29 Biomechanics of Cruciate Retaining and Posterior Stabilised Total Knee Arthroplasty and Return to Sports

A. Kropelnicki and D. A. Parker

29.1 Introduction

Total knee arthroplasty (TKA) has shown to be an effective and reliable treatment of end stage arthritis of the knee [1–5], once medical management has become ineffective [6]. Some 1.1 million knee joint replacements have been performed since the start of the National Joint Registry of the United Kingdom in 2003 [7], with this demand set to increase [4]. Knee replacement procedures produce obvious benefits in relieving arthritic pain, correcting deformity and improving ambulation, thus allowing an improvement in physical and mental health [1, 8–10]. Clinical studies on total knee arthroplasty demonstrate considerable variation in kinematics and functional performance [11].

The knee itself is a complex, incongruent joint [12] with little inherent stability [13] and correspondingly complex kinematics [14]. It is reinforced by the surrounding capsule, ligaments, menisci and muscles, all of which contribute to knee stability and movement [8, 15]. The normal anatomy of the knee varies widely, and pathological changes increase its variability further [14]. For example, approximately 20% of the population have varus knees of 3° or greater, such that a mechanically neutral-aligned TKA is a significant anatomical adjustment and would require considerable soft tissue re-balancing [14].

The movement of the knee is considered a complex hinge with femoral roll-back and the 'screw home' mechanism, which are unique to the knee [8]. These have been discussed in detail in earlier chapters. Restoration of the functional anatomy of the knee, including alignment, soft tissue balancing, and restoration of the joint line are integral to improving function [8]. The complexity of movement as described in previous chapters needs to be understood and reproduced as much as possible when performing a TKA, in order to achieve the best outcome.

The average age at which patients seek TKA surgery is decreasing. Comparing the cumulative TKA data from the 19th NJR report against that of 5 years ago, the mean age has dropped from 70 to 69 years [7, 16]. Year-by-year data is likely to reflect an ongoing trend. For example, in Canada the number of 45- to 64-year olds diagnosed with arthritis is set to double between 1991 and 2031 to 2.1 million [17]. In general, with decreasing age comes increasing expectations, and patients' functional demands and expectations of a TKR have evolved, with many wishing to resume some form of sporting activity after surgery [6, 18].

A. Kropelnicki
Sports Medicine Institute, Miranda, NSW, Australia
e-mail: anna@krop.co.uk, anna@headsafe.com

D. A. Parker (✉)
Sydney Orthopaedic Research Institute, Chatswood, NSW, Australia

University of Sydney, Sydney, Australia
e-mail: dparker@sydneyortho.com.au

J. Koh et al. (eds.), *Orthopaedic Biomechanics in Sports Medicine*,
https://doi.org/10.1007/978-3-030-81549-3_29

Furthermore, it is well understood that meeting patients' expectations is highly correlated with satisfaction following TKA [19]. It is well-established that regular physical activity has significant health benefits, yet sports activity after TKA has not been particularly well studied [2], and, to our knowledge, no prospective controlled trials exist assessing sporting outcomes with different TKA designs or techniques.

29.2 TKA Design

There are many designs in current use for total knee replacement. The Australian National Joint Registry lists 68 common total knee replacement designs with another 194 forming an 'Other' category [20].

Although knee replacement design has been based on native knee anatomy, it is not a pure anatomic reproduction of the native knee [1, 2, 14], particularly given the wide variation in individual anatomy, which clearly presents challenges and limitations when trying to reproduce normal knee function. The majority of total knee arthroplasty designs can be primarily divided into whether they are cruciate retaining (CR; sacrificing the ACL, but preserving the PCL) or cruciate sacrificing (PS; removing both cruciate ligaments) (Fig. 29.1). Both of these have good success rates over time with 4.9% revised at 10 years for the CR, and 6% for the PS [20]. At 15 years, these rates remain similar for the CR compared with the PS with revision rates of 7% and 8%, respectively [20]. However, it is well recognised that despite these relatively low revision rates, up to 20% of patients with a total knee replacement are dissatisfied with their outcome [14].

Forces transmitted across the articulating surfaces are determined by a combination of the alignment, movement and integrity of anatomical structures within the knee [8]. More constrained designs offer greater global stability and rely less on soft tissues, but increase the stresses on the bone–implant interface [21], whereas less constrained designs rely more on the soft tissues for stability. It is important to remember that the sta-

Fig. 29.1 Cruciate retaining TKA (left) and posterior stabilised TKA (right). (Reprinted with permission from Yagashita K, et al., J Arthroplasty 2012)

bility of the TKA is highly dependent on not only the conforming design of the prosthesis but also the surgical techniques employed whilst implanting the prosthesis [21]. Soft tissue releases may help with varus/valgus balance, but can introduce both antero-posterior and rotational instability [22].

