Smoking and reconstruction of the anterior cruciate ligament

We sought to determine whether smoking affected the outcome of reconstruction of the anterior cruciate ligament. We analysed the results of 66 smokers (group 1 with a mean follow-up of 5.67 years (1.1 to 12.7)) and 238 non-smokers (group 2 with a mean follow-up of 6.61 years (1.2 to 11.5)), who were statistically similar in age, gender, graft type, fixation and associated meniscal and chondral pathology. The assessment was performed using the International Knee Documentation Committee form and serial cruciometer readings.

Poor outcomes were reported in group 1 for the mean subjective International Knee Documentation Committee score (p < 0.001), the frequency (p = 0.005) and intensity (p = 0.005) of pain, a side-to-side difference in knee laxity (p = 0.001) and the use of a four-strand hamstring graft (p = 0.015). Patients in group 1 were also less likely to return to their original level of pre-injury sport (p = 0.003) and had an overall worse final 7 International Knee Documentation Committee grade score (p = 0.007).

Despite the well-known negative effects of smoking on tissue healing, the association with an inferior outcome after reconstruction of the anterior cruciate ligament has not previously been described and should be included in the pre-operative counselling of patients undergoing the procedure.

The use of tobacco is a significant contributor to preventable morbidity and mortality.1 A significant proportion of cardiovascular diseases,2 various oral3 and pulmonary neoplasms,4 non-malignant respiratory diseases5 and peripheral vascular disorders6 can be attributed to the use of cigarettes. Surgical outcomes can also be adversely affected as a result of smoking, with intra-operative and post-operative pulmonary, cardiovascular and cerebrovascular complications.7 Some surgical specialists refuse to perform elective surgery on patients who are heavy smokers or who will not stop during post-operative rehabilitation.8

Smoking is associated with impaired wound healing9 and delayed bony union10,11 as well as having an adverse effect on the immune system.12 Tobacco combustion in cigarettes releases tissue-damaging oxygen free radicals,13 in addition to tar, ammonia, formaldehyde, lead, and many other unidentified organic particulates.14 Inhaled carbon monoxide reduces tissue oxygenation and impairs the microcirculation within healing soft tissue and bone.11,14 Nicotine is also a potent vasoconstrictor15 and impairs the revascularisation of healing bone.11

Despite these associations, a detailed search of the literature failed to identify any publication on the effects of smoking on the outcome after reconstruction of the anterior cruciate ligament (ACL).

This paper compares the clinical outcome of this procedure between a cohort of smokers and a matched group of non-smokers.

Materials and Methods

From our prospective database of ACL reconstructions, we identified 79 patients who had reported being smokers both pre-operatively and during rehabilitation, and placed them in one cohort of the study (group 1). Patients under 18 years of age at the time of reconstruction, those undergoing revision surgery, those with multiple ligamentous laxity, or those followed up for less than one year were excluded, leaving 66 patients in group 1. A group of 238 non-smokers (group 2) who had undergone primary reconstruction of the ACL during the same period were also selected using the same criteria. All the operations were carried out by the senior author (NPT) between 1991 and 2005 and followed a standardised programme of rehabilitation.16 The same independent reviewer (FW) evaluated the results of all patients in both groups.
Evaluation. Annual subjective and objective evaluation was performed from one year after operation using the International Knee Documentation Committee (IKDC) evaluation proforma, with scores from the most recent evaluation being used in the analyses.

Measurements of laxity were carried out using the Westminster cruciometer (University College, London, United Kingdom), a validated tool which measures anteroposterior (AP) knee laxity applying a force of 89 N to the knee in 20° of flexion, which provides a quantitative evaluation of Lachman's test. The correlation between Westminster cruciometer and KT 2000 (MEDmetric Corp., San Diego, California) has been found to be excellent (Pearson's coefficient 97%). The KT 2000 reading can be obtained by using the equation KT 2000 value = 0.845 x Westminster reading - 0.5904.

Statistical analysis. The two groups were statistically comparable for age at the time of surgery, gender, duration of follow-up, type of graft and fixation, and associated meniscal and chondral pathology (p > 0.2) (Table I). The mean follow-up was for 5.67 years in group 1 (1.1 to 12.7) and 6.61 years in group 2 (1.2 to 11.5). The IKDC score was the main measurement of outcome. A difference of 10% in the IKDC scores (a mean of 70 versus a mean of 63, or seven points difference) was indicative of a clinically-significant difference between the groups. With a mean IKDC score of 70 (16.0 to 19.8) and a standard deviation (SD) of 20.2, a statistical power calculation confirmed that a study power of 70% with 5% statistical significance could be achieved with a sample size of 66 patients in group 1 and 238 patients in group 2.

