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Title: Biomechanical techniques to evaluate tibial rotation. A systematic review.

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Abstract: Purpose: This article systematically reviewed the biomechanical techniques to quantify tibial rotation, for an overview of how to choose suitable technique for specific clinical application.

Methods: A systematic search was conducted and finally 110 articles were included in this study. The articles were categorized by the conditions of how the knee was examined: external load application, physical examination and dynamic task.

Results: The results showed that two thirds of the included studies measured tibial rotation under external load application, of which over 80% of the experiments employed a cadaveric model. The common techniques used included direct displacement measurement, motion sensor, optical tracking system and universal force moment sensor. Intra-operative navigation system was used to document tibial rotation when the knee was examined by clinical tests. For dynamic assessment of knee rotational stability, motion analysis with skin reflective markers was frequently used although this technique is less accurate due to the skin movement when compared with radiographic measurement.

Conclusion: This study reports various biomechanical measurement techniques to quantify tibial rotation in the literatures. To choose a suitable measurement technique for a specific clinical application, it is suggested to quantify the effectiveness of a new designed surgical technique by using a cadaveric model before applying to living human subjects for intra-operative evaluation or long time functional stability assessment. Attention should also be paid on the study's purpose, whether to employ a cadaveric model and the way of stress applied to the knee.

Level of Evidence: IV

Response to Reviewers: Please see attachment.

Title Page

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ABSTRACT

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20 20 designed surgical technique by using a cadaveric model before applying to living
21 21 human subjects for intra-operative evaluation or long time functional stability
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23 23 cadaveric model and the way of stress applied to the knee.

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27 INTRODUCTION

28 The knee is the most commonly injured body site during sports, accounting for
29 roughly 40% of all sports injuries [75]. Traumatic knee injury such as ligament tear
30 may lead to knee instability, prohibiting athletes from returning to sports, and
31 resulting in early retirement [85] or even premature end to sport career [65]. In
32 clinical practice, knee laxity evaluations are based on physical examination performed
33 by trained physician. Force or torque is manually applied to the knee joint to see if
34 there is any abnormal motion when compared with the intact side. However, clinical
35 examination has a few limitations [73], including inability to produce sufficient
36 magnitude of force to simulate physical activity and subjective grading from
37 physician due to varying experience.

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39 In the literature, there are various studies to assess knee laxity and stability. Besides
40 clinical examination, self-reported outcome questionnaire is often used in clinical
41 research. Other passive knee laxity assessments include stressed magnetic resonance
42 imaging [99] and objective clinical devices [115]. These assessments involve a
43 controlled stress to the knee joint in a specific direction followed by an objective
44 biomechanical rating for the corresponding laxity. On the other hand, dynamic
45 movement is directly performed so that knee stability would be monitored during a
46 specific motion. For example, previous studies have suggested that abnormal joint
47 kinematics during dynamic movements after anterior cruciate ligament (ACL)
48 reconstruction would contribute to long-term joint degeneration [95,112].

49
50 It has been reported that excessive tibial rotation is found in ACL deficient and
51 reconstructed knees and this abnormal motion leads to a shift in functional load over
52 cartilage areas, resulting in osteoarthritis [7,109]. The restoration of knee rotational

1 53 stability is recently being emphasized because anatomic double-bundle ACL
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3 54 reconstruction has been suggested to restore rotational stability better than
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5 55 single-bundle ACL reconstruction [34]. The pivot shift test and the dial test are often
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7 56 employed by clinicians to measure knee rotational stability. However, due to the
8
9 57 limitations aforementioned, these clinical examinations cannot provide a reliable
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11 58 assessment and objective evaluation for patients with ligamentous injury.
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17 60 In view of the various methodologies in the literature, biomechanics plays an
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19 61 important role to objectively quantify knee rotational laxity and stability when
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21 62 compared with clinical examinations. However, there are no guidelines in the
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23 63 literatures regarding which measurement technique is suitable for specific clinical
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25 64 application. This information should be added so that orthopaedic specialists and sport
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27 65 biomechanists are able to choose the most suitable technique for solving clinical
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29 66 problems in relation to knee structure, injury diagnosis and effect of ligament
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31 67 reconstruction. This study aimed to systematically review the biomechanical
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33 68 techniques to quantify tibial rotation and provided an overview for choosing
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35 69 biomechanical technique for specific clinical application. Tibial rotation was defined
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37 70 as the relative movement of the femur and the tibia in the transverse plane.
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44 72 **MATERIALS AND METHODS**

