SURGICAL IMPLICATIONS OF VARUS DEFORMITY OF THE KNEE WITH OBLIQUITY OF JOINT SURFACES

T. DEREK V. COOKE, DAVID PICHORA, DAVID SIU, R. ALLAN SCUDAMORE, J. TIMOTHY BRYANT

From Queen's University, Kingston, Ontario

Some arthritic knees with varus deformity show excessive valgus angulation of the femoral joint surface with proximal tibia vara. This causes a downward and medial inclination of the articular surfaces in the coronal plane. The patients we studied had a medial shift of the standing load-bearing axis, and arthritic changes mainly in the medial compartment. Some also had lateral tibial subluxation with twisting of the distal femur and proximal tibia in opposite directions.

We assessed the articular geometry by precise radiographic analysis, and compared the results with those in normal volunteers and a group of osteoarthritic patients. The prevalence of this type of deformity in our osteoarthritic patients was 11.5%; its recognition allows the use of specific operative correction that may include double osteotomy or the precise orientation of prosthetic components.

Stability of the knee depends upon long-bone alignment, articular surface geometry and the resistance to subluxation provided by ligamentous and capsular structures. Instability may predispose to osteoarthritis (Cooke and Pichora 1985). Most authors agree that the ideal leg alignment when standing provides a load-bearing axis from hip centre to ankle centre, passing through the middle of the knee. In a bow leg, load-bearing is shifted medially, and there is an association with medial compartment arthritis. Conversely, in knock-knee deformity, the lateral compartment is usually worse affected (Cooke 1985).

The relationships between different knee surface alignments and patterns of arthritis are not well defined. Varus alignment of the articular surface of the proximal tibia (proximal tibia vara) has been noted in 88% of cases with medial compartment osteoarthritis (Iseki and Fujikawa 1980; Cooke, Siu and Fisher 1987), and excessive valgus alignment of the femoral condyles (distal femoral valgus) has been recognised in lateral compartment arthritis (Coventry 1973; Shoji and Insall 1973; Maquet and Pelzer 1977; Hood and Insall 1984). However, there are few reports about femoral condylar alignment in medial compartment arthritis or tibial surface alignment in lateral compartment arthritis.

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T. D. V. Cooke, MA, FRCSI(C), Professor of Surgery and Chairman of Clinical Mechanics Group
D. Pichora, MD, FRCSI(C), Assistant Professor of Surgery
D. Siu, MSc, PEng, Research Associate
R. A. Scudamore, MA, PhD, Research Associate
J. T. Bryant, PhD, PEng, Principal Investigator
Clinical Mechanics Group, Department of Mechanical Engineering,
Queen’s University, Kingston, Ontario, Canada, K7L 3N6.
Correspondence should be sent to Dr T. D. V. Cooke at Clinical Mechanics Group, Apps Medical Research Centre, Kingston General Hospital, Kingston, Ontario, Canada K7L 2V7.

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0301-620X/89/4134 $2.00
Our interest in the orientation of knee surfaces relative to the axial alignment of the long-bones has been stimulated by several cases in which excess proximal tibia vara, excess distal femoral condylar valgus, and a medial shift of the load-bearing axis into a bow-legged alignment occur with medial arthritis. These combined deformities produce an increased downward and medial inclination of the joint surfaces in the coronal plane (Fig. 1) (Cooke and Pichora 1985). In this paper we examine the articular geometry underlying this condition, assess the prevalence of this type of alignment in an osteoarthritic population, and use two cases to illustrate the implications for corrective surgery.

PATIENTS AND METHODS

We studied 19 patients who presented to the first author over a period of nine years, and were selected as a group showing varus limb alignment, exaggerated distal femoral valgus and proximal tibia vara. Each showed arthritic changes in the medial compartment. Four had rheumatoid arthritis and 15 osteoarthritis. Three of the patients were male, and the age range was 17 to 82 years (mean 66 years). Bilateral radiographs were taken of each patient, but only the 34 knees which had not had an osteotomy or a total joint replacement were included in the study.

![Fig. 2](Image)

Angular measurements used in this study

FSTS: femoral shaft–tibial shaft; angle between a line from the centre of the femoral shaft to the intercondylar notch and the line from the mid-tibial eminence to the centre of the tibial shaft. Negative angles denote varus deviation from neutral alignment.

TPTS: tibial plateau–tibial shaft; angle between the tibial articulating margins and the tibial axis (mid-tibial eminence to centre of tibial shaft); varus shown as negative deviation from 90°.

