■ KNEE

The identification and quantification of instability in a primary total knee replacement prior to revision

D. F. Hamilton,
R. Burnett,
J. T. Patton,
C. R. Howie,
A. H. R. W. Simpson

From University of Edinburgh, Edinburgh, United Kingdom

Instability is the reason for revision of a primary total knee replacement (TKR) in 20% of patients. To date, the diagnosis of instability has been based on the patient's symptoms and a subjective clinical assessment. We assessed whether a measured standardised forced leg extension could be used to quantify instability.

A total of 25 patients (11 male/14 female, mean age 70 years; 49 to 85) who were to undergo a revision TKR for instability of a primary implant were assessed with a Nottingham rig pre-operatively and then at six and 26 weeks post-operatively. Output was quantified (in revolutions per minute (rpm)) by accelerating a stationary flywheel. A control group of 183 patients (71 male/112 female, mean age 69 years) who had undergone primary TKR were evaluated for comparison.

Pre-operatively, all 25 patients with instability exhibited a distinctive pattern of reduction in 'mid-push' speed. The mean reduction was 55 rpm (SD 33.2). Post-operatively, no patient exhibited this pattern and the reduction in 'mid-push' speed was 0 rpm. The change between pre- and post-operative assessment was significant (p < 0.001). No patients in the control group exhibited this pattern at any of the intervals assessed. The between-groups difference was also significant (p < 0.001). This suggests that a quantitative diagnostic test to assess the unstable primary TKR could be developed.

Cite this article: *Bone Joint J* 2014;96-B:1339–43.

■ D. F. Hamilton, PhD, BSc (Hons), BSc (Hons), Research Fellow
University of Edinburgh, FU413, Chancellor's Building, 49 Little France Crescent, Edinburgh, EH16 4SB, UK.

■ R. Burnett, FRCS (Ed), Hon Senior Lecturer and Orthopaedic Surgeon
■ C. R. Howie , FRCS (Ed), Professor of Orthopaedics, Orthopaedic Surgeon
■ J. T. Patton, FRCS (Ed), Hon Senior lecturer and Orthopaedic Surgeon
■ A. H. R. W. Simpson, DPhil FRCS (Eng. and Ed), Professor of Orthopaedics and Orthopaedic Surgeon
University of Edinburgh, Department of Trauma and Orthopaedics, Edinburgh, EH16 4SB, UK.

Correspondence should be sent to Dr D. F. Hamilton; e-mail: d.f.hamilton@ed.ac.uk

doi:10.1302/0301-620X.96B10.33654 $2.00

Bone Joint J 2014;95-B:1339–43.
Received 10 December 2013; Accepted after revision 4 July 2014

Instability is a common cause of a poor result from total knee replacement (TKR),[1-4] and is estimated to be the reason for revision in up to 20% of patients.[3] The causes of instability are thought to include inadequate soft-tissue balancing; loss of ligamentous integrity; component wear; improper component sizing and component malpositioning.[2] However, it is often difficult to establish a diagnosis in these cases,[2] which has, therefore, to be based on the patient's symptoms and clinical and radiological assessment.

Knee instability presents as a failure to maintain normal knee function. Patients typically report the knee 'giving way' during load-bearing activity on a flexed knee. Bracing and exercise rehabilitation may help to reduce the symptoms in some patients with mild or moderate instability,[5] but in most cases surgical intervention is needed. Few studies report the outcome of revision for instability. Azzam et al[2] reported good outcomes in a consecutive series of 67 patients, but highlighted the difficulty of quantifying the degree of instability as a shortcoming of their study. They relied on a subjective diagnosis made by the surgeon, which was difficult to measure and open to bias or misdiagnosis. Attempts to use biomechanical testing or dynamic imaging remain both experimental and prohibitively expensive.[2]

Assessment of lower limb muscle power has been increasingly reported as a method of assessing outcome after knee replacement.[6-8] It is a standardised functional assessment which correlates strongly with the patient's performance of functional tasks such as stair-climbing, timed walking and timed up-and-go tests.[8] We hypothesised that performing an assessment of lower limb power would demonstrate and potentially quantify the patient's symptoms of instability, as it involves the application of force through a flexed knee which mimics to some extent the situation in which patients report symptoms of instability.

