes in patellofemoral joint arthroplasties compared with TKAs

Author Contribution, Funding, and Dissemination

I used the cleaned datasets and led the statistical analysis relating to patient-reported outcome measures. In addition, I led the interpretation of findings, and manuscript preparation.

Publications

Vella-Baldacchino M, Bottle A, Cobb J, Liddle AD. Patient-reported outcomes following patellofemoral and total knee replacement: an analysis of the 6-18 months postoperative period from the National Joint Registry. Acta Orthop. 2026 Jan 23;97:42-49. doi: 10.2340/17453674.2025.45115. PMID: 41575538; PMCID: PMC12829338.

Chapter 6. Comparison of patient-reported outcomes in patellofemoral joint arthroplasties compared with TKAs

6.1 Introduction

PROMs are a validated, patient-centered measure for assessing patient experience after surgery (243,244). There are a range of different PROMs, each with different characteristics, advantages and disadvantages. One important consideration is the ceiling effect, where the tool is less successful in differentiating between patients with the very best scores compares to those with the scores closer to the centre of the range (245). Harrison et al. (2023) gives a real-world example whereby the OKS is unable to differentiate between a patient who goes back to doing their shopping and gardening after knee arthroplasty and a patient who is able to go back to playing competitive tennis (110).

In addition, PROMs data completeness and follow-up remain important limitations in registry-based studies. Missing data may occur due to loss to follow-up, barriers to questionnaire completion, inequality in patient representation and lack of standardisation(246,247). The PROMs Working Group of the International Society of Arthroplasty Registries has proposed that PROM studies should aim for response rates greater than 60%, however in England, similar to other countries, long-term PROM follow-up rates have been reported to be approximately 37% which introduces an element of selection bias(246–248).

Previous studies have used PROMs to determine the probability for revision, defined as the

score from the patient-reported outcome measure at which the surgeon decides to revise the procedure (249). UKR, another type of partial knee replacement has been shown to have a lower clinical threshold for revision compared with a TKA, perhaps as revision of a TKA is more complicated than converting a UKR to a TKA (250,251). Some may question whether early scores are as representative as longer-term scores, such as at five-years, however, Rothwell et al. (2010) demonstrated that PROMs collected at six months were good predictors of subsequent revision, supporting the use of this time point for analysis(252).

In this study, the objective was to determine whether PROMs (EQ5D-3L and OKS) differs between the two interventions and compare the clinical probability for revision for both procedures.

6.2 Methods

6.2.1 Data sources

In Chapter 3, I described the steps taken to clean and link the data, for this study, combined datasets from NJR/HES/PROMs (2.4.3) were used. In this study PROMs submitted between six to eighteen months were used, since the majority of improvement occurs in the first six months after joint replacement surgery, with only minor improvement thereafter this resulted in 1,085 PFA and 339,364 TKA available for analysis (Figure 42) (253). As seen in the flowchart following removal of incomplete PROMs data, 3.2% of cases were excluded from the OKS analysis and 9.8% from the EQ5D-3L analysis, this allowed me to do a complete case analysis.

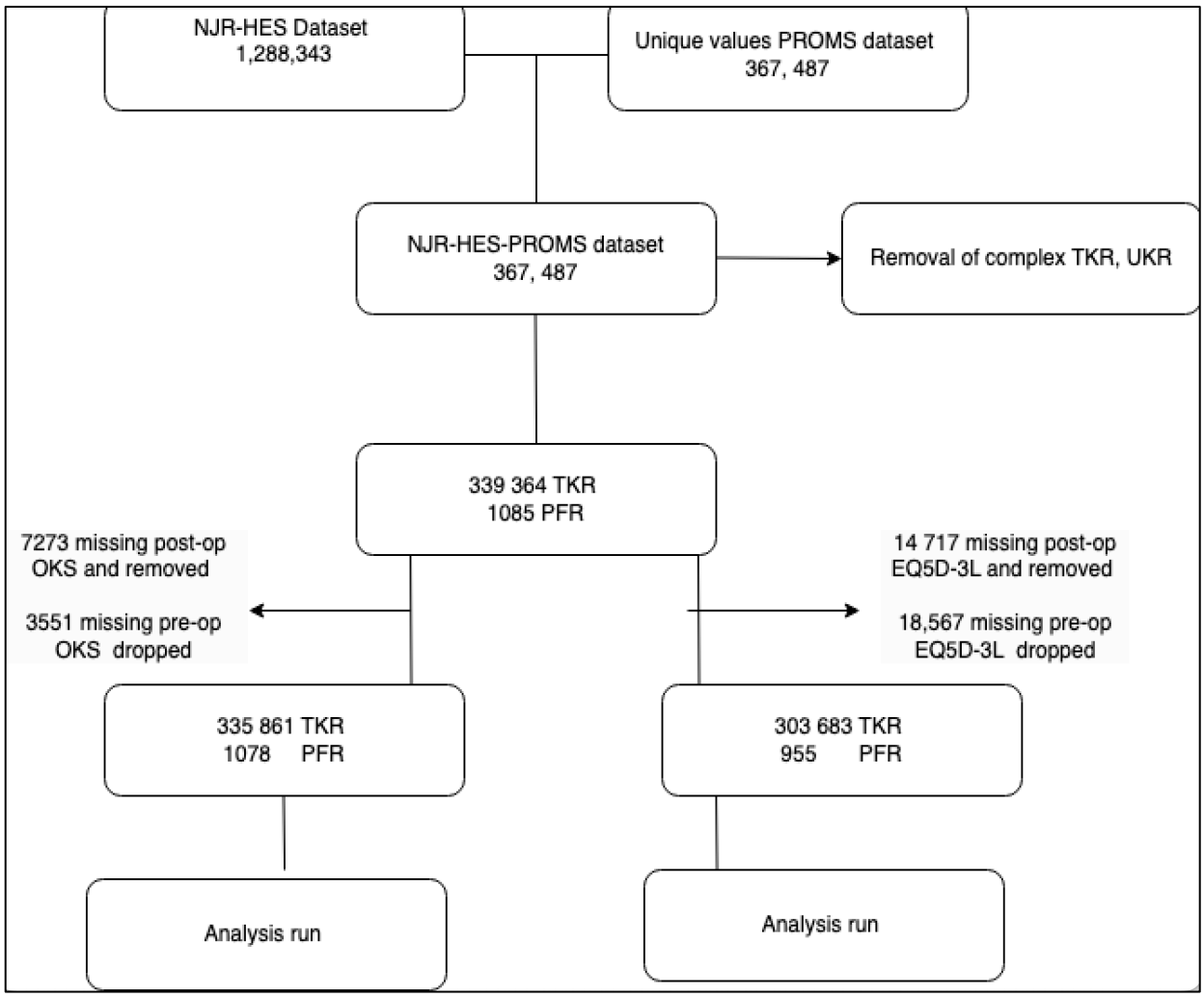


Figure 42. The total TKA and PFA implants available for analysis which are listed following removal of missing data.

6.2.2 Exposures

Patients undergoing primary PFA were compared to patients undergoing a primary TKA using inverse treatment probability treatment weighted methods. The analysis was limited to osteoarthritis as an indication, while arthroplasties with augmentations or stems (indicating

a complex deformity) were excluded from the analysis.

6.2.3 Outcomes

Two outcome measures were used: EQ5D-3L and OKS. The OKS variable was analysed in two ways, as a continuous variable and as a categorical variable. In the OKS, there are 12 questions, with an equally weighted score ranging from 0 to 4, with 4 being the best outcome (254). According to previously published research, questions 3, 5, 7 and 12 of OKS best reflect patellofemoral joint function, so these were assessed individually(255).

The UK version of the EQ5D-3L is a measure of health-related quality of life which generates a numerical score of 1 which is considered full health and 0 which equates to death(199). Negative scores are also possible, ranging from -0.594 to 0 which means worse than death. In its name, the '5D' system describes health states using five dimensions: mobility, self-care, usual activities, pain/discomfort, and anxiety/depression(200). Each dimension includes three levels of difficult, corresponding to no, moderate, and extreme problems in the pain/discomfort and anxiety/depression dimensions, as well as none, some, and inability to in mobility, usual activities, and self-care dimensions (200,201). As part of the analysis, the clinical probability for revising TKAs or PFAs based on the value of patient-reported outcome scores, using both EQ5D-3L and OKS, was compared (250).

6.2.4 Confounding factors

In this analysis, the following confounders were considered, gender, age, ASA physical status classification system, index of multiple deprivation, regional anaesthesia, provider (private or NHS), operating surgeon level (consultant vs non-consultant grade), CCI, and pre-operative

score (OKS or EQ5D-3L).

6.2.4.1 Statistical analysis

6.2.4.1.1 IPTW

Prior to analysis, PROMs data were restricted to submissions received within 18 months post-operatively, as the majority of improvement occurs in the first 6 months after arthroplasty surgery with only minor improvement thereafter (256). In my data, most records were submitted between 6-12 months plateauing at 18 months, therefore a decision was made to analyse all PROMS received up to the 18-month post-operative period (Appendix E). Following this, in the same manner as described in Section in 4.2.5.1, IPTW methods were used to adjust patients who had a PFA and TKA due to the confounding factors listed in Section 6.2.4. A comparison of the mean and SD of the weights was conducted to ensure that baseline covariates were distributed similarly between treatment and control. This was reported in both graphical and tabular form. A standardised difference over 10% was considered an indication of an imbalance in covariates between treatment and control (214). Following IPTW, a kernel density plot was plotted to illustrate the pre- and post-operative distribution of OKS and EQ5D-3L patients' reported outcome scores in TKA and PFA.

6.2.4.1.2 Categorisation of PROMs

Kalairajah et al. (2005) classified the OKS as excellent (>41), good (34 to 41), fair (27 to 33), and poor (<27), the same method of categorisation was used to compare both treatment groups (257). In this study, EQ5D-3L scores were categorised using Pareto analysis (201). Patients were categorised as better, worse, the same or non-comparable based on their scores.

A comparison was made between patients with excellent OKS scores and those with poor OKS scores, and those with better EQ5D-3L scores were compared to those with poor EQ5D-3L

scores, using the following grouping variables: age, pre-operative score, socioeconomic status, ethnicity, and type of volume surgeon. Continuous independent variables were assessed for a normal distribution using box plots and a T-test then followed. For categorical covariates, a Chi-squared test was performed.

6.2.4.1.3 Clinical probability for revision PFA versus TKA

A survival analysis was run to determine the likelihood of revision, which was defined in Section 6.2.3. Using the confounding factors listed in 6.2.4, backward selection was used to run Cox regressions with revision as the endpoint. The final model fit was evaluated using AIC (Appendix E). Schoenfeld residuals were used to assess proportional hazards, and time-varying coefficients were identified (Appendix E). A flexible parametric survival model was fitted using splines and degrees of freedom with the *stpm2* package within Stata (Statacorp, College Station, TX) factoring in the time-varying coefficients, which were OKS and procedure type (258,259). As a sensitivity analysis, the outputs of the parametric survival model were compared with the originally specified Cox model (215). Following this, a survival graph was plotted as a function of the 6-18-month patient-reported outcome score (OKS and EQ5D-3L) for both procedures.

6.2.4.1.4 Patellofemoral joint function

OKS questions 3, 5, 7 and 12 have been used in previous studies to represent patellofemoral joint function, therefore these questions were used to compare patellofemoral joint function between PFA and TKA (255). A mixed effects multilevel logistic model was run, with random intercepts for hospitals, to examine the relationship between pre-operative and post-operative scores for each question and determine whether there is a difference between PFAs and TKAs.

6.2.4.2 Results

6.2.4.2.1 IPTW results

Figure 43 and Table 25 illustrate the quality of confounder adjustment by IPTW for OKS.

A table of results of the EQ5D-3L IPTW adjustment is found in Table 26. The table illustrates the balance of covariates before and after IPTW for EQ5D-3L. and illustrated in Figure 44.

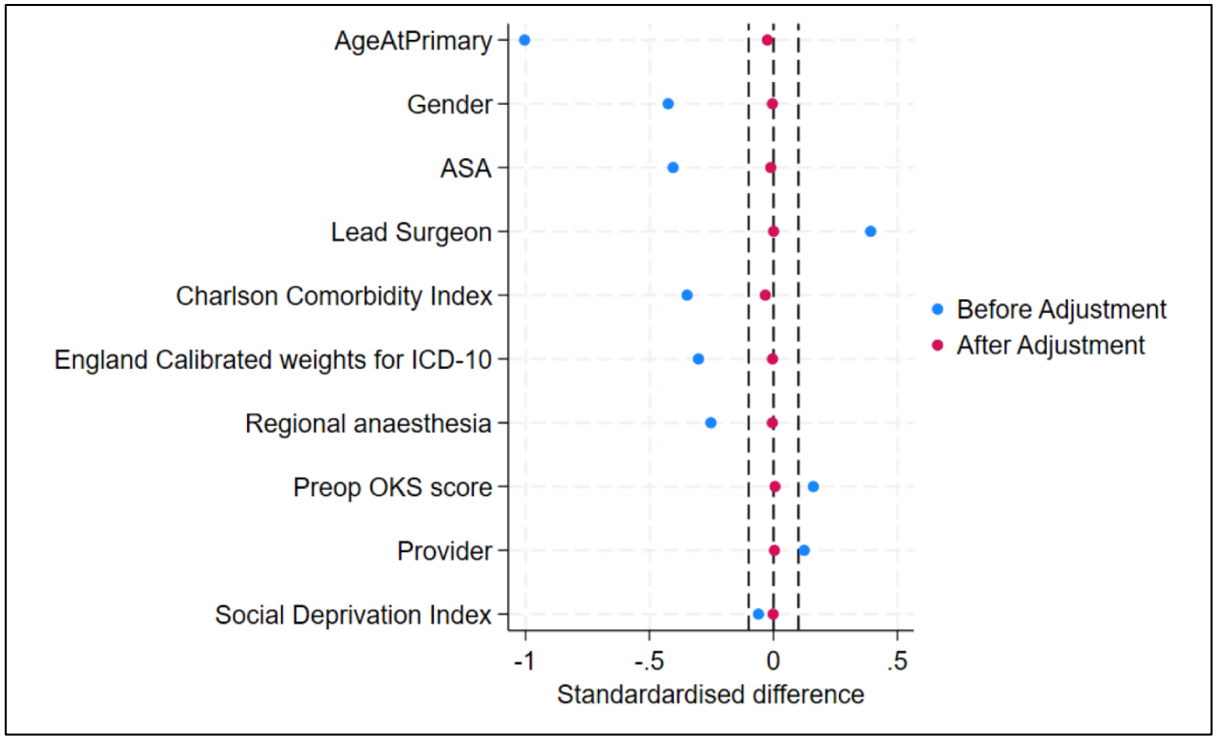


Figure 43. Graphical representation of inverse proportional treatment weighting – After adjustment (Oxford Knee Score – OKS)

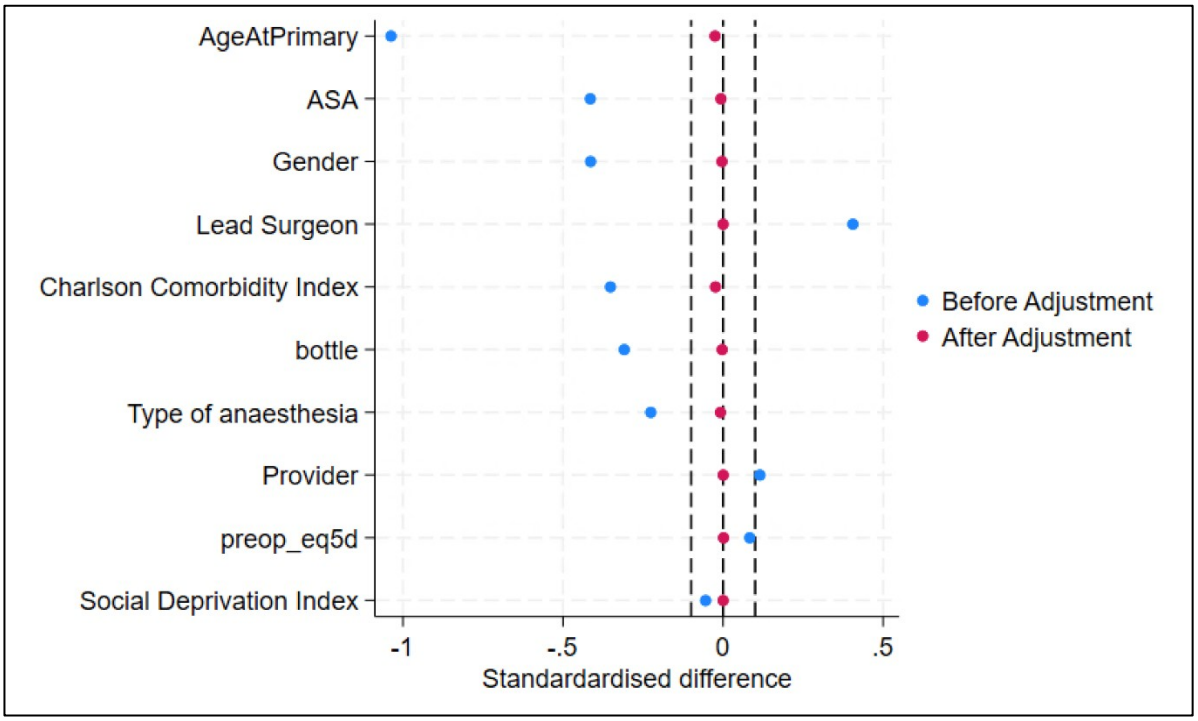


Figure 44. Graphical representation of inverse proportional treatment weighting – After adjustment (EQ5D-3L)

Table 25. The table illustrates the balance of covariates before and after IPTW for OKS.

	BEFORE ADJUSTMENT - OKS					**AFTER ADJUSTMENT - OKS**				
	TKA N= 333,369		PFA N=1063		Standardised mean difference	TKA N= 300,542		PFA N=944		Standardised mean difference
	Mean weight	Number and (%)	Mean weights	Number and (%)		Mean weight	Percent (%)	Mean weights	Percent (%)	
Pre-operative OKS	19.2		20.4		0.16	**20.4**		**20.4**		0.00
Patient age	70.4		59.9		-1.05	60.1		60		-0.02
Gender	0.43		0.23		-0.43	**0.23**		**0.23**		**-0.01**
Female		189, 077 (56)		817 (77)			38		39	
Male		144, 287 (43)		246 (23)			12		12	
ASA †	**2.08**		**1.90**		**-0.36**	**1.90**		**1.90**		**-0.01**
ASA-1		28,023 (8.4)		201 (19)			10		11	
ASA- 2		249,076 (75)		772 (73)			36		36	
ASA- 3		56, 270 (17)		90 (8.4)			5		5	
SDI	**3.39**		**3.31**		**-0.05**	**3.32**		**3.31**		**-0.01**
1st - Most deprived		42, 969 (14.2)		161(17)			8.4		8.6	
2nd		30, 741 (10.1)		88 (9.2)			4.7		4.7	
3rd		73, 816 (24.3)		215 (22.7)			11.3		11.4	
4th		79, 800 (26.3)		257 (27.2)			13		14	
5th - Least Deprived)		75, 622 (25)		225 (24)			12		12	
Regional anaesthesia	0.77		**0.68**		**-0.21**	**0.68**		**0.68**		**-0.00**

Regional anaesthesia		257,587 (77)		720 (68)			16		17	
Absence of regional anaesthesia		75,782 (23)		343 (32)			34		34	
Provider	**0.28**		**0.33**		**0.12**	**0.33**		**0.33**		**0.00**
NHS		243, 164 (73)		720 (68)			33.2		33.4	
Private		90, 161 (27)		342 (32)			17		17	
Lead surgeon	**0.81**		**0.94**		**0.41**	**0.94**		**0.94**		**0.00**
Consultant lead		269,189 (81)		64 (6)			47		47.4	
Non-consultant lead		64,180 (19)		999(94)			2.8		2.8	
CCI	**0.64**		**0.41**		**-0.32**	**0.43**		**0.41**		**-0.03**
None		173,808 (52)		710(67)			32.2		34	
Mild		114,542 (34)		282 (27)			15		13	
Moderate		32, 979(10)		54 (5)			3		3	
Severe		12,040 (4)		17 (2)			1		1	
Recalibration of the CCI with England-calibrated weights	2.44		1.55		-0.27	**1.56**		**1.55**		**-0.00**

Table 26. The table illustrates the balance of covariates before and after IPTW for EQ5D-3L.

	BEFORE ADJUSTMENT - EQ5D-3L					**AFTER ADJUSTMENT - EQ5D-3L**				
	TKA N= 336, 852		PFA N=1070		Standardised mean difference	TKA N= 303,683		PFA N= 955		Standardised mean difference
	Mean weight	Number and (%)	Mean weights	Number and (%)		Mean weight	Percent (%)	Mean weights	Percent (%)	
Pre-operative EQ5D-3L	0.61		0.63		0.07	0.63		0.63		0.00
Patient age	70.3		59.6		-1.08	60.0		60.0		-0.02
Gender	0.44		0.24		-0.42	**0.24**		**0.24**		**-0.01**
Female		170, 344 (51)		723 (68)			38		38	
Male		133, 334 (40)		232 (22)			12		12	
ASA †	**2.08**		**1.89**		**-0.37**	**1.89**		**1.89**		**-0.01**
ASA-1		25,831 (8)		185 (17)			10		10	
ASA- 2		226, 974 (67)		691 (65)			36		36	
ASA- 3		50, 878(15)		79 (7.3)			4		4	
SDI	**3.38**		**3.32**		**-0.05**	**3.33**		**3.32**		**-0.00**
1st - Most deprived		38, 817 (12)		143 (13)			8.3		8.5	
2nd		27, 900 (8.2)		79 (7)			4.5		4.5	
3rd		67, 144 (20)		192 (18)			11.3		11.4	
4th		73, 007 (22)		228 (21)			13		14	
5th - least deprived)		69, 186 (21)		205 (19)			12		12	
Regional anaesthesia	**0.78**		**0.69**		**-0.20**	**0.69**		**0.69**		**-0.00**

Regional anaesthesia		235, 114 (70)		659 (62)			15		15	
Absence of regional anaesthesia		68, 569(20)		296 (28)			35		35	
Provider	**0.28**		**0.34**		**0.12**	**0.34**		**0.34**		**0.00**
NHS		220, 796 (66)		645 (60)			33		33	
Private		82, 844 (24)		309 (29)			17		17	
Lead surgeon	**0.81**		**0.95**		**0.42**	**0.95**		**0.95**		**0.00**
Consultant lead		245, 518 (73)		900 (84)			47.1		47.6	
Non-consultant lead		58, 165 (17)		55 (5)			2.6		2.7	
CCI	**0.64**		**0.40**		**-0.34**	0.42		**0.40**		**-0.03**
None		158, 881 (47)		646 (60)			32.5		34	
Mild		104, 144 (31)		247 (23)			14		12.8	
Moderate		29, 804 (9)		49 (5)			2.4		2.6	
Severe		10, 854 (3)		13 (1)			0.5		0.7	
Recalibration of the CCI with England-calibrated weights	2.42		1.52		-0.30	1.52		**1.52**		**-0.00**

6.2.4.2.2 OKS analysis

Figure 45 shows the distribution of OKS in PFA and TKA pre- and post-operatively. The median post-operative OKS for PFA was 35, with a range of 1 to 48. TKA patients had a median post-operative OKS of 38, with a range of 0 to 48. There was a difference of –2.37 (CI -3.06 – -1.70, P <0.01).

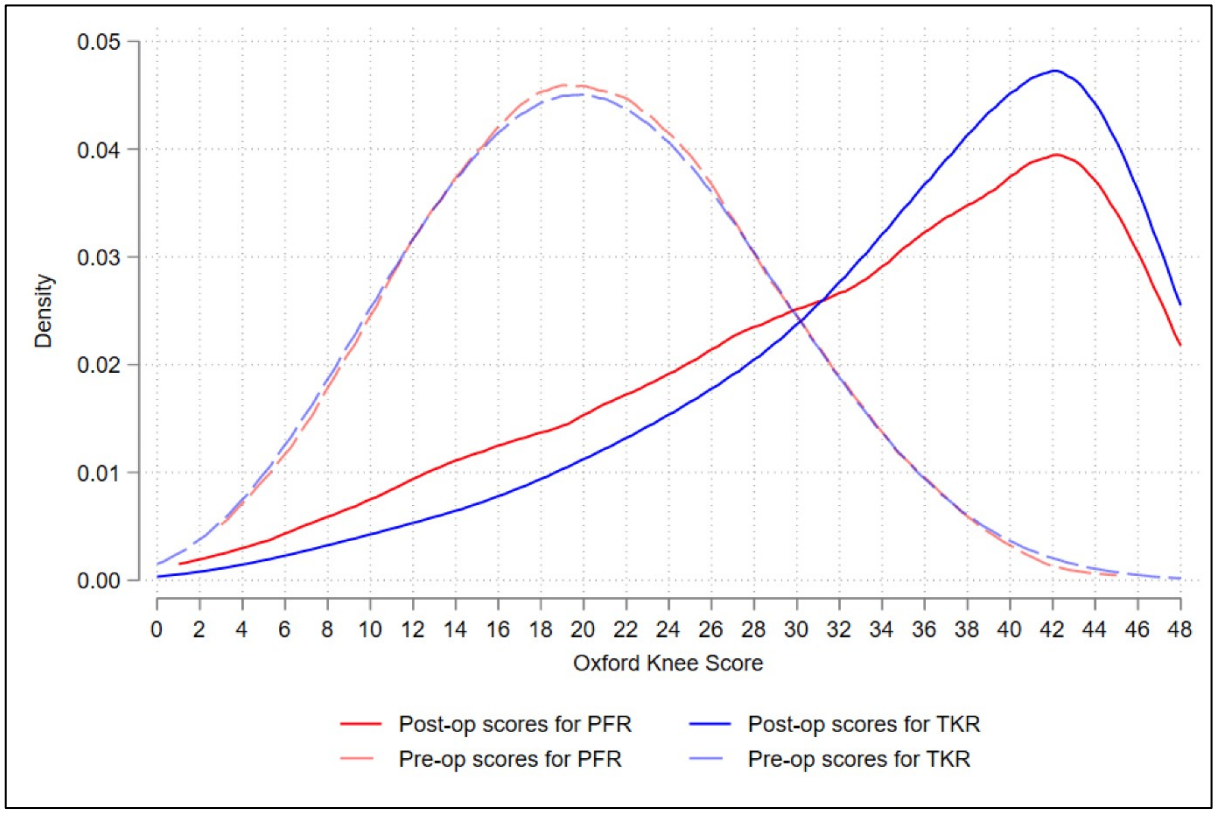


Figure 45. Kernel density plots of pre-operative and post-operative OKS for PFA and TKA. Fig 2a: Kernel density plots of pre-operative and post-operative OKS for PFA and TKA.

Based on the OKS categorisation as described in 5.2.4.1.2, TKA patients were more likely to achieve excellent scores, while PFA patients were more likely to achieve poor OKS scores, as shown in Table 27.

Table 27. OKS categorical outcomes analysed using logistical regression.

OKS subscale	TKA n (%)	PFA n (%)	OR (95% CI)	P-value
Excellent	103,339 (34.4)	267 (28.3)	0.76 (CI 0.66 – 0.88)	0.01 Favour TKA
Good	95,375 (32)	255 (27)	0.79 (CI 0.68 – 0.91)	0.01 Favour TKA
Fair	49, 754(17)	164 (17.3)	1.10 (CI 0.93 – 1.30)	0.28 No difference
Poor	52,074 (17)	258 (27.3)	1.76 (CI 1.52 – 2.04)	0.01 Favour PFA

To understand the differences in patient characteristics between patients who achieved excellent versus those who achieved poor scores in PFA patients, it was found that older patients had a higher probability of obtaining excellent scores than younger patients, 62 (60.7 - 63.3) versus 57.2 (56.0 - 59.0) p=0.05. In addition, patients who achieved excellent scores were more likely to have a higher pre-operative OKS 24.0 (23.0 - 25.0) compared with 16.0 (15.0 - 17.0) p = 0.01 and more likely to have a higher EQ5D-3L of 0.70 (0.68 - 0.72) compared with 0.51 (0.49-0.54). High-volume PFA surgeons were more likely to have patients who scored excellent compared with low-volume surgeons OR 1.9 (1.07 – 3.54), p= 0.03. There was no difference in terms of ethnicity.

6.2.4.2.3 EQ5D-3L analysis

The kernel density plots in Figure 46 illustrate the pre- and post-operative distribution of EQ5D-3L within PFA and TKA. The median post-operative EQ5D-3L for PFA was 0.77, with a range of 0.001 to 1. Meanwhile, the median post-operative EQ5D-3L for TKA was 0.80, with a range of –0.24 to 1. Using a regression, the difference between both procedures was –0.03 (CI -0.05 – -0.00, P <0.01).

