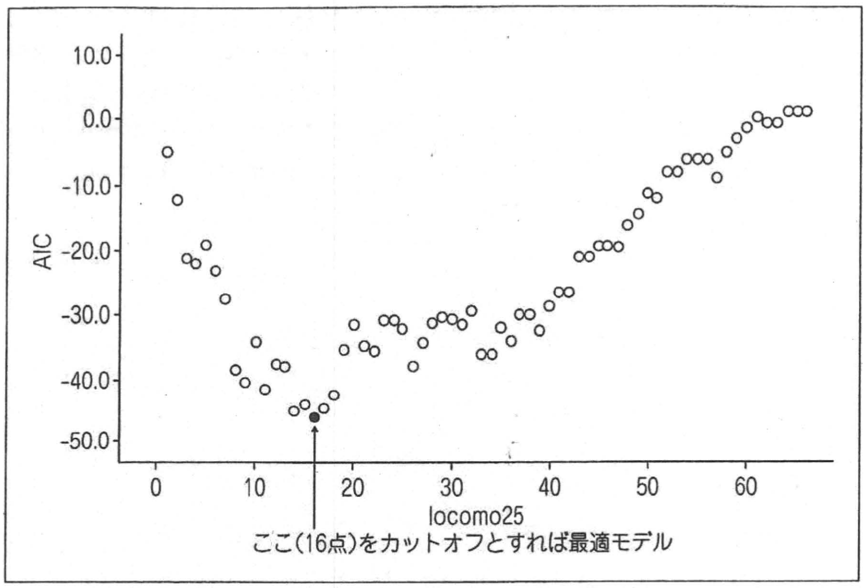

図-5◆軽症者（429例：無症状，歩行支障なし，特定高齢者相当）における特定高齢者相当ピックアップのカットオフ値
AIC が小さいほどモデルのあてはまりがよい．

者，例えば家庭医，さらには医師以外の行政担当者などでも，ロコモを早期に高い精度で発見できる可能性が示されたのである．つまり，65歳以上の高齢者全員を足腰指数25を用いて効率よく調査し，3,000万人の中から数百万人と思われるロコモ該当者をピックアップし，この人たちにはさらに詳細な検討を加え，適切な介入，例えば健康増進スポーツや運動器リハビリテーションなどを指導し，寝たきり高齢者を作らないようにする施策が可能なのではないかと考えている．

日整会は種々の報告を元にして，ロコチェック2009という簡便な自己チェックツールをすでに公表している$^{3)}$．これは５項目ある中で１つでも該当するとロコモの疑いが濃いと知らせる内容であり，国民に自分の運動機能の低下に気づいて欲しいという，いわば啓発のためのツールである．５項目の問い方は該当するか否かの二者択一であり，また複数該当が重症というものではない．つまり，このロコチェックは足腰指数25とは性格が異なり，ロコモに気づかせるためのものであり，その重症度の判定に用いることは想定していないのである．

一方，足腰指数25は０（無症状）～100（最重症）点であり，重症度を定量的に数値として表すことができるのみでなく，運動機能のわずかな変化を検出できる感度を有しており，これにより介入研究の効果を判定するツールとしても使用できると考えている．ただし，その感度などの検証は今後の研究課題である．

まとめ

1．ロコモの早期診断ツールとして，足腰指数25（０（無症状）～100（最重症）点）を策定した．

2．全国多施設における731名の足腰指数25結果から，ロコモ診断のカットオフ値は16点が妥当という結論を得た．つまり，足腰指数25において16点以上の症状を有する者は，歩行・移動になんらかの支障がある者と判定することができる．

3．この診断ツールは，日整会がすでに公表している啓発のためのロコチェックとは性格が異なり，ロコモの重症度を定量的に評価するものである．

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5．高齢者運動器障害のリスクと早期発見ツールの開発

Development of a screening tool for risk of locomotive syndrome in the elderly

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key words

高齢社会
(super-aged society)
スクリーニングツール
(screening tool)
ロコモティブシンドローム
(locomotive syndrome)

「運動器機能不全の早期発見，診断ツールの開発」研究班によるコンセンサス会議により，危険因子を有する運動器機能不全高齢者をスクリーニングする簡便な早期診断ツール(質問票)試案の検討を重ね，25項目の質問票を策定した(仮称：足腰指数25)．足腰指数25は0点から100点(最重症)の得点範囲からなる．信頼性，妥当性の検証を行い，16点以上でロコモティブシンドロームと判定することが妥当であるとの結論を得た．

はじめに

本特集号においてロコモティブシンドローム提唱の意義については別稿で記載されている．日本整形外科学会，日本運動器リハビリテーション学会，日本臨床整形外科学会は2006年4月に「運動器不安定症」の概念を定めた．3学会は，「高齢化により，バランス能力および移動歩行能力の低下が生じ，閉じこもり，転倒リスクが高まった状態」をもって運動器不安定症と定義している．運動機能低下をきたす疾患の主な原因疾患は，骨粗鬆症，変形性関節症，変形性脊椎症，下肢骨折などであり，これらに伴う廃用性の運動機能低下が重症化の要因となる．運動器不安定症の高齢者は，転倒への恐怖，移動能力の低下により家庭内に引きこもりがちとなり，ますます歩行能力が低下するという悪循環に陥る．運動器不安定症患者の増加は，介護面からみると要支援・要介護者の増加へとつながる．それは個々人の健康寿命を損ない，さらには医療費のひっ迫をも招くために，運動器不安定症予防の重要性が認識されるようになってきた．運動器疾患患者の疾患管理・障害発生予防・機能回復・機能代償を含んだ総合的治療戦略を確立することが，介護予防対策を進める上からも求められるようになった．運動器不安定症となって要支援・要介護状態になる前に，あらかじめその予備群(ハイリスク群)を軽症のうちに検出して介入を加えることにより，要支援要介護者の増加を抑えようという戦略である．