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46 73 A systematic literature search was conducted based on the guidelines by Wright et al.
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48 74 [128]. A search in MEDLINE (from 1966) was conducted during the last week of
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50 75 December in 2010. The search keyword was (knee OR tibial OR tibia) AND (rotation
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52 76 OR rotational OR rotatory OR pivot OR pivoting) AND (biomechanics OR
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54 77 biomechanical OR kinematics OR displacement) AND (stability OR laxity), which
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56 78 appeared in the title, abstract or keyword fields. After duplicates were removed, the
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1 79 initial total number of articles in the database was 532. The title and abstract of each
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3 80 entry was read to identify non-relevant articles. Non-English articles, animal studies
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5 81 and non-related articles were excluded. After this trimming, the number of appropriate
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7 82 articles was reduced to 190. Online and library searches for the full text of these
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10 83 articles were conducted. A hand search was conducted to identify articles not captured
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12 84 in the above searches. Only full text of two articles could not be retrieved, and the
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14 85 final number of articles with full text was 188.

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19 87 The full text of each of the 188 retrieved articles was read to determine the inclusion
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21 88 and exclusion criteria in the systematic review. To be included in the systematic
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23 89 review, three criteria must be fulfilled: (1) the study must employ human, either
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25 90 cadaver specimen or living subject, (2) the study must explore tibial rotation,
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27 91 measuring the relative movement of femur and tibia in the transverse plane as a
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29 92 dependent parameter to quantify the knee rotational laxity and stability, (3) the study
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31 93 must not involve total knee arthroplasty or the prescription of knee prosthesis, since
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33 94 the knee anatomy is greatly altered in these studies. Current concepts, reviews, case
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35 95 reports, computerized models such as finite element model and studies without
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37 96 detailed description of the measuring technique were excluded. After the screening
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39 97 process, the final number of articles included in the analysis was 111.

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48 99 The included biomechanical techniques in these 111 selected articles were categorized
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50 100 by the conditions of how the knee was examined: (1) external load application – when
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52 101 the knee was under a certain rotational load in a controlled manner; (2) physical
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54 102 examination – when the knee was being clinically examined by an orthopaedic
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56 103 specialist, a physiotherapist or a biomechanist; (3) dynamic task – when the patient
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58 104 was performing a specific dynamic movement. The techniques to quantify tibial
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1 105 rotation in each category were summarized followed by the discussion of these
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3 106 biomechanical techniques.

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7 108 **RESULT**

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10 109 All 111 included articles were divided into three categories: external load application
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12 110 (67%), physical examination (14%) and dynamic task (19%). Over 60% of all the
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14 111 articles employed a cadaveric model. While various measurement techniques were
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16 112 used in external load application category, intra-operative navigation and optical
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18 113 motion analysis system were commonly used in physical examination and dynamic
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20 114 task categories, respectively.
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26 116 Of the 110 included articles, 74 articles (67%) were classified as external load
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28 117 application. Of these, 61 studies (82%) used human cadaver for the testing subjects
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30 118 and the rest (13 studies) used living human. The techniques included direct
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32 119 displacement measurement, magnetic sensing, optical tracking system, navigation
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34 120 system, radiographic measurement and universal force moment sensor.
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41 122 In physical examination category, fifteen studies (14%) were included. All studies
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43 123 were conducted after 2002. The three major techniques for measuring tibial rotation
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45 124 when an examiner performed clinical tests were goniometer, electromagnetic sensing
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47 125 and intra-operative navigation. These techniques were tested on both cadaver
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49 126 specimens and living human subjects.
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55 128 The last category, dynamic task, included twenty two studies (19%) and all were
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57 129 published after 2000 except two from the 1980s. In earlier years, the
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59 130 electrogoniometer was used for measuring knee rotational displacement during
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1 131 treadmill running [23,62]. Before roentgen stereophotogrammetric analysis (RSA)
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3 132 was applied on living human who performed dynamic task in 2001, there were about
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5 133 10 years of vacuity where no journal papers were published specifically investigating
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7 134 on knee rotational stability during dynamic task. All the biomechanical techniques
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9 135 discussed were summarized in Table 1.