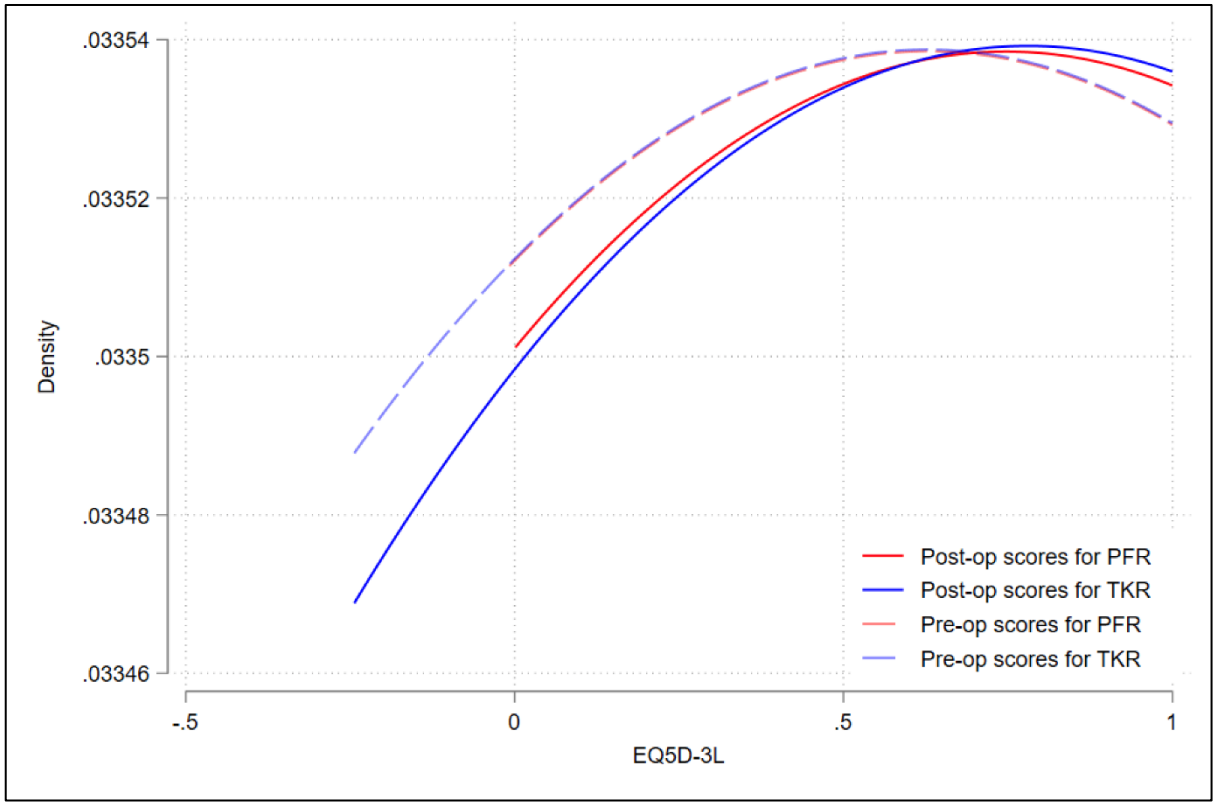


Figure 46. Kernel density plots of pre-operative and post-operative EQ5D-3L for PFA and TKA

As shown in Table 28 using the EQ5D-3L categorisation described in 5.2.3.1.2, TKA patients have a greater chance of receiving better scores than PFA patients.

Table 28. EQ5D-3L categorical outcomes analysed using logistical regression.

EQ5D-3L Pareto analysis	TKA n (%)	PFA n (%)	OR (95% CI)	P-value
Better	213,810 (78)	555 (66)	0.49 (0.37 –0.66)	0.01 Favour TKA
Worse	23,515 (8.5)	129 (15)	2.18 (1.51 – 3.16)	0.01 Favours PFA
No Change	25, 898 (9)	116 (14)	1.54 (1.02 – 2.33)	0.01 Favour PFA
Mixed Change	11,224 (4)	47 (6)	1.27 (0.66 – 2.42)	0.48 No difference

As with the OKS, those patients who achieved the best EQ5D-3L scores after a PFA operation were more likely to be older than those who reached the poorest results: 60.1 (59.2-61.0) versus 58 (55.8-60.0) p=0.04. Patients who achieved better scores were less likely to be deprived (p=0.01). Similar to the OKS findings, there were no differences in ethnicity and whether the surgeons were high-volume PFA surgeons or low-volume PFA surgeons.

6.2.4.2.4 Clinical probability of revision

Appendix E illustrates the process for selecting models for OKS and EQ5D-3L. In the final analysis, there was only one covariate that was found to significantly affect revision: the patient's age. When revision was adjusted for age at primary surgery, PFA operations were more likely to be revised at a lower patient-reported outcome score (OKS or EQ5D-3L), resulting in a higher hazard ratio, as seen in Table 29.

Table 29. Hazard ratios comparing PFAs to TKAs as a function of the patient-reported outcome score.

Outcome Score	Hazard ratio (95% Confidence Interval)	p-value
OKS	3.15 (95% CI 2.44–4.07)	p=0.01
EQ5D-3L	3.40 (95% CI 2.66–4.35)	P=0.01

Figure 47 and Figure 48 plot the 5-year survival as a function of OKS and EQ5D-3L, demonstrating that PFA patients were more likely to be revised regardless of the value of the patients' reported outcome score.

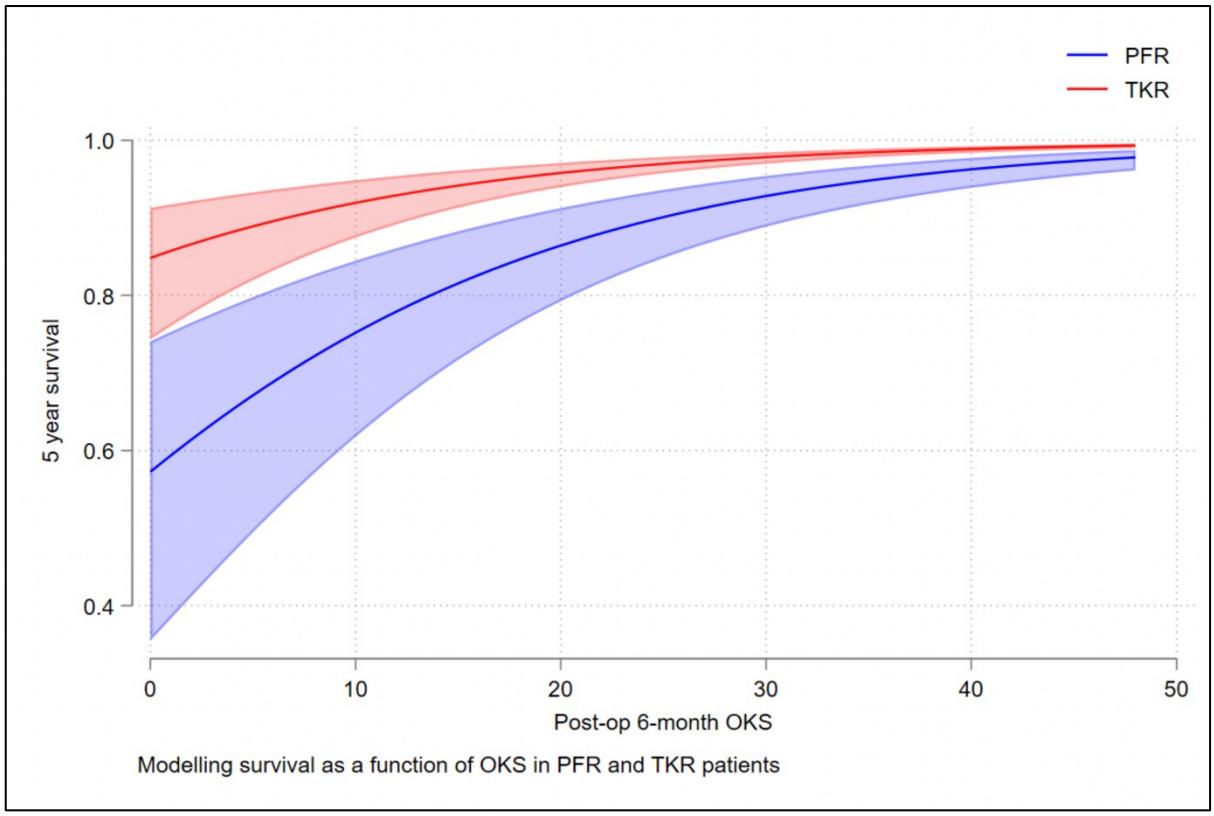


Figure 47. Probability of revision at 5 years as a function of OKS for both PFAs and TKAs.

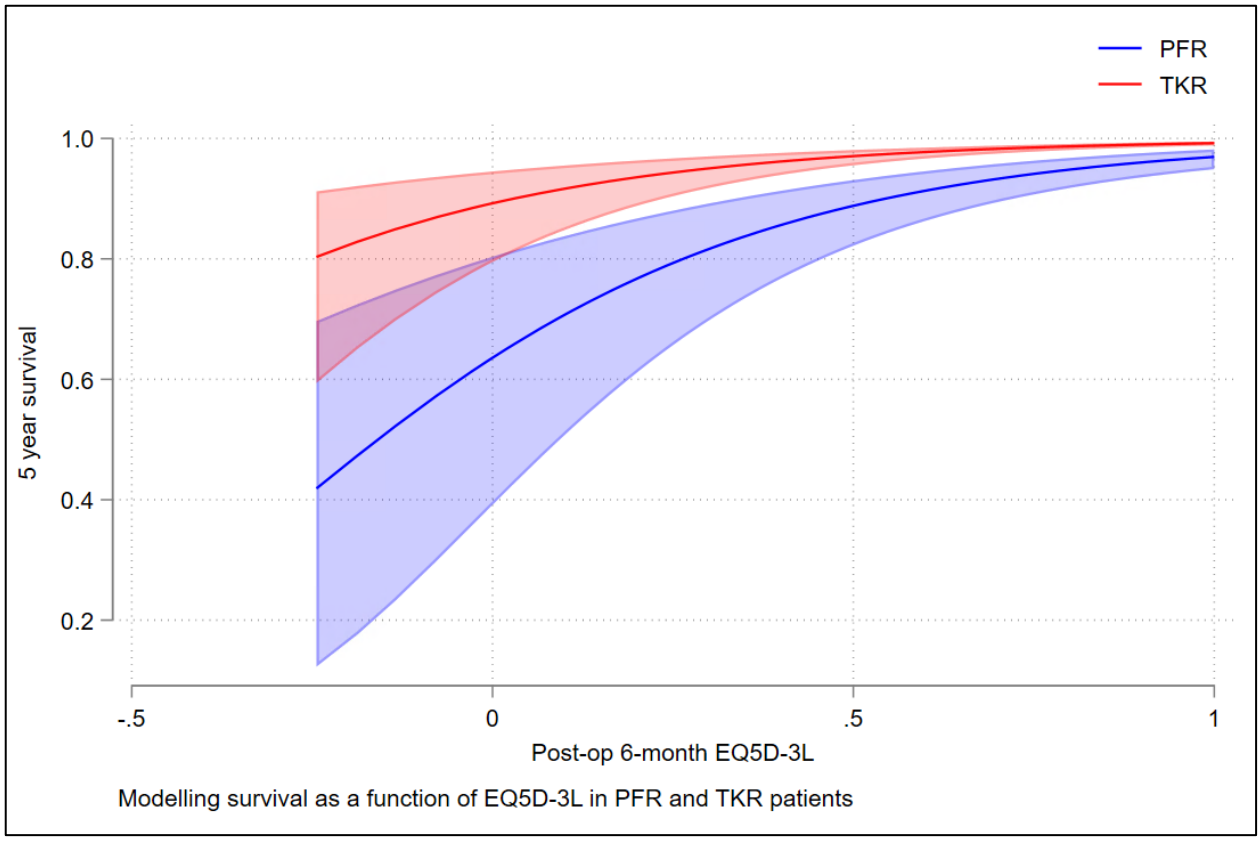


Figure 48. Probability of revision at 5 years as a function of EQ5D-3L for both PFAs and TKAs.

Across every category of patient-reported outcome, a PFA was more likely to be revised than a TKA with the same PROM score. This increased susceptibility to revision may reflect the fact that surgeons are generally more willing to revise a PFA than a TKA, as revision of a TKA is often technically more challenging and associated with higher surgical risk(260). In contrast, PFA is a less invasive primary procedure, and revision to TKA is typically straightforward, often allowing the use of standard primary components(159). This relative ease of conversion may lower the threshold for recommending revision in cases of persistent symptoms or unsatisfactory outcomes following PFA, similar to UKA(261,262).

6.2.4.2.5 Patellofemoral joint function

For each question representing patellofemoral joint function, a figure is presented showing the probability of scoring 0 (worst outcome) and 4 (best outcome) in the pre-operative period and post-operative period, for both PFA and TKA. Each figure is followed by a table presenting the numerical results. As seen from Figure 49- Figure 52, Table 30-Table 33, TKA patients were more likely to score a higher score (4) compared to PFA, with the strongest significant difference, of 11.4% for question 5, *"After a meal (sat at a table), how painful has it been for you to stand up from a chair because of your knee?"* For ease, the Table 34 provides a quick overview of the probability of achieving the best outcome (score 4) for all questions for both surgical procedures.

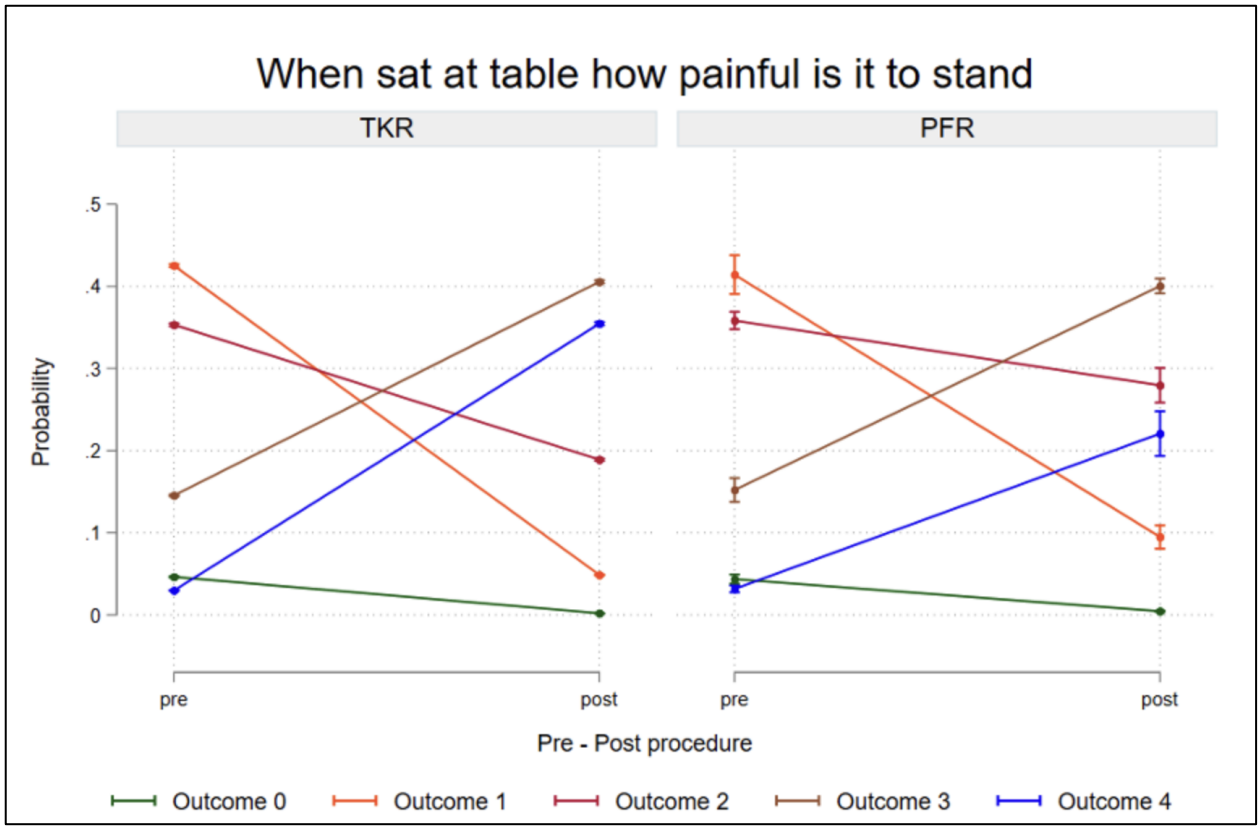


Figure 49. Graphical representation of probability scoring 0-4 for OKS question: After a meal (sat at a table), how painful has it been?

Table 30. Actual probability values of scoring 0-4 for OKS question: After a meal (sat at a table), how painful has it been?

After a meal (sat at a table), how painful has it been	Pre-op % TKA probability of scoring (CI)	Post-op % TKA probability of scoring (CI)	Pre-op % PFA probability of scoring (CI)	Post-op % PFA probability of scoring (CI)
Score 4	3.1 (3.0 – 3.1)	35.7 (35.6- 35.8)	3.2 (2.8 – 3.5)	24.3 (21.8 – 26.9)
Score 3	14.4 (14.3- 14.5)	40 (39.8 -40.1)	14.8 (13.6– 16.0)	40 (39.4- 40.5)
Score 2	35.2 (35.1- 35.4)	19.2 (19.0 – 19.3)	35.6 (34.6 – 36.5)	26.6 (24.8-28.5)
Score 1	43.1 (43 – 43.3)	5.0 (4.9 – 5.0)	42.5 (40.4 – 44.6)	8.7 (7.6 – 9.9)
Score 0	4.0 (4.0 – 4.2)	0.2 (0.2 – 0.2)	4.0 (3.5 – 4.3)	0.3 (0.3 – 0.4)

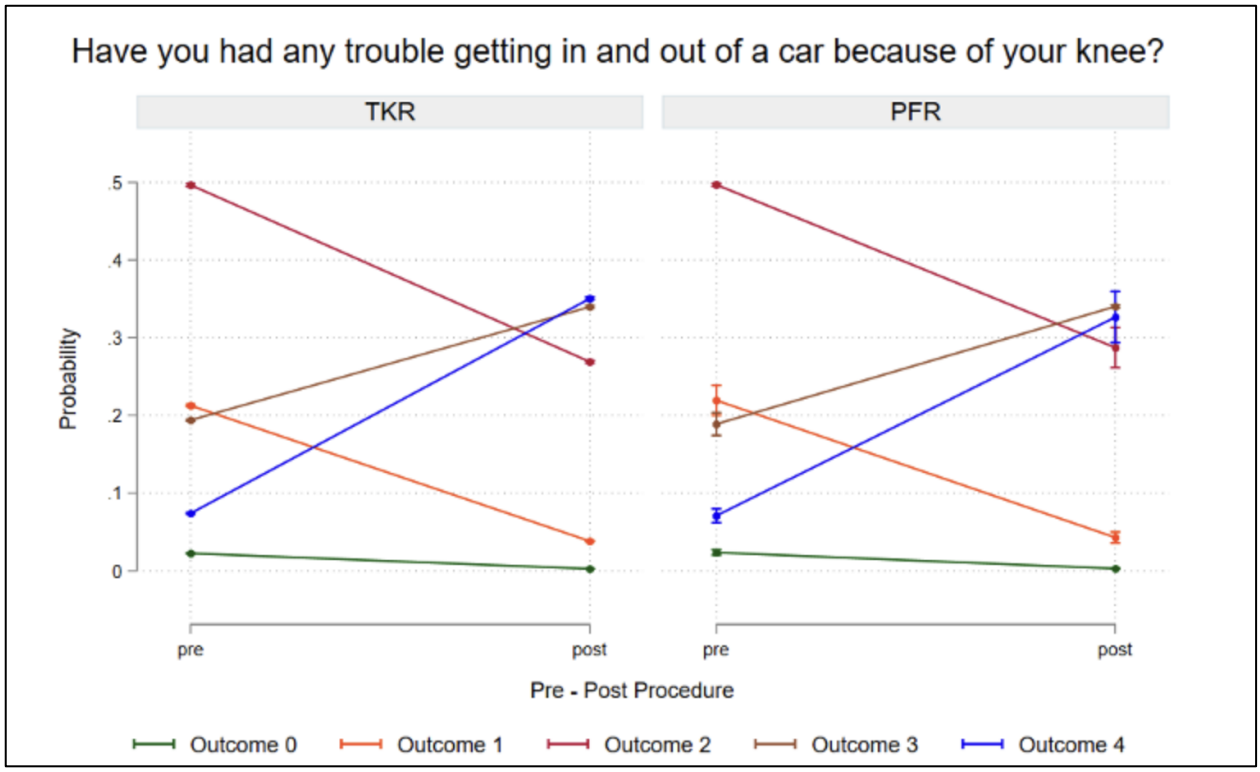


Figure 50. Graphical representation of probability scoring 0-4 for OKS question: Have you had any trouble getting in and out of a car or using public transport because of your knee?

Table 31. Actual probability values of scoring 0-4 for OKS question: Have you had any trouble getting in and out of a car or using public transport because of your knee?

Have you had any trouble getting in and out of a car or using public transport because of your knee?	Pre-op % TKA probability of scoring (CI)	Post-op % TKA probability of scoring (CI)	Pre-op % PFA probability of scoring (CI)	Post-op % PFA probability of scoring (CI)
Score 4	7.4 (7.4 - 7.5)	34.9 (34.8 – 35.1)	7.1 (6.4-8.0)	33.7 (30.8-36.6)
Score 3	19.2 (19.0-19.3)	33.6 (33.4 – 33.7)	18.7 (17.4-20.0)	33.6 (33.5 – 33.8)
Score 2	49.6 (49.5-49.8)	27.3 (27.1-27.4)	49.7 (49.5-50.0)	28.2 (26.0 – 30.4)
Score 1	22.2 (22.0-22.3)	4.0 (4.0-4.0)	22.8 (21.1-24.6)	4.2 (3.6 – 4.9)
Score 0	1.6 (1.6-1.7)	0.2 (0.2-0.2)	1.7 (1.5-1.9)	0.2 (0.2-0.2)

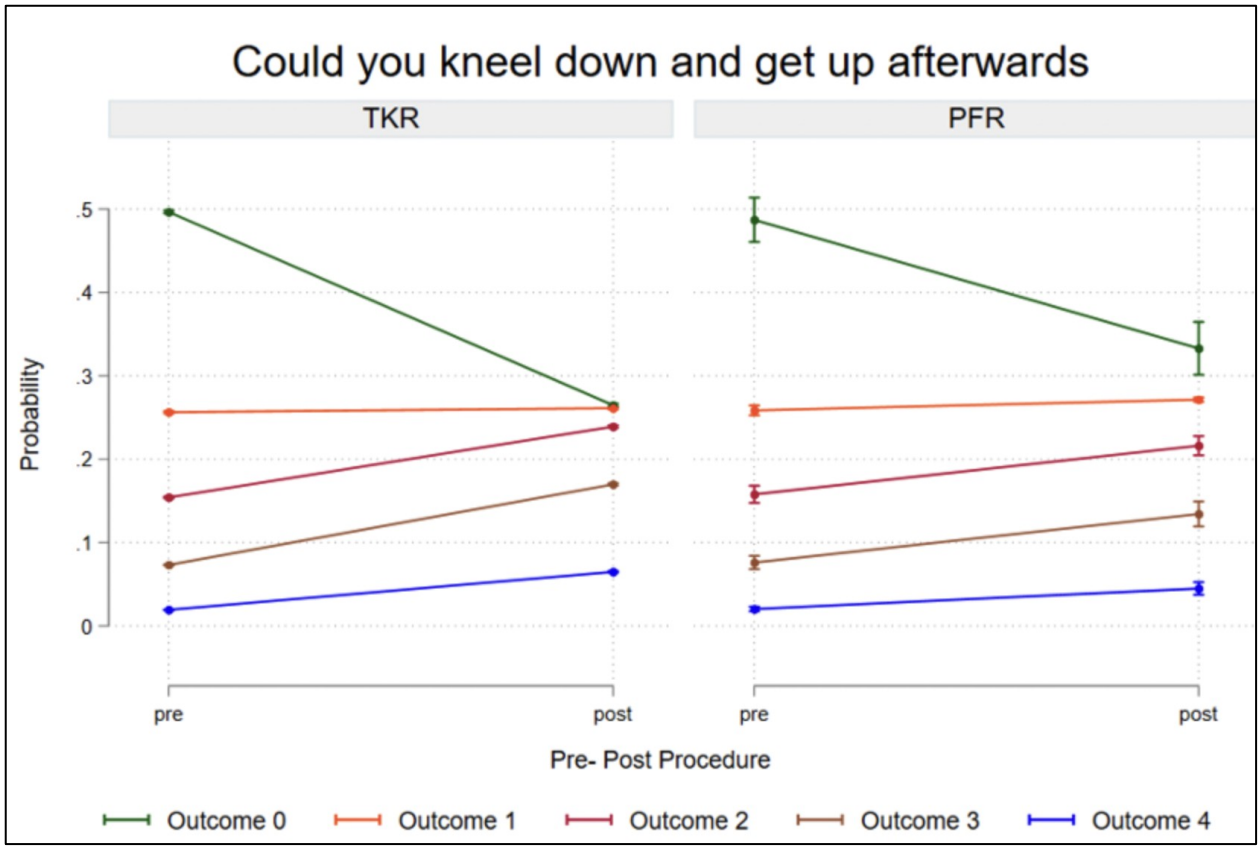


Figure 51. Graphical representation of probability scoring 0-4 for OKS question: Could you kneel down and get up again afterwards?

Table 32. Actual probability values of scoring 0-4 for the OKS question: Have you had any trouble getting in and out of a car or using public transport because of your knee?

Could you kneel down and get up again afterwards?	Pre-op % TKA probability of scoring (CI)	Post-op % TKA probability of scoring (CI)	Pre-op % PFA probability of scoring (CI)	Post-op % PFA probability of scoring (CI)
Score 4	2.0 (2.0-2.0)	6.4 (6.4-6.5)	2.2 (1.9-2.4)	5.0 (4.3-5.7)
Score 3	7.3 (7.2-7.3)	17.0 (17.0 – 17.0)	7.8 (7.2-8.5)	14.3 (13.0 – 16)
Score 2	15.4 (15.3-15.5)	23.9 (23.7-24.0)	16.2 (15.3-17.0)	22.3 (21.4-23.3)
Score 1	25.8 (25.7-25.9)	26.3 (26.2-26.4)	26.2 (25.7 – 26.7)	27.1(26.8-27.4)
Score 0	49.6 (49.5-50.0)	26.7 (26.5-26.9)	47.6 (45.4-50.0)	31.3 (28.6-34.0)

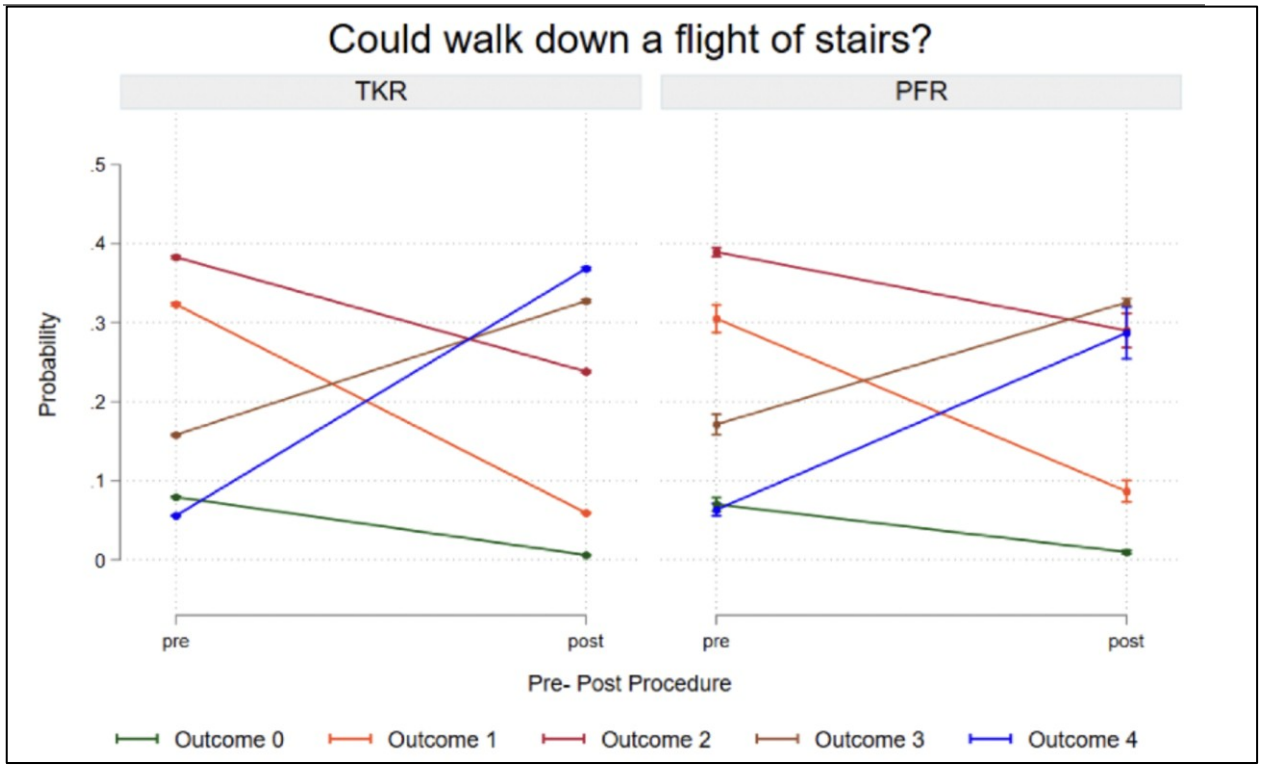


Figure 52. Graphical representation of probability scoring 0-4 for OKS question: Could you walk down one flight of stairs?

Table 33. Actual probability values of scoring 0-4 for OKS question: Could you walk down one flight of stairs?