The aim of this study was to assess whether standardised forceful closed-chain (with the foot fixed, and the femur moving on the tibia) leg extension activity could be used to assess instability after primary TKR.

Patients and Methods

Local ethical approval was received and 25 consecutive patients who were to undergo revision TKR for instability were identified

Table I. Descriptive data on the symptomatic patient undergoing revision total knee replacement (TKR) for instability and a control group of patients undergoing primary TKR

	Revision for instability	Primary TKR (control)	p-value
n	25	183	
Gender (M/F)	11/14	71/112	0.62*
Age (yrs)	70.28 (SD 8.73)	68.64 (SD 9.02)	0.31
Instability 'double-push' pattern			
Pre-operative	25/25	0/183	< 0.001*
Six-weeks post-operative	0/25	0/183	n/a
26 weeks post-operative	0/25	0/183	n/a
'Mid-push' reduction (rpm)			
Pre-operative	55.30 (33.02)	0	< 0.001†
Six weeks	0	0	n/a
26 weeks	0	0	n/a
Contralateral limb	0	0	n/a
Power output (W)			
Pre-operative	19.45 (20.07)	44.64 (40.66)	< 0.001
Six weeks	56.6 (42.8)	52.79 (35.81)	0.72
26 weeks	62.35 (44.74)	74.67 (42.07)	0.23
Contralateral limb	75.28 (45.38)	85.05 (41.12)	0.48

* Mean with standard deviation (SD). Significance tested with independent samples *t*-test unless otherwise stated
† Mood's test
n/a, no analysis carried out as both group values equal zero rpm, revolutions per minute

and assessed over a two-year period between January 2011 and December 2012. Patients were recruited from a single high-volume orthopaedic teaching hospital. There were 11 men and 14 women, with a mean age of 70.28 years (49 to 85; SD 8.73).

Knee instability was diagnosed clinically by the surgical team on the basis of the patient's symptoms and an assessment of the laxity of the knee in all planes and in both flexion and extension.

All patients were assessed pre-operatively in the pre-admission clinic, which generally took place two weeks before surgery. They were then followed-up at six and 26 weeks post-operatively.

All the revisions were of a primary TKR (24 cruciate retaining (CR) and one posterior stabilised (PS) cemented implant). The mean time of revision was 4.4 years (3 to 7; SD 1.4) following index surgery, with patients reporting symptoms of instability for an average of 2.4 years (1 to 5; SD 1.1). The revision implant was selected at the discretion of the operating surgeon according to the extent of bone loss and the level of constraint required in each case. In all, 14 patients received a semi-constrained (posterior-stabilised) implant (Triathlon Total Stabilizer, Stryker, Mahwah, New Jersey) and 11 received a constrained implant (nine patients an Endo-Modell Rotational Knee Prosthesis, Link, Hamburg, Germany; and two patients a Modular Rotating Hinge, Stryker). Surgery was carried out by multiple consultant orthopaedic surgeons and their supervised trainees. All patients received identical post-operative care in accordance with the standard protocol of our unit. Rehabilitation included mobilisation on the day of surgery and inpatient physiotherapy.

A control group of 183 patients with cemented, CR primary TKRs were evaluated for comparison and had the same gender distribution and mean age as the revision group (Table I). This cohort also formed part of a randomised controlled trial performed in our unit investigating lower limb power output following primary TKR for osteoarthritis (OA),[6] and was chosen as it had corresponding power-output assessments at the same intervals.