FSXC: femoral shaft–transcondylar; angle between the transcondylar tangent and the femoral axis, expressed as valgus (+) or varus (−) deviation from 90°.

CMXC: capitomidcondylar–transcondylar; angle between the transcondylar tangent and the capitocondylar axis, expressed as valgus (+) or varus (−) deviation from 90°.

Our ‘normal group’ comprised 48 young adult volunteers aged 20 to 29 years (mean 24 years), of whom 25 were men. The group was selected as having no history of knee problems, with no clinical and radiographic evidence of osteoarthritis. Both knees (96 in all) were studied.

The ‘osteoarthritic’ (OA) group were of 220 consecutive patients presenting between 1981 and 1985. Of these 82 were men, and the age range was 29 to 88 years (mean 66 years). Bilateral radiographs were taken, but only 419 knees with no previous osteotomy or total replacement were used in the study.

**Radiography.** The normal and OA groups received Questor Precision Radiography (QPR). In this method (Wevers, Siu and Cooke 1982; Siu et al. 1986; Cooke et al. 1987), the patient stands on a turntable with the knees and ankles located in relation to radiographic markers embedded in plexiglass panels mounted on the frame. The position of the feet is recorded. Rotation of the turntable permits radiographs to be taken in anteroposterior and lateral directions, without changing the position of the patient. This provides biplanar orthogonal assessment of knee geometry with reference to the location of the hip and the ankle. Key bony landmarks are marked on the radiographs, and the information is digitised and processed by computer to provide a graphic display of linear and angular measurements.

The four angles we used, shown in Figure 2, are:

- femoral shaft–tibial shaft (FSTS);
- femoral shaft–transcondylar (FSXC);
- capitomidcondylar–transcondylar (CMXC);
- tibial plateau–tibial shaft (TPTS).

Angles between long-bone axes and articulating surfaces are expressed as degrees of variance from a right angle (negative for varus, positive for valgus).

In the study group, 10 patients (19 knees) had been seen before QPR facilities were available at the Kingston General Hospital, so radiographs were taken by the normal standing method, and the angles were measured without computer assistance. CMXC angles were not available for this group. The other 12 patients (15 knees) had precision radiography.

**Data analysis.** Mean values and standard deviations of the four angles (FSTS, FSXC, CMXC, and TPTS) were calculated for each group, and the significance of differences between the groups was determined by two-tailed t-tests.

The prevalence of combined distal femoral condylar valgus and proximal tibia vara was examined by generating scatterplots of FSXC against TPTS and CMXC against TPTS for each of the three populations. From these plots, we counted the number of subjects having both a more valgus FSXC (or CMXC) and a more varus TPTS, than the mean values for the ‘normal’ group.

The relationship between the angles CMXC and FSXC (both of which record angulation of the femoral articular surface) was examined by linear regression analysis.
RESULTS

Articular geometry. Radiographic data and relevant information for the study group are listed in Table I. The mean values, standard deviations, and statistical comparisons of FSTS, FSXC, CMXC and TPTS are shown in Table II.

The OA group had a relatively varus inclination of the distal femur (FSXC, CMXC) and relative valgus inclination of the proximal tibia (TPTS) compared to the normal group. However, there was no difference in mean limb alignment (FSTS). Compared to the other groups, the study group had significantly greater varus limb alignment, distal femoral valgus and proximal tibia vara. This merely confirms the pattern of abnormality for which they were selected.

The pattern of abnormality seen in the study group is associated with FSXC (or CMXC), TPTS and FSTS angles all outside the mean values for knees of the normal group. Table III shows the percentages of knees in each group which satisfy just two of these criteria (FSTS ignored). Of the study group 80% did so, the remainder narrowly failing. Only 11.5% of the OA group compared with 26% of the normal group have the type of alignment represented by the study group. We cannot explain why this type of alignment is less common in OA patients than in the normal population (Tables II and III).

The correlation coefficient for FSXC against CMXC was 0.958 (p<0.01) in the osteoarthritic group (Fig. 3), and 0.794 (p<0.01) in the 15 knees of the study group measured by precision radiography.