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13 137 **DISCUSSION**

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17 138 The most important finding was that two thirds of the included studies measured tibial
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19 139 rotation under external load application, of which over 80% of the experiments
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21 140 employed cadaveric model. This kind of study design enhances a well controlled
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23 141 laboratory setting for accurate comparison. Secondly, intra-operative navigation
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25 142 system has been commonly used to quantify tibial rotation when the knee is examined
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27 143 by physical tests. For dynamic assessment of knee rotational stability, motion analysis
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29 144 with skin reflective markers has been frequently employed although this technique is
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31 145 less accurate due to the skin movement when compared with RSA technique.
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37 147 **External load application**

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41 148 In the cadaveric studies, both the femur and tibia were mounted in fixation systems,
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43 149 which provided three to six degrees of freedom (DOF) including primary motion
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45 150 (flexion-extension) and secondary motion (anterior-posterior translation,
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47 151 internal-external rotation and abduction-adduction) [28] for free movement under
48
49 152 certain testing conditions. Most of the mounting systems were self designed. A few
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51 153 studies have been reported to recruit living human as subjects
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53 154 [11,54,55,57,59,74,86,90,105-107,110,115]. These studies employed a
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55 155 self-customized fixation system, in which hip rotation was controlled by fixation of
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57 156 thigh segment while external load was applied to the knee joint.
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3 158 The external load applied on the testing specimens includes isolated external internal
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5 159 rotation torque [2], valgus varus torque [74], anterior tibial load [47], muscle load [69]
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7 160 and increased graft tension [12]. These specific loads provide controlled stress to the
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9 161 knee joint. However, due to the experimental nature, it is not ethical to apply load to
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11 162 living human subjects, explaining why over 80% of the external load application
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13 163 studies were based on cadaveric models. Still, there was one study recruiting living
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15 164 humans as subjects where load was applied until the subjects reached their limit of
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17 165 comfort [90]. The amount of load should be carefully designed before employing to
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19 166 living human subjects. In regards to the amount of torque applied, over 50% of the
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21 167 cadaveric studies used 5Nm while other studies varied from as low as 1.5Nm to as
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23 168 high as 20Nm. The torque was much lower when applied to living subjects, ranging
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25 169 from 1.5Nm to 10Nm with 4 out of 13 studies using 5Nm as the testing torque.
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34 171 Among the four techniques used in studies with external load application, magnetic
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36 172 sensing was reported to have highest accuracy with 0.15 degree [88] followed by
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38 173 radiographic measurement with 0.2 degree and reproducibility with 1.4 degrees [59].
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40 174 Since most of the included studies employed cadavers, measuring tools such as
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42 175 magnetic sensor or pin marker could be directly attached or implanted to bone, which
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44 176 guarantees in a high accuracy measurement. There is always a concern that skin
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46 177 motion artifact exists when measuring knee rotation on living human subjects. Skin
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48 178 artifact would be a considerable error if load was applied to living human with
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50 179 magnetic sensors attached on the skin since there is muscle movement during load
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52 180 application. Not taking the ethical problem into account, RSA with bony marker
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54 181 implantation would be considered the best technique for measuring tibial rotation on
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56 182 living human subjects.
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3 184 **Physical examination**

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5 185 Physical examination is one of the most feasible and practical ways to evaluate knee
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7 186 rotational stability in orthopaedic clinics. The main problem, its subjective and
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9 187 discontinuous rating, has limited its application to research area. Different from an
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11 188 experimental laboratory, the operation theatre is not an ideal place to provide
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13 189 controlled load of application due to instrument size and hygiene concern. In view of
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15 190 the measurement tool, intra-operative navigation system would be the most suitable
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17 191 technique inside the operation theatre. Since the torque should be applied manually by
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19 192 the tester, it is suggested that all physical examinations should be performed by one
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21 193 tester and reliability test should be conducted to ensure good consistency across
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23 194 studies.
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31 196 Intra-operative navigation system provides immediate evaluation of surgical treatment
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33 197 while the registration requires an extra 10-minute time in addition to original surgical
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35 198 procedures [78]. The extra time is considered acceptable as it provides a more reliable
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37 199 clinical result and an objective way to quantify knee kinematics [92]. Moreover, this
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39 200 technique has a good repeatability [78] and a comparable result with mechanical
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41 201 testing devices (KT1000 and goniometer) [60]. Therefore, it would be useful for
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43 202 evaluation and comparison of different reconstruction methods in the field of
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45 203 orthopaedics.
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53 205 Despite the fact that there are a number of advantages as discussed above, more
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55 206 attention should be paid to the drawbacks. One should keep in mind that the procedure
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57 207 is invasive and may cause extra wounds in the thigh and shank of the subjects. To
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59 208 accurately locate the relative movement, transmitters with markers need to be screwed
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1 209 into the femur and tibia. The invasive procedure would result in additional bone loss
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3 210 and surgical scars to patients. To minimize the invasive effect, an alternative
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5 211 procedure would be to attach magnetic sensors on the skin with plastic braces [128].
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7 212 However, validation between two techniques should be established before its
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9 213 application to living human.