Lower limb power assessment. Lower limb extension power (LEP) output was assessed with the well-validated Nottingham rig (Medical Faculty Workshops, Nottingham, United Kingdom),[9,10] which has been used in both epidemiological surveys[11] and studies of knee replacement.[6-8] This test is a forceful single-leg extension activity that simulates the situation where 'giving way' is reported. The patient is asked to depress a pedal in a single movement, thereby moving the knee from a flexed to an extended position. The LEP rig consists of a seat and footplate connected by a lever and chain to a flywheel. The patient applies force to the footplate, which accelerates the flywheel from rest, and the output is recorded as maximum watts (W) generated. The distance between the pedal and the seat is set according to the length of the lower limb of the individual. The seat position for each patient was determined with the knee in full extension and the footplate in full depression. The patient was instructed to depress the pedal fully by pushing the leg into extension with maximum effort. The largest value obtained from a minimum of three (maximum of six) tests were recorded. A command of 'push as hard and as fast as you can' was given prior to each effort, as required by the manufacturer's instructions. A minimum rest period of 20 seconds between attempts was enforced.[6] Knee instability was categorised as an inability to maintain

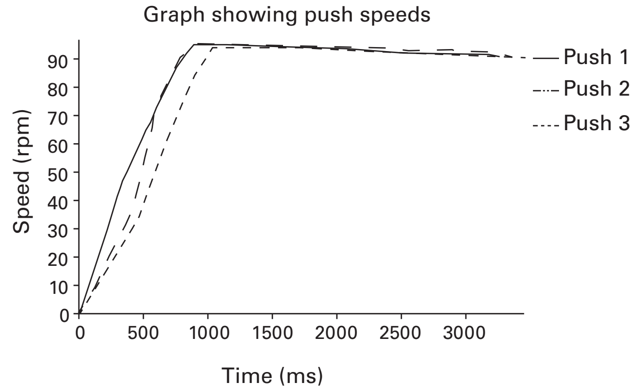

Fig. 1a

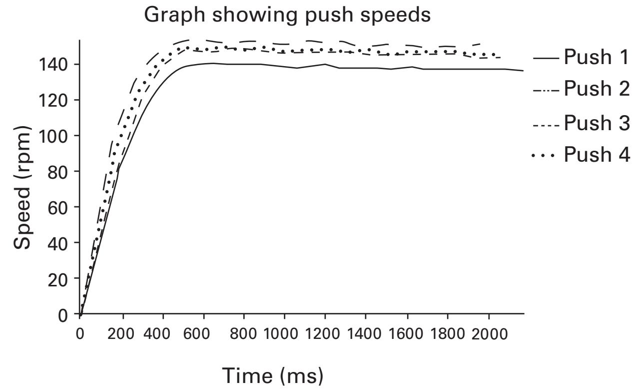

Fig. 1b

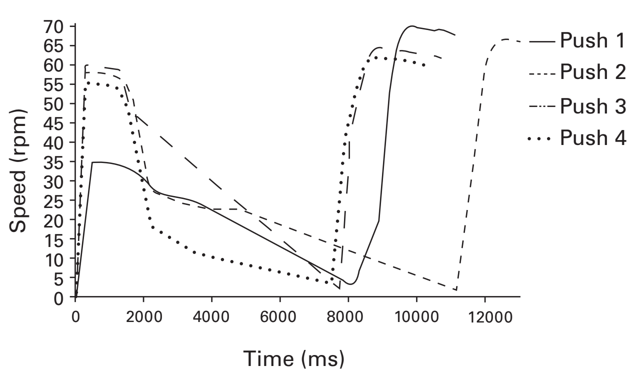

Fig. 1c

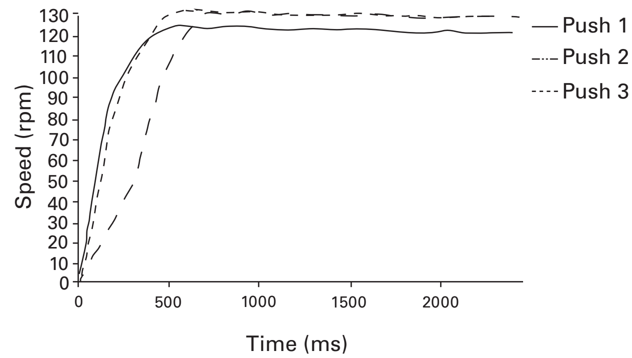

Fig. 1d

a) Example of a typical pre-operative output pattern displaying multiple tests in a single patient from the control group, showing a linear increase in speed of the flywheel as the pedal is fully depressed. This trace highlights the comparatively slow depression of the pedal and final flywheel speed achieved prior to surgery in patients with osteoarthritis of the knee. This test achieved an output of 20 W. b) Example of 'normal' post-operative output pattern at six months, displaying multiple tests in the same single patient from the control group, showing a linear increase in speed of the flywheel as the pedal is fully depressed. This trace highlights the comparatively quick depression of the pedal and final flywheel speed compared with the pre-operative test. This test achieved an output of 70 W. c) Example of the pre-operative 'unstable' output graph, highlighting multiple tests in a single patient, showing the distinctive 'double-push' pattern of linear acceleration, then deceleration, then secondary acceleration as the patient attempts to depress the pedal in a single forceful action. d) Example of the post-operative resolution of 'unstable' pattern following revision knee replacement, displaying multiple tests in the same single patient from the unstable group. This test achieved an output of 49 W.