Two-sample t-tests and chi-squared tests were used to compare the IKDC subjective scores, with a level of significance of p = 0.05. All statistical methods and calculations were checked and approved by an independent medical statistician (RW).

Results
The mean subjective IKDC score for group 1 was 60.8 (16.0 to 97.8), and for group 2 was 70.1 (17.8 to 98.8) (p < 0.001).

Individual subjective IKDC question analysis demonstrated a significantly increased frequency (p = 0.005) and intensity of pain (p = 0.005), a decreased level of activity before the onset of pain (p = 0.022), an increased incidence of locking and catching of the knee (p = 0.021) and subjective instability (p = 0.089) in the smoking group. With regard to sports, there was no difference in pre-injury limitations (p = 0.451) between the two groups. However, following reconstruction of the ACL a higher proportion of patients in group 1 were unable to return to their original level of sport (p = 0.003) (Table II).

The patients’ own functional assessments of their knees after operation, using the IKDC evaluation proforma, showed no difference between the two groups in the ‘go upstairs’ (p = 0.075) and ‘rise from chair’ (p = 0.067) evaluation categories. In the remaining categories, patients in group 1 had significantly worse scores for ‘go downstairs’ (p = 0.009), ‘knee on knee’ (p = 0.046), ‘squat’ (p = 0.008), ‘sit with knee bent’ (p = 0.005), ‘run straight ahead’ (p = 0.029), ‘jump and land on affected knee’ (p = 0.011) and ‘stop and start quickly’ (p = 0.026) (Table II).

Analysis of ‘overall knee function’ IKDC scores demonstrated no difference in pre-injury scores between the two groups (p = 0.346). However, following reconstruction, patients in group 1 had a significantly worse subjective score (p = 0.002) (Table II).
Analysis of the graft construct revealed a higher mean IKDC score with the use of bone-patella tendon-bone grafts than with hamstring constructs in group 1 (p < 0.001) and group 2 (p < 0.001). Comparisons of scores for graft type between the two groups demonstrated a difference with the use of bone-patellar-tendon-bone (p = 0.042), although a more pronounced difference was detected when hamstring grafts were used (p = 0.015). Analysis of laxity, using the Westminster cruciometer, demonstrated a mean difference in side-to-side laxity of 2.2 mm (0 to 12) in group 1, compared with 1.4 mm (0 to 14) in group 2 (p = 0.001). No difference was detected in laxity of the contralateral knee (p = 0.312) (Table III).

An analysis of radiographs at the most recent follow-up from both groups by two independent reviewers (AK, HP) showed no significant differences in widening of the ACL tunnel (p = 0.913) or in the angles of the tibial tunnel (p = 0.990), compared with matched films taken immediately after operation. The patient identities on the radiographs were concealed and they were viewed and measured on two separate occasions. All possible measures were taken to reduce inter- and intra-observer error.

A combination of the subjective and objective scores for each group of patients was used to calculate the ‘final 7 group IKDC analysis grade’, as laid out in the IKDC examination proforma. The calculation involved an assessment of effusion, deficit in passive movement, ligament examination, compartment findings, pathology of the harvest site, radiological findings and functional knee tests. The lowest scoring criterion from the seven tests (graded A to D) was used to grade the final outcome of surgery and rehabilitation. Again, group 2 was found to have a significantly better outcome than group 1 (p = 0.007) (Fig. 1).

Discussion
The results of this study suggest that people who smoke have a worse functional outcome following primary reconstruction of the ACL. Symptoms of instability and laxity are reported by patients subjectively, and are demonstrated objectively with side-to-side differences in ACL cruciometry. In our graft subgroup analysis, bone-patellar tendon-bone grafts were found to be superior to hamstring grafts in both smokers and non-smokers. However, non-smokers who had hamstring grafts were found to do worse