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15 215 **Dynamic task**

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17 216 Compared with the cadaveric study which is of limited clinical utility [34], dynamic
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19 217 task provides important information of knee stability of the intact [114], injured [48]
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21 218 or reconstructed [14] knees. In early years, techniques involving external fixation
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23 219 structure attached to subjects' limb would highly affect the gait pattern [23]. Optical
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25 220 motion analysis and radiographic measurement have therefore become the most
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27 221 frequently adopted techniques to measure knee rotational stability.
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34 223 When comparing the drawbacks of the two techniques, RSA obviously involves
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36 224 invasive procedures and radiation exposure [13,14,55]. Although the amount of
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38 225 exposure has been reported to be similar to a single clinical knee computerized
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40 226 tomography scan [112], the controversial issue of implanting bony markers through
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42 227 arthroscopic surgery is another difficulty for subject recruitment. On the other hand,
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44 228 error due to skin movement when applying optical motion analysis with reflective
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46 229 skin marker has also been claimed [113]. A point cluster method was developed in
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48 230 1998 to tackle the problem [6]. This method aims to minimize the effects of skin
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50 231 motion artifact by employing an overabundance of markers on each segment. The
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52 232 limitation of computational complexity [5] has become the major technical challenge
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54 233 to orthopaedic specialists while biomechanists are advised to understand the principle
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56 234 in order to achieve high accuracy result.
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3 236 Motion analysis with skin marker technique is non-invasive, practical and applicable
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5 237 not only in research laboratory settings but also in orthopaedic clinics. The system
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7 238 consists of two or more high-speed cameras and a few spherical markers.
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10 239 Commercialized software system also includes auto-digitizing and kinematics
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12 240 calculation. Nevertheless, results of knee internal and external rotation from different
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14 241 marker-set protocols are poorly correlated [31]. For example, Thambyah et al.[114]
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16 242 used 17 skin markers while Georgoulis et al. [36] adopted the model with 15 skin
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18 243 markers developed by Vaughan [120]. Self-compiled programs for calculating knee
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20 244 kinematics are furthermore not standardized and comparison between studies with
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22 245 different marker-set protocols would be highly difficult if not impossible.
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29 247 In recent years, Tashman and coworkers [111,112] have employed the RSA technique
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31 248 to evaluate knee kinematics of human ACL reconstructed knee during treadmill
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33 249 running after the application to canine ACL deficient knee in 2003. Similar to the
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35 250 protocol of biplane radiography generation with a transverse plane computer
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37 251 tomography scan to determine transformations between marker-based and anatomical
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39 252 coordinate systems, the exposure frequency of the RSA technique was highly
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41 253 increased to 250Hz, resulting in sufficient smooth continuous kinematics data during
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43 254 most of the human dynamics movements.
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50 256 **Clinical recommendations**

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53 257 To choose a suitable technique for a specific clinical application, it is recommended
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55 258 that the study's propose should be considered, as well as the experimental setup and
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57 259 the stress applied on the knee. It would be better to quantify the effectiveness of a new
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59 260 designed surgical technique by using a cadaveric model before application to living
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1 261 human subjects for intra-operative evaluation or long time functional stability
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3 262 assessment. For example, Ho et al. [44] used navigation system to evaluate a double
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5 263 femoral-tunnel posterolateral corner reconstruction technique on cadaveric model
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7 264 while Ristanis et al. [95] employed motion analysis with skin reflective markers for
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9 265 evaluation of knee rotational stability after ACL reconstruction on living human
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11 266 subjects. For the applied stress, 50% of the cadaveric study used 5Nm rotational
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13 267 torque while Kanamori et al. [56] used a combined 10Nm valgus torque and 10Nm
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15 268 internal rotation torque to simulate pivot shift test. Stair walking, running, single-leg
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17 269 lunge and pivoting movement are also commonly used in dynamic stability
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19 270 assessment.
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25 272 **Limitations and future research direction**

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27 273 The limitation of the present study was that computational technique such as finite
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29 274 element model was excluded. Since this technique does not involve any specimen or
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31 275 subject and is only based on the computational model, it is suggested that this kind of
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33 276 technique should be reviewed separately. Moreover, the other secondary motions of
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35 277 the knee joint were not included in the present study. Currently, the assessments for
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37 278 anterior-posterior translation and abduction-adduction motion mainly rely on clinical
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39 279 examination. Techniques to measure these motions would be useful for objective
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41 280 evaluation of knee joint laxity.
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50 282 The biomechanical technique for measurement of tibial rotation is well developed in
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52 283 the cadaveric model. Accuracy of most of the techniques is reported to be high as
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54 284 bone to bone information could be obtained directly. There is still room for
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56 285 improvement on the techniques applied on living human, especially in the
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58 286 development of a practical and accurate technique for dynamic tasks. Future studies
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1 287 should focus on validity between magnetic measurement and radiographic
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3 288 measurement because the non-invasive magnetic sensor would be useful in
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5 289 orthopaedic clinics if it could produce reliable and valid measurements. Moreover, for
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7 290 the optical motion analysis with skin reflective marker, a consensus should be
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10 291 obtained for a standardized market-set protocol for measurement of tibial rotation
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12 292 during dynamic task. This is important since the results of studies using different
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15 293 protocols are unable to be compared by other researchers.
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19 295 **CONCLUSION**