日本整形外科学会(中村耕三理事長)は，2008年に「運動器の障害によって要介護になるリスクの高い状態」をロコモティブシンドロームと称することを提唱した[1)2)]．すでに要介護状態になった運動器不安定症患者は重度のロコモティブシンドローム(ロコモ)ということになるが，どちらかというと運動器不安定症に至っていない軽症群，予備群を意識した概念といえる．

介護予防の成果を上げるためには，ハイリスクアプローチのみならずポピュレーションアプローチが必要といわれており，介護リスクが高い者とともに，あまりリスクは高くないが境界域のリスクをもつ者を効率よく抽出し，確実に保健指導，予防医療に結びつけ

ることも重要である．以上のような背景のもと，厚生労働省は長寿科学総合研究事業の一環として「運動器機能不全の早期発見，診断ツールの開発」研究班（主任研究者：自治医科大学 星野雄一）の立ち上げを2008年春に認定した．

研究班の目的

本研究班の目的は，ロコモティブシンドロームが原因で要介護になる高齢者を早期発見する簡便な診断ツールを開発することである．具体的には，科学的な根拠のあるツールを作成することにより保健所レベルでの早期発見を可能とするものを策定することであり，これによって医療機関受診を薦めるべき対象を選別するのである．ハイリスク群と一見健常にみえる者とを対象とした調査を通じて要介護リスクを抽出し，ロコモティブシンドロームの簡便な診断法（診断ツール）を作成し，次の段階としてのポピュレーションアプローチ（保健指導，治療）に結びつけることを意図している．なお，日本整形外科学会はロコチェックという5～7つの質問項目をすでに発表しているが，学術的な手順を踏んで作成されたチェック項目ではなく，あくまで広報用のものといえる．

方法1．質問票の策定

先述の研究班によるコンセンサス会議により，危険因子を有する運動器機能不全高齢者をスクリーニングする簡便な早期診断ツール（質問票）の試案の検討を重ね，内容的妥当性の検証とした．1つの質問において複数の内容を問いかけないこと，反応性が鈍くならないよう選択肢は5つとすること，疼痛，日常動作，移動能力，ADL（日常生活動作），社会的活動，転倒に対する不安，など運動機能に関連する可能性の高い項目をすべてカバーできるものであることに策定の主眼を置いた（表1）．一方で質問数が多すぎることは高齢者を対象とする場合に問題となるため，30問を超えないよう絞りこみを行うことも念頭においた．

結果1．質問票試案

上記のように検討を重ね，我々は25問の質問票試案を完成させた（表2：仮称 足腰指数25）．

方法2．多施設調査

日本臨床整形外科学会と自治医科大学関連の整形外科診療施設および併設された介護施設において，約800名を目標対象数として，足腰指数25による調査を行うこととした．なお今回の医師調査票として，視力，聴力，その他の基本情報，診断結果のほか，調査対象群分けの外的基準として，介護度，支援度を医師が評価し記入することとした（表3，4）．この分類は2008年の時点で介護保険認定に使用されている評価法に基づき作成した．実際に介護認定を受けているかどうかではなく，日本整形外科学会専門医による判定を"真実に近い実態" つまり重症度判定のゴールドスタンダードとみなすこととした．

基準関連妥当性検証のため，よく知られたQOL（quality of life）尺度であるEURO-QOL（EQ-5D）を同時調査することとした[3]．

完成した質問票試案を日本臨床整形外科学会会員の診療機関46施設および自治医科大学関連病院11施設に発送することとした．調査の目標症例数約800名は，下肢や体幹の運動機能障害度が

表1　質問票がカバーする項目

疼痛	動作	歩行	ADL	社会性	不安
上肢痛			上着着脱	身だしなみ	
体幹痛	起き上がる		下着着脱	近所外出　近いつきあい	
下肢痛	立ち上がる		洗身	買い物外出　イベント参加	
運動痛	歩く	階段		バス外出	
		急ぎ足		軽い仕事	転ぶ不安
		休まずに歩く		やや重い仕事	歩けなくなる不安
				スポーツ	

表2　足腰指数25質問用紙

「運動器疾患と日常生活での困難さについての調査」

「お体の状態」と「ふだんの生活」について，手足や背骨のことで困難なことがあるかどうかをおたずねします。この１ヵ月の状態を思い出して以下の質問にお答え下さい。それぞれの質問に，もっとも近い回答を１つ選んで，□に✓をつけて下さい。

この1ヵ月のからだの痛みなどについてお聞きします。

1.頚・肩・腕・手のどこかに痛み（しびれも含む）がありますか。
□痛くない　□少し痛い　□中程度痛い　□かなり痛い　□ひどく痛い

2.背中・腰・お尻のどこかに痛みがありますか。
□痛くない　□少し痛い　□中程度痛い　□かなり痛い　□ひどく痛い

3.下肢（脚のつけね，太もも，膝，ふくらはぎ，すね，足首，足）のどこかに痛み（しびれも含む）がありますか。
□痛くない　□少し痛い　□ 中程度痛い　□かなり痛い　□ひどく痛い