29.2.1 Anatomy

The role of the cruciates is debated in TKA with most prosthetic designs requiring complete excision of the ACL [15]. This is frequently justified by the fact that in end stage arthritis the ACL is often compromised or ruptured, and also that patients in this demographic are unlikely to experience instability when not competing in more vigorous twisting and pivoting activities. Many current TKA designs can result in anterior tibial subluxation in full extension [15], which could potentially compromise certain movements involved in sports, such as jumping and pivoting. There have been several attempts to design an ACL preserving TKA, but with limited success and ongoing investigation.

29.2.1.1 Soft Tissues

Accurate soft tissue balancing with preservation of normal anatomy is an important component of success with TKR, influencing range of motion, proprioception and kinematics [8, 15]. Balance of the flexion–extension gaps is required to produce stability throughout the arc of motion [1]. Navigated or computer-assisted surgery enables the surgeon to more accurately achieve alignment of the implants in the three planes and provides feedback on soft tissue balancing [12]. Carefully planned and accurately executed surgical technique, therefore, contributes to achieving optimal range of motion with good stability [12].

Restoration of the native joint line has been shown to be important for both tibiofemoral and patellofemoral kinematics, and achieving optimal soft tissue balance [1]. Modelling also showed that the most influential factor was restoration of the joint line and coronal plane alignment [11]. Recent debate has centred around the concept of 'kinematic' or 'constitutional' alignment, which aims to recreate a patient's presumed pre-arthritic anatomy, with early reports from selected centres reporting improved functional outcomes when compared to more traditional mechanical alignment strategies [23]. At this point in time, the debate continues, but these more anatomical strategies do seem to show some promise in improving outcomes and restoring more normal function for TKA recipients. Longer term outcomes studies will be necessary to demonstrate that these early promising results are sustained and that there is no compromise to longer term survival.

29.2.2 Design Considerations

29.2.2.1 Femoral Component

Design features influence tibiofemoral contact mechanics and kinematics [11]. There are many different femoral designs on the market; however, substantial differences in patient outcomes has not been proven [13].

The trochlea grooves of many modern designs has been deepened, laterally flared and flattened to improve patella tracking and congruity throughout the range of motion [13].

The single axis total knee replacement was designed on the concept of a single flexion extension axis of the knee. The single radius design, however, lengthens the quadriceps moment arm, with a resulting decrease in quadriceps force [8]. Consistent with this, biomechanical studies have shown less eccentric knee extensor muscle activation and greater mediolateral stability during the stand-to-sit movement with this single-radius design. Multiple radius designs of the femoral component have been shown to develop several compensatory mechanisms, such as increased hamstring co-activation in order to increase joint stability [8]. Overall, the increased power output shows better functional recovery for the patient [8]. However, the multi-radius knee has been associated with mid-range instability despite rectangular flexion and extension gaps at 0 and 90° [14].

29.2.2.2 High Flexion Implants

Range of motion is an important component of patient satisfaction after TKA. In an effort to improve flexion post TKA, designers have produced femoral prostheses with both increased posterior femoral condylar offset and shortened posterior condyles to improve 'clearance' in deep flexion and reduce pressure over the extensor mechanism. Such designs also aim to achieve a larger contact area during high flexion, thus theoretically reducing contact pressures and wear, whilst a deepened trochlea avoids impingement of the extensor mechanism [13]. Reviews have however failed to show sufficient evidence of consistently improved function or range of motion [8].

29.2.2.3 Mobile Bearing Versus Fixed Bearing

Conformity of the femoral implant with the polyethylene insert has a conflicting impact on native knee kinematics and contact stresses. A highly conforming design in a fixed bearing prosthesis decreases contact stress and hence polythene wear but adversely affecting normal knee kinematics [13]. A low conforming design, however, results in high contact stresses increasing wear and the prospect of failure whilst allowing more normal knee kinematics [13]. Reproducing the natural movement of the knee requires a design that allows movement in all three planes [8], and mobile bearing prosthesis was designed with the intention of allowing both antero-posterior and axial rotation to be accommodated along with greater congruency, theoretically providing improved kinematics and reduced polyethylene wear [8]. Yet, clinical and cadaver studies have failed to show any significant benefit of these prostheses, for either kinematics or polyethylene wear [8]. Furthermore, there are concerns that the mobility of the bearing increases the risk of polyethylene wear and osteolysis.

29.2.3 Cruciate Retaining

The CR prosthesis was developed based on the concept that motion is guided by the soft tissue, with the ligaments helping to drive the kinematics of the knee [13]. Preservation of the PCL has potential advantages of bone preservation, improved proprioception, femoral rollback, kinematics closer to that of the native knee, and improved stability [15]. In this design, the PCL alone provides antero-posterior stability and rollback of the femoral condyles as long as its structure is preserved by careful surgical technique, and normal function preserved by adequately balancing the flexion and extension gaps [1, 8]. The tibial surface must be relatively flat in order to allow this rollback and prevent excessive tension in the PCL [8], yet have a degree of concavity to contribute towards the antero-posterior stability of the prosthesis [21]. Previous kinematic studies have, however, demonstrated limited success with the PCL alone consistently producing roll-back, and do not reproduce the screw-home mechanism [1].