22 296 The biomechanical techniques to measure tibial rotational were summarized,
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24 297 providing an overview of biomechanical measurement techniques. We systematically
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26 298 reviewed the techniques according to the conditions in which the knee is examined:
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29 299 external load application, physical examination and dynamic task. To choose a
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31 300 suitable measurement technique for a specific clinical application, it is suggested to
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34 301 quantify the effectiveness of a new designed surgical technique by using a cadaveric
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36 302 model before applying to living human subjects for intra-operative evaluation or long
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41 304 purpose, whether to employ a cadaveric model and the way of stress applied to the
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43 305 knee.
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737 placement. *Am J Sports Med* 32:1825-1832

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741 study. *BMC Musculoskelet Disord* 9:25

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744 anterior tibial translation and internal rotation. *Am J Sports Med* 35:223-227

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746 RB, Sekiya JK (2008) Comparison of a double bundle arthroscopic inlay and
747 open inlay posterior cruciate ligament reconstruction using clinically relevant
748 tools: a cadaveric study. *Arthroscopy* 24:472-480

GENERAL

This is the first revision of a systematic review concerned with tibial rotation. A lot - and I really mean a lot - of work is still needed.

First of all, and I repeat this, you must read and follow "Instructions to Authors". In your cover letter you claim that you have done so. However, it is very obvious that it is not the case. If you for instance look at the Abstract, it is not anywhere close to the journal requirements. If you look at the references, all references are incorrectly formatted. There is more than one error in every single reference. I counted to more than 300 (!!!) errors in your reference list. So please make sure that this is correctly done before you resubmit your work. I know it is cumbersome and I know it is a lot of work to do this but it must be done. You are as corresponding author responsible for this.

I have the following detailed comments.

1. TITLE

Change the title to the following: "Biomechanical techniques to evaluate tibial rotation. A systematic review".

Response: This has been revised in the title page.

2. ABSTRACT

The journal now requires structured abstracts. Therefore the abstract should be reorganized under the following subheadings: Purpose, Methods, Results and Conclusion. This is in the "Instruction to Authors".

Response: This was revised. (line 1-23)

The journal now requires "Level of Evidence". This information should be added at the end of the Abstract. This must be given for all clinical studies. Please read and follow the information found in "Instructions to Authors" for the level of evidence.

Response: Level of evidence was added after the abstract. This study is classified as Level IV. (line 24)

At the end of the Abstract, under the last subheading, what is the clinical relevance and usefulness of your work?

Response: This was added. (line 17-23)

'This study reports various biomechanical measurement techniques to quantify tibial rotation in the literatures. To choose a suitable measurement technique for a specific

clinical application, it is suggested to quantify the effectiveness of a new designed surgical technique by using a cadaveric model before applying to living human subjects for intra-operative evaluation or long time functional stability assessment. Attention should also be paid on the study's purpose, whether to employ a cadaveric model and the way of stress applied to the knee.'

3. INTRODUCTION

I still fail to understand what is the research question? What is the problem and what is new? This should really be added to the Introduction in order to make this paper interesting and more reader friendly.

Response: The last paragraph of the introduction was revised. (line 59-69)

'In view of the various methodologies in the literature, biomechanics plays an important role to objectively quantify knee rotational laxity and stability when compared with clinical examinations. However, there are no guidelines in the literatures regarding which measurement technique is suitable for specific clinical application. This information should be added so that orthopaedic specialists and sport biomechanists are able to choose the most suitable technique for solving clinical problems in relation to knee structure, injury diagnosis and effect of ligament reconstruction. This study aimed to systematically review the biomechanical techniques to quantify tibial rotation and provided an overview for choosing biomechanical technique for specific clinical application. Tibial rotation was defined as the relative movement of the femur and the tibia in the transverse plane.'

4. MATERIAL AND METHODS

This section should be called "Materials and Methods" and not "Method" only.

Response: This was revised. (line 71)

In the Materials and Methods section you must make sure that the readers understand whether you have followed the rules of how a systematic review should be done. Have you followed either the CONSORT or STROBE guidelines? This must be stated.