constant force throughout depression of the pedal. We recorded this as a reduction in revolutions per minute (rpm) of the flywheel generated in a single test, and assessed this by direct measurement of the LEP output graphs (Fig. 1).

Statistical analysis. Data were analysed using Minitab release 16 software (IBM, Armonk, New York). Normally distributed data are reported as means with standard deviation (SD) as a measure of dispersal. Change in continuous variables over time was assessed by repeated-measures analysis of variance (ANOVA) and comparative analysis between revision and control groups was assessed by independent samples *t*-test or by chi-squared/Moods testing. Significance was accepted as $p \le 0.05$.

Results

Inability to generate a continuous force was indicated by an initial increase in flywheel speed, a subsequent reduction, and a secondary recovery within a single depression of the footplate by the patient (Fig. 1c). All 25 patients who were to undergo revision of their primary TKR for instability exhibited this distinctive 'double-push' pattern pre-operatively.

The mean pre-operative 'mid-push' reduction in flywheel speed was 55 rpm (SD 33.2), this change represented a 64% mid-push reduction in flywheel speed from the maximum value achieved. After revision TKR, none of the 25 patients exhibited this pattern of output: the 'mid-push' reduction in speed was 0 rpm in all cases at both six and 26 weeks (Fig. 2). Change between pre- and post-operative assessment (at both six and 26 weeks) was highly significant (ANOVA, $p \le 0.001$). *Post-hoc* analysis found no difference in pre-operative mid-push reduction in flywheel speed (independent *t*-test, $p = 0.81$) or in the graph output pattern between the different implants used (Fig. 3). No patients in the control group exhibited this output pattern at any of the time points assessed (Table I), the between-group difference was therefore also significant (Fig. 2; Table II) (chi-squared test, $p < 0.001$).

Pre-operatively, lower limb power output (W) was significantly less in the revision group than in the control group, although no significant differences were seen between groups post-operatively at either interval. Power output in the contralateral limb did not differ between groups (Table I).

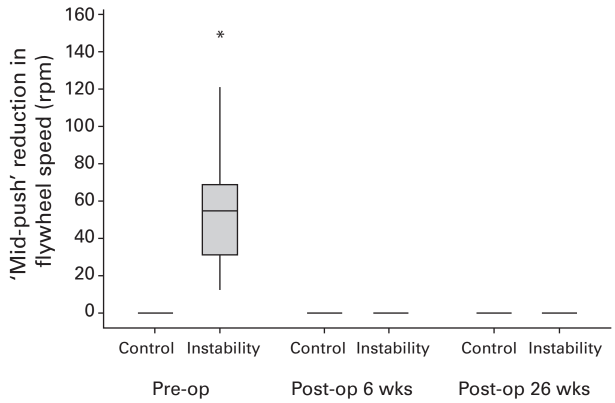

Fig. 2

Box plot highlighting mid-push reduction in flywheel speed by the revision and the control group pre-operatively (pre-op) and at both post-operative (post-op) intervals. The horizontal bar represents the group median reduction in mid-push speed, with the whiskers highlighting the spread of the data. The surrounding box highlights the interquartile range, and the whiskers the overall range.