29.2.4 Cruciate Sacrificing

When the posterior cruciate ligament is sacrificed, the posterior stabilised (PS) design uses a cam-post mechanism to create an artificially produced roll-back [1, 15, 21]. This implant is based more on a functional philosophy than an anatomical one with the implant driving the kinematics rather than the soft tissues [13]. The PS implant produces more reliable rollback, and therefore usually results in improved flexion, but does not reproduce the screw-home mechanism [1, 13, 15]. The centre post may also contribute to antero-posterior stability in the case of extensor mechanism weakness [8]. The PS however may have decreased mid-range stability [1] and have greater lift-off in the gait cycle that may be detrimental to the polyethylene bearing [1].

29.2.5 Kinematics of CR Compared with PS

The decision to retain or sacrifice the posterior cruciate ligament has been a longstanding debate within orthopaedics [24, 25]. Both prostheses came about at a similar time, and the PS is obviously required in the event of PCL insufficiency. However, the selection of the sub-type of TKA is often driven by the surgeon's training and experience rather than biomechanical or kinematic evidence [25]. As discussed in previous chapters, there are arguments that the CR implant retains more natural knee kinematics, better proprioception and thus greater stability [24], whereas those arguing for the PS total knee replacement suggest this implant produces more predictable kinematics, reduces tibiofemoral loads and is simpler to balance [24]. Overall, the PS is also considered to allow a greater range of movement post-operatively [24]. In order to address this, many using the CR implant increase the posterior slope as part of their surgical technique [26]. However, fluoroscopic studies show that all total knee arthroplasties reduce the range of motion compared with native knees regardless of subtype [27]. On average, TKA does not gain flexion above 120° [28]. Despite the above differences, there is no good evidence to support functional superiority between these two implant sub-types [29]. Singleton et al. [29] did note less stiffness at 1 year post-operatively in the PS knee, but in comparisons at 5 and 10 years showed there was no difference between the outcomes of the CR and PS knees. Whilst efforts to reproduce anatomy and function more closely to the native knee continue, it would certainly be universally agreed that, although TKR usually results in good outcomes, it does not reliably reproduce normal knee kinematics, irrespective of the design.

29.2.5.1 Gait

Gait in patients following a TKA does not normalise, rather frequently returns to pre-surgery joint loading patterns and abnormal biomechanics or adaptive changes to compensate to the effects of a TKA [38]. Modelling shows that there is a complex interaction of patient, surgical and implant design factors which vary in their predominance throughout the gait cycle [11]. Therefore, it is extremely difficult to tease out the sole influence of the biomechanics of the TKA prostheses. Gait analysis has been criticised for its diversity in reporting due to comparing different patient characteristics, different prosthetics and different methodologies of analysis [5]. A systematic review by McClelland et al. [5] found that patients do not demonstrate a normal walking gait after TKA, the most consistent findings being walking with a reduced range of motion, specifically less flexion, compared with control subjects, as well as reduced loading in the stance phase. These findings would certainly be consistent with reduced ability to play a pivoting or twisting sport, but should allow a reasonable level of leisure activity such as golf or hiking.

Comparing the gait achieved with CR or PS TKA designs, Andriacchi found that the CR implant produced statistically normal ranges of motion compared to the PS implant [39]. This was attributed to the lack of dynamic interaction between the PCL, tibial rollback with flexion, and the changing of the lever arm of the quadriceps during flexion. Patients with the PS implant leant forward in order to compensate for a lack of flexion, despite those with a PS implant having an identical range of motion to those with a CR TKA, which was then interpreted to reflect either weakness or avoidance of use of the quadriceps [39]. More recently, as prosthetic designs have improved, studies have failed to find a significant difference in gait when comparing CR and PS prostheses [5]. It is noted that quadricep avoidance is a phenomenon also seen in the ACL-deficient gait [39]. It is therefore possible that the ACL is more critical than previously thought for stability, and its absence an explanation for these gait changes seen post-operatively, regardless of the type of TKA.

29.3 Sports After TKA

As discussed above, no TKA restores normal knee biomechanics. The abnormal kinematics are likely to be detrimental to the performance of the TKA [30], and it is this that necessitates activity restrictions that are discussed below. Since TKA does not restore normal knee function, the challenging movement patterns and speed required to perform sports could be significantly impacted. More than half of patients report some degree of limitation in their activities following TKA, compared with only one fifth in age-matched subjects with no previous knee disorders [31]. Further, up to one quarter of patients have reported dissatisfaction following TKA [15]. Therefore, clinicians are increasingly forced to question how much activity a TKA patient can perform and what sports are acceptable [10].