Response: Since the CONSORT and STROBE are the quality appraisal guidelines for randomized trials and observational study, it is not appropriate to be stated here. However, in order to the readers to understand that we have followed the rules and procedures of a systematic review, we added a reference (Wright et al) in the first sentence under 'materials and methods'. (line 72-73)

5. RESULTS

The Results section is very short and doesn't give any conclusions. I think you would do a better work of giving a short outline of the most important results.

Response: A paragraph outlining the most important findings was added in the Results. (line 108-113)

'All 111 included articles were divided into three categories: external load application (67%), physical examination (14%) and dynamic task (19%). Over 60% of all the articles employed a cadaveric model. While various measurement techniques were used in external load application category, intra-operative navigation and optical motion analysis system were commonly used in physical examination and dynamic task categories, respectively.'

In lines 118 and 119 you claim that RSA studies were applied on living humans first in 2001. This is incorrect. Even in your reference list you have given citations to Jonsson and Kärrholm from 1990. This should be corrected.

Response: The sentence here refers studies using dynamic task. The study by Jonsson and Kärrholm in 1990 used living human subjects but the stress applied to the knee was 8Nm rotational torque, so this study was under external load application category. To make it clear in the text, the sentence was revised. (line 130-133)

'Before roentgen stereophotogrammetric analysis (RSA) was applied on living human who performed dynamic task in 2001, there were about 10 years of vacuity where no journal papers were published specifically investigating on knee rotational stability during dynamic task.'

6. DISCUSSION

Please start the Discussion with a short sentence like "The most important finding of the present study was?".

Response: The first paragraph in the Discussion was revised. (line 137-144)

'The most important finding was that two thirds of the included studies measured tibial rotation under external load application, of which over 80% of the experiments employed cadaveric model. This kind of study design enhances a well controlled laboratory setting for accurate comparison. Secondly, intra-operative navigation system has been commonly used to quantify tibial rotation when the knee is examined by physical tests. For dynamic assessment of knee rotational stability, motion analysis with skin reflective markers has been frequently employed although this technique is less accurate due to the skin movement when compared with RSA technique.'

Limitations of your study must be mentioned and discussed in detail somewhere close to the end of the Discussion section. This is always an important part of every

manuscript and is something that will lead to new scientific studies in the future.

Response: Two paragraphs regarding study limitations and future research direction were added at the end of the Discussion. (line 271-292)

'The limitation of the present study was that computational technique such as finite element model was excluded. Since this technique does not involve any specimen or subject and is only based on the computational model, it is suggested that this kind of technique should be reviewed separately. Moreover, the other secondary motions of the knee joint were not included in the present study. Currently, the assessments for anterior-posterior translation and abduction-adduction motion mainly rely on clinical examination. Techniques to measure these motions would be useful for objective evaluation of knee joint laxity.

The biomechanical technique for measurement of tibial rotation is well developed in the cadaveric model. Accuracy of most of the techniques is reported to be high as bone to bone information could be obtained directly. There is still room for improvement on the techniques applied on living human, especially in the development of a practical and accurate technique for dynamic tasks. Future studies should focus on validity between magnetic measurement and radiographic measurement because the non-invasive magnetic sensor would be useful in orthopaedic clinics if it could produce reliable and valid measurements. Moreover, for the optical motion analysis with skin reflective marker, a consensus should be obtained for a standardized market-set protocol for measurement of tibial rotation during dynamic task. This is important since the results of studies using different protocols are unable to be compared by other researchers.'

At the end, please mention the clinical relevance of your work. How can this work be useful in the day by day clinical work?

Response: This study provided an overview for orthopaedics specialists to choose a suitable technique for a specific clinical application. An example was illustrated of how the effectiveness of a new designed surgical technique is quantified using biomechanical measurement techniques. This paragraph is under the subheading 'Clinical recommendations' in the Discussion. (line 255-269)

'To choose a suitable technique for a specific clinical application, it is recommended that the study's propose should be considered, as well as the experimental setup and the stress applied on the knee. It would be better to quantify the effectiveness of a new designed surgical technique by using a cadaveric model before application to living human subjects for intra-operative evaluation or long time functional stability assessment. For example, Ho et al. [44] used navigation system to evaluate a double femoral-tunnel posterolateral corner reconstruction technique on cadaveric model

while Ristanis et al. [95] employed motion analysis with skin reflective markers for evaluation of knee rotational stability after ACL reconstruction on living human subjects. For the applied stress, 50% of the cadaveric study used 5Nm rotational torque while Kanamori et al. [56] used a combined 10Nm valgus torque and 10Nm internal rotation torque to simulate pivot shift test. Stair walking, running, single-leg lunge and pivoting movement are also commonly used in dynamic stability assessment.'