4.ふだんの生活でからだを動かすのはどの程度つらいと感じますか。
□つらくない　□少しつらい　□中程度つらい　□かなりつらい　□ひどくつらい

この1ヵ月のふだんの生活についてお聞きします。

5.ベッドや寝床から起きたり，横になったりするのはどの程度困難ですか。
□ 困難でない　□少し困難　□中程度困難　□かなり困難　□ひどく困難

6.腰掛けから立ち上がるのはどの程度困難ですか。
□困難でない　□少し困難　□中程度困難　□かなり困難　□ひどく困難

7.家の中を歩くのはどの程度困難ですか。
□困難でない　□少し困難　□中程度困難　□かなり困難　□ひどく困難

8.シャツを着たり脱いだりするのはどの程度困難ですか。
□困難でない　□少し困難　□中程度困難　□かなり困難　□ひどく困難

9.ズボンやパンツを着たり脱いだりするのはどの程度困難ですか。
□困難でない　□少し困難　□中程度困難　□かなり困難　□ひどく困難

10.トイレで用足しをするのはどの程度困難ですか。
□困難でない　□少し困難　□中程度困難　□かなり困難　□ひどく困難

11.お風呂で身体を洗うのはどの程度困難ですか。
□困難でない　□少し困難　□中程度困難　□かなり困難　□ひどく困難

12.階段の昇り降りはどの程度困難ですか。
□困難でない　□少し困難　□中程度困難　□かなり困難　□ひどく困難

13.急ぎ足で歩くのはどの程度困難ですか。
□困難でない　□少し困難　□中程度困難　□かなり困難　□ひどく困難

14.外に出かけるとき，身だしなみを整えるのはどの程度困難ですか。
□困難でない　□少し困難　□中程度困難　□かなり困難　□ひどく困難

15.休まずにどれくらい歩き続けることができますか（もっとも近いものを選んで下さい）。
□2～3km 以上　□1km 程度　□300m 程度　□100m 程度　□10m 程度

16. 隣・近所に外出するのはどの程度困難ですか。
□困難でない　□少し困難　□中程度困難　□かなり困難　□ひどく困難

17. 2 kg 程度の買い物（1リットルの牛乳パック2個程度）をして持ち帰ることはどの程度困難ですか。
□困難でない　□少し困難　□中程度困難　□かなり困難　□ひどく困難

18. 電車やバスを利用して外出するのはどの程度困難ですか。
□困難でない　□少し困難　□中程度困難　□かなり困難　□ひどく困難

19. 家の軽い仕事（食事の準備や後始末，簡単なかたづけなど）は，どの程度困難ですか。
□困難でない　□少し困難　□中程度困難　□かなり困難　□ひどく困難

20. 家のやや重い仕事（掃除機の使用，ふとんの上げ下ろしなど）は，どの程度困難ですか。
□困難でない　□少し困難　□中程度困難　□かなり困難　□ひどく困難

21. スポーツや踊り（ジョギング，水泳，ゲートボール，ダンスなど）は，どの程度困難ですか。
□困難でない　□少し困難　□中程度困難　□かなり困難　□ひどく困難

22. 親しい人や友人とのおつき合いを控えていますか。
□控えていない　□少し控えている　□中程度控えている　□かなり控えている
□全く控えている

23. 地域での活動やイベント，行事への参加を控えていますか。
□控えていない　□少し控えている　□中程度控えている　□かなり控えている
□全く控えている

24. 家の中で転ぶのではないかと不安ですか。
□不安はない　□少し不安　□中程度不安　□かなり不安　□ひどく不安

25. 先行き歩けなくなるのではないかと不安ですか。
□不安はない　□少し不安　□中程度不安　□かなり不安　□ひどく不安

（足腰指数25 ©2009 自治医大整形外科学教室 All rights reserved ：複写 可，改変 禁．学術的な使用，公的な使用以外の無断使用 禁）

さまざまな程度の階層から構成されることとした．

対象

65歳以上を対象とするが，運動器に特化したツール作成を念頭に置くこととしたので，認知症や重篤な脳疾患などを除外することとし，視力，聴力障害や痴呆のために質問票に回答困難な者も除外対象とした．ロコモティブシンドロームを念頭に置いたものであるため介護度3以上の者，自力で立ち上がることのできない者も除外した．同意日6ヵ月以内に下肢または脊椎骨折を起こした者，急性外傷治療中の者も状態が安定していないため除外した．

データ解析

多施設調査の結果から，足腰指数25の信頼性，妥当性を計量心理学的手法にて検証した．専門医が判定する介護度(表3)を基準として，足腰指数25でロコモティブシンドロームと判定するためのカットオフ値を算出することとした．統計解析にはSPSS ver.17, R2.8を用いた．構成概念妥当性の検証には，赤池情報量規準(Akaike information criterion ： AIC)を用いた．従来，構成概念妥当性の検証には因子分析が，カットオフ値の決定にはROC (receiver-operating-characteristic curve)分析が慣習的に用いられてきたが，AICはこれらを凌駕する優れた方法である．AICは質問項目間の関連の度合いを定量化する方法であり，最適な