Patients are increasingly involved in the shared decision-making process, thus the clinician must be able to counsel and inform them according to the available evidence [10]. However, to the best of our knowledge, there are no studies that specifically compare CR and PS implants with regard to sporting activity, as studies tend to group all TKA designs together. Furthermore, there appear to be no trials looking specifically at biomechanics and the challenges of pivoting sports. Much of the evidence in this field of return to sports and TKA is sparse and appears to be low level retrospective studies predominantly using questionnaires on self-reported outcomes. They are, therefore, heavily flawed with recall bias.

Return to sports is a complex and multifactorial outcome, and of course there will always be examples of patients who get back to relatively high-level sports, largely related to preoperative fitness, skill, experience, and motivation. There will also be others who are at the other extreme and fail to return to any level of sport. The reason for this variation goes well beyond the design of the TKA implant. Healy et al. [32] suggest the ability to return to sports participation after TKA is dependent on several factors: (1) pre-operative athletic ability, (2) pre-operative (p)rehabilitation, (3) surgical reconstruction, (4) implant failure, (5) implant fixation, (6) wear of the bearing surface and (7) trauma [1]. Further, others show that sports participation is dependent on ageing and motivation [31].

Functional results in athletes are primarily linked to the flexion of the knee and strength of the quadriceps [12]. Flexion is multifactorial concerning the patient, the surgical technique, the implant design and post-operative rehabilitation [12]. These factors influencing return to sport could simply be divided into the implant design, surgical technique and patient variables [11]. It might therefore be reasonable to question how critical a factor the biomechanics of the TKA implant actually is in a patient's ability to return to sport.

29.3.1 What Is Sport?

Most surgeons recommend low impact, low demand, low duration sports following TKA [1, 33]. Flecher et al. [12] state that the majority of activities can be resumed excluding team sports, ball sports and jogging. However, there is little evidence to support these suggestions, which are largely based on first principles and left to surgeons' discretion [33]. Guidelines published by Healy et al. [34] after surveying the members of the Knee Society (1999) [34] set out their recommendations for sports considered appropriate after TKA (see Table 29.1). Furthermore, these recommendations appear based on opinion rather than evidence, thus it is not entirely clear what should and should not be recommended for each individual after TKA. It is, of course, important to define what may be considered 'sport' versus 'leisure activities' in order to clearly counsel patients appropriately and ensure their expectations are addressed accurately.

29.3.2 Patient Concerns

Patients in general are not as likely to return to sports after a TKA compared with those having a total hip replacement [6], and tend to decrease their participation in, and intensity of, athletic activities [4]. Recommendations for participation in sports after TKA appear to be based predominantly on opinions rather than evidence [1]. However, as discussed above, if the average age of the TKA patient is decreasing and the demand and expectations are rising, we must consider sporting options for the more active patient.

Kawamura showed that preoperative flexion (positively) and varus/valgus deformity (nega-

Table 29.1 1999 Knee Society Survey Recommendations for Activity after TKA

Recommended	Allowed with prior experience	Not recommended	No conclusion
Walking	Road cycling	Squash	Fencing
Swimming	Doubles tennis	Soccer	Downhill skiing
Low-impact aerobics	Rowing	Jogging	Rollerblading
Stationary bike	Weight machines	Singles tennis	Weightlifting
Hiking	Cross-country skiing	Volleyball	
Ballroom dancing		Hockey	
Bowling		Basketball	
Croquet		Handball	
Golf		Rock climbing	

Modified from [4, 34]

tively) affects post-operative flexion [12], supporting the importance of good physiotherapy prior to surgery. Silva et al. note that quadriceps strength decreases by around 30% compared with the contralateral side following a TKA [12]. Lamb et al. state that the two most predictive factors of post-operative strength are BMI and pre-operative strength, again highlighting the increasingly recognised importance of 'pre-habilitation'.

Regarding the impact of body weight, biomechanical modelling has shown a significant effect of vertical hip load (related to body weight) on compressive load to the knee and the contact areas of both the tibio-femoral and patellofemoral joints, demonstrating the potentially deleterious effect of obesity on outcomes [11].

Table 29.2 Knee joint reaction forces during different sports

Knee joint reaction forces	Body weight
Walking	3
Cycling	1.2
Stair ascent	5
Stair descent	6
Isokinetic knee extension	9
Jogging	8–9
Running	14
Skiing	3.5–10

Adapted from Hartford et al. [1]

29.3.3 Implant Concerns

Typically the concern over sports participation relates to early component failure through excessive polyethylene wear, and excessive stress leading to loosening or trauma [1, 32]. Accumulating data suggests that prosthetic wear is not simply a function of time but one of use [3, 32]. The forces encountered by the TKA vary from 3 to 8 times body weight when ascending and descending stairs [1]. Jogging exceeds 7 times body weight and isokinetic exercise can exceed 12 times body weight [1]. Even whilst hiking, flexion between 40 and 60° loads the joint by 5–10 times body weight [10]. Thus, even the most basic of anticipated activities could be significantly contributing towards early wear of the prosthesis. This raises concerns about implant longevity for those wishing to return to sports [12, 33], and surgeons should educate patients regarding these risks. Table 29.2 illustrates the joint reaction forces through the knee during various activities.