Lines 211 onwards: You should reflect the original work being done by Jonsson/Kärrholm and Brandsson et al. Also there is a recent publication in KSSTA by Isberg et al. The last publication is still only Online First published but it should be added to the reference list and to the running text.

Response: Three references from Jonsson and Kärrholm, and Brandsson et al. were added in the paragraph. (line 222-223) The article by Isberg was included in the search and under 'dynamic task' category. (Table 1) It was added in the reference list [50] and in the text. (line 470-474)

7. CONCLUSION

I still fail to understand the clinical relevance of your work. This information should be added

Response: The content in the 'clinical recommendation' was summarized and added in the Conclusion. (line 295-304)

'The biomechanical techniques to measure tibial rotational were summarized, providing an overview of biomechanical measurement techniques. We systematically reviewed the techniques according to the conditions in which the knee is examined: external load application, physical examination and dynamic task. To choose a suitable measurement technique for a specific clinical application, it is suggested to quantify the effectiveness of a new designed surgical technique by using a cadaveric model before applying to living human subjects for intra-operative evaluation or long time functional stability assessment. Attention should also be paid on the study's purpose, whether to employ a cadaveric model and the way of stress applied to the knee.'

8. REFERENCES

As I mentioned already I counted to an incredible number of errors in the reference list. The references are in correct order; however, all of them are incorrectly formatted and must be reformatted.

Concerning order and format of references, please read and follow "Instructions to Authors" carefully. The references should be in alphabetical order in the reference list and must be organized accordingly in the text body.

Please make sure that your references are updated with recent relevant citations. When it comes to updating your references I have the following suggestions.

1. Ho EP et al

Comparisons of 2 surgical techniques...

Arthroscopy, 2011; 27: 89-96

2. Zamarra G et al

Biomechanical evaluation of using...

Knee Surg Sports Traumatol Arthrosc, 2010; 18: 11-19

3. Bedi A et al

Transtibial versus anteromedial portal...

Arthroscopy, 2011; 27: 380-390

4. Branch TP et al

Double-bundle ACL reconstruction...

Knee Surg Sports Traumatol Arthrosc, 2011; 19: 432-440

5. Lorbach O et al

A non-invasive device to objectively...

Knee Surg Sports Traumatol Arthrosc, 2009; 17: 756-762

6. Feeley BT et al

Comparison of posterolateral corner...

Arthroscopy, 2010; 26: 1088-1095

7. Rossi R et al

Evaluation of tibial rotational...

Knee Surg Sports Traumatol Arthrosc, 2010; 18: 889-893

8. Lertwanish P et al

A Biomechanical Comparison...

Arthroscopy, 2011; 27: 672-680

9. Kopf S et al

A systematic review of the femoral...

Knee Surg Sports Traumatol Arthrosc, 2009; 17: 213-219

10. Casino D et al

Intraoperative evaluation of total knee...

Knee Surg Sports Traumatol Arthrosc, 2009; 17: 369-373

Besides I also mentioned the work by Isberg et al. This should also be added.

Response: The entire reference list was revised according to the guidelines of 'Instruction to authors'. The reference list is now correctly formatted as follows (showing the first 3 references). (line 305-747)

1. Allen CR, Wong EK, Livesay GA, Sakane M, Fu FH, Woo SL (2000) Importance of the medial meniscus in the anterior cruciate ligament-deficient knee. J Orthop Res 18:109-115
2. Andersen HN, Dyhre-Poulsen P (1997) The anterior cruciate ligament does play a role in controlling axial rotation in the knee. Knee Surg Sports Traumatol Arthrosc 5:145-149
3. Anderson CJ, Westerhaus BD, Pietrini SD, Ziegler CG, Wijdicks CA, Johansen S, Engebretsen L, Laprade RF (2010) Kinematic impact of anteromedial and posterolateral bundle graft fixation angles on double-bundle anterior cruciate ligament reconstructions. Am J Sports Med 38:1575-1583

9. TABLES

The tables are more or less in good order. However, concerning RSA you mention under issue 3 "Because of its invasive procedure, this technique has been employed in cadaveric studies". This is not entirely correct, because it has also been employed on living humans. This must be corrected.

Response: The description refers to the studies under 'external load application' only. To make it clear, the sentence has been revised. (Table 1)

'In the external load application category, this technique has been employed in cadaveric studies although some studies applied to living human subjects during dynamic task.'

When all corrections are done, and please make sure that they are properly done this time, you are welcome to resubmit your work.