Illustrative case reports

Case 1. This patient had bilateral varus knees with a five-year history of osteoarthritis in the right medial compartment (Fig. 4a). Lateral tibial thrust was observed during walking. We performed double closing wedge osteotomies (varus femoral and valgus upper tibial) about the right knee. These over-corrected the proximal tibia vara (TPTS) from −10.5° (varus) to +2° (valgus), and distal femoral valgus (FSXC) from 13.5° to 4°. The long-bone alignment (FSTS) changed from −3.5° varus to +6° valgus with some improvement of the narrowing of the medial joint space and reduced subluxation (Fig. 4b). The knee has been asymptomatic since operation, with an excellent functional range of movement.

Case 2. This patient, first seen 15 years ago, had a sudden onset of rheumatoid arthritis superimposed on a longstanding history of mild bilateral knee pain and stiffness. Standing radiographs showed severe distal femoral valgus deformity and proximal tibia vara (Fig. 5a). Within a year of onset, destructive changes were seen in both knees (Fig. 5b) and progressive varus deformities with lateral subluxation of the tibiae occurred in the next 12 months. Her radiographs then showed marked loss of joint space, especially on the medial side, lateral tibial subluxation and increased obliquity of the joint line (FSXC 14°, TPTS −9°).

Left total knee replacement, using an Irvine femorotibial prosthesis was performed (Fig. 5c). Unfortunately, the femoral component was set in excessive valgus, with some internal rotation that followed the existing articular geometry: standing radiographs showed that the joint line was still oblique with 13° FSXC and −6° TPTS; lateral views of the knee in flexion showed patellar dislocation (Fig. 5d). Ultimately, implant subsidence occurred and revision was required.
Replacement of the other knee required bone resection from the distal and posterior aspects of both the medial femoral condyle and the lateral tibial plateau with wide lateral patellar release. The result was excellent until the patient died three years later, from vasculitic complications.

**DISCUSSION**

We draw attention to a pattern of deformity in which distal femoral valgus and proximal tibia vara are combined in a bow-legged limb. This pattern can be defined in terms of deviation from normal alignment (Table II) as a combination of:

i) femoral shaft–transcondylar angle (FSXC) greater than 9°, or CMXC greater than 3.8°

ii) tibial plateau–tibial shaft (TPTS) more negative than −3.3°

iii) femoral shaft–tibial shaft (FSTS) less than 3.9°.

We feel that the exaggerated inward inclination of the joint surfaces, relative to the load-bearing axis, will generate lateral subluxing forces on the tibia, and tend to overload the medial compartment (Cooke and Pichora 1985). There was clinical evidence of both effects in the patients studied.

Although relatively uncommon, this pattern of deformity warrants special consideration. Case I illustrates that stabilisation may be achieved by combined femoral and tibial osteotomies to restore the slant of the joint surfaces to near horizontal, and we would anticipate a lower success rate with tibial osteotomy alone (Jackson and Waugh 1961; 1974).

In total knee replacement, we also advocate horizontal alignment of the articulating surfaces. However, it is possible that the femoral component becomes positioned according to the internal axial rotation of the femoral condyles, which we have noted in several such cases. This accentuates any lateral shift of the patella (predisposing to patellar subluxation) and may complicate closure of the wound. Our strategy in such cases is to centre the femoral component on the transepicondylar line, square to the load-bearing axis (Yoshioka, Siu and Cooke 1986; Yoshioka and Cooke 1987).

Another problem in management may arise from rapid progression of destructive changes when inflammatory disease occurs in patients with this type of deformity, as was seen in our Case 2. One may speculate that in such cases the abnormal biomechanics acts synergistically with inflammatory processes to accelerate joint destruction.

Careful diagnostic radiology is needed to identify this pattern of deformity. A full length standing radiography is the minimum requirement, but QPR provides a standardised method. This improves the accuracy and reproducibility of measurements, and enables close monitoring of alignment changes resulting from disease or surgery.

Some of the joint angles measured by precision...
Table I. Pre-operative radiographic analysis of 34 knees in 19 patients