29.3.3.1 Longevity

Studies taken from the Norwegian Arthroplasty Registry find a higher risk of revision of TKA in males under 65 year of age [2]. To our knowledge, there are no long-term studies on TKA longevity as related to sporting activities, but it would seem to be a reasonable assumption that younger age is a surrogate for higher activity levels, which in turn contributes to the higher revision rate.

Trauma caused by athletic participation remains a primary concern in advising on return to sports. Component dislocation, particularly in the PS TKA, and periprosthetic fracture are two severe complications that may occur during sports participation [1].

29.3.4 Sports/Leisure Activities Following TKA

Several retrospective studies have suggested athletic activity decreases after TKA, which is applicable to all ages [32]. In a survey of patients with TKA, Dahm et al. [3] found the mean activity level reported according to the UCLA activity scale was 'regularly participating in active events' (level 7). However, what one interprets as an 'active event' is open to interpretation as the only example given is cycling. About 16% of patients reported participating in heavy lifting, strenuous tasks or 'not recommended' sports. Baumann et al. [17] found a similar mean level of activity as assessed by the UCLA scale (mean of 6—moderate activity) as reported by Dahm et al. [3], but with no patients involved in any impact activity.

Bock et al. also reported a reduction in higher impact-type sports such as climbing, soccer and tennis, with no one returning to these sports, but an increase in participation of low-impact activities such as walking and swimming [10]. Bradbury et al. [6] also found that no one could return to high impact/pivoting sports and noted a decrease in participation in most low-level activities with the exception of cycling, in which participation increased. In a retrospective survey in Korean patients by Chang et al. [35] participation in a number of low-impact activities increased following TKA, but more challenging and higher impact sports showed a decrease in participation. Similarly, Bradbury et al. [6] showed an overall decrease in all activities following TKA with only 77% returning to any level of activity. There was an increase in cycling, but a complete avoidance of any high impact/contact sports such as running, skiing, football (soccer) and rugby.

Diduch et al. [36] found that only 24% of TKA patients reached level 5 on the Tegner activity scale. Bonnin et al. [18] used a retrospective self-reported questionnaire to TKA patients, with an average length of time from surgery to study of 44 months and a low respondent rate. More than a quarter reported they were less active than prior to the operation, and more than half considered their activities to be limited by their knee. Only 10% of patients participated in what was considered 'strenuous sports', defined as skiing, tennis and running over 500 m. However, a closer look at the data showed only 1 of the 347 respondents actually participated in tennis and only 3 could run more than 500 m. Furthermore, the level of activity was only rated in terms of level of participation rather than the level of performance. This study highlights the importance of appropriately counselling prospective TKA patients and managing their expectations.

Hepperger et al. [37] reported that sports activity is maintained or increased following TKA for 78% of their cohort. Their prospective study was based on standardised outcome scores over 2 years and showed statistical improvements, although the median Tegner score, for example, did not change from level 3 at any time point from pre-operative to 24 months post-operative. This is a lower level than reported by Diduch et al. [36]. The sports chosen in this cohort were not discussed in detail but was predominantly cycling, swimming, hiking and skiing, and did not include any more vigorous pivoting sports. Bradbury reported that the 75% of patients who performed a sport (walking, bowling, golf) pre-operatively could continue post-operatively, but only 20% of those who played tennis could return [12, 33]. Clearly the baseline level of activity within any cohort will influence patients' expectations for activity post TKA and the potential for improvement in activity level.

The difficulty with interpreting survey data is that it is always prone to selection bias, in that only those who want to participate respond, usually selecting those with the more positive outlook and results. Further caution must always be placed on measurement of level of participation in any sport. There is a clear difference between performing at a competitive level compared with social level, and self-reporting is not always reliable or objectively accurate. Furthermore, the retrospective nature of these surveys is additionally subject to recall bias, and bias based on the relationship between the patient and surgeon. No data exists with regard to TKA kinematics during running, turning, cutting or pivoting sports [1], only modelling and cadaver studies. Return to sport must be gentle and progressive with moderate activities limited to short sessions. Some TKA patients may be able to return to moderate activities proving they have prior experience and an adequate level of technique for that sport [2].

29.3.4.1 Specific Sports

Golf

Golf is a sport that patients would usually expect to be able to return to after TKA, and indeed an inability to play golf or walk the course is a common catalyst for patients to seek surgery. The reported results around patients returning to golf after TKA have been somewhat variable. Limitations affecting patients' ability to return to golf largely relate to the ability to walk comfortably over relatively long distances on an uneven soft surface (requiring good proprioception) and a tolerance for the pivoting movement involved with the golf swing (Fig. 29.2).

Mallon and Callaghan studied 83 active golfers who had undergone TKA. All returned following surgery, although 87% used a cart whilst playing and 36% reported experiencing a mild ache in the operated knee after playing. Naal et al. [40] reported an increase in golf participation from 5 to 8 within their cohort. However, other authors have found a significant reduction (19 to 9) in those continuing to play golf following TKA [33]. The total of those leaving the sport represented a reduction of 44% (109 to 61), suggesting golf may be a realistic sport to anticipate returning to post-operatively, but very unlikely as a new sport to undertake.