Could you walk down one flight of stairs?	Pre-op % TKA probability of scoring (CI)	Post-op % TKA probability of scoring (CI)	Pre-op % PFA probability of scoring (CI)	Post-op % PFA probability of scoring (CI)
Score 4	5.7 (5.7 – 5.8)	36.6 (36.5- 37.0)	6.3 (5.6 – 7.0)	30.2 (27.4 – 33.1)
Score 3	15.7 (15.6 – 15.8)	32.3 (32.1 – 32.4)	16.7 (15.6– 17.8)	32.2 (31.9 32.5)
Score 2	38.1 (37.9 – 38.2)	24.2 (24.1 -24.4)	38.6 (38.0 - 39.1)	28.3 (26.4 – 30.1)
Score 1	33.0 (32.9 – 33.2)	6.3 (6.2 – 6.3)	31.6 (30.1 – 33.2)	8.4 (7.3 -9.6)
Score 0	7.5 (7.4-7.6)	0.6 (0.6 – 0.6)	6.8 (6.1-7.5)	8.6 (0.7-1.0)

Table 34. The likelihood percentage of scoring 4 points (maximum score) in question represents the function of the patellofemoral joint.

Likelihood of Scoring 4	PFA (%, 95% CI)	TKA (%, 95% CI)
After a meal (sat at a table), how painful has it been for you to stand up from a chair because of your knee?	24.3 (21.8 – 26.9)	35.7 (35.6- 35.8) p<0.01
Have you had any trouble getting in and out of a car or using public transport because of your knee?	33.7 (30.8-36.6)	34.9 (34.8 – 35.1) p <0.01
Could you kneel down and get up again afterwards?	5.0 (4.3-5.7)	6.4 (6.4-6.5) p <0.01
Could you walk down one flight of stairs?	30.2 (27.4 – 33.1)p <0.01	36.6 (36.5- 37.0)

6.3 Discussion

Summary of results

Overall for OKS, TKA patients had a difference of -2.37 (CI –3.0 – 1.7, P < 0.01) over PFA patients, favouring TKA over PFA. However, the minimal clinical difference is regarded as 5, meaning that although there was a statistical difference, this would not be considered to be clinically important (263). Similarly, for EQ5D-3L, the overall difference was -0.03 which falls below the minimal clinical difference of 0.085 (199). The scores for PFAs were generally lower than those for TKAs, it's important to recognise the limitations of interpreting these differences purely through categorisation. Although categorising continuous outcome data (e.g., dividing Oxford Knee Scores into bands like "excellent" or "poor") can help summarise trends, it significantly reduces the sensitivity of statistical tests, particularly when the underlying treatments only differ marginally. This loss of granularity can mask subtle but

clinically meaningful differences, and introduces greater reliance on assumptions about distribution and cut-off thresholds (264). Moreover, the distribution of OKS and EQ5D-3L are heavily skewed, with many patients reporting high scores and a long tail of poorer outcomes. In such cases, the mean is a poor measure of central tendency, as it is disproportionately influenced by outliers. Recognising this, median values were used in our analysis, providing a more robust representation of typical patient outcomes and improving the validity of comparisons between PFAs and TKAs. Even so, skewed distributions and categorisation should be acknowledged as important limitations when interpreting patient-reported outcome data.

The patients who scored poorly were typically younger, whereas those patients who scored well were often older. Knee arthroplasty surgery has evolved so that it is no longer just intended to eliminate pain, but also to fulfil the functional demands and expectations of the patient, which include returning to sports such as tennis, skiing, golf, jogging, and swimming (265,266). Researchers in a registry-based analysis of 8231 patients reported that 65-year-olds were more likely to be dissatisfied than 70 to 80-year-olds because the motivation to resume strenuous activity is inevitably higher in younger patients, and 52.3% of those who did not achieve the level of function they hoped for were dissatisfied (267).

For both EQ5D-3L and OKS, a PFA was more likely to be revised than a TKA with the same PROM score. Perhaps as surgeons are more likely to revise a partial knee replacement than a TKA, primarily because it is technically less challenging than revising a TKA, which is associated with less bone loss and rarely requires stems and augmentations. It is possible that the results are related to the simplicity of the PFA procedure, as described in several other studies (12,104,249,268).

Application to practice

The OKS was originally developed at a time when knee replacements were primarily performed in sedentary populations (269). As a result, it lacks the scope to accommodate either patients with complex comorbid conditions or those without such conditions. In the current generation of older adults, active life is expected to be a part of their daily routine, with older people over the age of 55 striving to improve their level of physical activity.

Research should focus on activity levels instead of solely on the OKS, as its precision decreases after 40, indicating a ceiling effect (270). It does not distinguish between, for example, people who go back to their shopping and those who play competitive tennis (110). OKS and EQ5D-3L show minimal differences, the data should be supplemented with results from other scores.

Limitations

EQ5D-3L and the OKS were this study's only PROMs which with a relatively short follow up of up to 18 months. Far fewer patient-reported outcome scores were available for PFA than for TKA. Some of these issues may be because some of the PFAs that were lost were done in the private sector, where it has been slower to introduce PROMs into routine clinical practice with a much lower response rate than in NHS England (271). In addition, this study used a complete case analysis approach. Previous literature has suggested that missing PROMs data are unlikely to be completely random, and no imputation method has been shown to adequately address this issue(272).

A number of joint arthroplasty registries routinely collect PROMs, but no such registries are linked to radiographic images. Although this limits their effectiveness in assessing outcomes,

they are useful for collecting a large amount of data that would not be possible in a randomised controlled trial, in fact, they have been used in several key studies on partial knee replacements (196,273,274).

Scott et al. (2021) have shown that the relationship between the pattern of osteoarthritis and severity and the resulting patient-reported outcomes is inconsistent. This raises an important question about the role of radiography in evaluating the post-operative outcome when comparing two surgical procedures in terms of patient-reported outcomes (275).

Chapter 7. Comparison of physical activity and step count in patellofemoral joint arthroplasties compared with TKAs – a randomised controlled trial

Author Contribution, Funding, and Dissemination

This study represents a long-term follow-up of a previously published randomised controlled trial initiated approximately 10 years ago. I contacted the senior author of the original trial, Professor Odgaard to develop this follow-up study assessing physical activity and objective functional outcomes . Together with Professor Odgaard, I prepared and submitted an addendum to the existing research protocol. The study was registered and approved by The Central Denmark Region Committees on Health Research Ethics, case number1-10-72-195-21 (M-20070025).

I independently sought funding for this work and won the ISAKOS New Clinical Researcher Grant. I coordinated patient recruitment and follow-up, contacting all Danish participants using an electronic communication platform called Krello to confirm their willingness to participate in the study. I organised the dataset and allocated patients to the different clinical centres. Julie Heegaard, a Danish PhD student, assisted with telephone follow-up for patients who did not respond to text messages. I organised international dispatch of the accelerometers from the United Kingdom via DHL. I then collected the devices whilst in Denmark at the participating centres, and collected the additional objective outcome measures presented in Chapter 8.

Publications

Vella-Baldacchino M, Heegaard J, Stephensen S, Rytter S, Wagner PK, Asghar Z, Liddle A, Cobb J, Odgaard A. *Equivocal physical activity outcomes 10 years after patellofemoral vs total knee replacement: Follow-up of a previously reported randomized controlled trial in isolated patellofemoral joint osteoarthritis*. Journal of ISAKOS. 2026;17:101037. https://doi.org/10.1016/j.jisako.2025.101037

Presentations

- Poster presentation: *Physical Activity Outcomes in Patellofemoral vs Total Knee Replacements: A Randomised Controlled Trial for Isolated Patellofemoral Joint Osteoarthritis* - ISAKOS Congress.
- Oral presentation at the European Knee Society (EKS) Congress - Awarded 3rd Prize in the “Best of the Best” section at EKS.

Chapter 7. Comparison of physical activity and step count in patellofemoral joint arthroplasties compared with TKAs – a randomised controlled trial

7.1 Introduction

As seen from Chapter 6, patient-reported outcomes for both procedures were equivocal in their findings. As discussed in Section 6.1, the OKS has a ceiling effect which renders it difficult to distinguish between very high and high functioning patients (110). The study by Odgaard et al (2018) remains one of the most important randomised controlled trials between PFA and TKA for isolated patellofemoral osteoarthritis. Odgaard et al. (2018) included 100 patients who reported outcomes at 2 and 6 years post-operatively(167,168). In the first six months, there were improvements from baseline for KOOS pain, SF-36 physical functioning, and OKS. However, in the long term, there was no difference in terms of patient-reported outcomes, length of stay, revisions, reoperations, or complications at 6 years.

As patient-reported outcomes often have ceiling effects, I decided to evaluate health outcomes using physical activity (245). Sedentary behaviour has been linked to poor health outcomes, and the World Health Assembly has adopted a global target to increase physical activity among adults (276–278). Activity intensity can be assessed with wrist-worn accelerometers (279,280).

This chapter aims to compare the physical activity performed by PFA and TKA patients at 10 years following the procedure and to determine which patients were more likely to adhere to the WHO Physical Activity 2020 guidelines using GENEActiv accelerometers(281).

7.2 Methods

All patients recruited from a blinded randomised controlled trial comparing PFA and TKA, who were operated on between June 2007 and October 2014, were contacted and invited back to estimate their total activity. As patients were recruited into the original randomised controlled trial over several years, follow-up duration at the time of reassessment ranged from 6 to 10 years postoperatively. Patients enrolled earlier in the trial therefore had longer follow-up compared with those recruited later. The study was performed in Denmark and registered and approved by the Central Denmark Region Committees on Health Research Ethics 1-10-72-195-21 (M-20070025).

Patients initially presented with debilitating symptoms of patellofemoral joint osteoarthritis, with isolated PFJ OA and preserved tibiofemoral joint, where conservative treatment had failed. Clinical examination indicated isolated PFJ OA, and radiographic examination, including tangential radiographs (no more than 30° of flexion) showed PFJ OA. The exclusion criteria have already been published here and are found below in Table 35 (167,168)

Table 35. Patient and knee-specific exclusion criteria.

Patient-specific conditions	Knee-specific conditions
• **Age younger than 18 years of age** • **Psychiatric conditions, including senile dementia** • **Not capable of understanding oral or written trial information** • **Alcohol or drug abuse** • **Disseminated malignant disease**	• Radiologic tibiofemoral osteoarthritis • More than 5° mal-alignment on clinical examination • Sagittal or coronal instability • Ongoing claim for workers compensation • Patella infera

• **Severe neurologic condition** • **Symptomatic hip or back condition** • **Rheumatoid arthritis** • **Employed in one of the participating orthopaedic departments** • **Non-Danish citizenship**	• Pronounced patella alta • Limited range of movement (extension deficit of >10°or flexion <90°) • Complex regional pain syndrome or arthrofibrosis in case of previous procedure

Participants who did not initially respond were approached through repeated telephone calls and mailed correspondence, in order to minimise loss to follow-up and ensure that all potential respondents were included.

7.2.1 Activity

The device was sent to the patients by postal mail set to pre-record on a set date and the participants were instructed to wear the device continuously for 7 days. GENEActiv Original (Activinsights, UK) devices were fitted on participants' non-dominant wrists, which were configured to record at 100Hz (282). During the testing period, patients were required to fill out a sleep diary to record their bedtime and wake-up time. The wrist-worn accelerometer was removed in the clinic and seen in Figure 53.



Figure 53. Photograph of GENEActiv Original (Activinsights, UK) device by the author of this thesis.

7.2.2 Data processing

The data which was collected as GENEActiv.bin files were analysed with GGIR R-Package (http://cran.r-project.org) (283,284)

Signal processing in GGIR includes the following steps: 1) autocalibration using local gravity as a reference; 2) detection of sustained abnormally high values; 3) detection of non-wear, and 4) calculation of the average magnitude of dynamic acceleration, i.e., the vector magnitude of acceleration corrected for gravity (Euclidean norm minus 1g- ENMO) for 5-s epochs (284). ENMO is a way of measuring physical activity using accelerometers. It combines movement from all three axes into a single value (284).

The detection of non-wear has been described in van Hees et al. (2013) previous publication, defined as periods of ≥60 min where the SD of acceleration in each of the three axes was <13 mg (283,285). Files were excluded from all analyses if the post-calibration error was greater than 0.02g or fewer than 16 h of wear time was recorded by either monitor during the 24 hr day of interest (284)

The Hillebrand et al. (2014, 2017) study defined inactive, light, moderate, and vigorous activity thresholds as follows: inactive as accelerometer values below 45.7 milligravity (mg), light 45.8-93.1 mg, moderate 93.2-418.2 mg, and vigorous activity above 418.3 mg (286,287). A graphical display of how the data looked for a single day may be found in Appendix F.

7.2.3 Statistical analyses

In the absence of other comparable GENEActiv accelerometer arthroplasty studies, using a

previously published study time at evaluating inactive time which found that 83% of TKA patients participate in sedentary activities (288). We hypothesised that 83% of TKA patients spend their time inactive. We further hypothesised that PFA patients would demonstrate a 10% reduction in inactive time compared to TKA patients. Sample size was calculated based on this assumption with a power of 0.8 and a significance level of 0.05 (288). A total of 22 participants with 11 in each group were required.

In both procedures, descriptive statistics (mean ± SD) were calculated. For both procedures, the total duration of inactivity, light activity, moderate activity, and vigorous activity were compared. Additionally, both groups were compared in terms of total physical activity and step count.

Statistical analysis was conducted on the distributions of each physical activity category, and transformation was attempted if the distributions did not follow a normal distribution.
The Kruskal-Wallis test was performed if non-normally distributed data persisted after transformation (Appendix F). Patients in both categories were assessed if they met World Health Organisation (WHO) 2020 physical activity guidelines, which specify that adults up to 64 years of age should do 150–300 minutes of moderately intense aerobic activity or 75–150 minutes of vigorously intense aerobic activity (278). People older than 65 should engage in moderate or vigorous physical activity at least three days a week (278). All analyses were performed using Stata statistical software version 18.0 (StataCorp LLC) (175).

As a sensitivity analysis, I compared PROMs pre-operatively and at the 10-year postoperative follow-up, between treatment groups. This was performed to assess the robustness of the primary findings and determine whether differences observed in physical activity levels were

similarly reflected in PROMs over long-term follow-up. In addition, I compared the PROMs and activity levels of participants included in the study with those who were contactable but declined to come to the visiting Centre to have their data recorded. This was undertaken to assess for potential selection bias, specifically whether more active patients were disproportionately represented within the study cohort, thereby strengthening the validity of the findings.

7.3 Results

The study participants included 30 patients, 17 of whom had PFA and 13 had TKA. Table 36 describes the patient characteristics of the study participants, while Table 37 summarises the amount and type of physical activity by each procedure, including the number of steps taken.

PFA patients did more minutes of total physical activity compared to TKA patients, with a total of 1,154 minutes in a week compared with 1,132 minutes, although there was no significant difference, p=0.89 (Figure 54). PFA patients were more likely to have a higher step count than TKA patients, 40,315.8 compared to 36,986.4, but there was no significant difference, p= 0.75 (Figure 55). There was no significant difference in the duration of inactive, light activity, moderate activity, and vigorous activity performed by both groups of patients ($p>0.05$) over a one-week period (Figure 56). The mean day ENMO acceleration over a one-week period was similar between both groups, and there was no statistical significance (Table 38). PFA and TKA patients all met the WHO physical activity guidelines as defined in the methods section, regardless of whether they were under 64 or over 65.

Table 36. Baseline patient characteristics of study participants. Data are presented as mean for continuous measures (SD) and n (%) for categorical measures.

	PFA (n=17)	TKA (n=13)	p-value
Age	75.2 (7.8)	74.2 (10.6)	P > 0.05
Gender **Female**	13 (76)	10 (77)	P > 0.05
Male	4 (24)	3 (23)	
Body Mass Index (kg/m^2)	28.1 (4.8)	27.8 (4.2)	P > 0.05
Charlson Comorbidity Index	3.6 (1.5)	3.8 (1.5)	P > 0.05

*Table 37. Summary of results over 7-day monitoring period. *Based on log-transformed data. Values are presented as mean ± standard deviation (SD) for data analysed with t-tests, and as median(range) for non-parametric data.*

Total weekly recordings	**PFA**	**TKA**	**Test statistic**	**p-value**
Duration of inactive activity (mins/week)	7485 (6538.6 - 8059)	7402.3 (6040 - 8166.3)	Wilcoxon test	p=0.29
Duration of light activity (mins/week)	697.1 (409.7 - 1602.8)	776 (393.8 - 1337.3)	Wilcoxon test	p=0.79
Duration of moderate activity (mins/week)	277.6 (98.3- 972.58)	305.8 (69.4 – 603.2)	Wilcoxon test	p=0.79
Duration of vigorous activity (mins/week)	39.7 (4.0 -166.3)	37 (2.0 -117)	Wilcoxon test	p= 0.85
Total physical activity (mins/week)	1154.2 (496.3)	1132.1 (482.3)	T-Test*	p = 0.89
Total step count	40315.77 (26032.2)	36986.4 (19687.0)	T-Test*	p =0.75

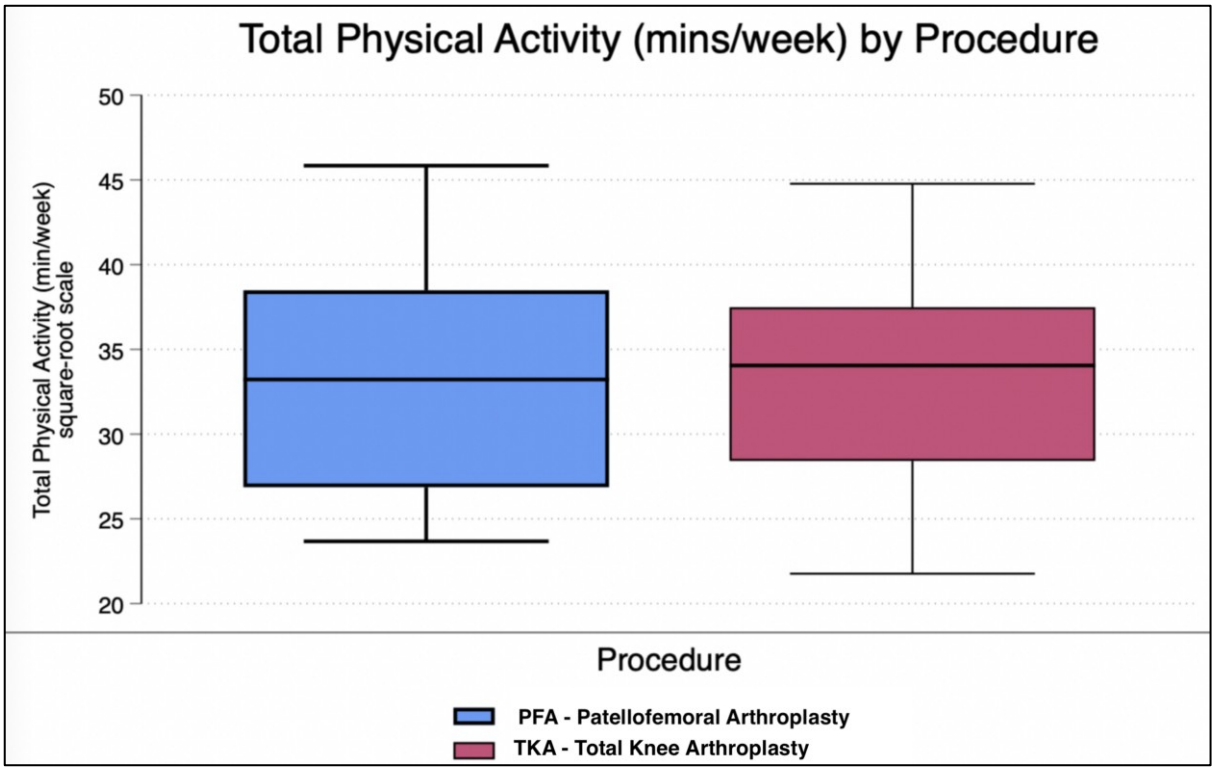


Figure 54. Distributions of time of total physical activity over study period by procedure.

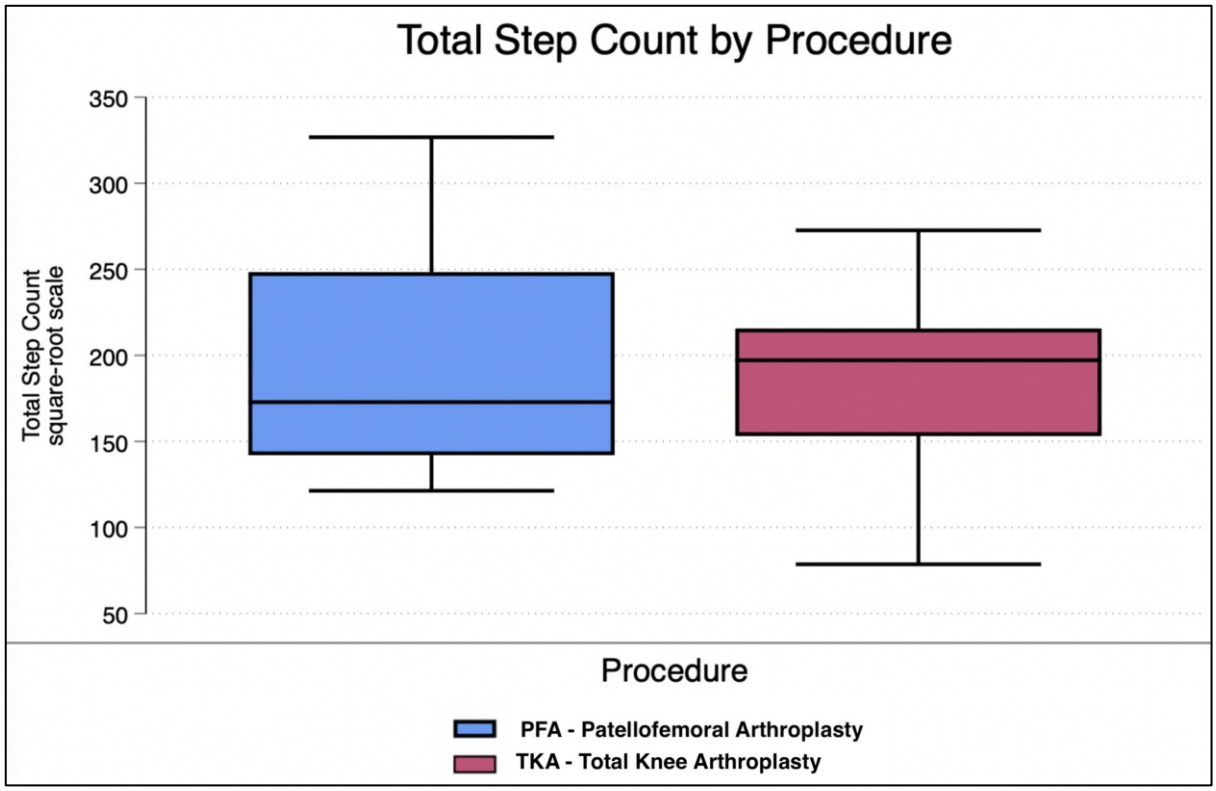


Figure 55. Total step count by procedure.

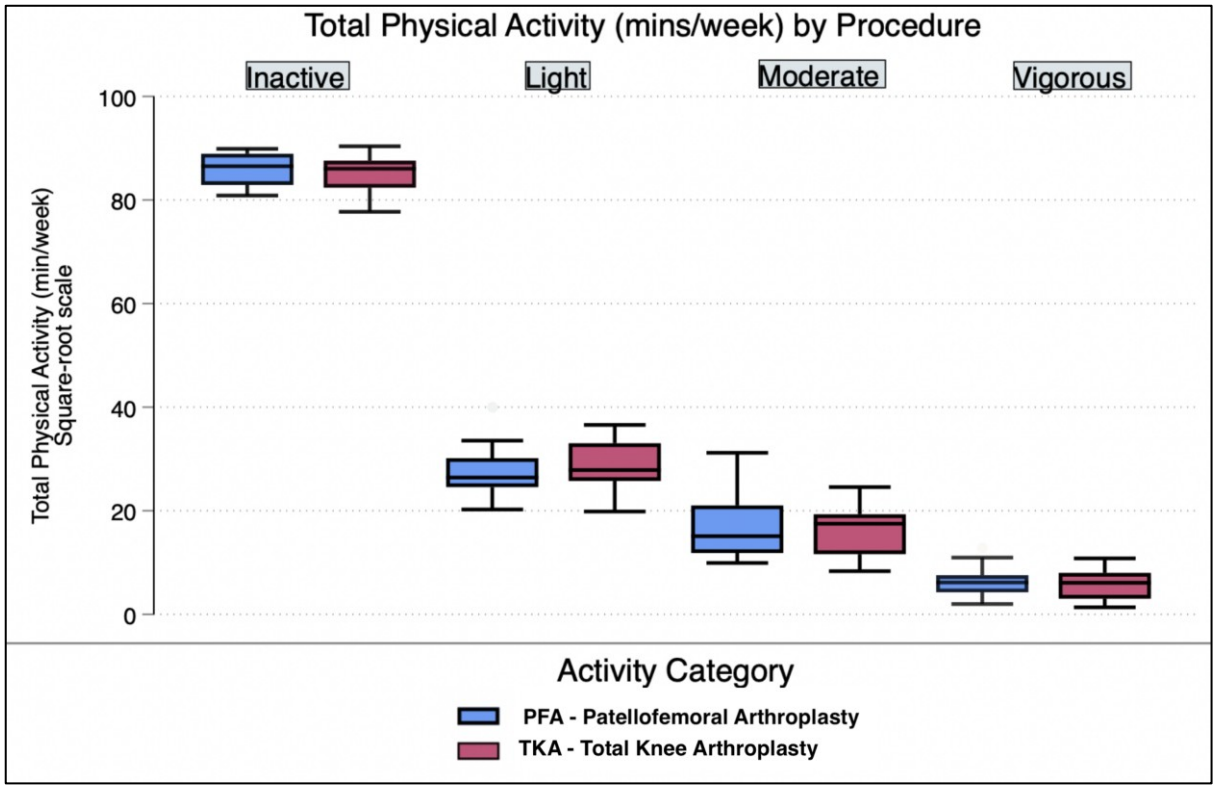


Figure 56. Distributions of time spent in different activities by procedure.

Table 38. Mean 24-hr day acceleration over a one-week period. Data from the Wilcoxon test are presented as medians (interquartile range), and data from T-tests are presented as mean (±SD).

Mean 24-hr day recordings	PFA	TKA	Test statistics	P-value
ENMO acceleration (mg)	21.4 (6.0)	21.0 (8.0)	T-Test	P=0.94

Sensitivity Analysis

In the cohort that consented to participate in the activity component of the study, there were no significant differences in 10-year PROMs, which included the OKS, EQ-5D-3L, and KOOS subscales (Pain, Symptoms, Activities of Daily Living (ADL), Sport, and Quality of Life (QoL)).

All PROMs improved postoperatively in both groups, with no statistically significant differences observed between PFA and TKA at any time poin (Table 39).

For OKS, median scores improved from 22 preoperatively to 37.5 postoperatively in PFA, and from 25.5 to 36 in TKR (p = 0.488). For EQ-5D-3L, median values improved from 0.723 preoperatively to 0.800 postoperatively in PFA, and from 0.723 to 0.776 in TKA (p = 0.519). KOOS subscales (Pain, Symptoms, ADL, Sport, and QoL) also improved from their preoperative baselines in both groups, with no statistically significant differences between procedures (all p > 0.05).

Table 39 Comparison of preoperative and 10-Year patient-reported outcome measures between participants in the Activity Study for PFA TKA Cohort

PROM	Timepoint	PFA (Median [Min–Max])	TKA (Median [Min–Max])	p-value
Oxford Knee Score	Pre-op	22 [14–31]	25.5 [14–35]	0.380
	Post-op	37.5 [14–48]	36 [12–48]	0.488
EQ-5D-3L	Pre-op	0.723 [0.329–0.824]	0.723 [0.296–0.886]	0.727
	Post-op	0.800 [0.592–1.000]	0.776 [0.356–1.000]	0.519
KOOS Pain	Pre-op	50.0 [27.8–69.4]	51.4 [13.9–80.6]	0.770
	Post-op	91.7 [44.4–100.0]	86.1 [27.8–100.0]	0.108

KOOS Symptoms	Pre-op	50.0 [28.6–75.0]	48.2 [25.0–96.4]	0.884
	Post-op	89.3 [46.4–100.0]	78.6 [32.1–100.0]	0.258
KOOS ADL	Pre-op	57.4 [32.4–72.1]	52.2 [25.0–79.4]	0.547
	Post-op	76.5 [51.5–100.0]	77.9 [19.1–97.1]	0.620
KOOS Sport	Pre-op	5.0 [0–30.0]	5.0 [0–40.0]	0.704
	Post-op	20.0 [5.0–95.0]	25.0 [0–85.0]	0.632
KOOS QoL	Pre-op	25.0 [6.3–56.3]	25.0 [6.3–43.8]	0.357
	Post-op	68.8 [18.8–100.0]	62.5 [0–100.0]	0.241

KOOS - Knee Injury and Osteoarthritis Outcome Score

KOOS ADL - Knee Injury and Osteoarthritis Outcome Score -Activities of Daily Living

KOOS QoL - Knee Injury and Osteoarthritis Outcome Score- Quality of Life

A comparison between responders and non-responders (who provided PROMs remotely; n = 31 for TKA, n = 24 for PFA) of the activity component of this study, for both TKA and PFA cohorts showed no significant differences and are presented in Table 40- Table 41.