表3　医師によるロコモティブシンドローム重症度判定

1. 無症状
2. 整形外科的愁訴を有するが歩行・移動に支障のないもの
3. 特定高齢者相当
4. 要支援相当
5. 要介護１相当
6. 要介護２相当

表4　各階層の定義

1	無症状・障害なし	運動器に関する症状がなく，日常生活にも制限がない者
2	有症状・歩行移動に支障ない者	運動器に関する愁訴・症状はあるが，歩行・移動に制限がない者
3	特定高齢者相当者	運動器に関する症状があって，歩行・移動に支障があるが，日常生活は自立しており，要支援・要介護に該当しない者
4	要支援相当者	日常生活上の基本的動作については，ほぼ自分で行うことが可能であるが，日常生活動作の介助や現在の状態の防止により要介護状態となることの予防に資するよう手段的日常生活動作について何らかの支援を要する状態
5	要介護(1,2)相当者	日常生活上の基本的動作についても，自分で行うことが困難であり，何らかの介護を要する状態

要介護１，２

5－1．要介護１	要支援状態から，手段的日常生活動作を行う能力がさらに低下して，部分的な介護が必要となる状態
5－2．要介護２	要介護1の状態に加え，日常生活動作についても部分的な介護が必要となる状態

注：日常生活上の基本的動作：食事，排泄，起き上がり，歩行，階段の昇降，入浴などの動作
　　手段的日常生活動作：薬の内服，電話の利用，炊事，部屋の片付け，日用品の買い物，金銭管理など

モデル選択や複雑な事象の予測に使用される[illegible]．整形外科領域でもアウトカム測定法の開発に寄与しており[illegible]，縦断的調査が困難な状況において横断的調査から危険因子を抽出することにも使用できる．

結果2．定腰指数25の信頼性，妥当性

回収できた症例数は781名であった．そのうちデータに欠損のあるものを除外した731名を解析の対象とした．専門医による診断名(複数回答あり)は，変形性膝関節症304名，変形性脊椎症253名，骨粗鬆症208名，腰部脊柱管狭窄症121名，健常者82名などとなっていた．医師判定による重症度は，無症状82名，整形外科的愁訴を有するが歩行・移動に支障のないもの219名，特定高齢者相当138名，要支援相当165名，要介護1相当82名，要介護2相当45名という内訳であった．足腰指数25の各質問に対する回答には，どれも大きな偏り(天井―床効果)はなかった．信頼性分析ではクロンバック α 係数0.961とすべての質問間に強い相関があり，不要な質問がないことが判明した．折半法による再現性分析では信頼係数0.899ときわめて良好であった．基準関連妥当性の検討において，EQ-5Dの効用値と強い相関があった(スピアマンの順位相関係数：$P<0.001$)．

構成概念妥当性

各質問についてAICの値が小さい，すなわち関連度が高い2つを選び，Graph-Layout (Sun Microsystem Ⅰ，Graph java 1.9，1999)により質問項目間の関連を視覚化したものを図に示す[illegible]．この結果から，痛み，屋内動作，身の回りのこと，不安，活動・参加と名付けるべき5つのドメインが浮かびあがり，さらにいずれのドメインとも関連の深い5項目(質問12：階段昇降，質問13：急ぎ足，質問15：休まず歩ける距離，質問17：2kg買い物持ち帰り，質問20：やや重い家事)が全体の中心的役割をもっていることがわかった．25の質問数をさらに絞りたい場合にはこの5問，もしくは質問16：近所外出