Tennis

Tennis demands a higher level of impact than golf and requires more rapid movements including pivoting and lunging. In a small survey of 33 highly experienced tennis players (mean experience of 35 years, range 15–70 years) who had undergone TKA, Mont et al. [42] found a 100% return to tennis, both singles and doubles play. These players returned to the same level as pre-operatively, but at a relatively low level, and all players reported a significant loss of court speed [42].

These findings are not replicated when looking at non-selected patient groups with all of these studies reporting a significant drop in par-

Fig. 29.2 Demonstration of knee movement during the golf swing. Note the valgus stress and pivot stability required

ticipation. Table 29.3 shows a number of studies citing rates of participation in tennis before and after TKA. Totalling the numbers from these studies, the expected percentage returning to tennis is considerably lower than thought, at 18% (15 from 84 pre-operative tennis players). Thus, the experience, motivation and conditioning of the patient prior to surgery would appear to be a significant factor in return to tennis rather than specific TKA implant.

Tennis demands knee stability in antero-posterior and medial-lateral directions in both extension and flexion extension and flexion (Fig. 29.3).

Table 29.3 Return to tennis following total knee arthroplasty

Study	No. playing tennis pre-operatively	No. playing tennis post TKA	Percentage drop (%)
Bock et al. [10]	2	0	100
Bradbury et al. [6]	30	6	80
Chatterji et al. [33]	14	2	86
Huch et al. [43]	6	2	67
Naal et al. [40]	21	3	86
Walton et al. [41]	11	2	88

29.4 Summary

The understanding of native knee kinematics has been, and continues to be, used by implant manufacturers to innovate and improve TKA outcomes and longevity, as well as accommodate patient demands with a goal of allowing patients to return to their chosen activities, including sports, postoperatively and increase patient satisfaction. The result is a wide spectrum of TKR implant designs with varied biomechanical philosophies. Following this review, it would seem that being able to reliably restore a patient's ability to return to sports is affected by multiple factors, of which implant design is only one. Only with all of these factors including patient characteristics, surgical technique and implant factors considered, can the surgeon offer the patient realistic and evidence-based information regarding the likely outcomes of TKA and create valid expectations.

The other concern is the actual definition of 'sport'. In the case of the vast majority of the studies reviewed above, one might question if the activities described can be fairly described as sport or should be more accurately labelled as' leisure activities'. Cycling, swimming and hiking once or twice a week at a Tegner-defined level 3 is, at best, recreational. It is unfair to give the impression to patients that they might return to sports quoting upwards of 77% when in fact

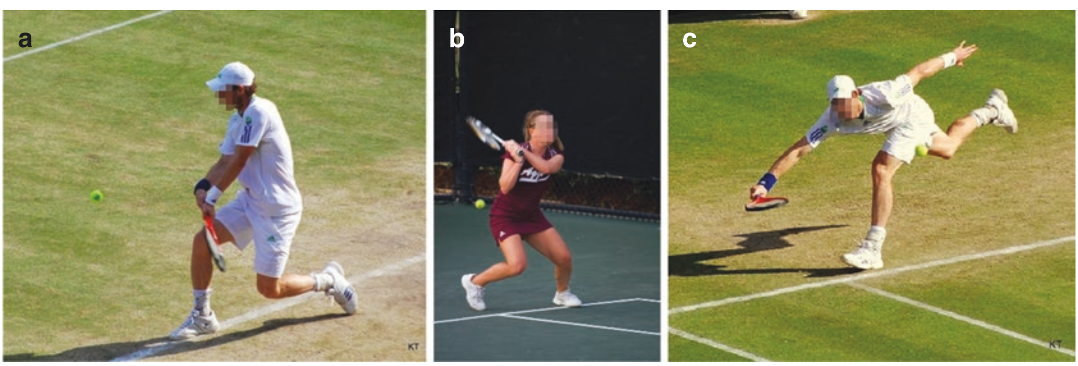

Fig. 29.3 (**a**) Knee flexion in tennis. (CC Search (creativecommons.org). "Andy Murray" by Carine06 is licensed with CC BY-SA 2.0. To view a copy of this license, visit https://creativecommons.org/licenses/by-sa/2.0/. Andy Murray | Andy Murray during his semi-final with Rafael … | Flickr). (**b**) Pivoting on knee. ("Aggie Women's Tennis—58" by StuSeeger is licensed with CC BY 2.0. To view a copy of this license, visit https://creativecommons.org/licenses/by/2.0/)). (**c**) High loads are experienced by the knee. (CC Search (creativecommons.org). "Andy Murray" by Carine06 is licensed with CC BY-SA 2.0. To view a copy of this license, visit https://creativecommons.org/licenses/by-sa/2.0/. Andy Murray | Andy Murray during his semi-final with Rafael … | Flickr)

the numbers of patients involved in pivoting sports is less than 5%, and all of these had significant prior experience within that sport. Patients' expectations should be fully explored on an individual basis and a good understanding of the actual activities one is able to participate in should be realistically discussed. This discussion should clearly include advice around which sports the patients are realistically likely to be capable of returning to, as well as which sports are less advisable due to concerns for implant longevity.