Table 40 Comparison of 10-Year PROMs Between Participants and Non-Participants in the Activity Study for PFA Cohort

PROM	Timepoint	Accepted (Median [Min–Max])	Declined (Median [Min–Max])	p-value
OKS	Pre-op	22 [14–31]	24 [13–38]	0.311
	Post-op	37.5 [14–48]	38 [11–48]	0.934
EQ-5D	Pre-op	0.723 [0.329–0.824]	0.723 [0.324–0.824]	0.878
	Post-op	0.800 [0.592–1.000]	0.824 [0.268–1.000]	0.843
KOOS Pain	Pre-op	50.0 [27.8–69.4]	44.4 [13.9–83.3]	0.293
	Post-op	91.7 [44.4–100.0]	77.8 [27.8–100.0]	0.388
KOOS Symptoms	Pre-op	50.0 [28.6–75.0]	53.6 [25.0–95.8]	0.179
	Post-op	89.3 [46.4–100.0]	87.5 [39.3–100.0]	0.494
KOOS ADL	Pre-op	57.4 [32.4–72.1]	57.4 [28.1–85.3]	0.742
	Post-op	76.5 [51.5–100.0]	80.1 [23.5–100.0]	0.719
KOOS Sport	Pre-op	5.0 [0–30.0]	12.5 [0–30.0]	0.144
	Post-op	20.0 [5.0–95.0]	35.0 [0–100.0]	0.923
KOOS QoL	Pre-op	25.0 [6.3–56.3]	31.3 [12.5–62.5]	0.116
	Post-op	68.8 [18.8–100.0]	87.5 [12.5–100.0]	0.662

Table 41 Comparison of 10-Year PROMs Between Participants and Non-Participants in the Activity Study for TKA Cohort

PROM	Timepoint	Accepted (Median [Min–Max])	Declined (Median [Min–Max])	p-value
OKS	Pre-op	25.5 [14–35]	23 [5–33]	0.487
	Post-op	36 [12–48]	39 [9–48]	0.664
EQ-5D	Pre-op	0.723 [0.296–0.886]	0.723 [0.218–0.776]	0.563
	Post-op	0.776 [0.356–1.000]	0.770 [0.261–1.000]	0.920
KOOS Pain	Pre-op	51.4 [13.9–80.6]	50.0 [13.9–80.6]	0.904
	Post-op	86.1 [27.8–100.0]	88.9 [28.1–100.0]	0.135
KOOS Symptoms	Pre-op	48.2 [25.0–96.4]	67.9 [32.1–82.1]	0.094
	Post-op	78.6 [32.1–100.0]	89.3 [41.7–100.0]	0.063
KOOS ADL	Pre-op	52.2 [25.0–79.4]	50.0 [19.1–79.4]	0.400
	Post-op	77.9 [19.1–97.1]	83.8 [13.2–100.0]	0.334
KOOS Sport	Pre-op	5.0 [0–40]	5.0 [0–35]	0.630
	Post-op	25.0 [0–85]	35.0 [0–85]	0.426
KOOS QoL	Pre-op	25.0 [6.3–43.8]	31.3 [0.0–56.3]	0.164
	Post-op	62.5 [0.0–100.0]	75.0 [6.3–100.0]	0.146

7.4 Discussion

Summary of results

In this study, neither procedure showed a significant difference in the types of physical activity performed. Despite a higher step count and duration of total physical activity in PFA patients, there was no significant difference between PFA and TKA patients and therefore PFA may be no better than a TKA.

This could be because the differences were assessed at a maximum of 10 years after surgery. Studies have shown that the longer the post-operative period, the superiority of a procedure may become less obvious. It is possible that a type 2 error occurred in this case due to the use of a 10% difference in the power calculation. Rather than PFA patients having a 10% reduction in inactive time compared to TKA patients, a reduction of 5% may have been more suitable as differences are more subtle at the 10-year mark following surgery.

Data were collected from patients who consented to participate which may have introduced a potential source of selection bias, perhaps these were the patients who were more active. However, the sensitivity analysis demonstrated the robustness of the study, with no worse PROMs observed between participants and non-participants within each treatment group.

Application to practice

The study provides valuable evidence that outcomes should be assessed not only through PROMs but also objectively. The results from Chapter 6 show that PFA patients do worse than TKA patients. However, these objective results show that PFA patients are performing equivalently to TKA patients. In fact, they are performing more physical activity, even though

there was no significant difference due to a small sample size.

This population showed that all individuals adhered to WHO physical activity guidelines, confirming the Danish population is a physically active population(278,281). In contrast to the American study that evaluated total hip arthroplasty and total knee arthroplasty, none of the individuals met the WHO physical activity criteria (288). This only shows that conducting a study within one population and assessing differences does not guarantee its application to other populations as well.

Limitations

This is the first randomised controlled trial to measure the total physical activity following arthroplasty surgery. In addition, the results of this study can serve as a guide for future pilot studies, as it shows that differences after one year become minimal and that power calculations should be able to detect even smaller differences. The most noticeable changes usually occur within six months of surgery(289–291). The power calculation used should depend on the stage of the post-operative period at which patients are assessed.

Chapter 8. Comparison of functional outcomes in patellofemoral joint arthroplasties compared with total knee arthroplasties - a randomised controlled trial

Author Contribution, Funding, and Dissemination

This study represents a continuation of the randomised controlled trial described in Chapter 7. Once patients attended the clinical centres to return the accelerometers used for physical activity assessment, I conducted a series of objective functional outcome tests at each participating centre. I co-ordinated the data collection process across all sites and recorded the functional assessment data presented in this chapter.

I was assisted by Danish PhD student Dr Julie Heegaard, who helped translate and communicate with patients when language barriers arose during testing and data collection.
This work was funded through the ISAKOS New Clinical Researcher Grant. The manuscript arising from this study is currently under review in *The Knee*.

Presentations

- Poster presentation at The British Association for Surgery of the Knee (BASK): *Functional Objective Outcomes in Patellofemoral vs. Total Knee Arthroplasties: A Randomised Controlled Trial for Isolated Patellofemoral Joint Osteoarthritis*.

Chapter 8. Comparison of functional outcomes in patellofemoral joint arthroplasties compared with total knee arthroplasties – a randomised controlled trial

8.1 Introduction

Stair climbing places a three times greater demand on the knee than level walking, requiring a greater quadriceps contraction and a greater range of motion, resulting in a compressive force between the patella and femoral trochlea(292). Patellofemoral osteoarthritis can make climbing stairs difficult for patients. However, patellofemoral joint arthroplasties preserve bone stock and ligaments, which in previous studies have been found to result in better ability to climb stairs compared with TKA(8,59,62,86,148,293).

While walking, a person's heart, lungs, circulatory, nervous, and musculoskeletal systems are all put under strain, therefore, a slowing gait may reflect damaged systems, patients walking slower than 0.6m/s have a higher risk of early mortality, and gait speed parameters can identify these patients (294). Unlike TKAs, patients who have had a patellofemoral joint arthroplasty have been described as returning to regular fitness exercising such as tennis, cycling, skiing, and ballet(148).

This chapter aimed to compare patients who had total knee arthroplasties to those who had patellofemoral joint arthroplasties using objective functional tests such as walking speed, knee flexion and gait profile measurements in order to supplement the patient-reported outcome

findings in Chapter 6.

8.2 Methods

The same patients recruited in Section 7.2, were invited back to participate in this study. Once the patients returned their accelerometers used in Chapter 7, I applied the XSens MVN BIOMECH (Xsens Technologies B.V., Enschede, The Netherlands) system. It is a commercially available inertial sensor-based motion capture system carried by miniature inertial sensors placed on the body. The system has been validated to assess joint kinetics(295).

A Velcro attachment was used to secure the sensors on the extremities, and the sensors were calibrated using XSens MVN BIOMECH software (Xsens Technologies B.V., Enschede, The Netherlands). Sensors were applied as recommended by Xsens (296). In the lower leg, the sensors were positioned 50% from the tibial tuberosity to the medial malleoli. Thigh sensors were placed, applied midway between the first toe and the heel, between the greater trochanter and superior border of the patella. A pelvis sensor was applied in the middle of the pelvis, Figure 57 .

The patients performed the following tests described below. The battery of tests was selected to assess multiple aspects of functional performance. As mentioned previously, studies have demonstrated that PFA patients can achieve good functional outcomes, including improved stair-climbing ability and return to sporting activities such as tennis, cycling, skiing, and ballet(8).

The sit-to-stand, single-leg squat and stair climbing tests were selected to determine whether

patients undergoing PFA demonstrate improved functional flexion and movement patterns in real-world activities, rather than relying solely on goniometric measurements of knee range of motion. Timed walking tests at different speeds were included to determine whether differences existed in gait speed and gait profiles.

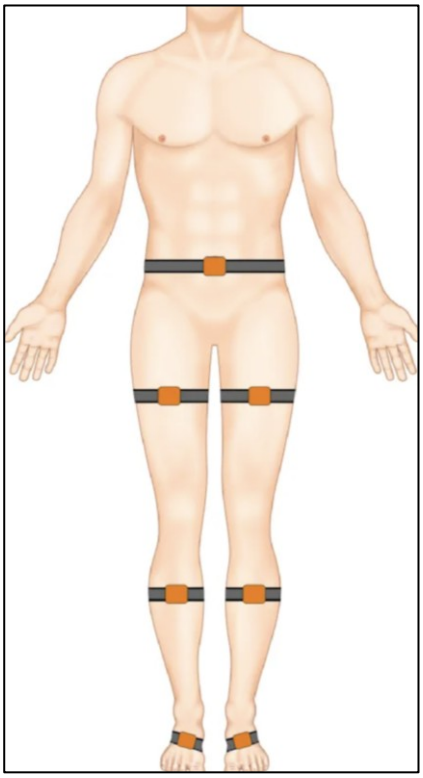


Figure 57 Illustration of sensor placement on patients

8.2.1 20-metre walk test and as fast as they can go

During the test, participants walked a straight distance of 20 metres on level ground at their normal, comfortable pace. In cases where the participant usually used a walking aid, they were asked to complete the test without it, but if they found it difficult, they completed the test using it (297)

Patients were then asked to repeat the test as fast as they could. Results were recorded in terms of gait profile and maximum walking speed. When the data were not normally distributed, medians were used (Appendix F).

For gait profile, one-dimensional Statistical Parametric Mapping (SPM1D) was calculated at each point of the waveform, if it exceeded the critical threshold of < 0.05, it was considered significant in that part of the waveform. SPM1D is a statistical method used to analyse movement data continuously over the entire gait cycle, rather than examining single points such as peak values or averages(298,299). As a result, SPM1D provides a more comprehensive analysis of biomechanical data, assessing differences in movement patterns.

8.2.2 Sit-to-stand at variable chair height

A height-adjustable chair was provided to participants. A predefined sit-to-stand protocol, previously described in studies assessing the effect of chair height in elderly populations, was used in this study (300–305). The chair height was adjusted so that it was at the same level as the upper end of the fibula head (100%). During the test, subjects crossed their arms in front of their chest to prevent their arms from supporting them, waited two seconds, and sat without supporting themselves with their hands. This was repeated five times. Seat heights were then adjusted to 80% and 110% of the subjects' lower leg lengths. The recorded outcome was the ability to perform the test and joint kinematics measured in the range of joint flexion. The test was repeated five times, and the median of the five attempts was obtained.

8.2.3 Single-leg squat

Patients were asked to squat down as far as possible on the operated leg (306,307). Patients could gently support themselves with a maximum of two fingers, and this test was repeated five times. The results recorded were the ability to perform the test and joint kinematics measured in the range of joint flexion. A median was obtained after repeating the test five times.

8.2.4 Stair climbing test

Participants completed this test in a no-traffic stairway. Patients were asked to ascend the steps, turn around, and descend the same steps with or without using the handrail (308). Both ascents and descents were timed, and the tests were repeated twice. The mean time to ascend or descend, per step, was calculated to streamline the variation in the total number of flights of stairs between the three hospitals, which varied between 10, 13, and 25 steps. Joint kinematics measured in relation to joint flexion and gait profile.

8.3 Results

A total of 34 patients were recruited for the study, 19 of whom had PFAs and 15 of whom had TKAs. An overview of the patient characteristics included in this study is shown in Table 42.

Table 42. Baseline patient clinical characteristics of study participants included in the study. Data are presented as mean for continuous measures (SD) and n (%) for categorical measures.

		PFA (n=19)	TKA (n=15)
Age		75.9 (7.9)	74.0 (10.3)
Gender	Female	14 (74)	11 (73)
	Male	5 (26)	4 (27)
Body Mass Index (kg/m^2)		27.7 (4.8)	28.6 (4.7)
CCI		3.8 (1.4)	3.9 (1.4)

8.3.1 20-metre walk test and 'as fast as they can go'

For the 20-metre walk test, PFA patients averaged 1.51 m/s (1.09 -1.95) and TKA patients averaged 1.49 (0.86-2.03). While PFA patients achieved a 0.06 m/s higher walk speed, they failed to reach statistical significance (p =0.57, -0.15 - 0.26).

In a fast 20-metre walk test, the maximum walking speed for PFA patients was 1.78 m/s (1.24 - 2.99), while the maximum walking speed for TKA patients was 1.75 m/s (0.94 - 2.61), PFA patients were 0.16 m/s faster than TKA patients, but did not reach statistical significance (p=0.36, -0.19 - 0.50).

8.3.2 20-metre walk test spatiotemporal parameters

Statistically significant differences in knee flexion were observed between PFA and TKA during all phases of the gait cycle ($p < 0.05$) (Figure 58-Figure 59). These differences were further pronounced during fast walking. Specifically, PFA patients exhibited greater maximum knee flexion during the swing phase when performing the fast walking test. On the other hand,

when TKA patients underwent a slow walking test, they were more likely to experience flexion during maximum knee extension at the terminal stance phase and heel strike, compared with PFA patients.

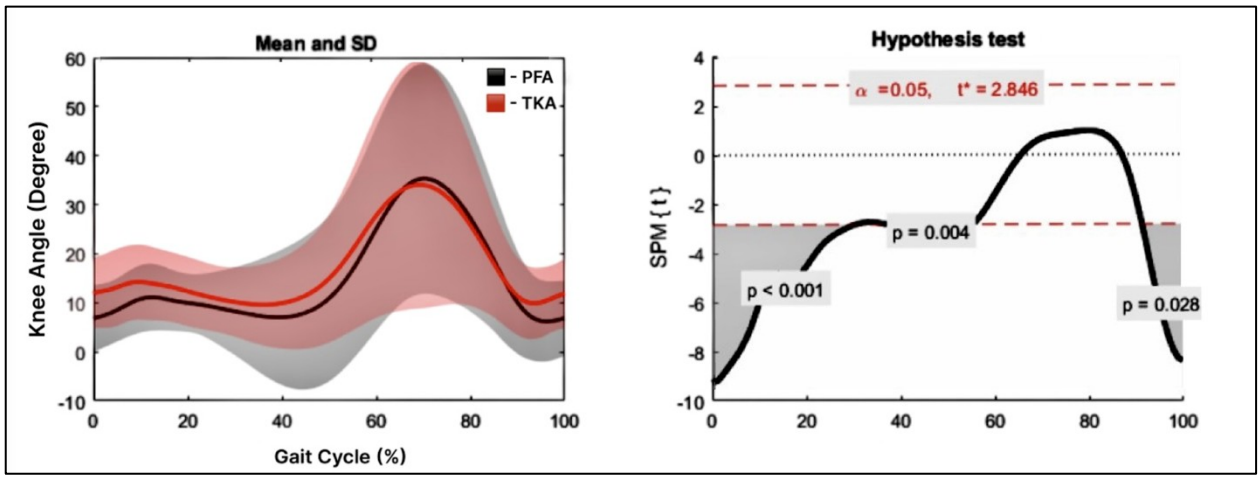


Figure 58. Knee action during the gait cycle in normal 20m walking test, comparing both PFA and TKA.

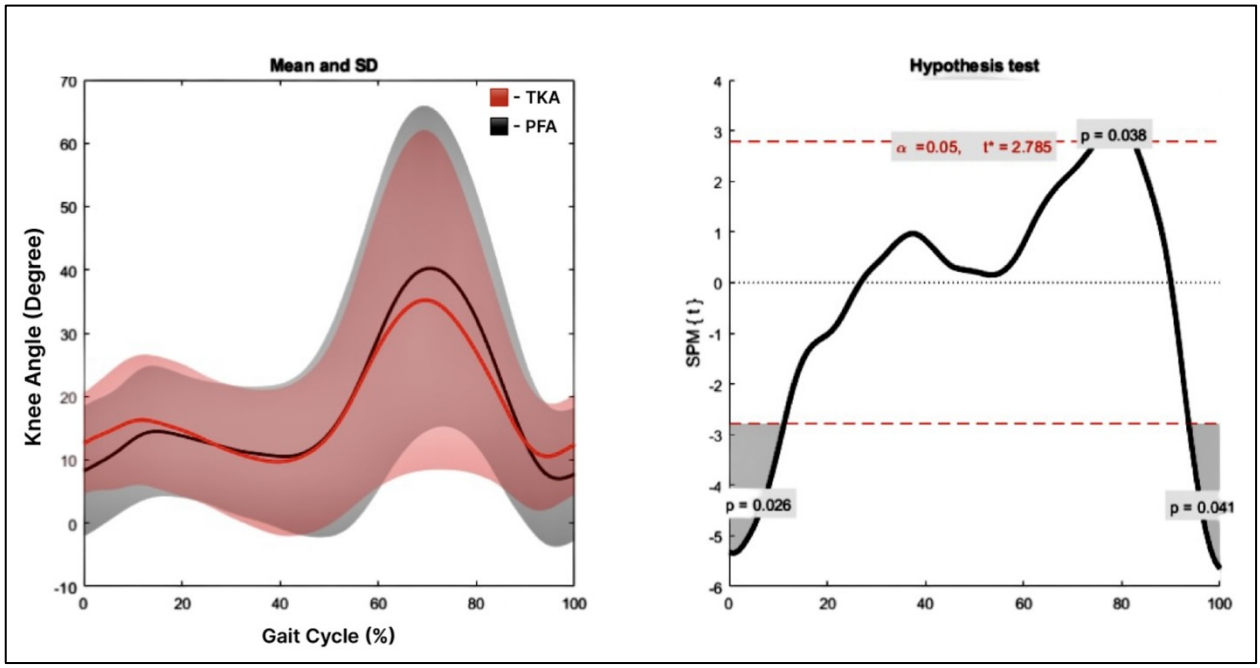


Figure 59. Knee action during the gait cycle in a fast 20m walking test, comparing both PFA and TKA.

8.3.3 Sit-to-stand at variable chair height

Table 43 presents the results of sit-to-stand tests. A total of 10 TKA cases and 15 PFA cases were available for analysis. A PFA at 100% chair height was associated with a 7.97° increase in knee flexion, but did not reach statistical significance (p =0.65, CI -7.12 – 23.1). Patients undergoing a PFA at 110% chair height were able to flex 4.01° more (p =0.30, CI -10.4 – 18.4). Finally, patients undergoing a PFA at 80% chair height were able to flex their knee 6.50° more (p=0.51, CI -17.2 –30.2). Patients with a PFA were able to perform standing from a lower chair height (80%) more frequently (n=5) than patients with TKA (n=3). All patients were able to perform 100% and 110% chair height tests.

Table 43. Comparison of range of flexion, minimum, maximum and SD for PFA and TKA at different chair heights with p-values and 95% confidence intervals.

Chair height	Procedure	Range of flexion (°)	Minimum flexion (°)	Maximum flexion (°)	SD (°)	p-value, 95% CI
80%	PFA	89.6	68	87	9.4	P=0.51, CI -17.2 – 30.2)
	TKA	68.2	65.6	93.2	15.2	
100%	PFA	70.8	50.1	85.1	12.0	P=0.65, CI -7.12 – 23.1
	TKA	66.0	8.8	91.3	24.3	
110%	PFA	64.2	29.0	79.2	15.8	p =0.30 CI -10.4 – 18.4)
	TKA	53.3	31.1	86.4	17.5	

7.3.4 Single-leg deep squat

Patients undergoing a PFA procedure had a median range of flexion of 40° in deep squatting, with a minimum of 11° and a maximum of 63°. TKA patients had a median flexion range of 36.6°, with a minimum of 18° and a maximum of 61.0°. PFA patients were able to flex their operated knees 4.1° more than TKA patients, p=0.50, CI -8.22 – 16.3.

8.3.5 Stair climbing test

Ascent and descent of the stairs were faster for PFA patients than for TKA patients. In PFA patients, the mean time for ascending stairs was 0.64 seconds (SD 0.29), while in TKA patients it was 0.76 seconds (SD 0.37). PFA patients were 0.13 seconds faster, but this did not reach statistical significance (p =0.29, CI -0.36 - 0.11).

A PFA patient's mean staircase descent time was 0.75 seconds (SD 0.47) whereas a TKA patient's average staircase descent time was 0.88 seconds (SD 0.37). PFA patients were 0.13 seconds faster, but did not reach statistical significance (p=0.43, CI -0.45 – 0.19).

8.4 Discussion

Summary of results

Objective functional tests performed at the 10-year post-operative mark revealed no statistical significance between patellofemoral joint arthroplasty patients and total knee arthroplasty patients. Patients undergoing patellofemoral joint arthroplasty had a significantly different and better gait composition during all phases of the gait cycle than those undergoing total knee arthroplasty.

There was no difference in walking speed between patients with patellofemoral joint surgery and those with total knee arthroplasty, but both types of patients walked 1.75 m/s - 1.78 m/s faster than the international standard crossing time for a crosswalk of 1.2 m/s (309).

Physical performance tests performed in this study included sit-to-stand tests with variable chair heights and single-leg squats, in which poor performance in these tests is associated with an increased risk of serious adverse events, though gait speed is more predictive (294). Reducing the seat height increases hip and knee joint moments and peak loads on the joints, making standing more demanding (310). As standing from a lower chair height requires a greater knee flexion angle, patients with patellofemoral joint arthroplasties performed this test more often than total knee arthroplasty patients (311). In both the single-leg deep squat and standing from a lower chair height, patients with patellofemoral joint arthroplasties had a greater range of motion than total knee arthroplasty patients, although there was no statistically significant difference. Patients with osteoarthritis of the patellofemoral joint experience greater difficulty ascending stairs than they do walking due to the increased patellofemoral pressure (312).

Despite not being statistically significant, patellofemoral arthroplasty patients were faster than total knee arthroplasty patients. This was possibly due to improved proprioception associated with both ligament retention. Loss of proprioception leads to decreased joint stability, loss of control over joint movement and an abnormal gait (313).

Based on spatiotemporal parameters at all gait cycle phases, patellofemoral joint arthroplasties had higher degrees of flexion than total knee arthroplasties (Figure 58-Figure 59). Patients with

decreased knee flexion require adjustments in other parts of the body that pull the hip into flexion, while the ankle must dorsiflex to keep the foot flat on the ground (314). In the absence of adequate ankle dorsiflexion, weight is shifted on the forefoot, creating a posture known as equinus (314). Although these differences in gait parameters were detectable, they were small in magnitude and therefore of uncertain clinical significance.

Application to practice

In view of the limitations presented below, patellofemoral joint arthroplasties function better than TKAs and have a better gait than TKAs. Despite the limitations outlined below, some evidence supports the assertion that patients with patellofemoral joint arthroplasties do better on stair climbing due to their increased range of motion. Therefore, there is still evidence to encourage patellofemoral joint arthroplasty as a treatment option for patients while acknowledging that the OKS of the patient will not be as high as that of a TKA in the first 6 months, as seen in Chapter 6. However, based on Chapter 7 and the findings in this chapter, there is no significant difference in objective outcomes at 10 years.

Limitations

In the same way as Chapter 7, limitations are due to the small sample size. However, this is the first randomised controlled trial comparing patellofemoral vs TKAs 10 years after surgery. The lack of preoperative data limits the conclusions that can be drawn from the data presented, as pre-operative measurements have been demonstrated to have a substantial effect on postoperative outcomes, irrespective of the procedure performed. However, this study is the first time these parameters have been compared in well-functioning, established PFAs and TKAs and the lack of large differences is an important finding. However, the results give us a brief indication of what happens during the late post-operative period.

Chapter 9: Discussion

9.1 Summary of findings

The work within this thesis has provided important insights into the advantages, disadvantages, objective outcomes and determinants of revision following patellofemoral joint arthroplasty. It is hoped that dissemination of the findings of this thesis can change the practice of those who perform PFA, those whose perform TKA in patients with patellofemoral joint osteoarthritis and those who tend to offer conservative treatment measures.

If more arthroplasty surgeons adopt the practices demonstrated to improve outcome, this will lead to a greater overall implant survival in patients undergoing PFA and allow more patients to benefit from the advantages PFA in terms of function, morbidity, and mortality.

Chapter 4 compares the patterns of adverse outcomes in PFA and TKA. This is the largest comparison study ever conducted in this field. Taking early outcomes to eliminate the effect of contamination we have demonstrated that PFA is safer than TKA.

Orthopaedic surgery is very common (in the UK, it is the second commonest type of surgery performed); therefore, accurate estimates of complications after routine procedures are important to inform treatment and shared decision-making(315). In the context of 200,000 arthroplasty procedures performed per year, even small differences in outcomes, costs or complications can have substantial effects on the health of the treated population(316). Adverse events have negative physical and psychological consequences for the patient(317). In addition, they are associated with increased healthcare system costs, primarily by increasing hospital lengths of stay and using additional resources(317). At 30 days following surgery, patients who

receive a PFA are less likely to sustain an adverse event (death, a lower respiratory infection, thromboembolism, urinary tract and wound infection than those who receive a TKA. Besides PFA surgery being safer for the patient, it is likely to save costs due to a shorter length of stay and a reduce risk of complications.

In PFA patients, the only complication associated with PFA was an increased risk of cerebrovascular complications (RR 1.69, P <0.05; 95% CI 1.26–2.27). The reason for this is not clear and is likely to be due to a combination of factors, which may include unmeasured clinical differences between the patients. Despite PFA patients receiving the same post-operative thromboembolic prophylaxis as TKA patients, general anaesthesia was more likely to be used. General anaesthesia may disturb circulatory homeostasis, which may lead to a higher risk of stroke (218–220). Furthermore, Ehlers-Danlos syndrome and Marfan syndrome are common connective tissue disorders that can cause generalised ligamentous laxity leading to patellofemoral instability, which predisposes to patellofemoral dislocations associated with a higher risk of patellofemoral joint osteoarthritis(318,319). These conditions have been linked to a predisposition to cerebrovascular complications in studies and may be the reason for a higher risk of cerebrovascular accidents following PFA (320). Alternatively, this may be a type II error, an effect of multiple testing or the result of a unmeasured confounding.

As with any partial knee replacement, PFA has a much higher revision rate than TKA, both follow similar trends with a higher revision rate at the 2.5-year mark. For PFAs and TKAs, the reasons for revision differ in the first 2.5 years, including pain and stiffness versus infection and mal-alignment. However, after this time point, TKAs are typically revised due to infection and loosening, while PFAs are revised due to osteoarthritis and pain. There are no significant differences in the reasons for revision between the sexes. However, male gender and obesity

are associated with a higher likelihood of progression of osteoarthritis following a PFA.

Complications vary in severity, and it is difficult to determine which has the greatest negative impact on the patient. Treatment of prosthetic joint infection is not only costly, costing between £30,011 - £35,668 but is described by patients as life-changing, “devastating”, “traumatic” and causing a “considerably restricted life”(102,321–323). Nevertheless, stiffness and pain are important adverse effects, as they can limit a patient's ability to perform daily tasks after arthroplasty(324). Revisions due to stiffness have shown to result in the worse revision outcomes(325). It is unclear what causes stiffness after surgery, it may be the result of technical errors, such as overstuffing the knee or overtightening the patellar retinaculum(324,326). Surgical experience and PFA surgery are further discussed in Chapter 5.

In Chapter 4, Section 4.3.2.3, the risk of revision of a PFA and TKA is modelled in terms of a patient's age. A 60-year-old female who had a TKA had a 95% (CI 0.94-0.95) 10-year survival probability, while a patellofemoral joint arthroplasty had an 83% (CI 0.82-0.85) 10-year survival probability. This is a substantial difference in risk of revision surgery, and is likely to be multifactorial with some factors being modifiable and some not. Reasons would be expected to include procedure-specific reasons for revision (particularly progression of osteoarthritis, but also patellofemoral instability in dysplastic patients), technical factors (with most surgeons performing a relatively small number of PFAs and so being more prone to technical numbers than the much more commonly-performed TKA) and threshold for revision (with PFA being straightforward to revise to a TKA, and in the expectation of better functional outcomes than expected with revision of a similarly symptomatic TKA). Whatever the cause, the substantially and stubbornly higher rate of revision must be balanced against any advantages of PFA in terms of safety and clinical outcomes as explored in other parts of this Thesis.

Chapter 5, the effect of surgical experience was examined further. Surgical caseload (the number of cases performed per surgeon per year) was demonstrated to exert a substantial effect on the revision rate at 5 cases per year, plateauing at more than 20 per year. High-volume surgeons had a lower risk of patients experiencing an adverse event; this may be inferred from the results suggesting they were better at patient selection and more likely to operate on a healthy patient (ASA-1) and those with prior patellofemoral disorders like dysplasia and instability. Higher-volume surgeons would also be expected to have greater surgical expertise. The better outcomes seen in surgeons more experienced in (and, by implication, specialised in) PFA may reflect their greater ability to offer patellofemoral realignment options such as tibial tubercle transfers, as are often required to obtain the best results in patients with a background of malalignment and/or instability (228). Both high-volume and low-volume surgeons report progressive osteoarthritis and pain as the leading causes of revision.