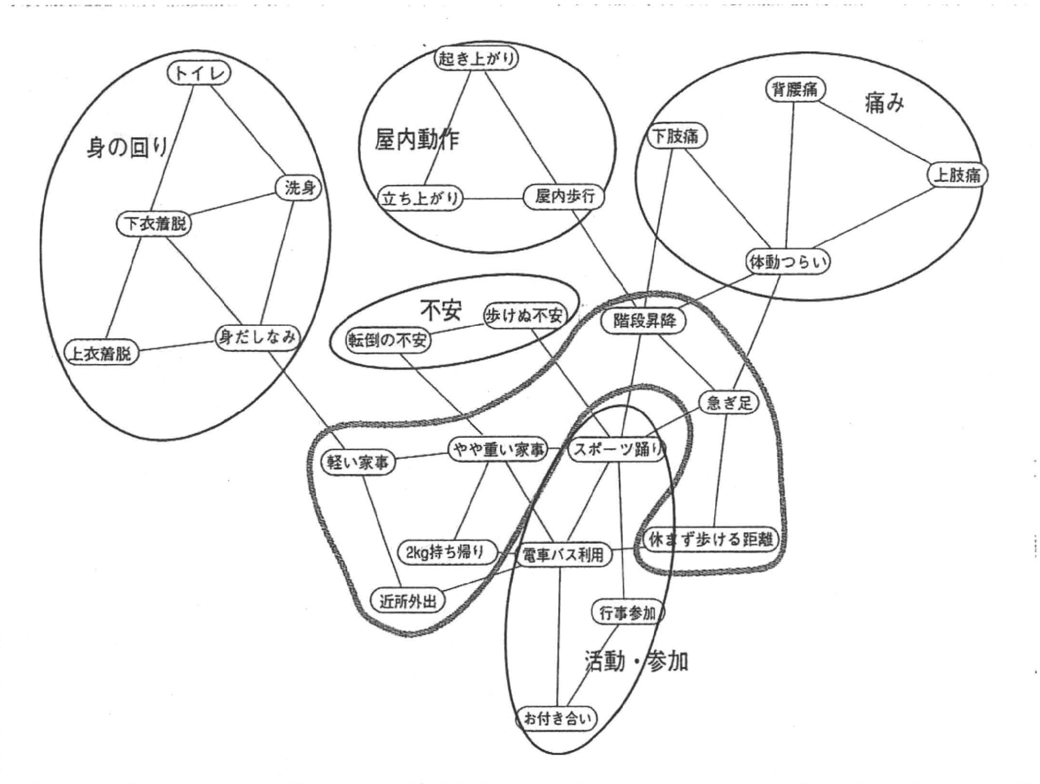

図　赤池情報量規準により構成概念妥当性検証結果を視覚化した図

項目名に対応する質問番号は以下の通りである．
質問1：上肢痛，質問2：背腰痛，質問3：下肢痛，質問4：体動つらい，
質問5：起き上がり，質問6：立ち上がり，質問7：屋内歩行，質問8：上衣着脱，質問9：下衣着脱，質問10：トイレ，質問11：洗身，質問12：階段昇降，質問13：急ぎ足，質問14：身だしなみ，質問15：休まず歩ける距離，質問16：近所外出，質問17：2kg買い物持ち帰り，質問18：電車バス利用，質問19：軽い家事，質問20：やや重い家事，質問21：スポーツ踊り，質問22：お付き合い，質問23：行事参加，質問24：転倒の不安，質問25：歩けぬ不安

と質問19：軽い家事を加えた7問をもって簡易版とすることができる．

カットオフ値の設定

各質問には同じような選択肢が5つあり，あえて得点の重み付けを行う必要性はなく単純加算尺度構成法を用いた．各質問に正常0点から最重症4点を割り振り最重症100点満点のスコアとした．要支援以上の重症群を除いた軽症者429名において足腰指数25特定高齢者への移行リスクのカットオフ値を，AICによる最適区分法で求めた結果，16点以上でロコモティブシンドロームと判定することが最適モデルであることを明確に算出できた．

今後の展望

再現性および反応性の検証など，つめるべき部分が残ってはいるものの，足腰指数25がロコモティブシンドローム早期発見ツールとして有望な方法であることを科学的に分析できた．このツールの反応性については，前向きコホートに組み入れて5年後，10年後の結果を待たざるを得ないが，急速な高

齢化が進むわが国の現状を鑑みるとこの結果を待ってから政府が動くのでは遅すぎる．一方，このようなツールが健康診査に採用された場合，受診者が結果を生かせなければ健診としての意義がない．転倒予防を目的とした運動療法が提示されてきてはいるが8)，高齢者にとって長続きする手段を開発することは容易ではない．ロコモティブシンドローム対策としても効果的なものを提供することが医療サイドにとって急務である．そうでなければ運動器健診に膨大な資金をかけることへの説得力が乏しいものとなる．

付　記

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Biomechanical characteristics of the knee joint in female athletes during tasks associated with anterior cruciate ligament injury

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ABSTRACT

This study was designed to compare biomechanical characteristics of the knee joint for several athletic tasks to elucidate their effects and to examine what tasks pose a risk for ACL injury.

Three athletic tasks were performed by 24 female athletes: single-limb landing, plant and cutting, and both-limb jump landing. Angular displacements of flexion/extension, abduction/adduction, and external/internal tibial rotation were calculated. Angular excursion and the rate of excursion of abduction and internal tibial rotation were also calculated.

During plant and cutting, from foot contact, subjects rotated the tibia more rapidly and to a greater degree toward internal tibial rotation. Moreover, excursion of knee abduction is greater than that during single-limb landing. During both-limb jump landing, the knee flexion at foot contact was greater than for either single-limb landing or plant and cutting; peak knee abduction was greater than for either single-limb landing or plant and cutting.

In plant and cutting, the risk of ACL injury is increased by greater excursion and more rapid knee abduction than that which occurs in single-limb landing, in addition to greater internal tibial rotation. Although single-limb tasks apparently pose a greater risk for ACL injury than bilateral landings, both-limb landing with greater knee abduction might also risk ACL injury.

1. Introduction

Anterior cruciate ligament (ACL) injury is a serious injury in sports activities. After ACL injury, most athletes must undergo ligament reconstruction and continue rehabilitation for 6 months to a year before returning to sports activities [1]. The rate of ACL injury is reportedly much higher for female athletes than for males [2,3]. Additionally, almost 70% of situations causing ACL injury are noncontact situations: landing from a jump, stopping after fast running, and cutting to a different direction [2,4].

Understanding the mechanisms of ACL injury is important for its prevention. Olsen et al. [5] described ACL injury mechanisms from viewing videotapes of ACL injuries. They concluded that the main injury mechanism for ACL injuries is a forceful valgus collapse with the knee close to full extension, combined with external or internal rotation of the tibia. However, ACL injuries occur rapidly during games and practice sessions. In most cases, it is difficult to determine the mechanisms of ACL injury from videotapes or pictures recording the injury situation because of the image quality. Therefore, many researchers have examined injury mechanisms from motion capture images taken in laboratory conditions.

Numerous studies using motion capture systems have examined the mechanism and risk factors of ACL injury during athletic tasks according to gender differences. As described previously, female athletes are more prone to sustaining ACL injury than male athletes. Therefore, female characteristic kinematics and kinetics are thought to be risk factors related to ACL injury mechanisms. Earlier studies have shown that female athletes demonstrate larger knee valgus than male athletes during landing or many other athletic tasks [6–12]. Hewett et al. [13] measured kinematics and joint loads using kinetics during a jump-landing task prospectively: results showed that female athletes with increased dynamic valgus and high abduction loads are at increased risk of anterior cruciate ligament injury. Therefore, knee valgus has been recognized as a risk factor and one mechanism of ACL injury. Tibial rotation during athletic tasks has been examined recently: we examined gender differences of tibial rotation during single-limb drop landing and estimated that the risk factor and mechanism of ACL injury would be greater for tibial internal rotation combined with knee valgus [14].