In summary, participation in leisure activities is deemed to be acceptable following a TKA, but this is based on consensus statements, surveys of orthopaedic surgeons and retrospective studies [17]. Recommendations regarding appropriate activities should be made on a case-by-case basis with a full understanding of the patient's expectations, preoperative activity level and sporting experience.

Life-long and ex-professional surfer following a right total knee replacement

References

1. Hartford JM. Sports after arthroplasty of the knee. Sports Med Arthrosc. 2003;11:149–54.
2. Dagneaux L, Degeorge B. Return to sport after total or unicompartmental knee arthroplasty: an informative guide for residents to patients. EFORT Open Rev. 2017;2(December):496–501.
3. Dahm DL, Barnes SA, Harrington JR, Sayeed SA, Berry DJ. Patient-reported activity level after total knee arthroplasty. J Arthroplasty. 2008;23(3): 401–7.
4. Healy WL, R Iorio, M J Lemos. Athletic activity after joint replacement. Am J Sports Med. 2001;29(3): 377–88.
5. McClelland JA, Webster KE, Feller JA. Gait analysis of patients following total knee replacement: a systematic review. Knee. 2007;14:253–63.
6. Bradbury N, Borton D, Spoo G, Cross MJ. Participation in sports after total knee replacement. Am J Sports Med. 1998;26(4):530–5.
7. Brittain R, Young E, Mccormack V, Swanson M. 16th Annual report. 16th Annual report 2019 National Joint Registry England, Wales, North Ireland and Isle of Man, December 2018; 2019.
8. Shenoy R, Pastides PS, Nathwani D. Biomechanics of the knee and TKR. Orthop Trauma. 2013;27(6):364–71. https://doi.org/10.1016/j.mporth.2013.10.003.
9. Collins M, Lavigne M, Girard J, Vendittoli P. Joint perception after hip or knee replacement surgery. Orthop Traumatol Surg Res. 2012;98(3):275–80. https://doi.org/10.1016/j.otsr.2011.08.021.
10. Witjes S, Gouttebarge V, Kuijer PPFM, Van Geenen RCI, Poolman RW, Kerkhoffs GMMJ. Return to sports and physical activity after total and unicondylar knee arthroplasty: a systematic review and meta-analysis. Sports Med. 2016;46(2):269–92.