Having demonstrated the safety of PFA relative to TKA, Chapter 6 explores the differences in patient-reported outcomes between both procedures at the 6-month mark. Using patient-reported outcomes, TKA patients fared better than PFA patients in both OKS and EQ5D-3L domains using continuous and categorical analyses. Although TKA demonstrated a statistically higher mean OKS than PFA patients, with a difference of –2.37 (CI -3.06 – -1.70, P <0.01) in favour of TKA, this falls below the minimal clinical difference of 5(263). Similarly, for EQ-5D-3L, the observed difference of -0.03 (CI -0.05 – -0.00, P <0.01) in favour of TKA but also falls below the minimal clinical difference of 0.085, indicating that the clinical impact of these differences is negligible (199). In addition, the chapter supports the expectation that surgeons will have a lower threshold for revising poorly-performing PFAs compared to similarly poorly-performing TKAs: in TKA and PFA patients with the same patient-reported outcome score, a PFA is significantly more likely to be revised. For OKS and EQ5D-3L, PFA patients had a

corresponding higher hazard ratios of 3.15 (95% CI 2.44–4.07, p = 0.01) and 3.40 (95% CI 2.66–4.35), respectively compared with TKA patients. This is likely to be in the expectation of more straightforward revisions with better clinical outcomes (104). In contrast, revision of a TKA consists of substantial bone loss and may require metaphyseal sleeve implants, which typically need specialised surgeons due to the complexity of such surgery(327,328).

Chapter 6 shows that patients who had a PFA demonstrate poorer patient reported outcomes compared to patients undergoing TKA. This is contrary to what is observed in other partial knee replacements, and is not what would be expected in a less invasive procedure which maintains more normal kinematics by preservation of the ACL and other structure (12–14). The reasons for this are again unclear; this may be a difference in the actual outcomes of well-performing PFAs and TKAs, or it may be due to unmeasured confounding, or the number of technically problematic PFAs that go on to revision reducing the overall mean scores. To explore this further, in Chapter 7 we used objective measurements based on the results of a randomised controlled trial at the 10-year mark. In the long term, PFA and TKA patients perform equally well overall, but with PFA patients achieving higher step counts and higher total minutes of activity. This was the first randomised controlled trial to measure total physical activity following arthroplasty surgery

Chapter 8 examines the differences between PFA and TKA patients as part of a randomised controlled trial using objective functional tests. This included gait analysis technology to assess walking speed, gait and joint kinematics during various tasks, including sitting-standing from variable chair heights, single-leg squats, and stair climbing abilities.

PFA patients had a faster walking speed and a better quality gait than TKA patients. These

differences were even more apparent at a faster walking speed. Additionally, PFA patients had greater flexion and could stand up from lower chair heights. However, none of these factors reached statistical significance, probably due to the small sample size which was limited by the size of the original study (which was powered to detect a difference in
inactive time, which was based on a hypothesised 10% reduction in inactive time among PFR patients, with a statistical power of 0.8 and a significance level of 0.05) and subsequent withdrawals from the study which would be expected at longer term follow-up. Statistically significant differences in knee flexion were observed between PFA and TKA during all phases of the gait cycle, with greater degrees of flexion seen during the swing phase. In terms of stair climbing ability, PFA patients appeared to out-perform TKA patients in both ascent and descent, although no statistical difference was achieved. The results of the PROMs and survival analyses should be balanced against the safety data and the encouraging data on gait and activity reported in Chapters 7 and 8. This is the first time data from a randomised controlled trial have used objective tests to compare PFA and TKA.

9.2 Limitations and future work

The results from Chapters 4 through 6 use data collected from the NJR, HES and national PROMS dataset. Its large sample size and robust. Using appropriate statistical methods, including propensity score analysis, we can analyse large amounts of data in a shorter, less resource consuming period than when using standard inferential statistics (329). In addition, uncommon outcomes such as death or surgical site infection may be analysed which is impossible in a randomised study.

Although all recorded confounders are included in the models presented from Chapters 4 to 6, there will always be unmeasured confounding factors. Arthroplasty registries do not have

imaging studies linked to the data. Therefore, the results can not consider the severity or pattern of osteoarthritis. Patients with more severe radiographic knee damage at the time of surgery may be more likely to have substantial gains, which may explain the differences in the results from the Chapter 6 PROM studies(330,331).

Future work may involve the analysis of pre-operative and post-operative radiographs to determine the effect of the pre-operative disease stage and success of surgical reconstruction on variable outcomes. Patient-reported outcome measure data were also incomplete, which impeded analysis. An incomplete data set results in a loss of statistical power and precision, which may lead to misrepresentation of patient responses or a skewing of treatment outcomes(332).

Observational studies use real-world evidence to determine the impact of treatment on an eligible demographic group (333,334). As seen in Chapter 5, the results represent current real-world surgical practices which may better inform clinical decisions rather than representing surgeons from institutions with a specific interest in this procedure. Since this is an observational study, residual confounding may remain despite adjusting for several clinically relevant variables. These variables include the amount of training a surgeon has had before starting as a consultant or the number of years in practice. The surgical volumes analysed do not take into account prior experience or expertise, we were restricted to analysing annual caseload as a surrogate measure.

While observational studies emphasise external validity in real-world populations, particularly in terms of the diversity of patients, surgeons and units, these studies reflect the overall use of PFA and TKA in England and Wales, in randomised controlled trials we can achieve better

information about causality. As a result of the small sample size, randomised controlled trials may not be able to capture rare adverse outcomes, such as revision and death, as compared to the 300,000 patients that were used in the previous study. Small sample sizes predispose the study to type II errors (335). However, the results from these studies should not be dismissed, as this is the first randomised controlled trial using accelerometers to measure the proportion of people meeting physical activity guidelines after PFA or TKA. This may act as a pilot study for future arthroplasty studies. The data presented in Chapters 7 and 8 belong to the Danish population already classed as an active population(281). Therefore, these results may not be applicable to other populations, such as the Australian population that remained inactive in the post-operative period(288). Therefore, future work may include participants from different populations to represent the activities of a wide range of people.

9.3 Future work

From a clinical perspective, further work is required to better understand the nature of persistent pain following PFA. It remains unclear whether patients reporting early postoperative pain after PFA represent the same clinical phenotype as those experiencing pain following TKA, or whether distinct pain mechanisms are involved. This may parallel findings in other orthopaedic subspecialties, such as hand surgery, where reviews have demonstrated no consistent epidemiological relationship between structural abnormalities and wrist pain in adults(336). Such findings suggest that postoperative pain may not be solely explained by the PFA implant position or structural pathology. A more detailed understanding of pain following PFA is required. Factors including patient expectations, occupational demands, psychological factors, and pre-existing hypermobility syndromes may all contribute to postoperative pain and patient dissatisfaction. Improved understanding of

these variables may help refine patient selection, counselling, and postoperative management strategies.

From an engineering and implant design perspective, the findings suggest that improvements in surgical precision alone may not be sufficient to achieve superior clinical outcomes. Although robotic-assisted PFA is thought to improve the accuracy of implant positioning, this did not translate into substantially improved clinical outcomes, as demonstrated in the study by Clement et al. (2026) (337). This raises the possibility that current implant geometry itself may represent a limiting factor.

At present, there is no PFA implant capable of precisely accommodating the wide anatomical variability of distal trochlear morphology across different populations worldwide. Future research may therefore involve large-scale anatomical mapping studies to better define trochlear and femoral geometry across diverse populations. Such work may facilitate the development of implants with improved geometric conformity and more patient-specific biomechanical restoration.

Future advances in PFA are therefore likely to require close collaboration between clinicians, engineers, and implant designers. Such collaboration may allow the integration of patient-specific anatomical data, advanced imaging, and robotic technology into the next generation of implant design, with the aim of improving both patient satisfaction and long-term functional outcomes.

9.4 Conclusion

- Patellofemoral joint arthroplasties (PFAs) have demonstrated advantages over TKAs in terms of reduced morbidity and mortality within the first 30 days following surgery.
- The surgical caseload has been shown to impact the revision rates of PFAs, with higher caseloads potentially leading to improved outcomes.
- PFAs are associated with lower Oxford Knee Scores (OKS) and EQ-5D-3L scores within the first six months post-operatively relative to TKAs.
- Surgeons also tend to exhibit a lower threshold for revising PFAs compared to TKAs at equivalent OKS and EQ5D-3L.
- In the long-term post-operative period, PFA is associated with improved gait outcomes relative to TKAs.

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Appendix A

List of ICD-10 codes used

HIV	B20 – B24 R75 Z21
Non-metastatic malignant neoplasms	C00 – C27 C30 – C40 C40 –C42 C43-C59 C60-C74 C74-C77 C80-C81 C88-C91 C96-C98 D00-D10 D37 D49
Metastatic Tumour	C77-C79 C96-C96 C799
Lymphoma	C81 - C86
Leukaemia	C91-C95
Benign Neoplasm	D10-D36
Uncomplicated Diabetes	E109 E119 E129 E139 E149
Diabetes with end organ damage	E10-E108 E11 – E118 E12 – E128 E13-E138 E14-E148
Stroke (CVA/TIA)	G45 – G453 G458-G45 I60-I69
Myocardial Infarction	I21 – I23 I252
Heart Failure	I50 I425 I43 I099

	I110 I130 I132 I255 I420
Peripheral vascular disease	I70 I73 I74 I79 I798 I739 R02 Z951 Z95
COPD	J40 J43 J684 J701 J703 J47
Peptic Ulcer disease	K25-K39
Severe Liver Disease	K703 & K766 & I850 & I1983 K717 & K766 & I850 & I983 K743 & K766 & I850 & I983 K744 & K766 & I850 & I983 K746 & K766 & I850 & I983
Moderate Liver Disease	K703 & K766 & I859 & I982 K717 & K766 & I859 & I982 K743 & K766 & I859 & I982 K744 & K766 & I859 & I982 K746 & K766 & I859 & I982
Mild Liver Disease	K703 K711 K704 K717 K743 K744 K746 K73 – K73 K767
Hemiplegia	G81 G830
Kidney Failure	N17-N19 **N051- <N06** N032-N036 N07

	N01 N17 –N19 N25 N999 Y841 Z940 Z490 Z491 Z492 Z992 I12 I131 - 132

Conditions	
Obesity	E66
Wound Infection	Skin infection: L024 L031 L043 SSI T814 T857 T827 T845 T846 T847 Wound dehiscence: T813 Sepsis: R572 B377 A021 A227 A267 A327 A409 –A41 R65 -R66
Pulmonary embolism	I26 I269

Deep vein thrombosis	I80 I82-I83
Hypertension	I10-I16
Lower respiratory tract infection	J09-J22 J85-J86
Urinary tract Infection	N309 N10 N12 N136 N308 N288 N340-N342 N300-N302 N390 N370
Delirium	F05
Recurrent patella dislocation	M220 M221
Patella disorders	M222 M223 M228 M229
Patella tendon rupture	W7583
Tibial tuberosity fracture	S821
Hemarthrosis	M2506
Lateral release	W7492
Arthrofibrosis	M2566
Knee pain	M2556
Manipulation under anaesthesia	W91 and Z846

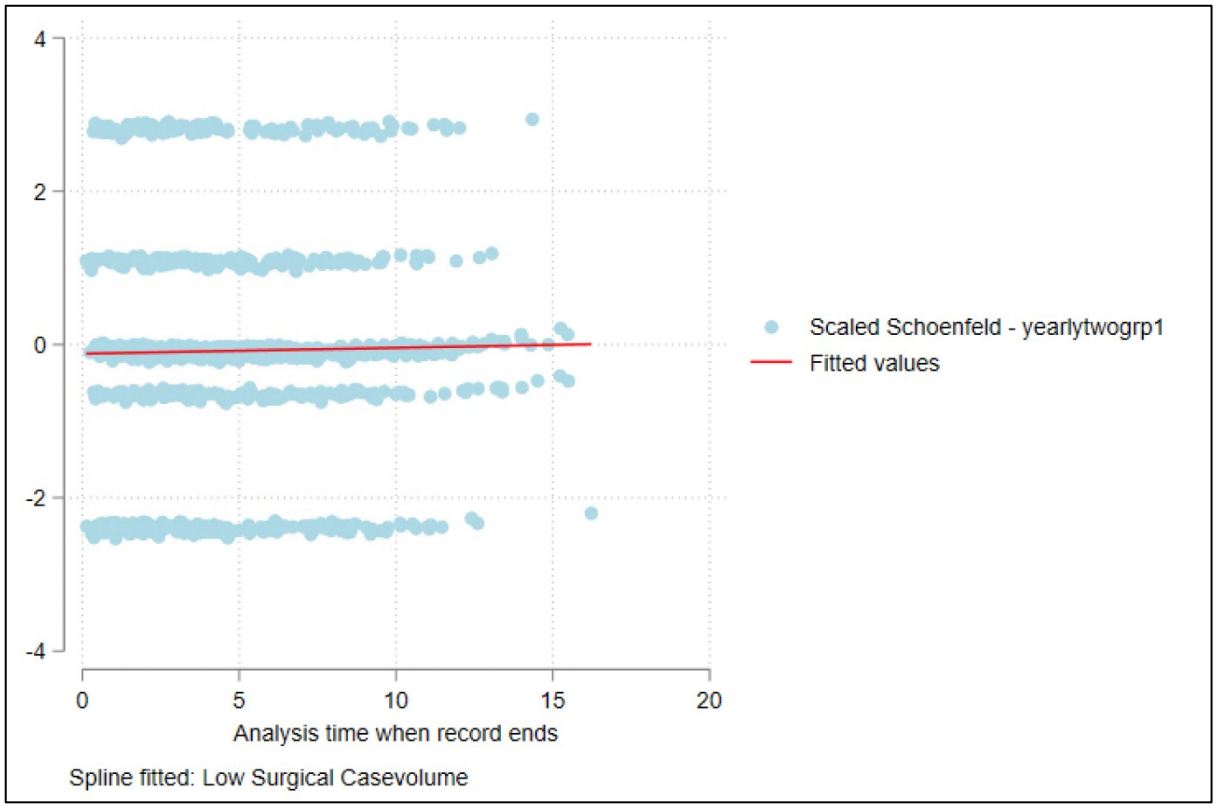
Appendix B

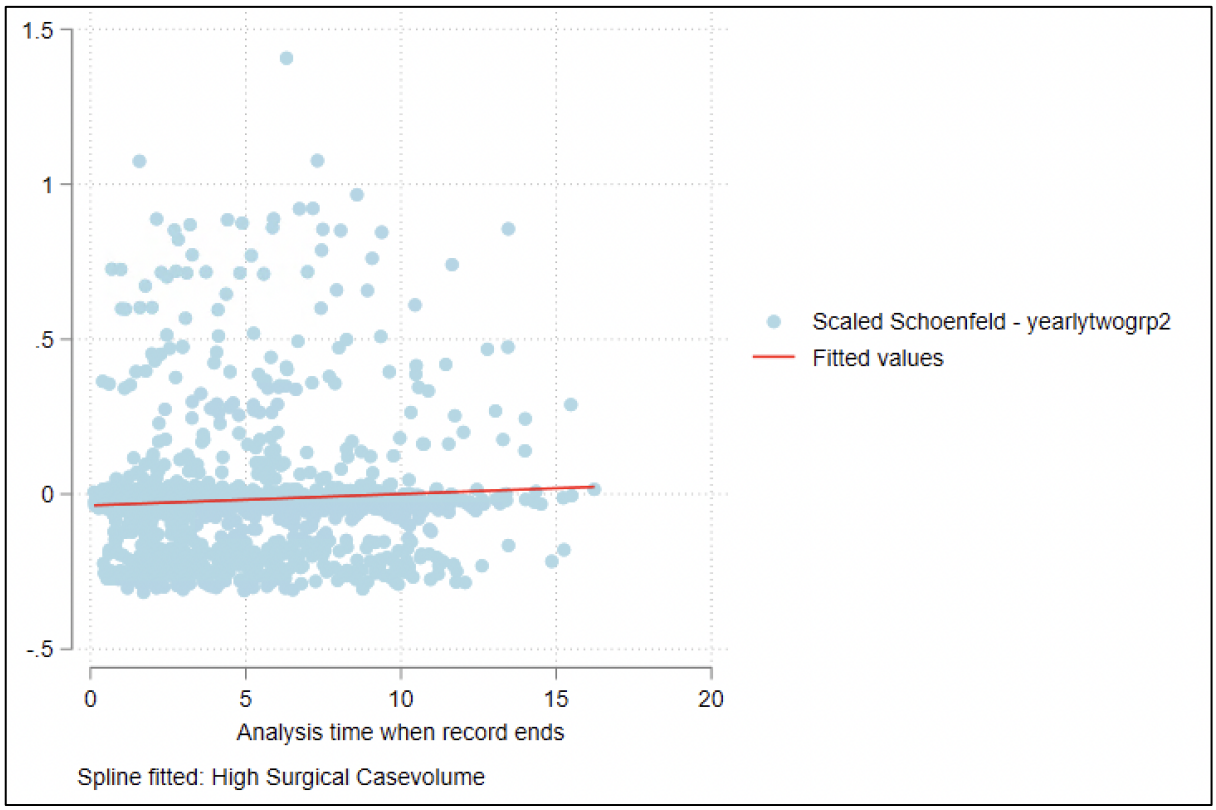
Model Fit

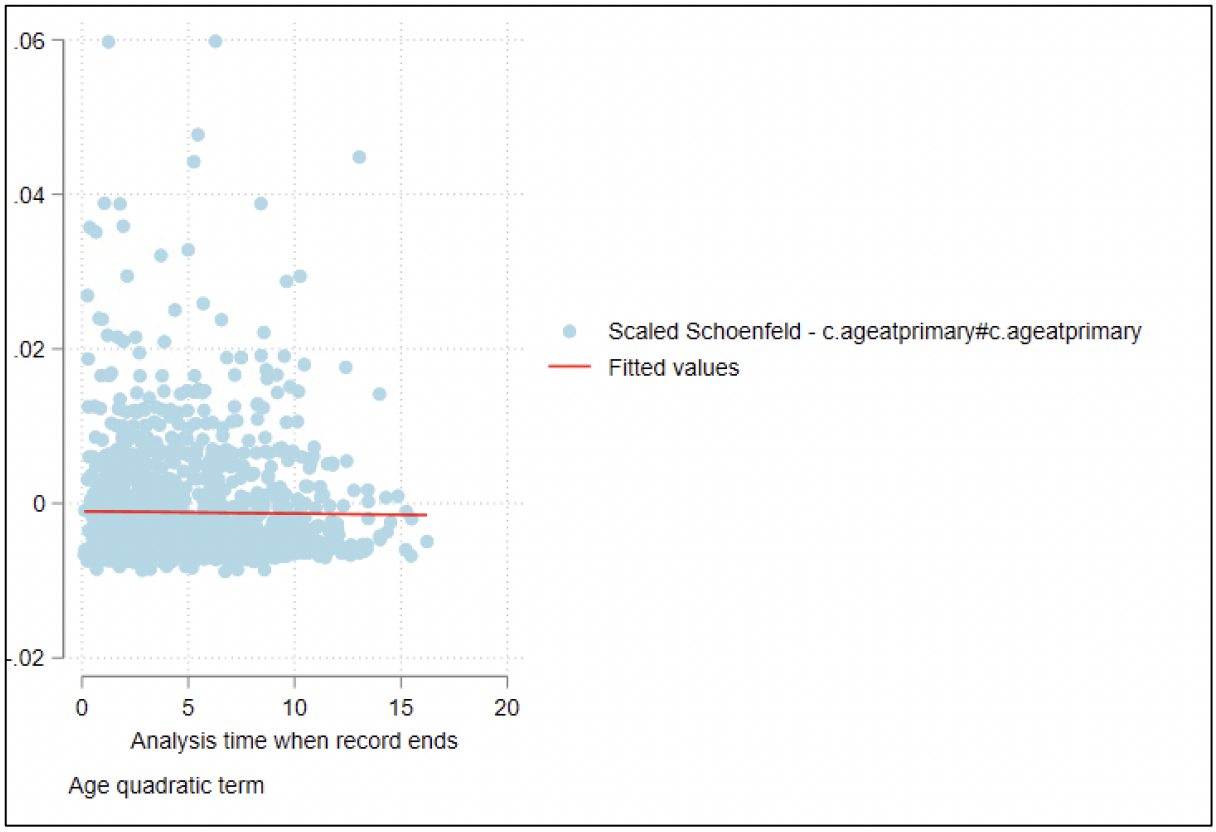
Models Hazard Ratios (Confidence Intervals)								
Predictors	**Model 1**		**Model 2**		**Model 3**		**Model 4**	
		P-value		**P-value**		**P-value**		**P-value**
Surgical Case Load								
Spline fitted Low Volume	0.92 (0.86–0.99)	0.02	0.92 (0.86–0.99)	0.02	0.92 (0.86–0.99)	0.02	0.92 (0.86–0.99)	0.02
Spline fitted High Volume	0.98 (0.97–0.99)	0.01	0.98 (0.97–0.99)	0.01	0.98 (0.97–0.99)	0.01	0.98 (0.97 – 0.99)	0.01
Patient Age at primary joint replacement	1.00 (1.00–1.00)	0.01	1.00 (1.00–1.00)	0.01	1.00 (1.00 – 1.00)	0.01	1.00 (1.00 – 1.00)	0.01
CCI	**0.96 (0.85–1.09)**	**0.53**						
Modified CCI	1.02 (0.97–1.08)	0.40	**1.01 (0.99–1.03)**	**0.49**				
Gender								
Female	1 {Reference}		1 [reference]		1 [reference]		1 [reference]	
Male	1.21 (1.08–1.38)	0.01	1.22 (1.08–1.38)	0.01	1.22 (1.08–1.39)	0.01	1.22 (1.08–1.39)	0.01
Provider								

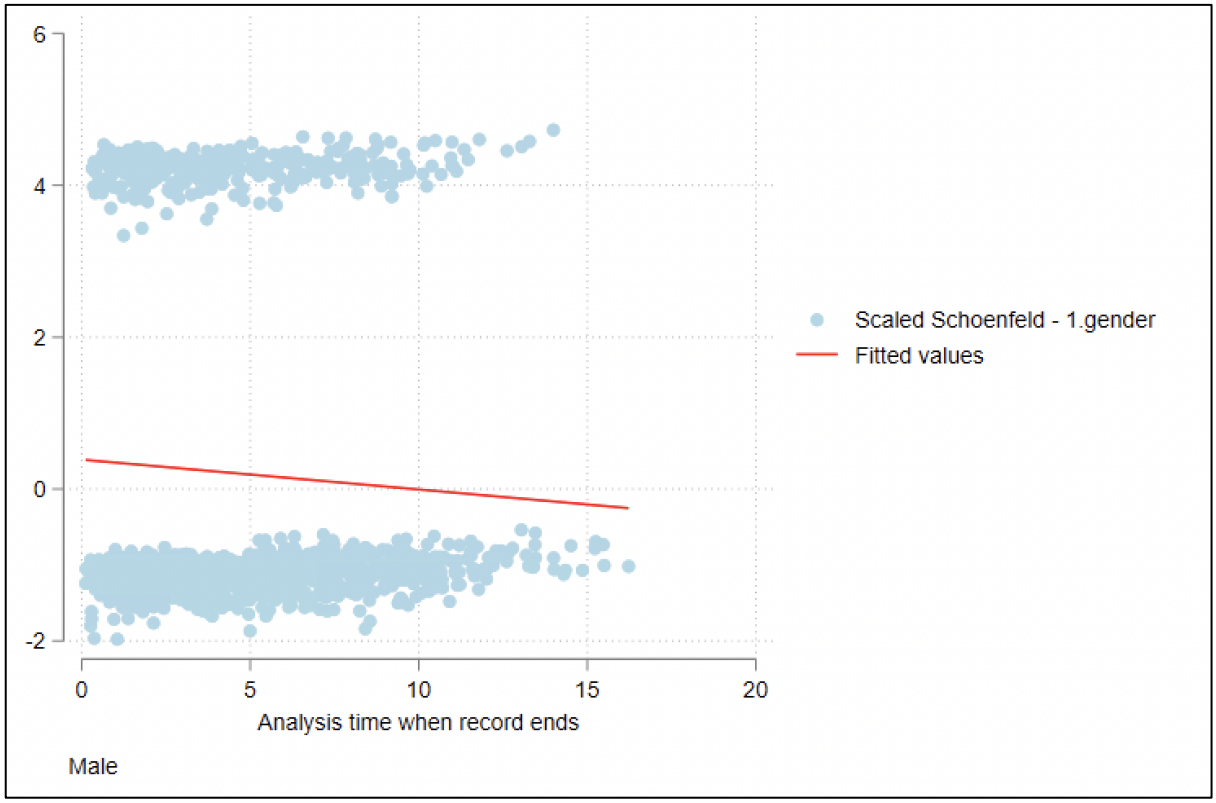
Private	1 [reference]		1 [reference]		1 [reference]			
NHS	1.09 (0.93–1.29)	0.30	1.09 (0.92–1.29)	0.31	**1.10 (0.92–1.30)**	**0.31**		
Type of anaesthetic								
Regional anaesthetic	1 [reference]		1 [reference]		1 [reference]			
General Anaesthetic	1.14 (1.02–1.27)	0.02	1.14 (1.02–1.27)	0.02	1.14 (1.02–1.27)	0.02	1.14 (1.02–1.27)	0.02
Model Performance measures								
AIC	22799.60		22798.00		22796.46		22795.53	

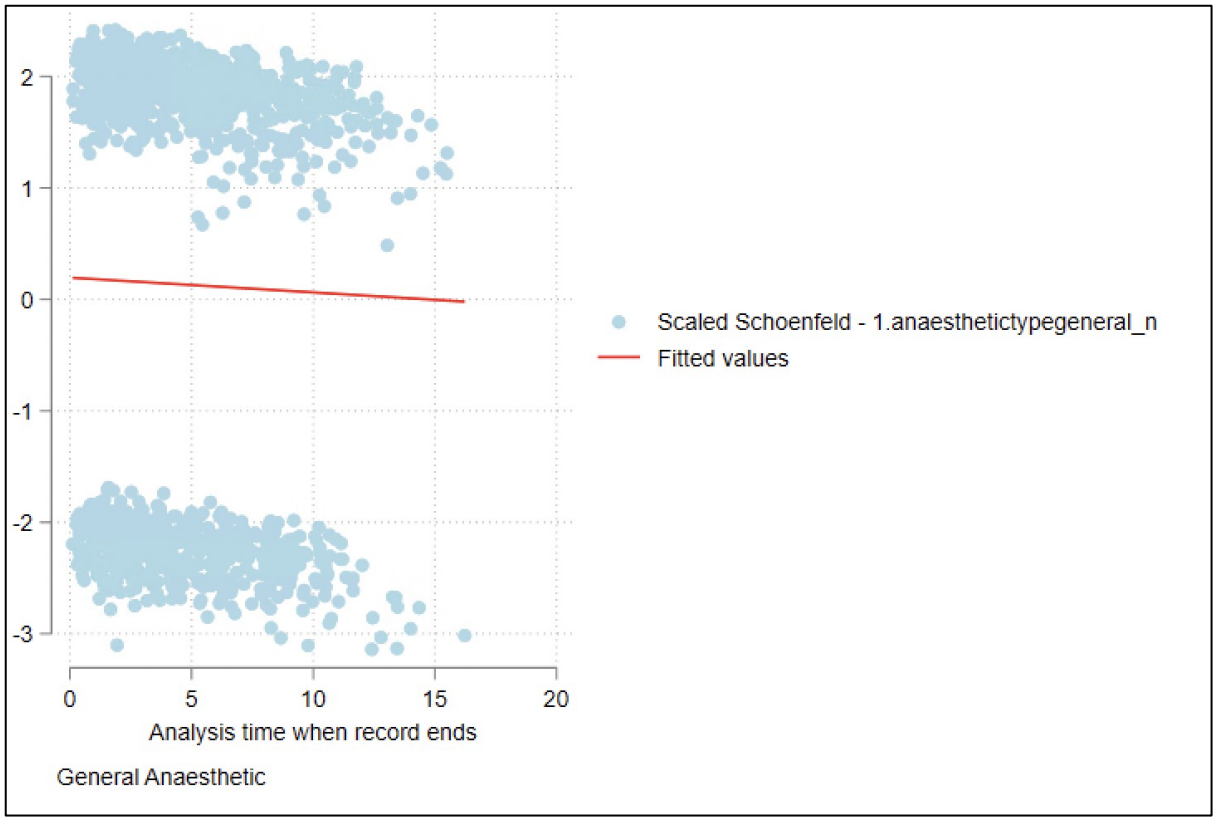
Schoenfeld Residuals following proportional hazards


4
2
0
-2
-4
0
5
10
15
20
Analysis time when record ends
Scaled Schoenfeld - yearlytwogrp1
Fitted values
Spline fitted: Low Surgical Casevolume