Table 1: A summary of biomechanical techniques for measurement of tibial rotation.

Category	Biomechanical technique	Reference	Brief description
External load application	Direct displacement measurement		
	<ul style="list-style-type: none"> ● goniometer [2,40,46,64,97,100,118,125,126] ● electrogoniometer [11,74,82,103,123] ● potentiometer [4,29,54,77,104,105,110] ● transducer [26,27,38,66,102,121] 		<ol style="list-style-type: none"> 1. Most direct way to measure rotational displacement 2. The rotational displacement is presented in a two dimensional plane, which is perpendicular to the axis of tibial rotation and on which the tibial rotation is quantified after placing the device on the plane. 3. One study employed bony pin to define rotational displacement such that the movement was restricted in transverse plane and relative movement between pins was then documented.
	Magnetic sensing		
	<ul style="list-style-type: none"> ● human cadaver [3,8-10,16,21,39,71,80,87,88,98,116] ● living human [106,107,115] 		<ol style="list-style-type: none"> 1. In cadaveric studies, sensors are attached directly to femur and tibia by nylon posts or fiberglass cylinders. 2. When applying to living human, sensors are attached to skin, for example the subjects' thigh and tibial shaft. 3. Signal is generated from an external receiver with the help of a computer-assisted program, which provides three dimensional position and orientation of the sensors.
	Optical tracking system		
	<ul style="list-style-type: none"> ● human cadaver [19,22,32,33,61,63,67,68,76,79,83] ● living human [90] 		<ol style="list-style-type: none"> 1. Similar principle to magnetic instrument. 2. Clusters consisting of 3-4 infrared emitting spherical markers are rigidly fixed to femur and tibia with metaphyseal bone screws. Infrared camera is used to

Radiographic measurement	[35,55,58,59]	<p>locate three dimensional coordinates of markers that needed to be further digitized to establish an anatomically based coordinate system.</p> <ol style="list-style-type: none"> 3. Tibial rotation is presented after mathematical calculation by the system software or self-complied program. 1. Most accurate technique since it provides direct bone to bone information. 2. Roentgen stereophotogrammetric analysis has been developed since 1989 for the application in living human. Bi-planar roentgenographic exposure films with 2-4 Hz is collected after inserting 3-6 tantalum markers to femur and tibia. The two dimensional coordinates of the markers are plotted on roentgen films and three dimensional coordinates are computed in relation to laboratory coordinate system. The displacement is then calculated by customized program. 3. In the external load application category, this technique has been employed in cadaveric studies although some studies applied to living human subjects during dynamic task.
Intra-operative navigation Universal force moment sensor	[30,44,57,84,86] [1,25,43,49,56,72,127,130,131,133]	<p>See below</p> <ol style="list-style-type: none"> 1. Developed since 1996 2. Provide 6 DOF knee kinematics and kinetics measurement 3. The femur is fixed by a femoral clamp while the tibia is also fixed and connected to the sensor

Physical examination	Direct displacement measurement (goniometer)	[101,124,134]	See above
	Magnetic sensing	[41,42,129]	See above
	Intra-operative navigation	[15,20,45,51-53,81,108,132]	<ol style="list-style-type: none"> 1. Provide an immediate evaluation of surgical outcome 2. The system consists of 2 transmitters with four markers, 1 calibration pointer and high speed camera. 3. Procedures include obtaining preoperatively radiographic film for creating virtual bone model, fixation of 2 sets of markers on femur and tibia, and registration through digitizing intra and extra articular landmarks. 4. Six degree of freedom knee kinematics measurement is obtained while clinical test were being performed.
Dynamic task	Direct displacement measurement (electrogoniometer)	[23,62]	See above
	Optical motion analysis with reflective skin markers	[17,18,28,36,37,48,91,93,94,96,114,117,122]	<ol style="list-style-type: none"> 1. A study of locomotion using continuous photographic technique. 2. Subjects perform specific motions, which probably would give a rotational stress to the knee. 3. Skin markers are placed on typical bony landmarks while the three dimensional coordinates of the markers are captured by optical instruments and transformed to global coordinates. Relative displacements between the femoral and tibial reference frames are calculated by computer programs.

Radiographic
measurement

[13,14,24,50,70,89,119]

4. Marker-set is critical in which location and number of markers varied. One of the frequently used models developed by Vaughan consisted of 15 markers on lower extremities.
 1. Invasive technique similar with roentgen stereophotogrammetric analysis.
 2. Recent studies have reduced its invasiveness. The subjects' knees are magnetic resonance scanned before their motions are captured by fluoroscopic testing system. The system combines the pre-scanned model and matches the outline of the bones in the fluoroscopic images.
-