Another approach to examination of the mechanism of ACL injury using motion capture systems is analysis of biomechanical characteristics during tasks that pose a high injury risk for ACL injury. In fact, ACL

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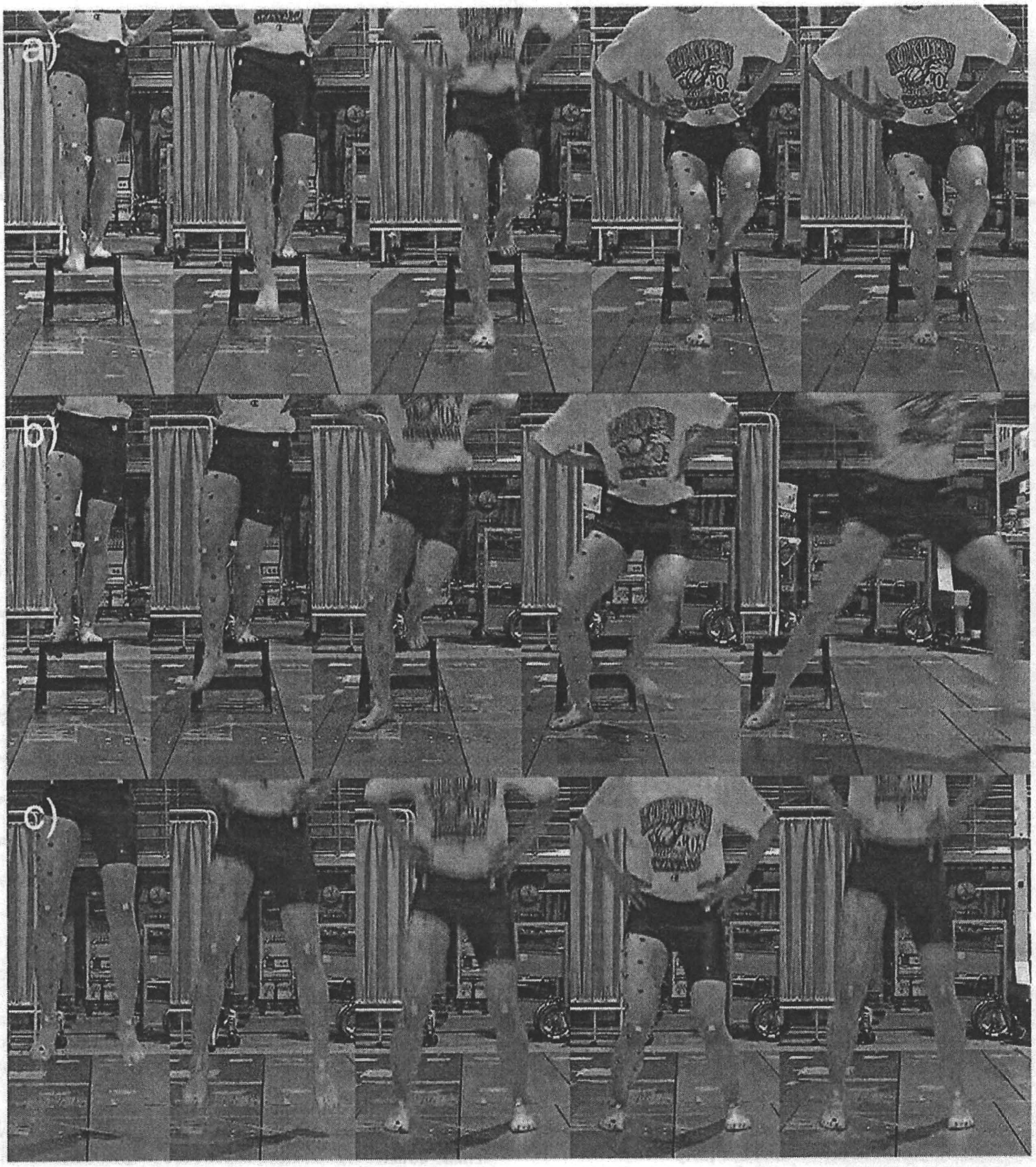

Fig. 1. Sequential photographs of experimental tasks: Single-limb landing (a), plant and cutting (b), and both-limb jump landing.

injuries often occur in plant and cutting movements while leaning on one leg and forcing a knee valgus [4,5]. Sell et al. [15] examined the effects of direction during a two-legged stop-jump task and concluded that lateral jumps are the most risky manoeuvres for ACL injury. Pappas et al. [16] compared bilateral and unilateral landings and found that, in unilateral landings, subjects performed high-risk kinematics with increased knee valgus, decreased knee flexion, and decreased relative hip adduction. However, they only analyzed knee valgus at initial contact during landings and did not examine the plant and cutting manoeuvre, which is thought to pose greater risk for ACL injuries. The characteristics of plant and cutting and several athletic tasks have never been well established.