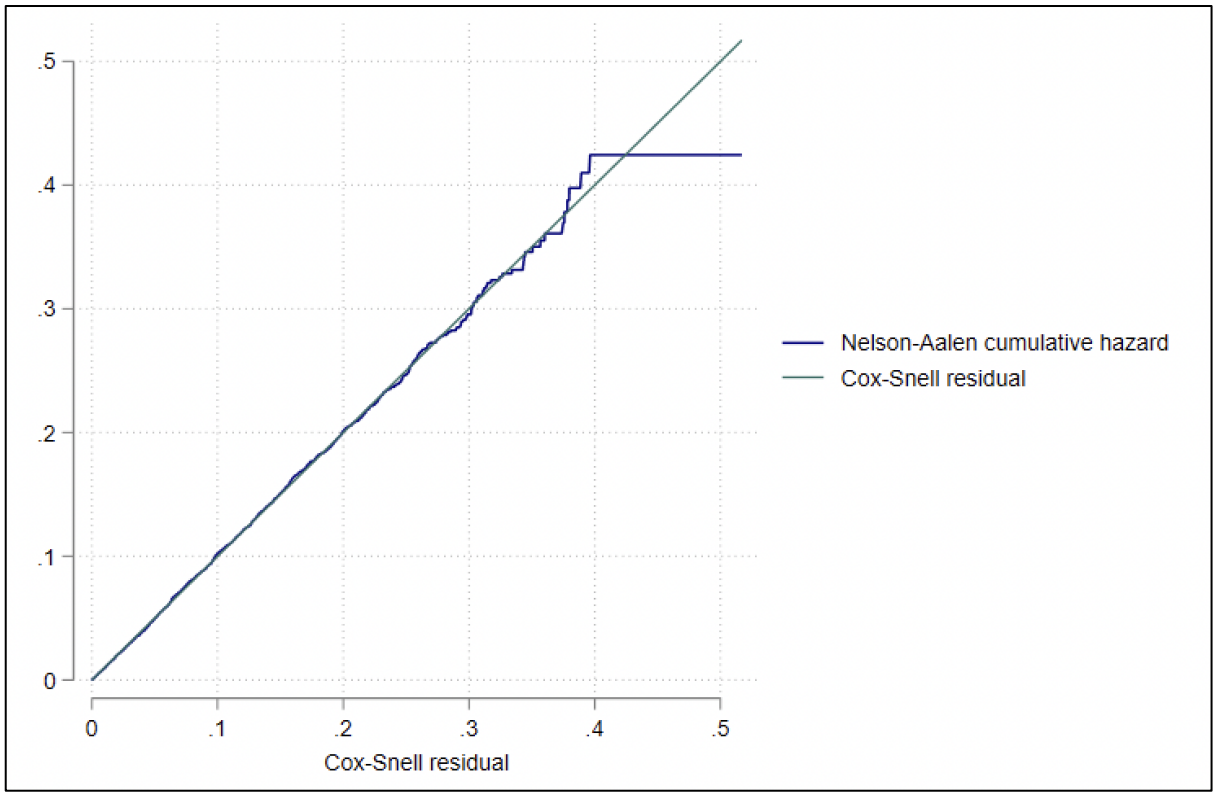

1.5
1
.5
0
-.5
0
5
10
15
20
Analysis time when record ends
Scaled Schoenfeld - yearlytwogrp2
Fitted values
Spline fitted: High Surgical Casevolume


.06
.04
.02
0
-.02
0
5
10
15
20
Analysis time when record ends
Scaled Schoenfeld - c.ageatprimary#c.ageatprimary
Fitted values
Age quadratic term


6
4
2
0
-2
0
5
10
15
20
Analysis time when record ends
Scaled Schoenfeld - 1.gender
Fitted values
Male



Cox-snell residuals



Comparison of Cox regression model with flexible parametric survival model

	Cox regression model Hazard ratio	Flexible parametric model survival model using splines and degrees of freedom (Stpm2) Hazard ratio
Surgical case load		
Spline fitted Low Volume	0.92	0.92
Spline fitted High Volume	0.98	0.98
Patient age at primary joint replacement	0.99	0.99
Gender		
Female	1 [reference]	1 [reference]
Male	1.22	1.22
Type of anaesthetic		
Regional anaesthetic	1 [reference]	1 [reference]
General anaesthetic	1.13	1.13
Model performance measures		
AIC	22828.83	9443.96

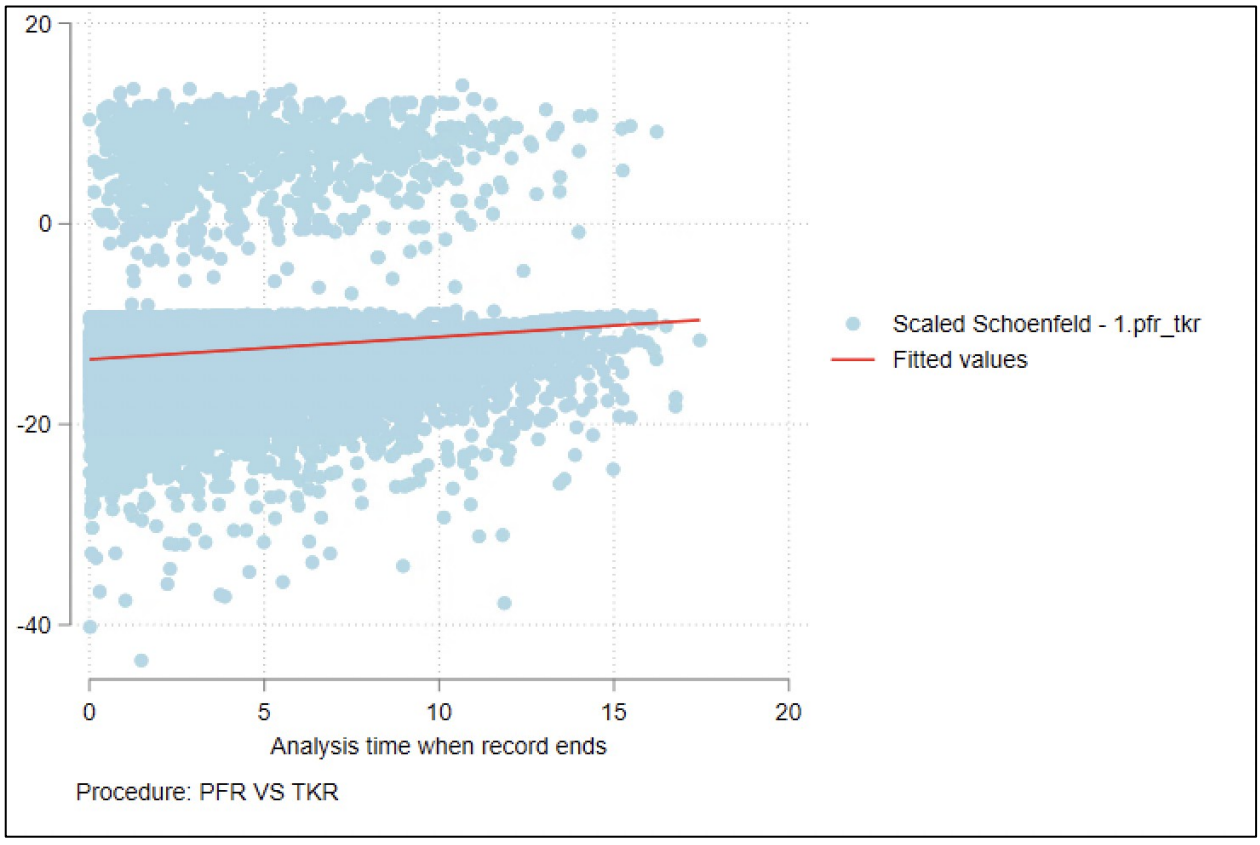
Appendix C

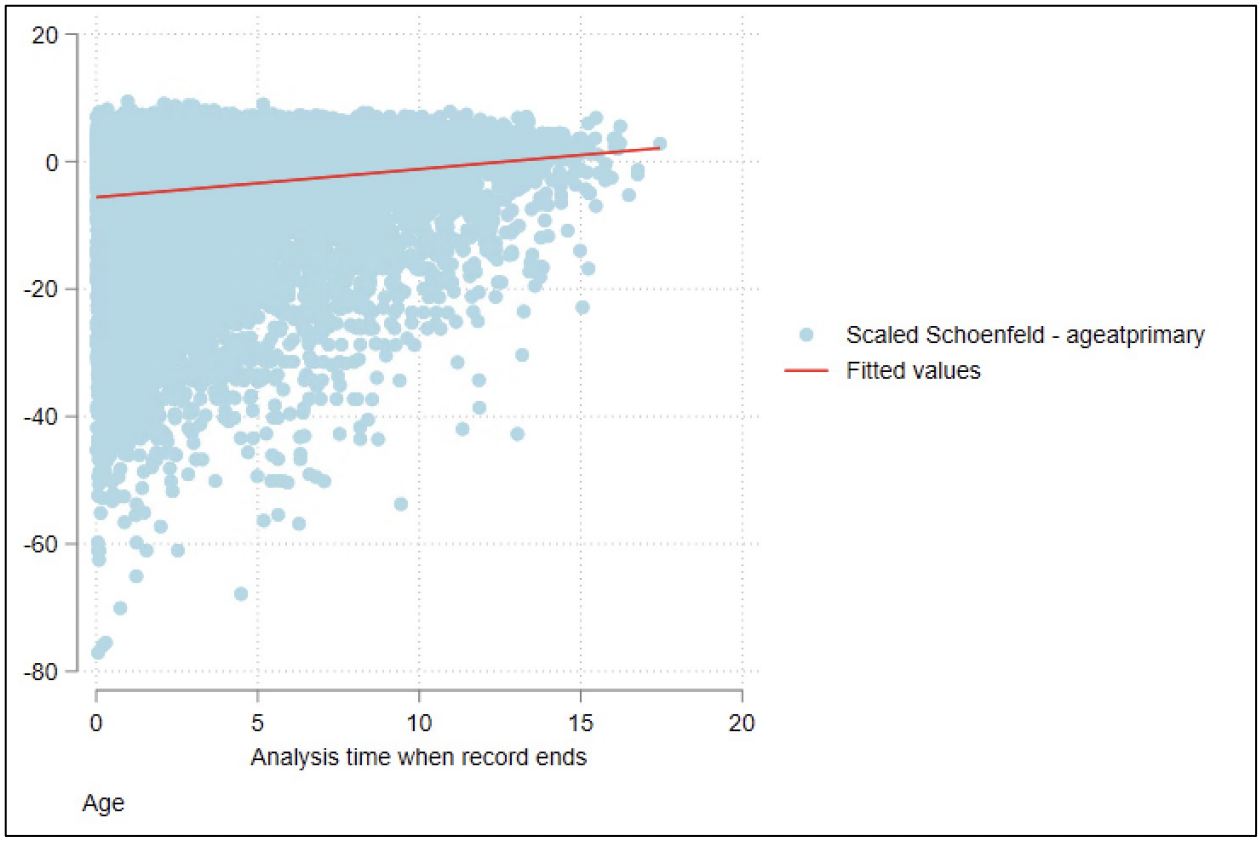
Model Building

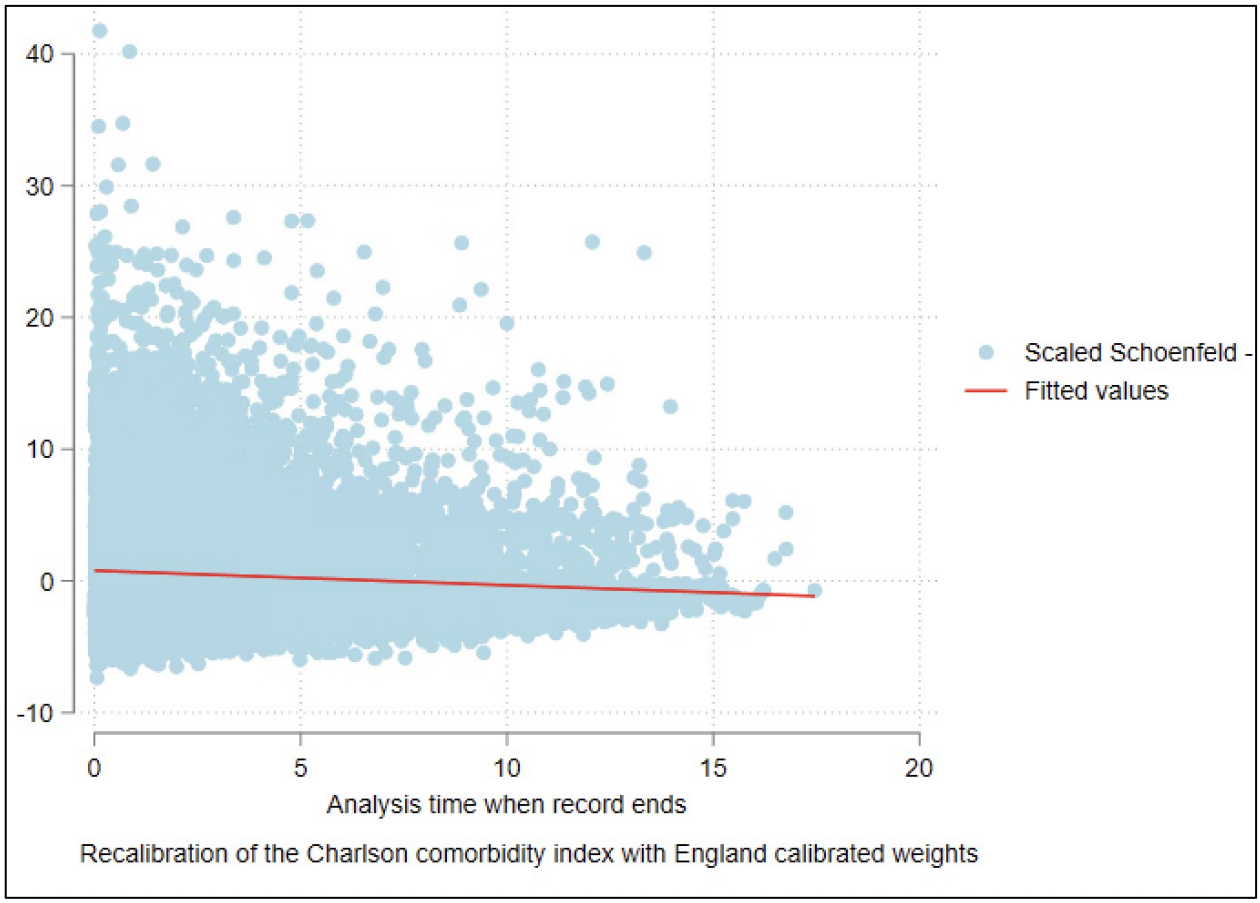
	Models Hazard Ratios (Confidence Intervals) Stcox with asa		**Models Hazard Ratios (Confidence Intervals)** Stcox without asa	
Predictors	**Model 1**		**Model 2**	
		P-value		**P-value**
Procedure				
PFA	3.46 (2.22-3.72)	0.01	3.46(3.22-3.73)	0.01
Patient Age at primary joint replacement	1.09 (1.05-1.13)	0.01	1.10 (1.04-1.13)	0.01
Modified Charlson Comorbidity Index	1.00 (1.00-1.00)	0.01	1.01 (0.98-1.02)	0.51
Gender				
Female	1 {Reference}		1 [reference]	
Male	1.26 (1.13-1.40)	0.01	1.26 (1.13-1.40)	0.01
Provider				
NHS	1 [reference]		1 [reference]	
Private	0.87 (0.74-1.02)	0.10	0.87 (0.74-1.02)	0.08
ASA				
ASA - 1	1 [reference]			
ASA -2	1.00 (0.89-1.10)	1.00		

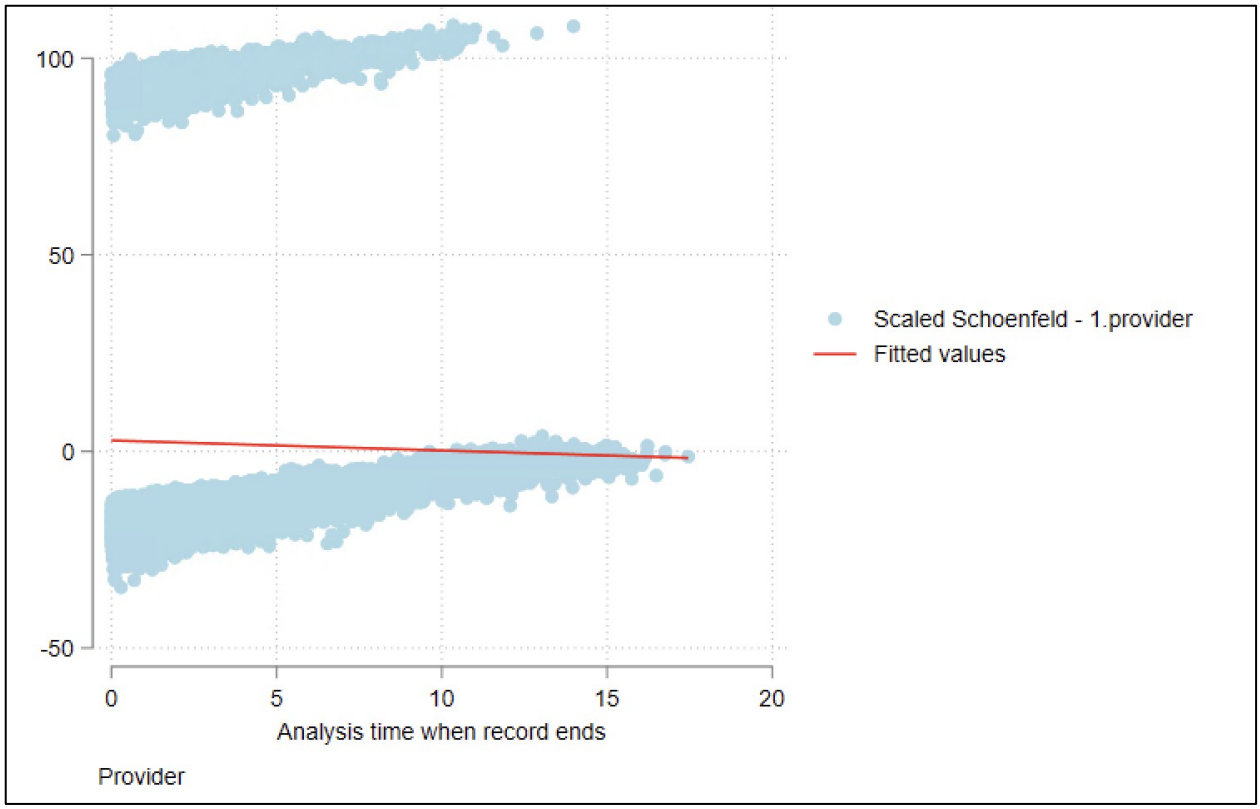
ASA- 3	1.01 (0.83-1.24)	1.00		
Model Performance measures				
AIC	24767.24		24763.31	
Likelihood ratio test * **Not sure if to include**				

Fig I-IV Schoenfeld Residuals following proportional hazards




20
0
-20
-40
-60
-80
0
5
10
15
20
Analysis time when record ends
Scaled Schoenfeld - ageatprimary
Fitted values
Age


40
30
20
10
0
-10
0
5
10
15
20
Analysis time when record ends
Scaled Schoenfeld -
Fitted values
Recalibration of the Charlson comorbidity index with England calibrated weights



Exploring TVC with finalised cox model

	Cox regression model Hazard ratio	Confidence interval	P-value	Time-varying effects Hazard ratio	Confidence interval	P-value
PFA	2.45	2.16 -2.78	0.01	1.33	1.22-1.45	**0.01***
Patient age at primary joint replacement	0.98	0.98-0.99	0.01	1.00	0.99-1.00	0.45
Modified CCI	1.01	0.99-1.03	0.38	0.99	0.97-1.01	0.25
Gender						

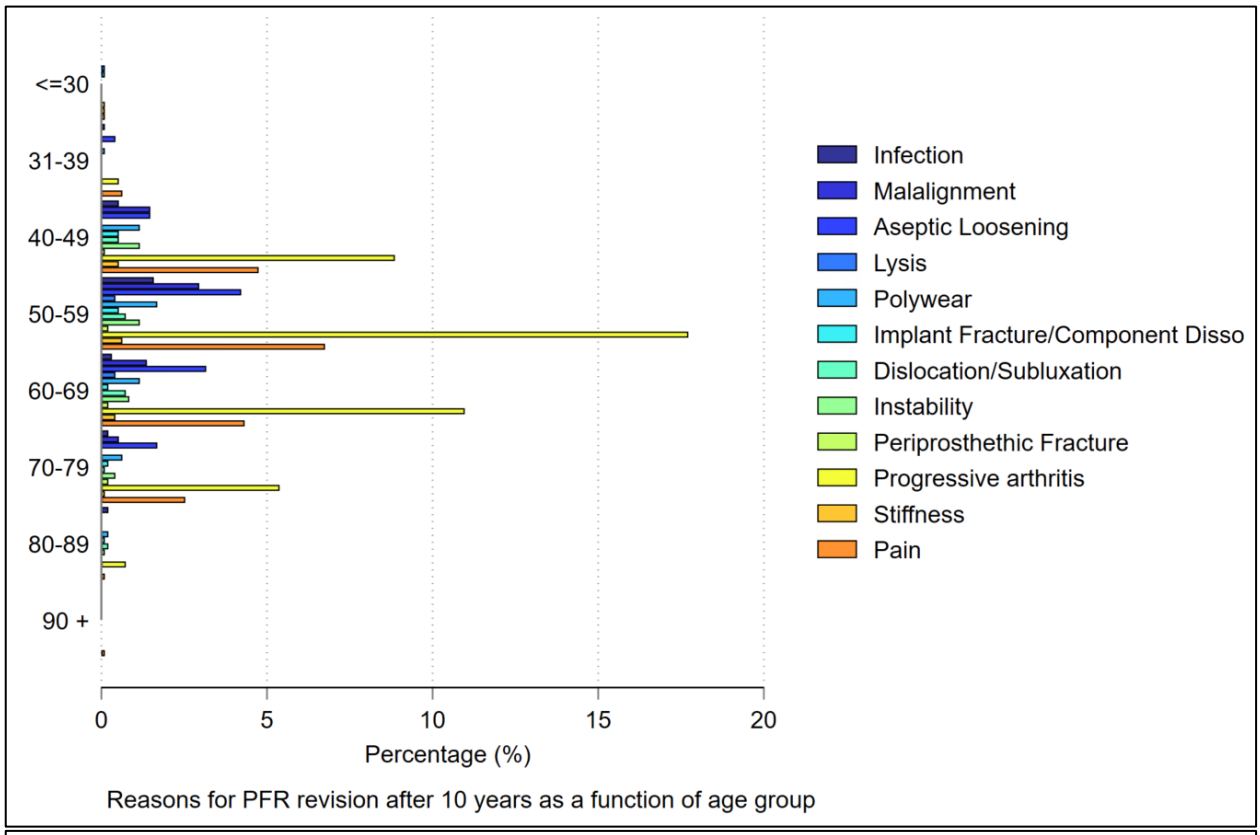
Female	1 [reference]			1 [reference]		
Male	1.60	1.35-1.89	0.01	0.81	0.72-0.91	**0.01***
Provider						
NHS	1 [reference]			1 [reference]		
Private	0.95	0.77-1.18	0.67	0.92	0.79-1.08	0.25

Table identifying time-varying covariate factors*

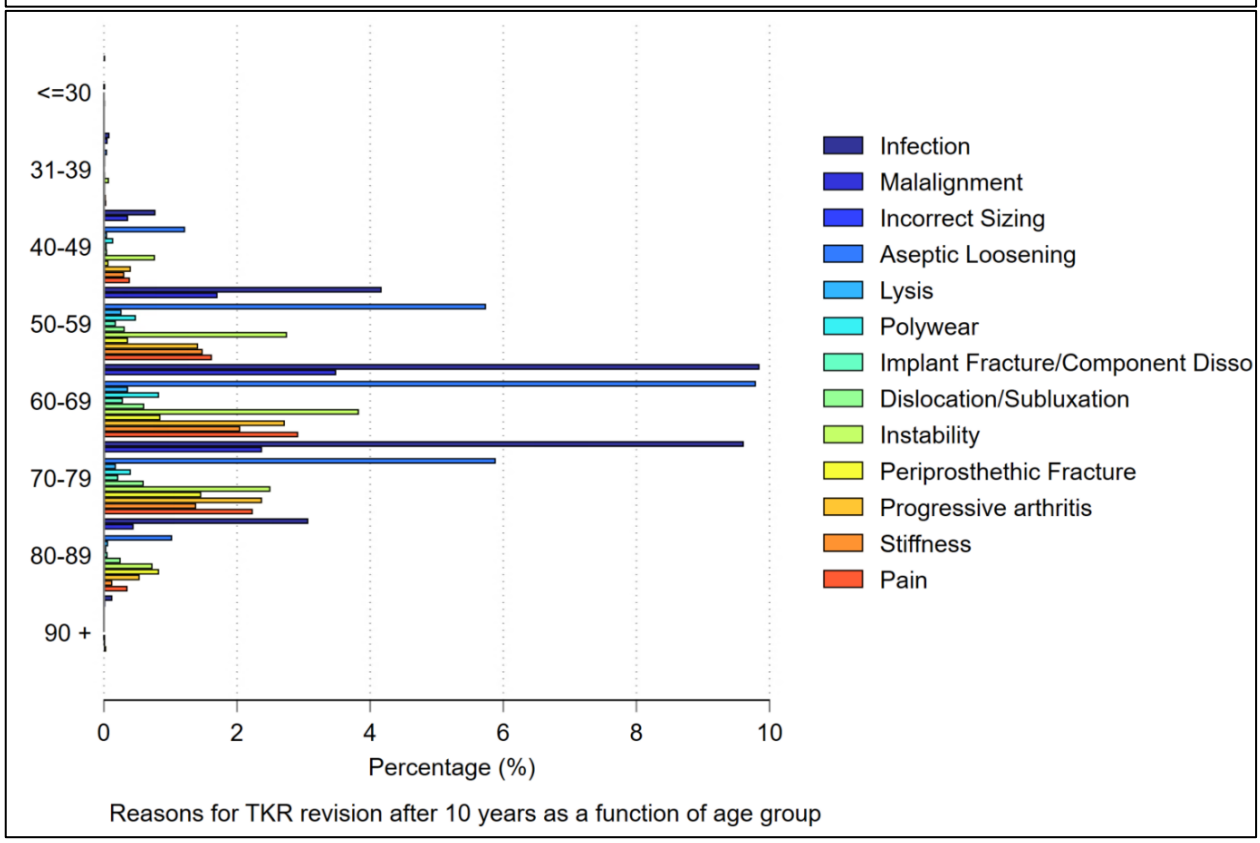
Comparison of Cox regression model with flexible parametric survival model

	Cox regression model **Hazard ratio**	**Flexible parametric model survival model using splines and degrees of freedom (Stpm2)** **Hazard ratio**
PFA	2.45	3.01
Patient age at primary joint replacement	0.98	0.98
Gender		
Female	1 [reference]	1 [reference]
Male	1.61	1.37
Provider		
NHS	1 [reference]	1 [reference]
Private	0.88	0.88
Model performance measures		
AIC	1510561.1	10817.04

Appendix D



Reasons for PFR revision after 10 years as a function of age group



Reasons for TKR revision after 10 years as a function of age group

Appendix E

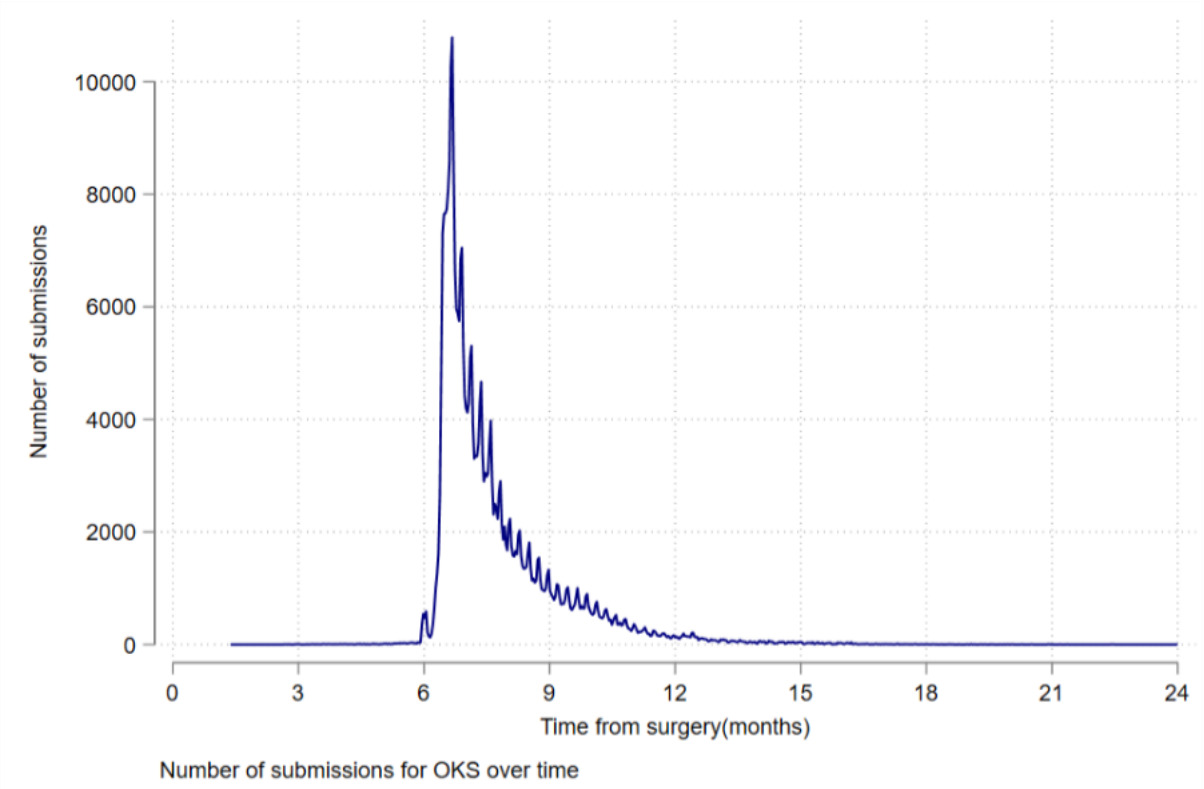


Fig 1a: Distribution of OKS Submissions Over Time, with peak Between 6 -12 Months Post-Surgery.