<table>
<thead>
<tr>
<th>Sex and age</th>
<th>Side</th>
<th>FSTS</th>
<th>TPTS</th>
<th>FSXC</th>
<th>CMXC</th>
<th>Operation</th>
</tr>
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<tbody>
<tr>
<td>Questor precision radiography</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>M75</td>
<td>L</td>
<td>+4.5</td>
<td>-1</td>
<td>11</td>
<td>6.5</td>
<td>Total knee replacement</td>
</tr>
<tr>
<td>F68</td>
<td>R</td>
<td>-5</td>
<td>-5</td>
<td>13</td>
<td>6</td>
<td>Triple osteotomy</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>-4</td>
<td>-6</td>
<td>12</td>
<td>5</td>
<td>Double osteotomy</td>
</tr>
<tr>
<td>F72</td>
<td>L</td>
<td>+4.9</td>
<td>-7.3</td>
<td>12</td>
<td>6.5</td>
<td>-</td>
</tr>
<tr>
<td>F46</td>
<td>R</td>
<td>+1.8</td>
<td>-6</td>
<td>11</td>
<td>4.5</td>
<td>Triple osteotomy</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>+3</td>
<td>-4.9</td>
<td>10.7</td>
<td>4.6</td>
<td>-</td>
</tr>
<tr>
<td>F65</td>
<td>R</td>
<td>-1</td>
<td>-1.8</td>
<td>9.1</td>
<td>3.4</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>-1.4</td>
<td>-6.2</td>
<td>10.7</td>
<td>4.3</td>
<td>-</td>
</tr>
<tr>
<td>F74</td>
<td>R</td>
<td>-1.5</td>
<td>-7</td>
<td>9</td>
<td>4</td>
<td>Total knee replacement†</td>
</tr>
<tr>
<td></td>
<td>L</td>
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<td>-5.9</td>
<td>8.7</td>
<td>3.8</td>
<td>-</td>
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<tr>
<td>F59</td>
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<td>8.6</td>
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<td>Triple osteotomy</td>
</tr>
<tr>
<td>F69</td>
<td>R</td>
<td>-0.2</td>
<td>-2.9</td>
<td>10.5</td>
<td>4</td>
<td>Triple osteotomy</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>+2</td>
<td>-5.3</td>
<td>11.2</td>
<td>5.2</td>
<td>-</td>
</tr>
<tr>
<td>F67</td>
<td>R</td>
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<td>-3.2</td>
<td>12</td>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>+4.9</td>
<td>-3.5</td>
<td>11.6</td>
<td>6.1</td>
<td>-</td>
</tr>
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<td>Standing radiographs</td>
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<td></td>
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<td>M82</td>
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<td>-7.5</td>
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</tr>
<tr>
<td></td>
<td>L</td>
<td>+1</td>
<td>-8.5</td>
<td>13</td>
<td></td>
<td>Total knee replacement†</td>
</tr>
<tr>
<td>M62</td>
<td>R</td>
<td>+4</td>
<td>-11.5</td>
<td>10</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>+4</td>
<td>-7</td>
<td>10</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>F52</td>
<td>R</td>
<td>-1</td>
<td>-10</td>
<td>12</td>
<td></td>
<td>Triple osteotomy (revision)</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>-1</td>
<td>-11</td>
<td>12</td>
<td></td>
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</tr>
<tr>
<td>F70</td>
<td>R</td>
<td>-3.5</td>
<td>-10.5</td>
<td>13.5</td>
<td></td>
<td>Double osteotomy</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>-3</td>
<td>-12</td>
<td>12</td>
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<td>R</td>
<td>+5</td>
<td>-5</td>
<td>12</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>+2</td>
<td>-4</td>
<td>11.5</td>
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<td>-</td>
</tr>
<tr>
<td>F81</td>
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<tr>
<td></td>
<td>L</td>
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<td>11</td>
<td></td>
<td>-</td>
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<tr>
<td>F70</td>
<td>R</td>
<td>+2.5</td>
<td>-3.5</td>
<td>11</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>F81*</td>
<td>R</td>
<td>-11</td>
<td>-6</td>
<td>10</td>
<td></td>
<td>Total knee replacement</td>
</tr>
<tr>
<td></td>
<td>L</td>
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<td>-5</td>
<td>13</td>
<td></td>
<td>Total knee replacement</td>
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<td></td>
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<td>+4</td>
<td>-8</td>
<td>13</td>
<td></td>
<td>Double osteotomy</td>
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<tr>
<td>F63*</td>
<td>R</td>
<td>0</td>
<td>-9</td>
<td>14</td>
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<td>Total knee replacement</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>0</td>
<td>-8</td>
<td>14</td>
<td></td>
<td>Total knee replacement</td>
</tr>
</tbody>
</table>

* patient with rheumatoid arthritis  † with osteotomy

Table II. Knee geometry in normal volunteers, OA group and the study group, with probability values for differences