### Table II. Results of subjective International Knee Documentation Committee (IKDC) analyses (mean; range)

<table>
<thead>
<tr>
<th>Category examined</th>
<th>Group 1</th>
<th>Group 2</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjective IKDC score</td>
<td>60.8 (16.0 to 97.8)</td>
<td>70.1 (17.8 to 98.8)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Level of highest activity score</td>
<td>3.2 (1 to 5)</td>
<td>3.5 (1 to 5)</td>
<td>0.022</td>
</tr>
<tr>
<td>Frequency of pain score</td>
<td>6.1 (1 to 10)</td>
<td>7.1 (1 to 10)</td>
<td>0.005</td>
</tr>
<tr>
<td>Severity of pain score</td>
<td>6.5 (1 to 10)</td>
<td>7.6 (1 to 10)</td>
<td>0.005</td>
</tr>
<tr>
<td>Level of activity limited by swelling score</td>
<td>3.3 (1 to 5)</td>
<td>3.5 (1 to 5)</td>
<td>0.102</td>
</tr>
<tr>
<td>Knee locking or catching score</td>
<td>0.5 (0 to 1)</td>
<td>0.4 (0 to 1)</td>
<td>0.021</td>
</tr>
<tr>
<td>Highest level of activity before giving way score</td>
<td>3.2 (1 to 5)</td>
<td>3.6 (1 to 5)</td>
<td>0.089</td>
</tr>
<tr>
<td>Highest level of pre-injury sport score</td>
<td>3.7 (1 to 5)</td>
<td>3.6 (1 to 5)</td>
<td>0.451</td>
</tr>
<tr>
<td>Highest level of post-rehabilitation sport score</td>
<td>3.1 (1 to 5)</td>
<td>3.5 (1 to 5)</td>
<td>0.003</td>
</tr>
</tbody>
</table>

### Table III. Graft construct and cruciometry analyses (mean; range)

<table>
<thead>
<tr>
<th>Category examined</th>
<th>Group 1</th>
<th>Group 2</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPTB graft IKDC score</td>
<td>68.6 (17.2 to 97.7)</td>
<td>76.1 (17.8 to 100)</td>
<td>0.042</td>
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<tr>
<td>Hamstring graft IKDC score</td>
<td>56.1 (16.02 to 90.8)</td>
<td>62.9 (17.2 to 98.8)</td>
<td>0.015</td>
</tr>
<tr>
<td>Cruciometry of ACLR side (mm)</td>
<td>8.5 (0 to 18)</td>
<td>7.2 (0 to 20)</td>
<td>0.013</td>
</tr>
<tr>
<td>Cruciometry contralateral side (mm)</td>
<td>6.6 (0 to 18)</td>
<td>6.3 (0 to 10)</td>
<td>0.312</td>
</tr>
<tr>
<td>Side-to-side difference (mm)</td>
<td>2.2 (0 to 12)</td>
<td>1.4 (0 to 14)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

* BPTB, bone-patella-tendon-bone; IKDC, International Knee Documentation Committee; ACLR, anterior cruciate ligament reconstruction
Reconstruction of the ACL is not a universally successful procedure, with reported rates of graft failure as high as 17% at one year. Failure of osteointegration at the graft-bone interface has been shown to decrease the overall strength of the graft and is thought to induce anterior instability. A comparative study of bone-bone repair and bone-tendon healing in patella-patellar tendon complexes in rabbits demonstrated that the healing interface of bone-bone was mechanically superior to bone-tendon, resisting greater loading stress.

Smoking has been shown to be the single most important risk factor for the development of complications after elective arthroplasty of the hip or knee. Wound complications have been shown to be related to smoking habits, and smokers are more likely to need further surgery. Many of the adverse effects of smoking are reversible, and cessation for six to eight weeks prior to surgery and during the period of rehabilitation has been proved to significantly reduce post-operative complications and improve the chance of success.

The counselling of patients undergoing reconstruction of the ACL may have included smoking as a general cardio-pulmonary risk, but in the light of these findings, a poorer outcome can be predicted for smokers undergoing this procedure. Our data do not allow us to assess whether a less aggressive rehabilitation regimen would yield more favourable results in this group.

Over 50 statistical analyses were performed in this study, with a significance level of $p = 0.05$. At least three of our significant findings may have occurred by chance. The importance of findings with significance levels between $p = 0.05$ and $p = 0.01$ must be carefully considered, especially if they are isolated observations which do not appear consistent with the overall findings of the study. The power calculation performed for this study demonstrated a power of only 70%, which is less than the conventional threshold of 80%. However, because of the number of significant differences detected, the risk of a type 2 error (lack of power) was deemed very small.

Despite being a prospective study, the exact quantification of the pack-years of smoking (number of packets of cigarettes, usually containing 20, smoked per year) undertaken by group 1 prior to surgery and during rehabilitation was not recorded. However, a significant sample, 35 (53%), of the patients who smoked were contacted and questioned regarding their smoking habits, and were found to smoke a mean of 17 cigarettes per day (2 to 20). Previous clinical studies of smoking habits have demonstrated significant discrepancies between actual and admitted use. Also, the unfavourable stigma of smoking associated with health-care and surgery may have resulted in some patients not disclosing their true level of smoking. We acknowledge that this small population of unidentified patients may exert some statistical favour towards group 1.

**References**