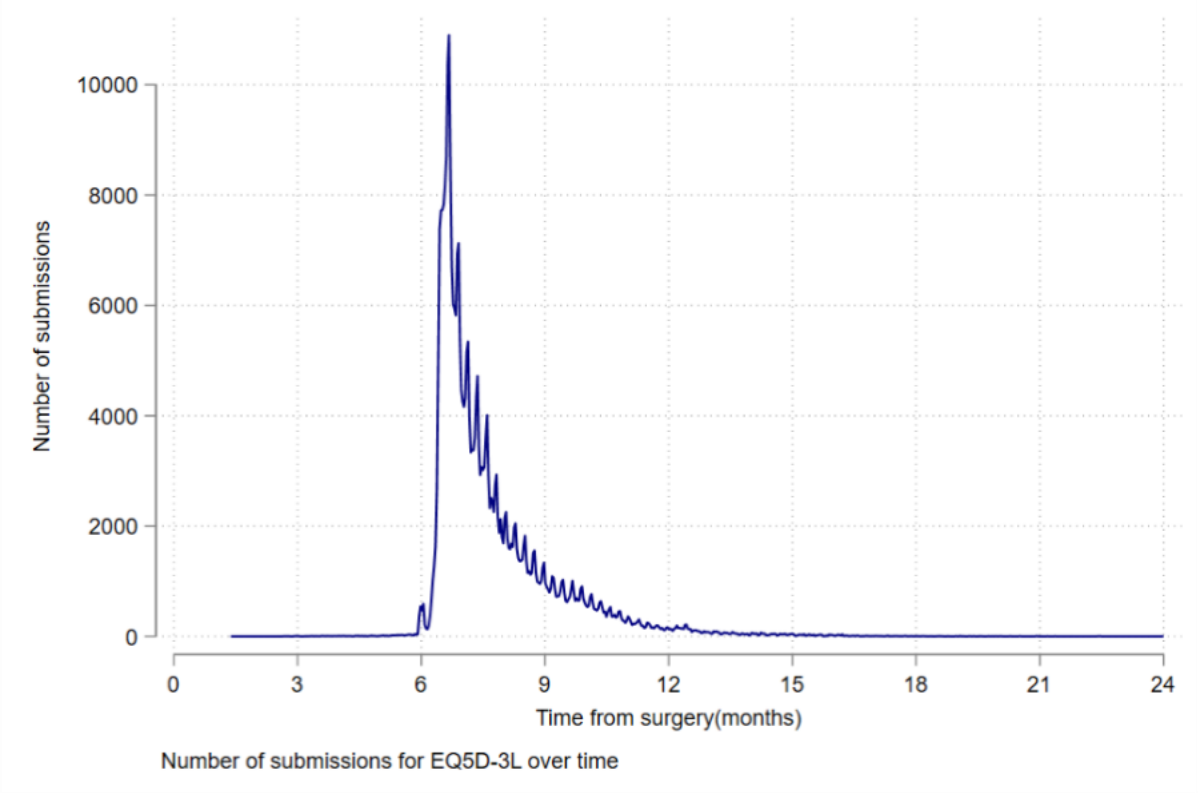


Fig 1b: Distribution of EQ5D-3L Submissions Over Time, with peak Between 6–12 Months Post-Surgery.

	Model 1 **Hazard ratio (Confidence intervals)**	P Value	**Model 2** **Hazard ratio (Confidence intervals)** Removal of obesity	P Value	**Model 3** **Hazard ratio (Confidence intervals)** Removal of gender	P Value	**Model 4** **Hazard ratio (Confidence intervals)** Removal of provider	P Value	**Model 5** **Hazard ratio (Confidence intervals)** Removal of social	P Value

									deprivation	
6-month Post-op OKS	0.94 (0.92-0.95)	0.01	0.94 (0.92-0.95)	0.01	0.94 (0.92-0.95)	0.01	0.94 (0.92-0.95)	0.01	0.94 (0.93-0.96)	0.01
Procedure type										
PFR	3.46 (2.70-4.45)	0.01	3.49 (2.71-4.50)	0.01	3.50 (2.72-4.51)	0.01	3.40 (2.66-4.36)	0.01	3.40 (2.66-4.35)	0.01
Gender										
Female	1 [Reference]									
Male	1.44 (0.97-2.15)	0.10	1.41 (0.95-2.11)	0.09						
Provider										
NHS	1 [Reference]									
Private	1.45 (1.00-2.16)	0.06	1.46 (0.97-2.19)	0.07	1.45 (0.96 – 2.17)	0.08				
Age	0.99 (0.97-1.00)	0.10	0.99 (0.97-1.00)	0.11	0.99 (0.97-1.00)	0.14	0.99 (0.97-1.00)	0.16	0.99 (0.98-1.00)	0.20

Social deprivation										
2nd	1.14 (0.61-2.15)	0.68	1.15 (0.61-2.17)	0.66	1.17 (0.62-2.21)	0.63	1.18 (0.63-2.25)	0.60		
3rd	1.09 (0.65-1.82)	0.73	1.10 (0.66-1.85)	0.71	1.13 (0.68-1.90)	0.64	1.19 (0.71-1.99)	0.51		
4th	1.34 (0.80-2.26)	0.33	1.32 (0.77-2.24)	0.31	1.30 (0.76-2.21)	0.33	1.33 (0.78-2.26)	0.30		
5th	0.96 (0.53-1.74)	0.90	0.97 (0.54-1.75)	0.91	0.97 (0.53-1.75)		1.10 (0.56-1.82)	0.97		
Obesity										
Not obese	1 [Reference]									
Obese	0.85 (0.52-1.36)	0.52								

Table 1: Model building for clinical threshold to revision for OKS.

Table 1 shows backward selection starting with the model including all potential predictors. Variables with the largest p-value above the significance level are eliminated one at a time from the model. The model is then refitted and the process repeated

	Model 1 **Hazard ratio (Confidence intervals)**	P value
6-month Post-op OKS	0.94 (0.93-0.95)	0.01
Procedure type		
PFR	3.60 (2.81-4.61)	0.01
Age##age	1.00 (1.00-1.00)	0.01

Table 2: Final Model with age transformation .

Table 2 shows transformation of the variable age (quadratic) in order to improve the model fit as it is deemed to be a clinically important variable.

	Cox regression model **Hazard ratio**	**P value**	**Time varying effects hazards ratio**	**P value**
6-month Post-op OKS	0.94 (0.93-0.95)	0.01	1.04 (1.02-1.06)	0.01*
Procedure type				
PFR	3.60 (2.81-4.61)	0.01	1.73 (1.25-2.40)	0.01*
Age##age	1.00 (1.00-1.00)	0.01	1.00 (1.00-1.00)	1.00

Table 3: Exploring time-varying coefficients with finalised Cox regression model.

Table 3 lists variables from a Cox Regression model with p-values less than 0.05 indicating time-varying coefficients.

	Cox regression model **Hazard ratio**	**Flexible parametric survival model using splines and degrees of freedom (Stpm2)** **Hazard ratio**
6-month Post-op OKS	0.90 (0.88-0.92)	0.93 (0.92-0.94)
Procedure type		
PFR	2.01 (1.31-3.10)	3.15 (2.44-4.07)
Age##age	1.00 (1.00-1.00)	1.00 (1.00-1.00)
AIC	**1278.37**	**785.88**

Table 4: Comparison of cox regression model with flexible parametric survival model.

Based on Table 4, it can be seen that the flexible parametric survival model with splines and degrees of freedom are conceptually very similar to the Cox models (and provide similar estimates), but offer advantages over Cox models if hazard ratios are not the only quantity one wants to estimate

	Model 1 **Hazard ratio (Confidence intervals)**	P Value	**Model 2** **Hazard ratio (Confidence intervals)** Removal of obesity	P Value	**Model 3** **Hazard ratio (Confidence intervals)** Removal of provider	P Value	**Model 4** **Hazard ratio (Confidence intervals)** Removal of social	P Value	**Model 5** **Hazard ratio (Confidence intervals)** Removal of gender	P Value

							deprivation			
Post-op EQ5D-3L	0.11 (0.05 – 0.24)	0.01	0.11 (0.05 – 0.24)	0.01	0.11 (0.05 – 0.25)	0.01	0.11 (0.05 – 0.24)	0.01	0.12 (0.05 – 0.24)	0.00
Procedure type										
PFR	3.90 (3.01 – 5.02)	0.01	3.89 (3.02 – 5.01)	0.01	3.84 (3.00 – 4.91)	0.01	3.84 (3.00 – 4.92)	0.01	3.83 (3.00 – 4.92)	0.00
Gender										
Female	1 [Reference]									
Male	1.48 (0.99 – 2.21)	0.06	1.48 (1.00-2.20)	0.06	1.47 (0.99-2.20)	0.06	1.48 (1.00 – 2.20)	0.05		
Provider										
NHS	1 [Reference]									
Private	1.21 (0.79 – 1.84)	0.40	1.21 (0.79 – 1.85)	0.38						
Age	0.98 (0.96-1.00)	0.04	0.98 (0.96-1.00)	0.04	0.98 (0.96-1.00)	0.04	0.98 (0.97-1.00)	0.05	0.98	0.08
Social										

deprivation										
2nd	1.15 (0.58 – 2.29)	0.69	1.15 (0.58 – 2.28)	0.67	1.16 (0.58 – 2.30)	0.67				
3rd	1.17 (0.68 – 2.00)	0.59	1.17 (0.68 – 2.00)	0.58	1.19 (0.70 – 2.04)	0.52				
4th	1.18 (0.67 – 2.08)	0.56	1.18 (0.67- 2.08)	0.57	1.20 (0.69 – 2.11)	0.52				
5th	0.92 (0.50 – 1.71)	0.80	0.92 (0.50- 1.71)	0.80	0.94 (0.51- 1.73)	0.85				
Obesity										
Not obese	1 [Reference]									
Obese	1.00 (0.62 – 1.64)	0.99								

Table 5: Model building for clinical threshold to revision for EQ5D-3L.

Table 5 shows backward selection starting with the model including all potential predictors. Variables with the largest p-value above the significance level are eliminated one at a time from the model. The model is then refitted and the process repeated

	Model 1 **Hazard ratio (Confidence intervals)**	P value
Post-op EQ5D-3L	0.11 (0.05-0.23)	0.01
Procedure type		
PFR	3.95 (3.08-5.07)	0.01
Age##age	1.00 (1.00-1.00)	0.16

Table 6: Final Model with age transformation .

The table shows transformation of the variable age (quadratic) in order to improve the model fit as it is deemed to be a clinically important variable.

	Cox regression model **Hazard ratio**	**P value**	**Time varying effects hazards ratio**	**P value**
Post-op EQ5D-3L	0.11 (0.05-0.23)	0.01	4.44 (2.41-8.18)	0.01*
Procedure type				
PFR	3.95 (3.08-5.07)	0.01	1.70 (1.21-2.37)	0.01*
Age##age	1.00 (1.00-1.00)	0.16	1.00 (1.00-1.00)	0.05

Table 7: Exploring time-varying coefficients with finalised cox model

Table 7 lists variables from a Cox Regression model with p-values less than 0.05 indicating time-varying coefficients.

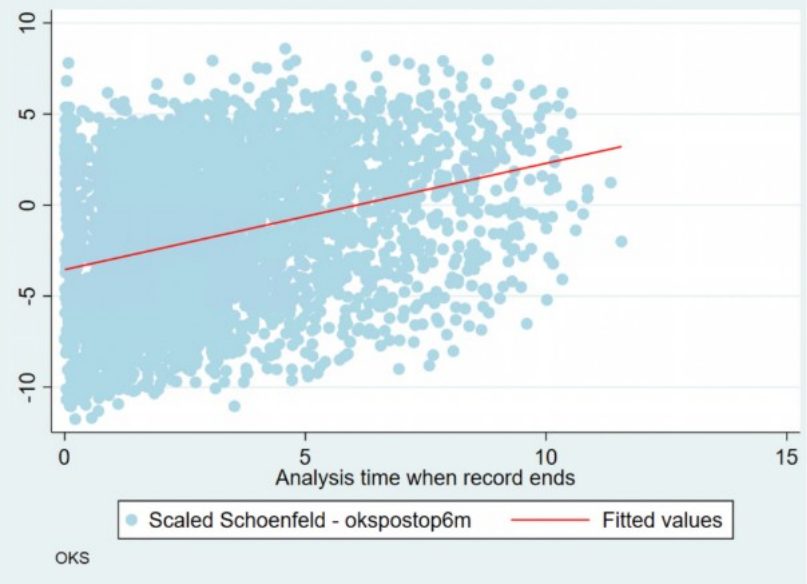
	Cox regression model **Hazard ratio**	**Flexible parametric survival model using splines and degrees of freedom (Stpm2)** **Hazard ratio**
Post-op EQ5D-3L	0.11 (0.05-0.23)	0.08 (0.40-0.15)
Procedure type		
PFR	3.95 (3.08-5.07))	3.50 (2.72-4.53)
Age##age	1 (1-1)	1 (1-1)
AIC	**1204**	**762**

Table 8: Comparison of cox regression model with flexible parametric survival model

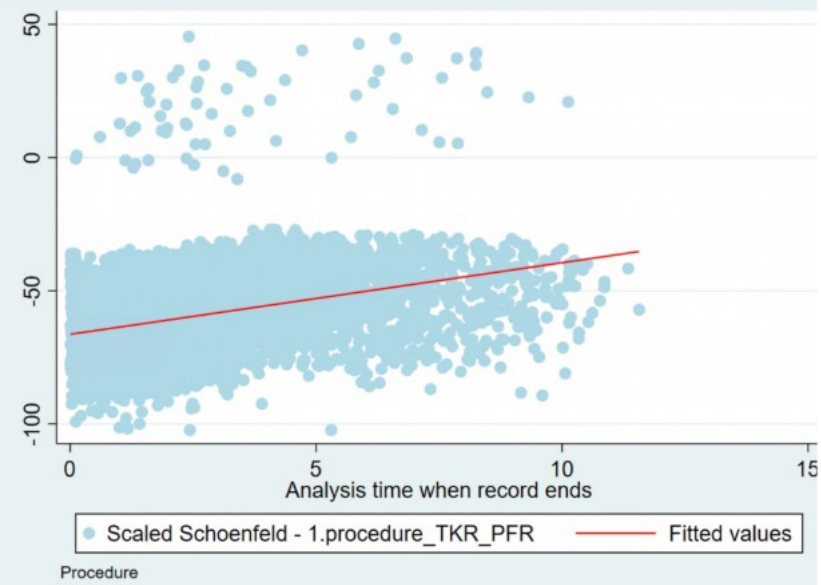
	Test type	P-value
Age	T-test	0.01
Social deprivation	Chi-squared	0.02
Ethnicity	Chi-squared	0.18
High volume: Low-volume surgeon	Chi-squared	0.86
Pre-operative EQ5D-3L	T-test	0.01

Table 9: Summary of statistical tests on EQ5D-3L better and worse categories using Pareto analysis.

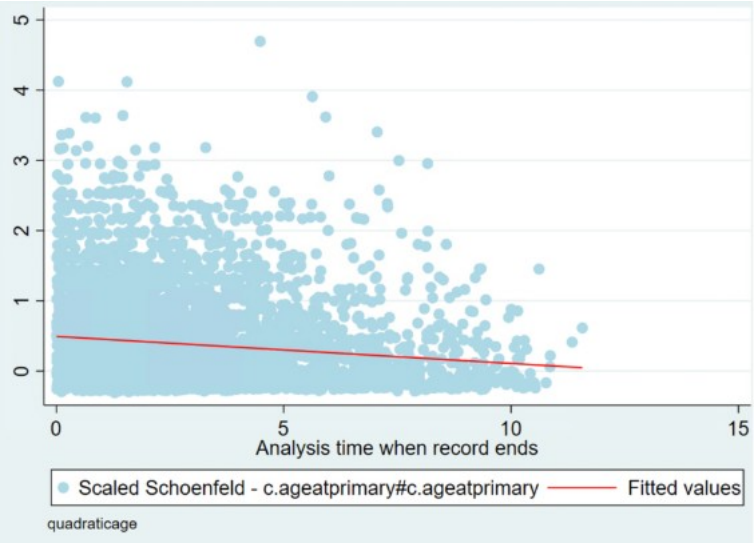
Figures 2a-c: Schoenfeld residuals for testing proportional hazards assumption for covariate Oxford Knee Score



Figures 2a: Schoenfeld residuals for testing proportional hazards assumption for covariate type of procedure

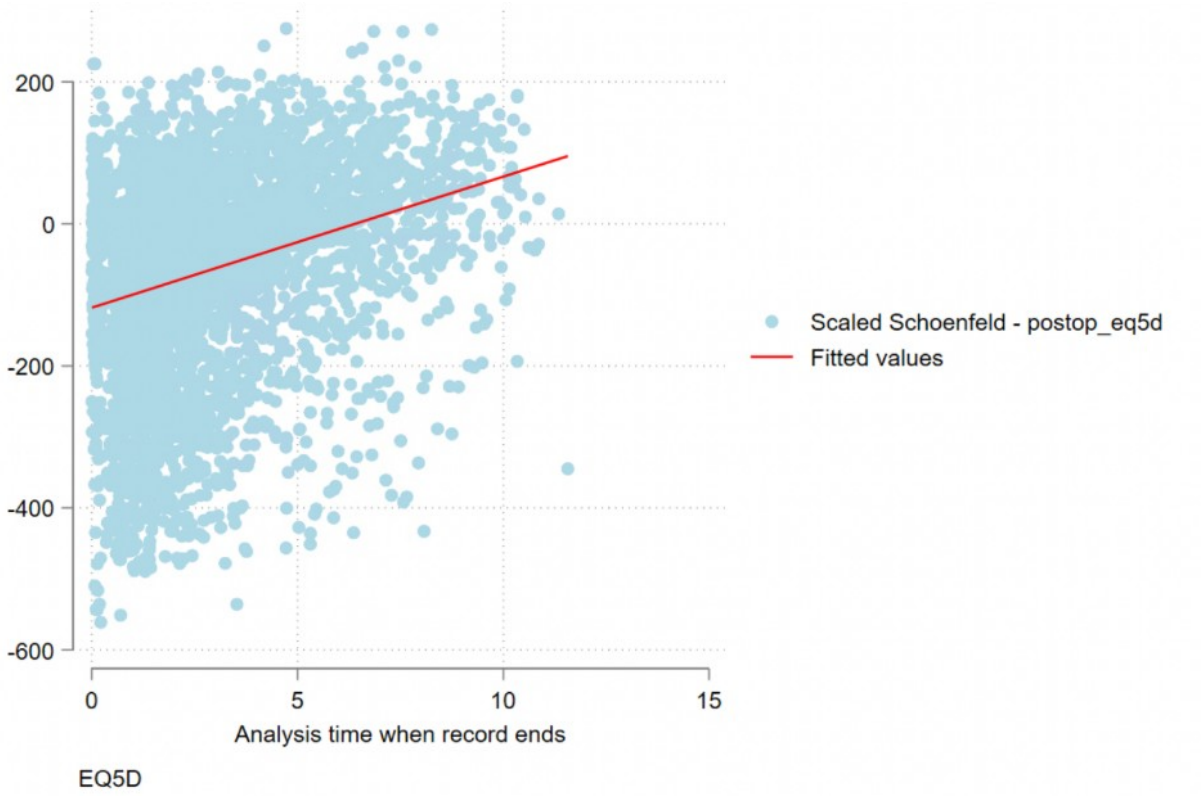


Figures 2b: Schoenfeld residuals for testing proportional hazards assumption for covariate quadratic age

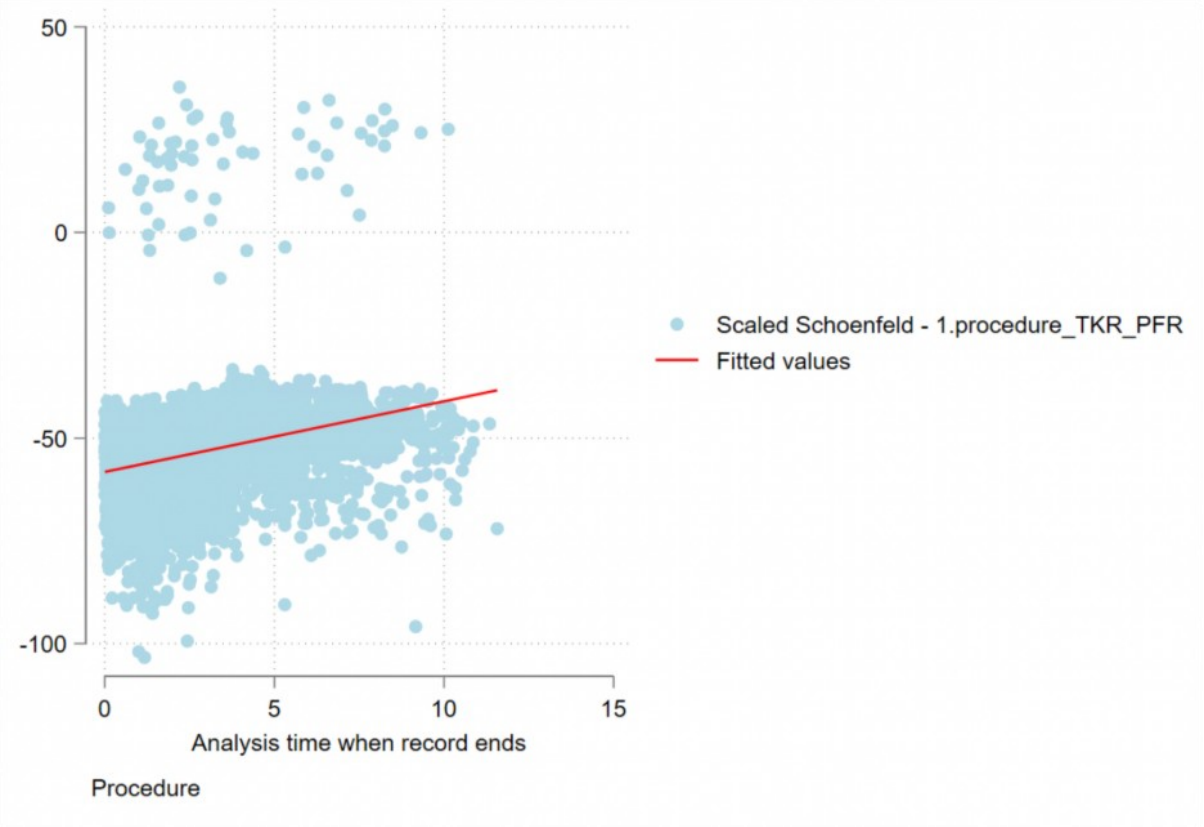


Figures 2c: The Schoenfeld residuals are calculated for each variable to see if each variable independently satisfies the assumptions of the Cox model. These are presented graphically, whereby if the covariate satisfies proportional hazards, the line should be flat centred around zero.

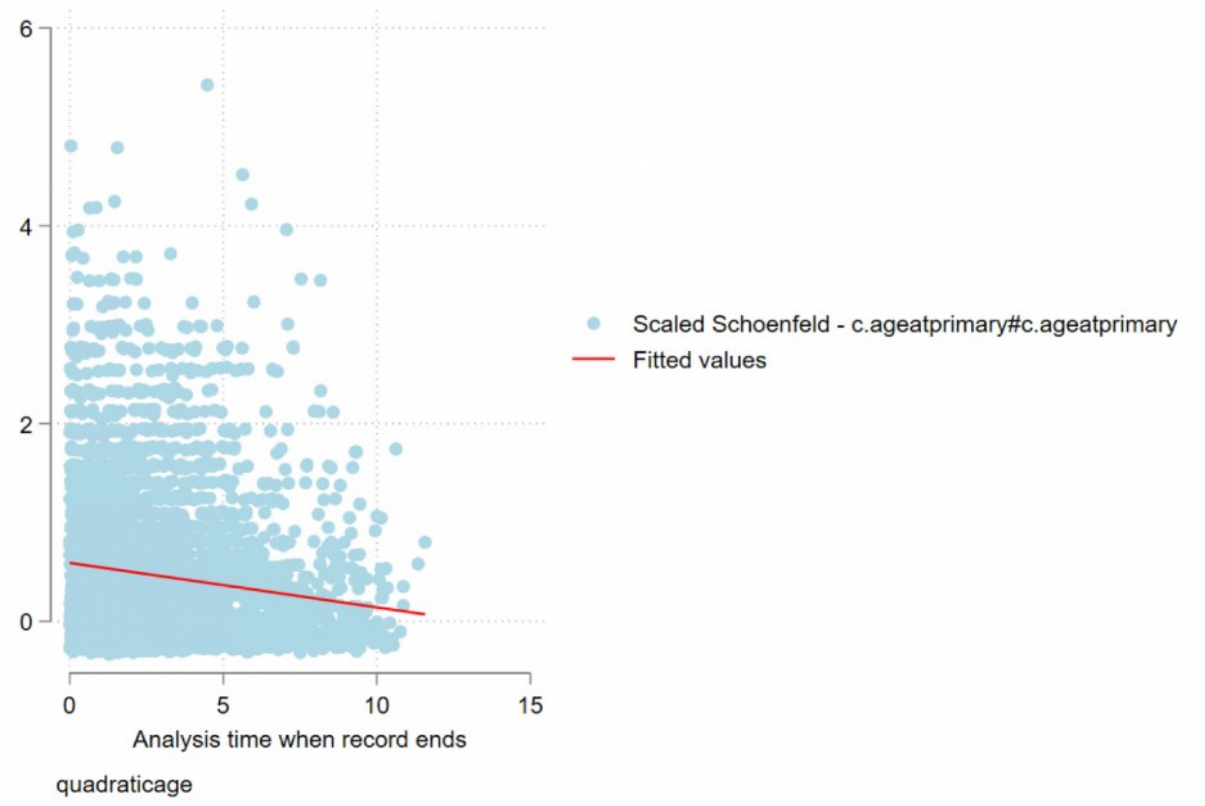
Figures 3a-c: Schoenfeld residuals for testing proportional hazards assumption for covariate EQ5D-3L



Figures 3a: Schoenfeld residuals for testing proportional hazards assumption for covariate EQ5D-3L

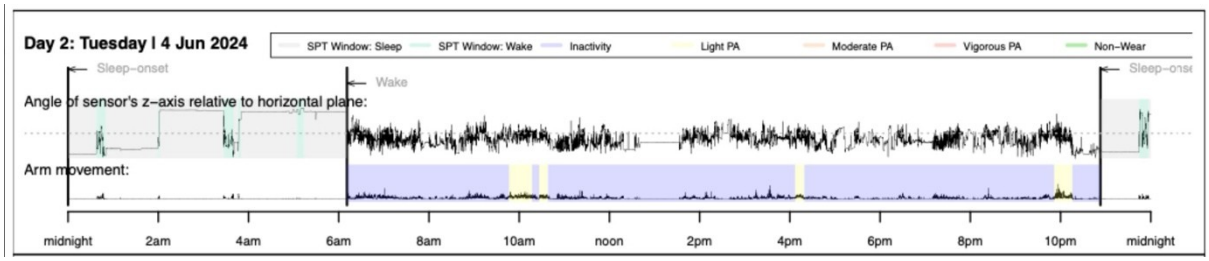


Figures 3b: Schoenfeld residuals for testing proportional hazards assumption for covariate type of procedure

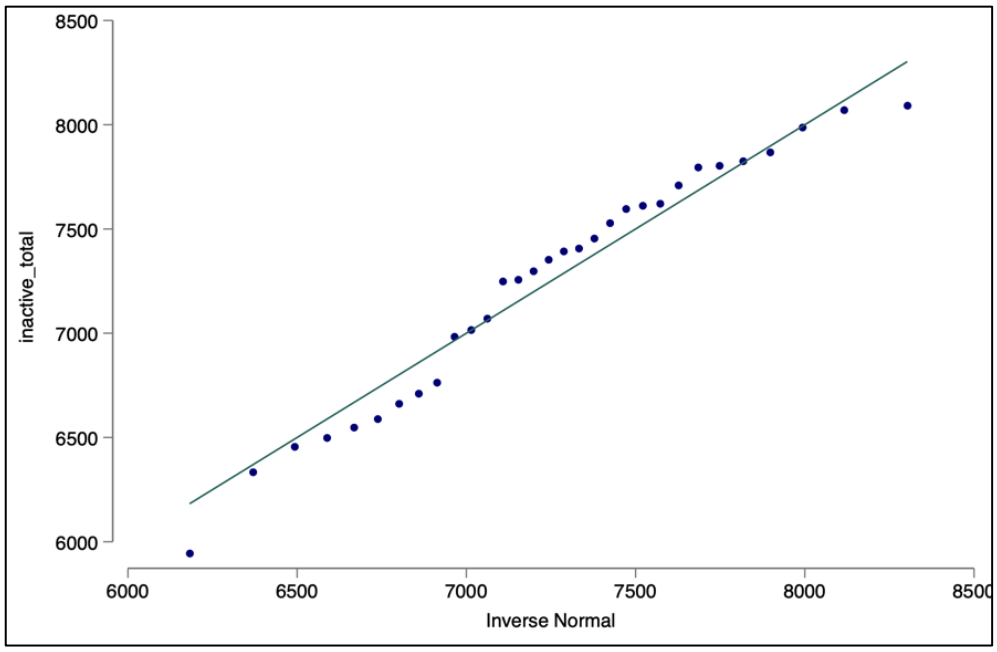


Figures 3c: Schoenfeld residuals for testing proportional hazards assumption for covariate age

Appendix F



A graph of a patient's physical activity profile recorded over a single day



An illustration depicting the assessment of normality distribution using Q-Q plots, highlighting data spread and deviations from the expected normal distribution for inactive activity