<table>
<thead>
<tr>
<th>Angle in degrees (s.d.)</th>
<th>Normal</th>
<th>OA group</th>
<th>Study group</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSTS</td>
<td>3.9 (2.6) p&gt;0.05</td>
<td>3.4 (6.9) p&lt;0.025</td>
<td>0.5 (3.8)</td>
</tr>
<tr>
<td>FSXC</td>
<td>9.0 (2.1) p&lt;0.005</td>
<td>8.1 (2.6) p&lt;0.001</td>
<td>11.7 (1.8)</td>
</tr>
<tr>
<td>CMXC</td>
<td>3.8 (2.1) p&lt;0.001</td>
<td>2.4 (2.7) p&lt;0.001</td>
<td>4.9 (1.0)</td>
</tr>
<tr>
<td>TPTS</td>
<td>-3.3 (2.2) p&lt;0.001</td>
<td>-1.7 (4.3) p&lt;0.001</td>
<td>-6.2 (2.8)</td>
</tr>
</tbody>
</table>

Table III. Percentages of the various groups studied that showed varus obliquity of the knee as defined in the text

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Normal</th>
<th>Osteoarthritic</th>
<th>Study group</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSTS&gt;9°; TPTS&lt; -3.3°</td>
<td>26</td>
<td>11.5</td>
<td>76.5*</td>
</tr>
<tr>
<td>CMXC&gt;3.8°; TPTS&lt; -3.3°</td>
<td>27</td>
<td>7.9</td>
<td>80.0</td>
</tr>
</tbody>
</table>

* 3 knees had too little proximal tibia vara to qualify; 3 knees had too little femoral condylar valgus to qualify; 1 knee was off limit on both accounts
radiography are unfamiliar, such as CMXC which defines
distal femoral (condylar) valgus relative to the hip centre.
We prefer this measurement to FSXC, which ignores the
geometry of the femoral neck. However, the high
correlation between CMXC and FSXC (Fig. 3) shows
that FSXC measured on normal standing radiographs
can be used to detect distal femoral valgus (Table III).
Torsional deformity is usually apparent in precision
lateral views, although this is best defined by CT methods
(Jakob, Haertel and Stüssi 1980; Yoshioka and Cooke
1987).

The authors wish to acknowledge the invaluable assistance of members
of the Clinical Mechanics Group at Queen’s University in the
development and use of the Questor precision radiography described
here, particularly B. Fisher, RN. We are also grateful for the support of
the radiology staff and technicians at Kingston General Hospital, and
the input of Dr C. Watson in the initial assessment of these cases.
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.

REFERENCES

Cooke TDV. Pathogenetic mechanisms in polyarticular osteoarthritis.
In: Sokoloff L, Guest Ed. Clinics in Rheumatic Diseases. London,

Cooke TDV, Pichora D. Knee dysplasia: an unusual but important

Cooke TDV, Siu D, Fisher B. The use of standardized radiographs to
identify the deformities associated with osteoarthritis. In: Noble
J, Galasko CSB, eds. Recent developments in orthopaedic surgery.

Coventry MB. Osteotomy about the knee for degenerative and
rheumatoid arthritis: indications, operative technique, and results.

Adult orthopaedics. Vol. 2. New York, etc: Churchill Livingstone,

Iseki F, Fujikawa R. [Clinical pictures of osteoarthritis in the knee joint.
(Author’s transl)]. Nippon Seikeigeka Gakkai Zasshi 1980;54:
563-74.

Jakob RP, Haertel M, Stüssi E. Tibial torsion calculated by computer-
ised tomography and compared to other methods of measurement.


Jackson JP, Waugh W. The technique and complications of upper

Maquet PG, Pelzer GA. Evolution of the maximum stress in osteo-

Shoji H, Insall J. High tibial osteotomy for osteoarthritis of the knee
A:963-73.

Siu D, Chow D, Fisher B, McKinven L, Cooke TDV. A standardized
radiographic method for the assessment of alignment geometry
and joint space loss in the knee: the Questor nomenclature. The
Canadian Orthopaedic Association 42nd Annual Meeting: The
Canadian Orthopaedic Research Society 20th Annual Meeting,

Wevers HW, Siu D, Cooke TD. A quantitative method of assessing
malalignment and joint space loss of the human knee. J Biomed

Yoshioka Y, Cooke TD. Femoral antversion: assessment based on

Yoshioka Y, Siu DW, Cooke TD. Femoral geometry in relationship to
the mechanical axes of knee ligament origins. Orthop Trans