This study was intended to compare biomechanical characteristics of the knee joint between plant and cutting tasks and normal single-limb landing, and to compare characteristics between both-limb jump landing and single-limb tasks. Comparison of kinematics among tasks can elucidate the characteristics of these tasks, and enable examination of what tasks pose a risk for ACL injury. Understanding risky tasks and movements can help prevent ACL injury because team trainers and coaches might thereby be better able to instruct their athletes to avoid such movements. Our hypotheses were two. During a plant and cutting manoeuvre, subjects demonstrate riskier kinematics for ACL injury than during normal single-limb landing because of greater knee valgus and greater internal tibial rotation. In addition, during single-

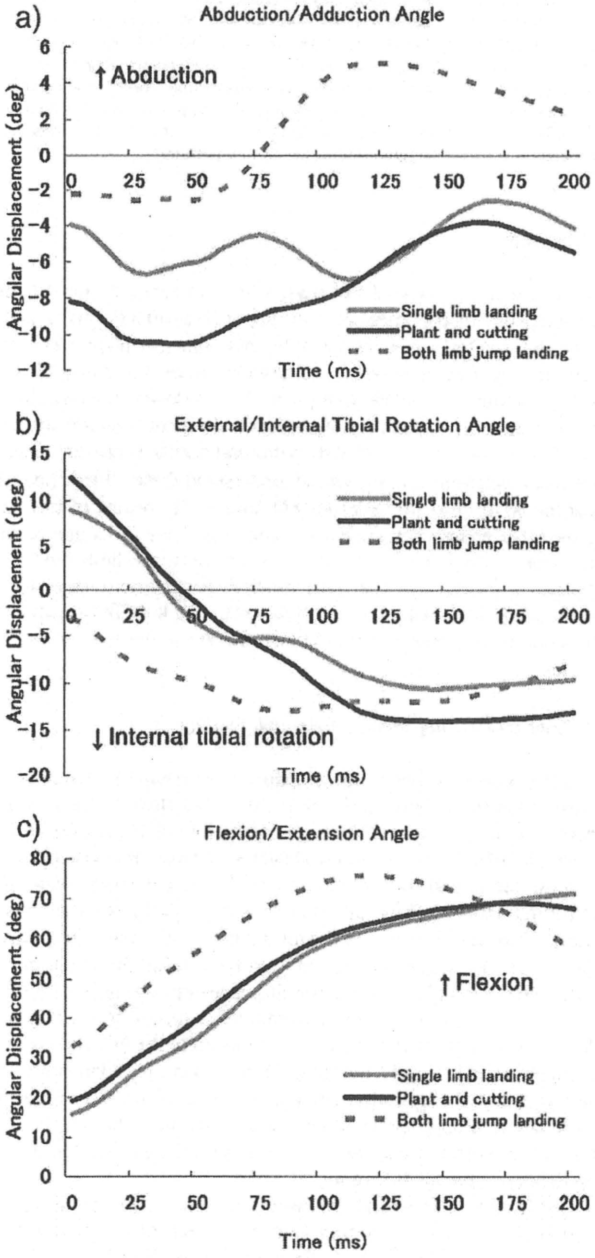

Fig 2. Comparisons of joint motion. Data are presented for knee abduction/adduction (a), external/internal tibial rotation (b), and knee flexion/extension (c).

limb tasks, subjects demonstrate riskier kinematics than during both-limb tasks.

2. Materials and methods

2.1. Subjects

A power analysis conducted during a pilot study revealed that at least 24 subjects were necessary to achieve 80% statistical power with an α level of 0.05. In all, 24 female athletes were recruited for the experiment. Half were basketball players; others were lacrosse players. Subjects were excluded from the study if they had a history of serious musculoskeletal injury, any musculoskeletal injury within the past 6 months, or any disorder that interfered with sensory input, musculoskeletal function, or motor function. Before participation, all subjects provided written informed consent in accordance with approval by the Institutional Review Board of National Rehabilitation Center for Persons with Disabilities. The average age of subjects was 21.1 (1.3) yr (Mean (SD)); their average height was 166.1 (8.3) cm and their average weight was 59.3 (8.2) kg. All subjects were right-leg dominant. The dominant leg was determined as the leg used to kick a ball.

Table 1
Mean (SD) for tasks observed power of joint angle at the time of foot contact

	Knee abduction		External tibial rotation		Knee flexion	
Single limb landing	−4.0 (2.6)		9.0 (3.4)		15.8 (5.0)	
Plant and cutting	−8.2 (3.1)**	*	2.4 (4.3)**	**	19.2 (7.0)**	**
Both limb jump landing	−2.2 (3.4)**		−3.0 (5.2)**		32.8 (7.1)**	
Observed power	1.0		1.0		1.0	

*: $p<0.05$, **: $p<0.01$.

2.2. Experimental task

All subjects were measured in a static standing position and during performance of three athletic tasks: single-limb landing, plant and cutting, and both-limb jump landing. For the single-limb landing, subjects stood on a 30-cm-high platform with the left limb, and landed on a platform 30 cm away with the right limb (Fig. 1a). They were required to unyoke their left foot from a platform, and, when they start a landing motion, not to land the right limb along with their left limb on a platform. A trial was considered successful if they retained the landing position. For the plant and cutting, subjects stood on a platform, as in the single-limb landing. They were required to land with their right foot 45 abducted from the original direction and to push off their foot perpendicularly (to the left) with the right foot to make a cut (Fig. 1b). They also were required to make three steps after the cut. A trial was considered successful if they landed with their foot at the prescribed angle and made a cut to the prescribed direction. For both-limb jump landing, subjects performed vertical jumps five times using both legs with maximum effort [17] (Fig. 1c). They were instructed to stand with their feet shoulder-width apart and face the frontal plane during testing. The subjects were given verbal instruction to shorten their foot contact time as much as they were able and to jump as high as they were able. The landings from the second to fourth time of their dominant limb were measured for analysis. Throughout the experiment, the subjects were barefoot and kept their hands on their lower torso. The subjects were allowed to perform several preparation trials. Measurements were continued for three successful trials: each was conducted consecutively.