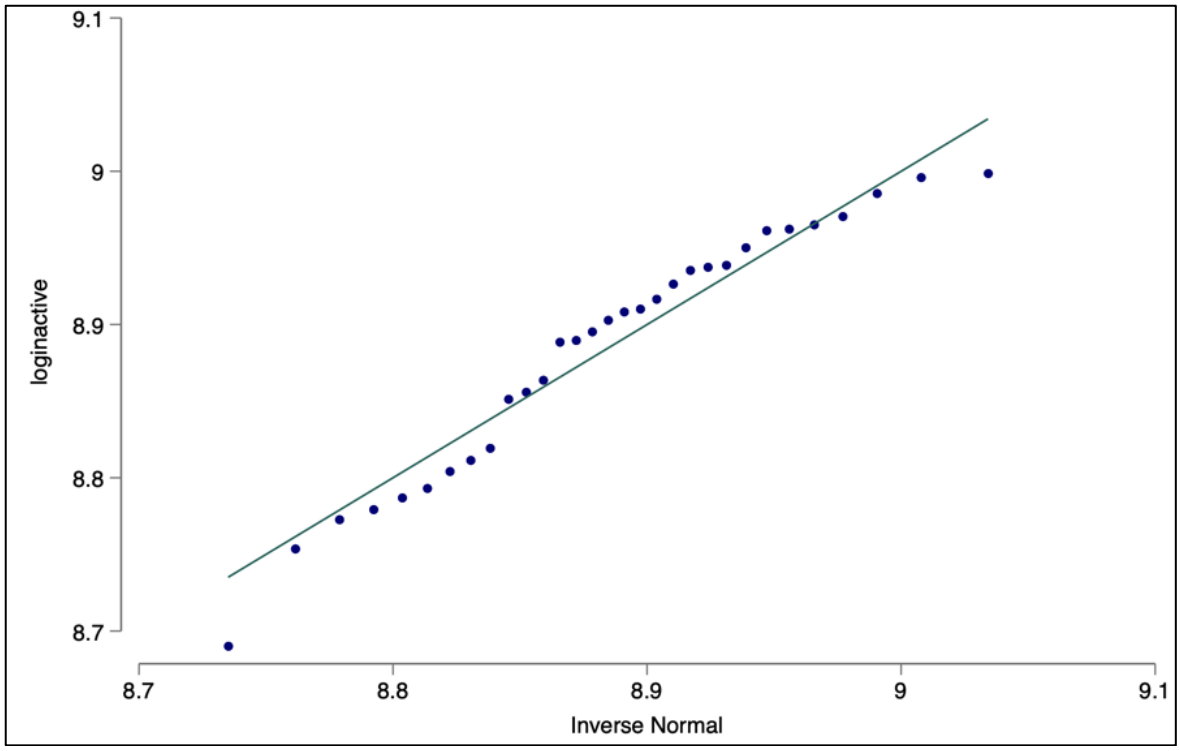
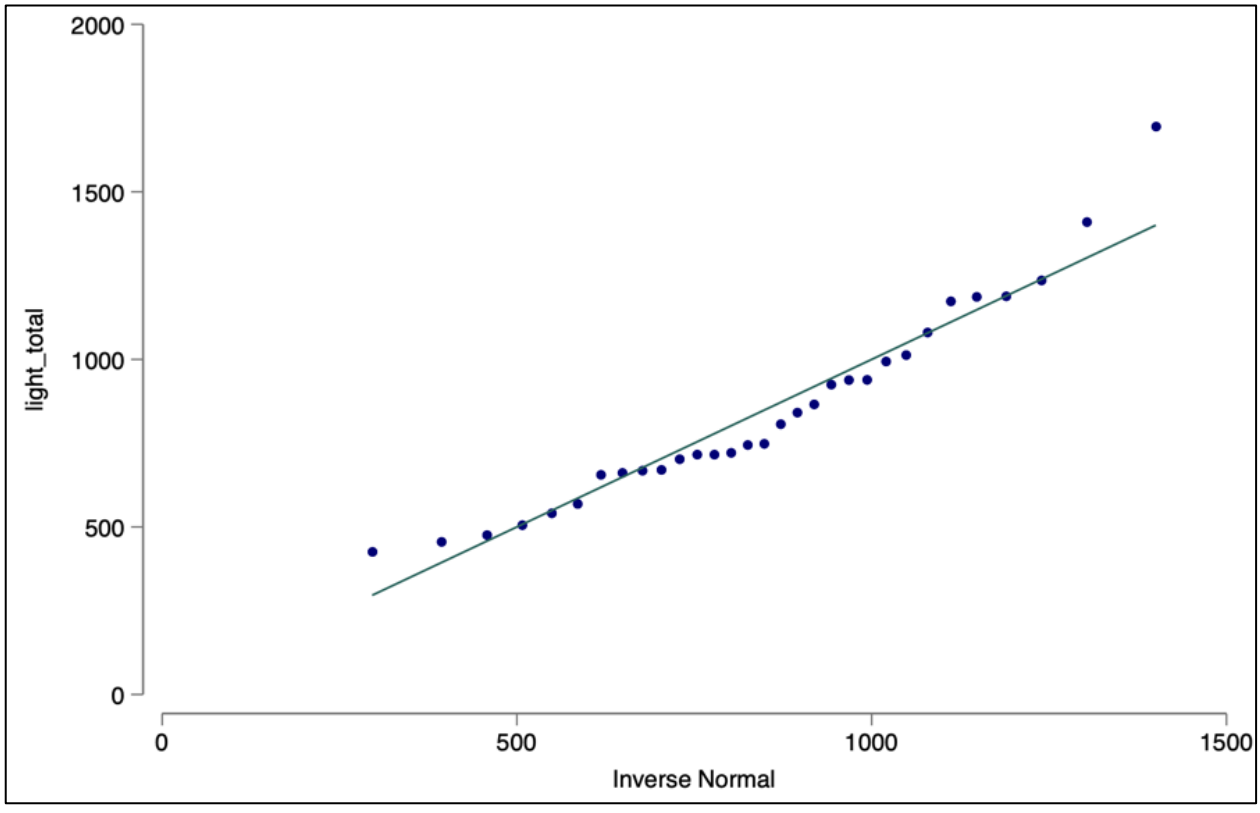


Illustration demonstrating log transformation to normalise skewed data, skewness and data symmetry was not improved therefore non-normally distributed data test were used for statistical analysis



An illustration depicting the assessment of normality distribution using

Q-Q plots, highlighting data spread and deviations from the expected normal distribution for light activity

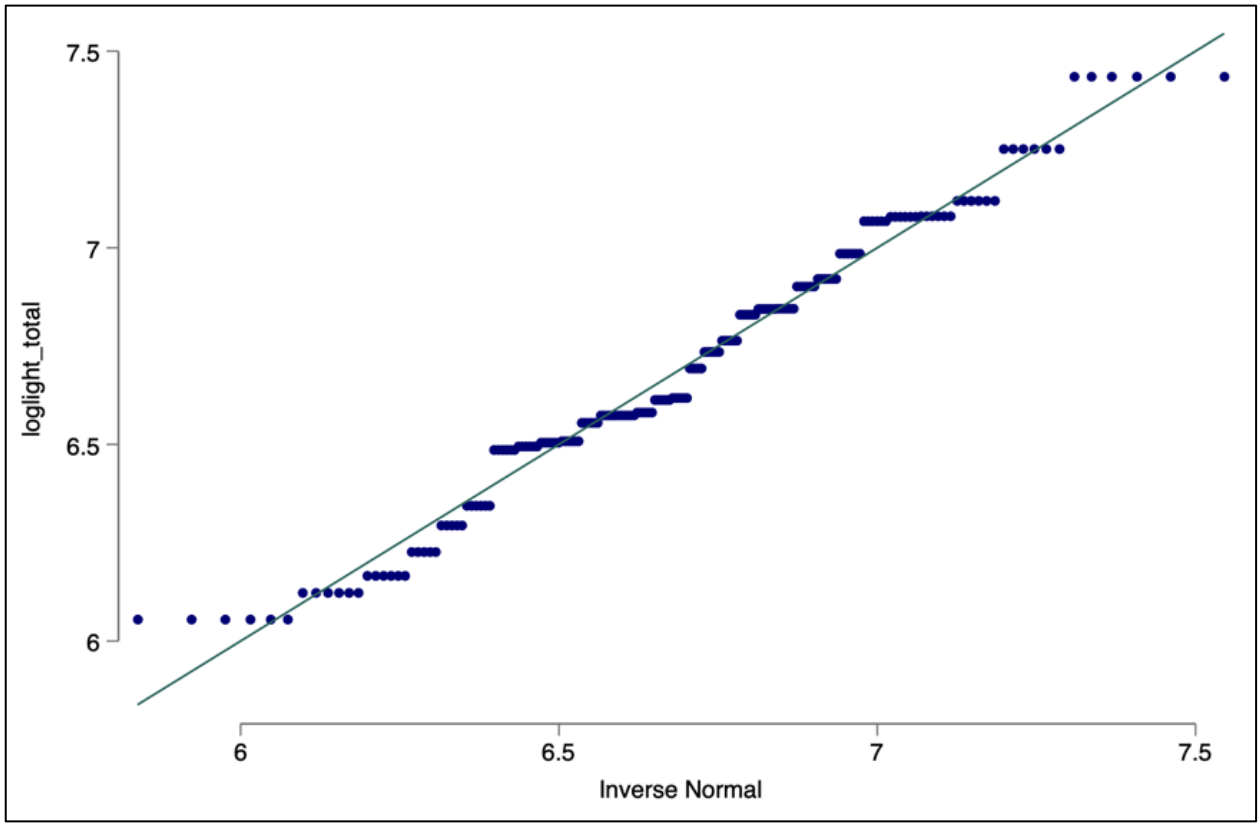
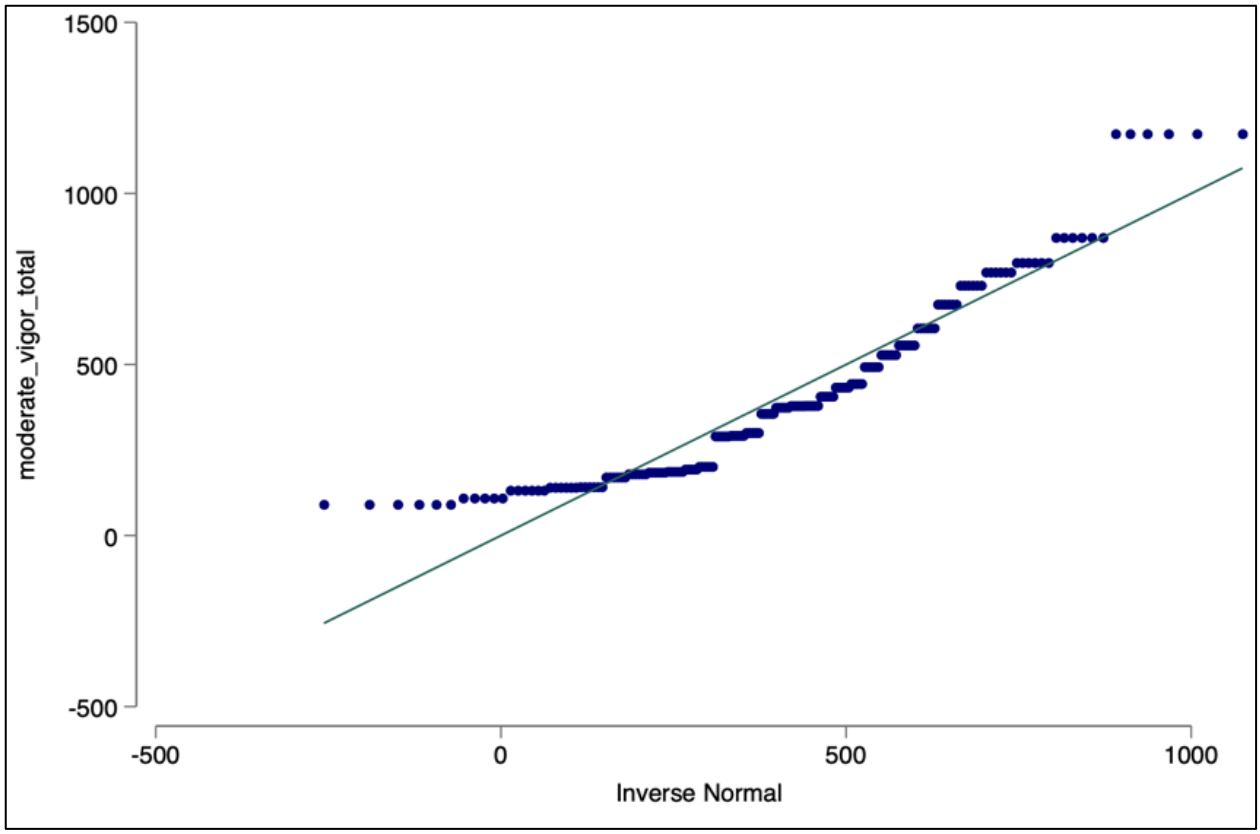


Illustration demonstrating log transformation to normalise skewed data, skewness and data symmetry was not improved therefore non-normally distributed data test were used for statistical analysis



An illustration depicting the assessment of normality distribution using Q-Q plots, highlighting data spread and deviations from the expected normal distribution for moderate activity

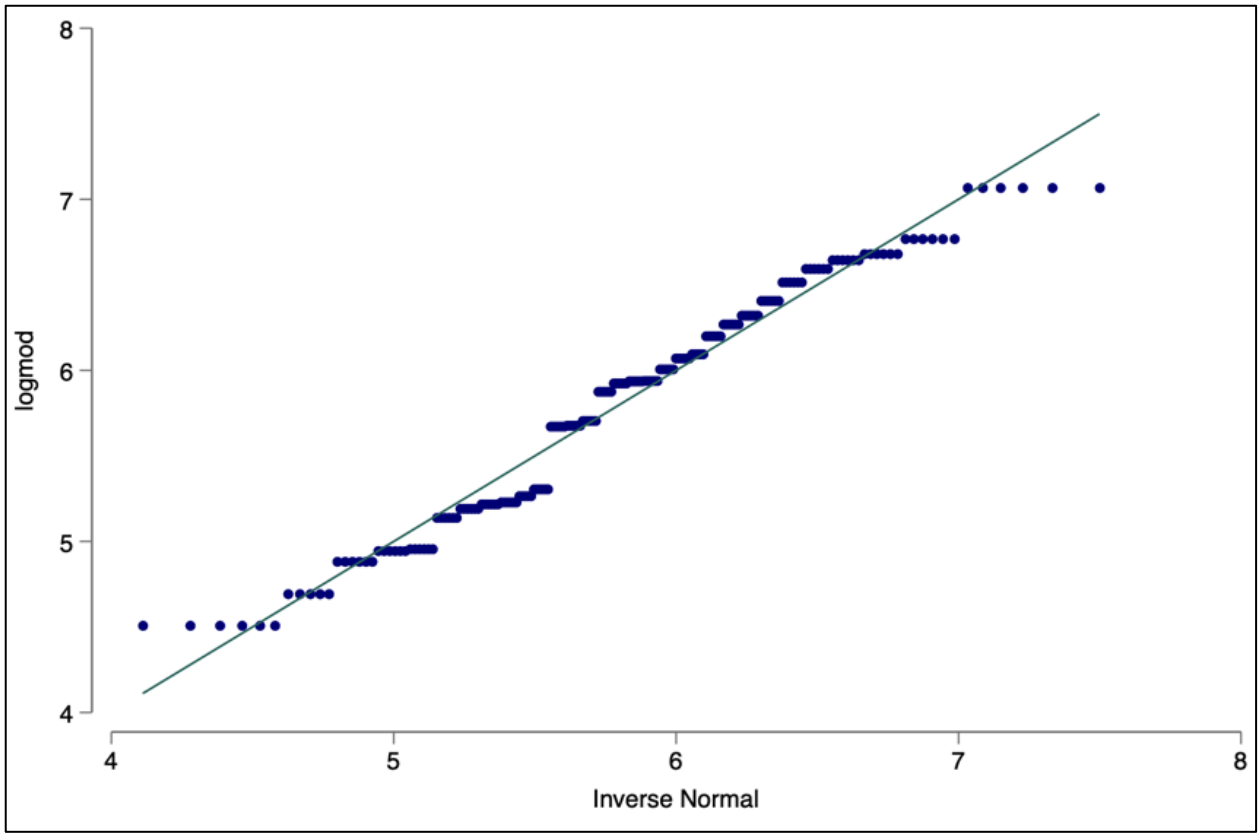
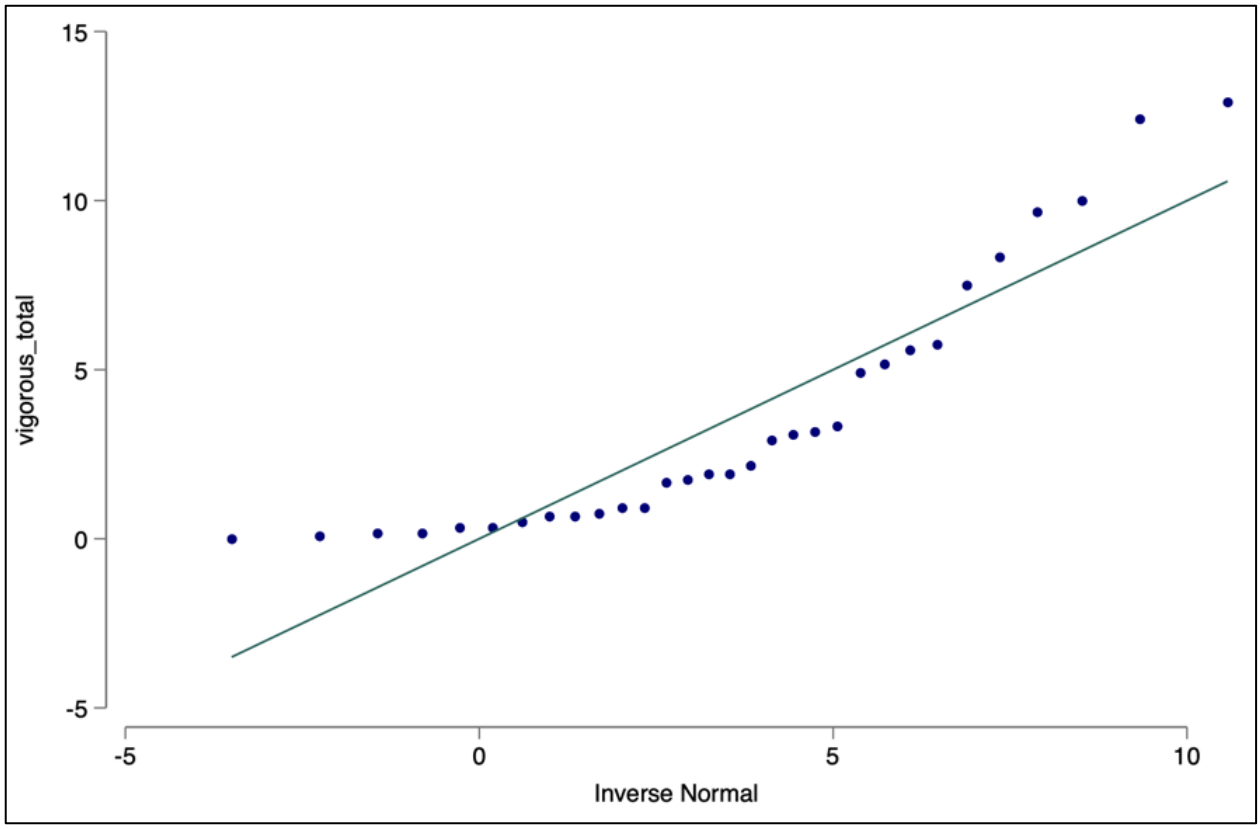


Illustration demonstrating log transformation to normalise skewed data, skewness and data symmetry was not improved therefore non-normally distributed data test were used for statistical analysis



An illustration depicting the assessment of normality distribution using Q-Q plots, highlighting data spread and deviations from the expected normal distribution for vigorous activity

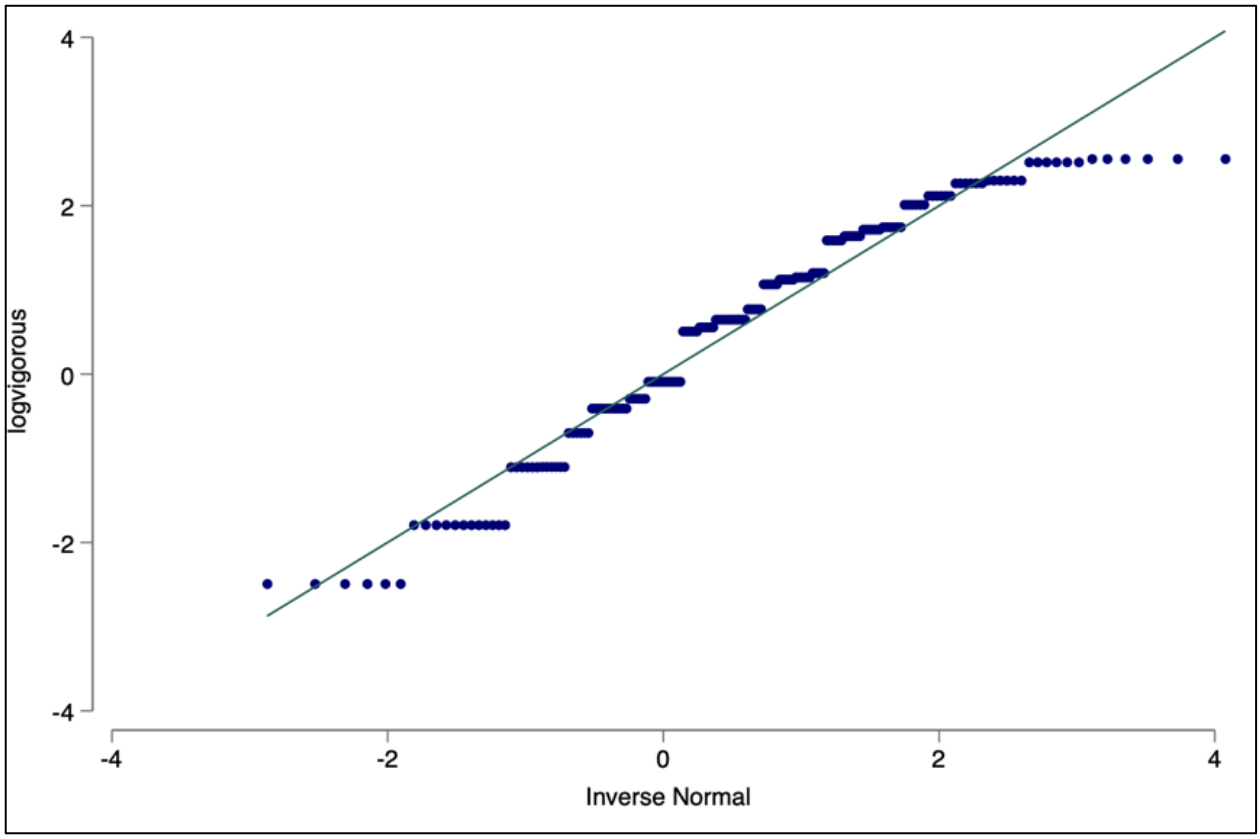
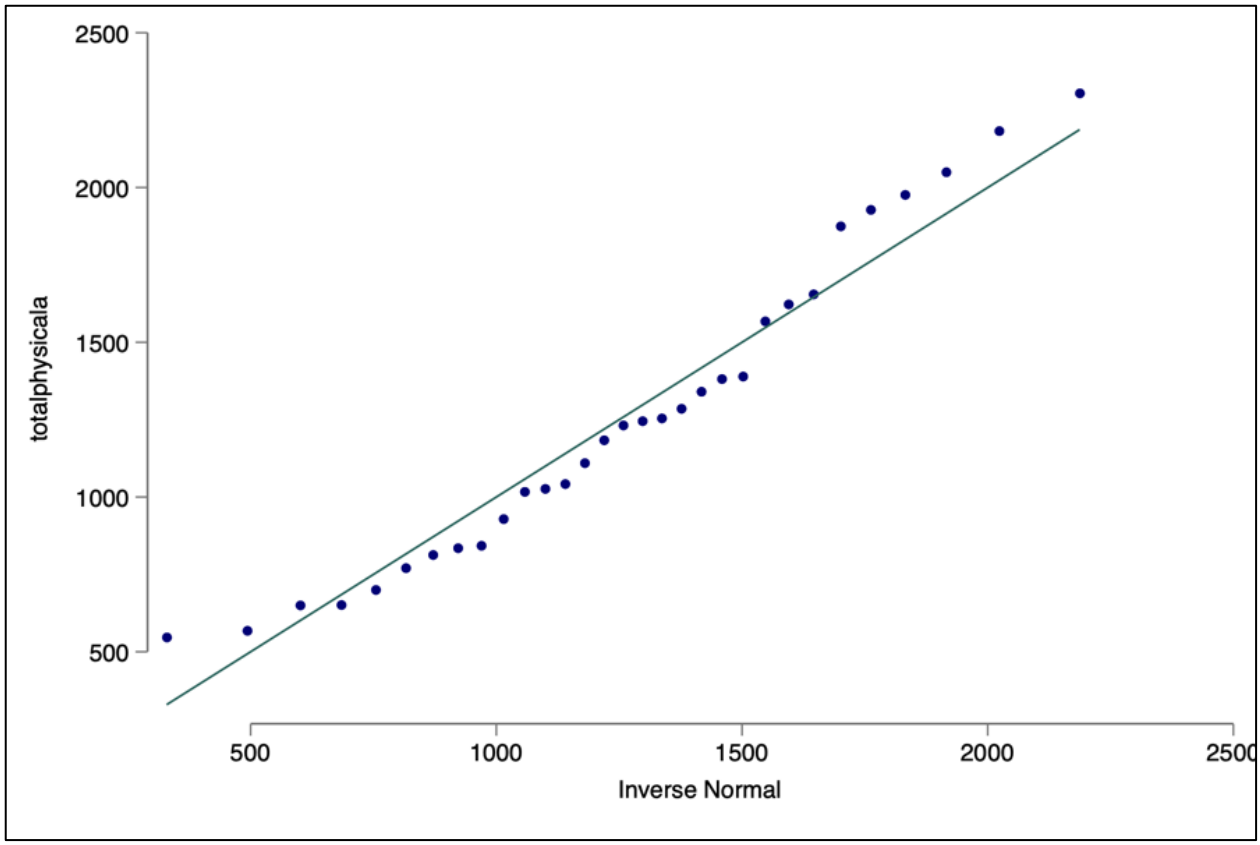
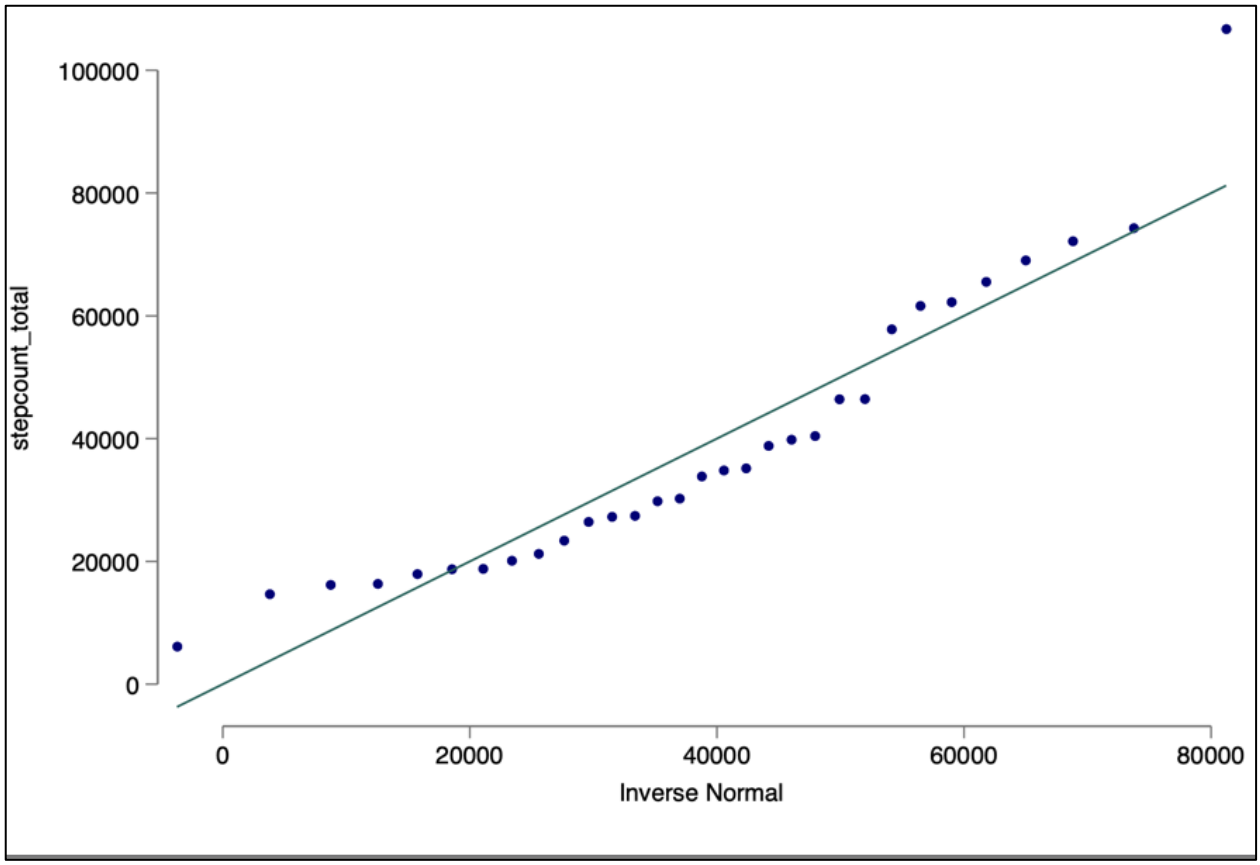


Illustration demonstrating log transformation to normalise skewed data, skewness and data symmetry was not improved therefore non-normally distributed data test were used for statistical analysis



An illustration depicting the assessment of normality distribution using Q-Q plots, highlighting data spread and deviations from the expected normal distribution for total physical activity



An illustration depicting the assessment of normality distribution using Q-Q plots, highlighting data spread and deviations from the expected normal distribution for total step count