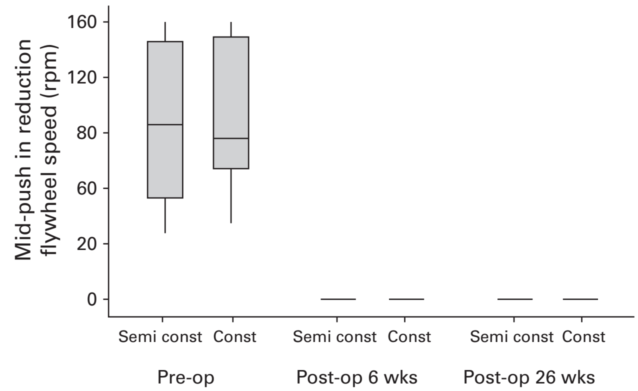

Fig. 3

Box plots highlighting mid-push reduction in flywheel speed pre-operatively (pre-op) and at both post-operative (post-op) intervals, according to the extent of constraint of the revision prosthesis. Const, constrained (hinged); semi-const, semi-constrained.

Table II. Chi-squared test for pre-operative between-groups differences in instability pattern

	Revision	Control	Total
Yes	25	0	25
No	0	183	183
Total	25	183	208

Chi-squared, 208.000; degrees of freedom, 1; p-value < 0.001

A comparison of the mid-push power reduction in the revision patients according to the type of revision implant they received found no significant difference between the versions at any interval (ANOVA, p = 0.8) (Fig. 3).

Discussion

In this paper we describe a simple, quantifiable lower limb power assessment which may have application as a diagnostic test for instability after TKR. All of our patients who were to undergo revision TKR for instability demonstrated a distinctive pattern pre-operatively that was corrected by surgery in every case. No difference in output pattern was seen between patients, irrespective of the degree of constraint of their revision implant, which suggests that adequate correction of the underlying problem is the primary factor in eliminating this 'abnormal' test result.

Paratte and Pagnano[3] suggest that a successful outcome of revision TKR for instability depends on identifying the cause of the instability, otherwise the surgeon risks repeating the errors of the original operation. A correct diagnosis of instability of the primary implant is thus of paramount importance if a successful outcome is to be achieved. Vince, Adbeen and Sugimori[12] suggest that the patient's report of instability is not a diagnosis but a presenting complaint, and that clinical examination is the key factor in determining the correct course of action. This is subjective and dependent on the clinician's skill and experience. The simple outpatient diagnostic tool we describe would potentially aid consistency in making the diagnosis.

The Nottingham rig measures single LEP in a seated upright position. A significant increase in LEP has been found after both total and unicompartmental knee replacement.[6,7] However, no-one has previously reported the use of this pushing action to assess knee stability. Forceful extension mimics the situation in which patients typically report symptoms of instability, with the added benefit that the effect of the symptoms can be quantified numerically from standard output graphs generated by the software.

Pre-operative power output (measured in watts generated) was much reduced in this revision cohort compared with that of patients undergoing planned primary TKR for OA,[6,8] although it was seen to recover at the same rate in the initial post-operative period. This suggests that after revision TKR for instability, a patient's functional ability at six weeks is similar to that after the primary procedure. Reduced power was seen at the six-month assessment when compared with the primary group, but this difference was not statistically significant (Table I) which suggests that the eventual physical recovery after revision for instability may not be the same as that after a satisfactory primary TKR.

The strengths of this study include linked pre- and post-operative data on flywheel acceleration and the resultant power output, and the fact that all the patients were drawn from a single high-volume centre which had a consistent rehabilitation programme. A further strength is the comparison with a well-defined control group of patients with a primary TKR and assessments at the same intervals.

Nevertheless, we acknowledge the limitations of our study. As we assessed implants which had been defined as unstable by the surgical teams, we cannot comment on the ability of this 'test' to distinguish unstable implants from those requiring revision for other causes. Accordingly, it is essential that the specificity and sensitivity of this method as a descriptive test is assessed. It is possible that other conditions could also cause a similar mid-push deceleration/secondary acceleration in output speed, however we have no such experience nor are aware of any report. Knee pain influences the output pattern by reducing the maximum flywheel speed achieved, and also the time taken to fully complete the depression of the pedal.[6] This pattern of reduced output is demonstrated in the pre-operative graphs from the control group of primary TKRs and can be contrasted with the post-operative output (Fig. 1a and 1b). When assessed clinically, all patients in the revision cohort reported some degree of pain as well as their symptoms of instability, but this was not described as a focal pain which occurred at the same time as an episode of instability. We believe that all the TKRs which required revision had true mechanical instability resulting in re-orientation of the tibiofemoral joint in the mid-push position, as opposed to pseudo-instability through pain inhibition of the quadriceps.