11. Fitzpatrick CK, Clary CW, Rullkoetter PJ. The role of patient, surgical, and implant design variation in total knee replacement performance. J Biomech. 2012;45(12):2092–102. https://doi.org/10.1016/j.jbiomech.2012.05.035.
12. Flecher X, Argenson JN, Aubaniac JM. Prothèse de hanche, du genou et sport Hip and knee replacement and sport. Rehabil Phys Med. 2004;47: 382–8.
13. Aweid O, Melton J. Biomechanics of the knee. Orthop Trauma. 2019;33(4):224–30. https://doi.org/10.1016/j.mporth.2019.05.004.
14. Vendittoli P, Blakeney W. Redefining knee replacement. Orthop Traumatol Surg Res. 2017; https://doi.org/10.1016/j.otsr.2017.09.003.
15. Muckenhirn K, Chahla J, Laprade RF. Anatomy and biomechanics of the native knee and its relevance for total knee replacement. Chapter 1, Anatomy and biomechanics of the native knee and its relevance for total knee replacement, ISAKOS. 2017;3–15.
16. Wishart N, Beaumont R, Young E, Mccormack V, Swanson M. The NJR 11th Annual Report 2014 (December 2013). https://doi.org/10.13140/2.1.1191.2481.
17. Bauman S, Williams D, Petruccelli D, Elliott W, De Beer J. Physical activity after total joint replacement: a cross-sectional survey. Clin J Sport Med. 2007;17(2):104–8.
18. Bonnin M, Parratte JRLS, Bissery FZRBA, Bissery A. Can patients really do sport after TKA? Knee Surg Traumatol Arthrosc. 2010;18:853–62.
19. Scott CEH, Howie CR, Macdonald D, Biant LC. Predicting dissatisfaction following total knee replacement. A prospective study of 1217 patients. J Bone Joint Surg Br. 2010;92(9):1253–8.
20. Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR). Hip, Knee & Shoulder Arthroplasty: 2019 Annual Report. Adelaide: AOA, 2019.
21. Athwal KK, Hunt NC, Davies AJ, Deehan DJ, Amis AA. Clinical biomechanics of instability related to total knee arthroplasty. Clin Biomech. 2014;29(2):119–28. https://doi.org/10.1016/j.clinbiomech.2013.11.004.
22. Whiteside LA. Soft tissue balancing: the knee. J Arthroplasty. 2002;17(4 Suppl 1):23–7.
23. Howell SM, Hull ML. Kinematic alignment in total knee arthroplasty. Chapter 121, Knee Arthroplasty 2011, p. 1255–69.
24. Broberg JS, Ndoja S, Macdonald SJ, Lanting BA, Teeter MG. Comparison of contact kinematics in posterior-stabilized and cruciate-retaining total knee arthroplasty at long-term follow-up. J Arthroplasty. 2020;35(1):272–7. https://doi.org/10.1016/j.arth.2019.07.046.
25. Song SJ, Park CH, Bae DK. What to know for selecting cruciate-retaining or posterior-stabilized total knee arthroplasty. Clin Orthop Surg. 2019;11:142–50.
26. Kang K, Koh Y, Son J, Kwon O, Lee J, Kwon SK. Comparison of kinematics in cruciate retaining and posterior stabilized for fixed and rotating platform mobile-bearing total knee arthroplasty with respect to different posterior tibial slope. Biomed Res Int. 2018; 5139074.
27. Cates HE, Komistek RD, Mahfouz MR, Schmidt MA, Anderle M. In vivo comparison of knee kinematics for subjects having either a posterior stabilized or cruciate retaining highflexion total knee arthroplasty. J Arthroplasty. 2008;23(7):1057–67.
28. Li G, Kernkamp WA, Rubash HE. In vitro and in vivo kinematics of total knee arthroplasty — a review of the research at the Orthopaedic Bioengineering Laboratory of the Massachusetts General Hospital (MGH). Ann Joint. 2016;1:20.
29. Singleton N, Nicholas B, Gormack N, Stokes A. Differences in outcome after cruciate retaining and posterior stabilized total knee arthroplasty. J Orthop Surg. 2019;27(2):1–8.
30. Stiehl J, Komistek R, Dennis D, Paxson R, Hoff W. Fluoroscopic analysis of kinematics after posterior-cruciate-retaining knee arthroplasty. J Bone Joint Surg Br. 1995;77:884–9.
31. Noble PC, Gordon MJ, Weiss JM, Reddix RN, Conditt MA, Mathis KB. Does total knee replacement restore normal knee function? Clin Orthop Relat Res. 2005;431:157–65.
32. Healy BWL, Sharma S, Schwartz B, Iorio R. Athletic activity after total joint arthroplasty. J Bone Joint Surg. 2008;90:2245–52.
33. Chatterji U, Ashworth M, Lewis P, Dobson P. Effect of total knee arthroplasty on recreational and sporting activity. ANZ J Surg. 2005;75:405–8.
34. Healy WL, Iorio R, Lemos MJ. Athletic activity after total knee arthroplasty. Clin Orthop Relat Res. 2000;380:65–71.
35. Chang MJ, Kim SH, Kang YG, Chang CB, Kim TK. Activity levels and participation in physical activities by Korean patients following total knee arthroplasty. BMC Musculoskelet Disord. 2014;15(1):2–7.
36. Diduch D, Insall J, Scott W, Scuderi G, Font-Rodriguez D. Total knee replacement in young, active patients: long-term follow-up and functional outcome. J Bone Joint Surg. 1997;79(4):575–82.
37. Hepperger C, Gföller P, Christian EA, Ulmer H, Herbst E, Fink C. Sports activity is maintained or increased following total knee arthroplasty. Knee Surg Sport Traumatol Arthrosc. 2018;26(5):1515–23.
38. Levinger P, Menz HB, Morrow AD, Pod M, Feller JA, Bartlett JR, et al. Lower limb biomechanics in individuals with knee osteoarthritis before and after total knee arthroplasty surgery. J Arthroplasty. 2013;28(6):994–9. https://doi.org/10.1016/j.arth.2012.10.018.
39. Andriacchi TP. Functional analysis of pre and post-knee surgery: total knee arthroplasty and ACL reconstruction. J Biomech Eng. 1993;115:575–81.
40. Naal FD, Impellizzeri FM, Leunig M. Which is the best activity rating scale for patients undergo-

ing total joint arthroplasty? Clin Orthop Relat Res. 2009;467(4):958–65.

41. Walton NP, Tr F, Lewis PL, Dobson PJ, Angel KR, Campbell DG. Patient-perceived outcomes and return to sport and work: TKA versus mini-incision unicompartmental knee arthroplasty. J Knee Surg. 2006;19(2):112–6.
42. Mont MA, Rajadhyaksha AD, Marxen JL, Silberstein CE, Hungerford DS. Tennis after total knee arthroplasty. Am J Sports Med. 2002;30(2):163–6.
43. Huch K, Muller K, Sturmer T, Brenner H, Puhl W, Gunther K-P. Sports activities 5 years after total knee or hip arthroplasty: the Ulm Osteoarthritis Study. Ann Rheum Dis. 2005;64:1715–20.