The overall mid-push reduction and restoration of speed pattern which we found after surgery was homogeneous. However, the comparatively small numbers we report do not provide sufficient power to make observations about preferential causative factors, such as differing mechanisms of developing instability. Such information would need a much larger study. More detailed confirmatory analysis with videofluoroscopy would help to elicit subtleties in the presentation of instability and might be dependent on different modes of failure, such as a fractured bone–cement interface or intrinsic ligamentous laxity.

A further limitation to the study is that the pre-operative data were collected at the pre-admission clinic and not during the outpatient assessment where the diagnosis of instability was made. Currently, there is no standard assessment for instability of a primary TKR, but instead the surgeon's diagnosis is accepted at face value. This apparent limitation is mitigated by the number of surgeons who assessed patients in this study, and the fact that all patients were found to present with the same pattern of instability.

The main finding of this study is that all patients who underwent a revision TKR for symptoms of instability demonstrated a distinctive pattern pre-operatively that was corrected by surgery. This suggests that a quantifiable test to assess the unstable primary TKR may be developed.

We thank our colleagues, Mrs C. Beadle, Prof S. J. Breusch, Mr P. Gaston, Mr G. Lawson, Mr M. Moran, Mr R. W. Nutton, Mr D. E. Porter, Mr P. Simpson and Mr F. A. Wade for their help with this study.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

This article was primary edited by G. Scott and first proof edited by A. Ross

References

1. **Sharkey PF, Hozack WJ, Rothman RH, Shastri S, Jacoby SM.** Insall Award paper: Why are total knee arthroplasties failing today? *Clin Orthop Relat Res* 2002;404:7.
2. **Azzam K, Parvizi J, Kaufman D, et al.** Revision of the unstable total knee arthroplasty: outcome predictors. *J Arthroplasty* 2011;26:1139–1144.
3. **Paratte S, Pagnano MW.** Instability after total knee arthroplasty. *J Bone Joint Surg [Am]* 2008;90-A:184–194.
4. **Callaghan JJ, O'Rourke MR, Saleh KJ.** Why knees fail: lessons learned. *J Arthroplasty* 2004;19(Suppl 1):31–34.
5. **Rodrigues-Merchan EC.** Instability following total knee arthroplasty *HSS J* 2011;7:273–278.
6. **Hamilton DF, Simpson AH, Burnett R, et al.** Lengthening the moment arm of the patella confers enhanced extensor mechanism power following total knee arthroplasty. *J Orthop Res* 2013;31:1201–1207.
7. **Barker KL, Jenkins C, Pandit H, Murray D.** Muscle power and function two years after unicompartmental knee replacement. *Knee* 2012;19:360–364.
8. **Lamb S, Frost H.** Recovery of mobility after knee arthroplasty: expected rates and influencing factors. *J Arthroplasty* 2003;18:575–582.
9. **Bassey EJ, Short AH.** A new method for measuring power output in a single leg extension: feasibility, reliability and validity. *Eur J Appl Physiol Occup Physiol* 1990;60:385–390.
10. **Robertson S, Frost H, Doll H, O'Conner J.** Leg extensor power and quadriceps strength: an assessment of repeatability in patients with osteoarthritic knees. *Clin Rehabil* 1998;12:120–126.
11. **Marsh AP, Miller ME, Saikin AM, et al.** Lower extremity strength and power are associated with 400-meter walk time in older adults: The InCHANTI study. *J Gerontol A Biol Med Sci* 2006;61:1186–1193.
12. **Vince KG, Adbeen A, Sugimori T.** The unstable total knee arthroplpasty: causes and cures. *J Arthroplasty* 2006;21(Suppl. 1):44–49.