2.3. Data collection

All experiments were performed at the National Rehabilitation Center for Persons with Disabilities in Saitama, Japan. A seven-camera high-speed motion analysis system (Hawk; Motion Analysis Corp., Santa Rosa, CA) was used to record the lower-limb movements three-dimensionally. The motion and force data were recorded at 200 Hz. The laboratory was equipped with six force plates (9287A; Kistler Japan Co., Ltd., Tokyo, Japan). Vertical ground-reaction force was used to signal the initial contact to determine the data capture period.

Table 2
Mean (SD) for tasks observed power of peak joint angle

	Knee abduction		Internal tibial rotation		Knee flexion	
Single limb landing	−1.2 (5.2)		12.3 (5.5)		72.5 (6.7)	
Plant and cutting	−2.6 (6.1)	*	14.4 (6.0)*	**	70.4 (8.5)	*
Both limb jump landing	7.1 (5.5)**		14.9 (5.5)		80.3 (16.4)	
Observed power	1.0		0.96		0.88	

*: $p<0.05$, **: $p<0.01$.

Table 3
Mean (SD) for angular excursion (deg) and rate of excursion (deg/ms)

	Knee abduction		Internal tibial rotation	
	Excursion	Rate	Excursion	Rate
Single limb landing	6.6 (3.6)	0.12 (0.05)	21.4 (6.4)	0.15 (0.06) **
Plant and cutting	9.8 (3.8)** **	0.13 (0.04)	26.8 (6.8)** **	0.22 (0.07)
Both limb jump landing	11.2 (3.6)	0.14 (0.05)	12.1 (4.9)**	0.14 (0.05) **

*: $p<0.05$, **: $p<0.01$.

To each subject, 25 reflective markers of 9 mm diameter were secured to the lower limb using double-sided adhesive tape, as described in a previous study [14]. The markers were used to implement the Point Cluster Technique (PCT) [18]. We calculated knee kinematics using the joint coordinate system proposed by Grood and Suntay [19]. For PCT, the skin markers are classified into two groups: a cluster of points representing a segment and points representing bony landmarks. For a cluster of points, 10 and 6 markers were attached respectively to the thigh and shank segments. The bony landmarks were the great trochanter, the lateral and medial epicondyles of the femur, the lateral and medial edges of the tibia plateau, the lateral (fibula) and medial malleoli, and the fifth metatarsophalangeal joint.

2.4. Data analysis

The coordinate data obtained from the markers were not smoothed because of the expected noise-cancelling property of the PCT. In each trial, we calculated the angular displacements of flexion/extension, abduction/adduction, and external/internal tibial rotation using the PCT. The reference position for these measurements was obtained during the static trial. We analyzed each variable at the time of foot contact and the peak value from the foot contact to 200 ms thereafter. Additionally, angular excursion for knee abduction and internal tibial rotation was calculated. A rate of excursion for knee abduction and internal tibial rotation was also calculated.

All dependent variables were calculated for each trial, then averaged across the three trials. A repeated measures one-way ANOVA was used to test for task differences in joint angle at the foot contact and peak joint angle. The alpha level was set at $p<0.05$. A post hoc Bonferroni multiple comparison test was performed for each variable to determine differences among tasks. Intraclass correlation coefficients (ICC (1, 3)) were calculated to determine the measurement consistency.

3. Results

Acceptable ICC (1, 3) values at the time of foot contact and a peak value were established for knee abduction/adduction (0.98, 0.97), external/internal tibial rotation (0.93, 0.98), and flexion/extension (0.96, 0.89). Fig. 2 portrays mean time course comparisons across tasks for the three angular displacements of the knee (abduction/adduction, external/internal tibial rotation, and flexion/extension).

Means, standard deviations and observed power for all variables at the time of foot contact are presented in Table 1. The adduction angle in plant and cutting was significantly larger than that for either single-limb landing or both-limb jump landing ($p<0.01$, respectively); that in single-limb landing was significantly larger than that of both-limb jump landing ($p<0.05$). The external tibial rotation angle in plant and cutting was significantly larger than for either single-limb landing or both-limb jump landing ($p<0.01$); that in single-limb landing was significantly larger than that of both-limb jump landing ($p<0.01$). The flexion angle in both-limb jump landing was significantly larger than that of either single-limb landing or plant and cutting ($p<0.01$); that in plant and cutting was significantly larger than that of single-limb landing ($p<0.01$).

Means and standard deviations of peak values for all variables are presented in Table 2. The peak abduction angle in both-limb jump landing was significantly larger than that of either single-limb landing or plant and cutting ($p<0.01$ and $p<0.05$, respectively). During single-limb landing or plant and cutting, their knee was abducted from foot contact with time. However, even at their peak, it is adducted. The peak internal tibial rotation angles in plant and cutting and both-limb jump landing were significantly larger than that of single-limb landing ($p<0.05$ and $p<0.01$, respectively). The peak flexion angle in plant and cutting was significantly smaller than both-limb jump landing ($p<0.05$).

The angular excursion and velocity for knee abduction and internal tibial rotation are presented in Table 3. The excursion for knee abduction in plant and cutting and both-limb jump landing was significantly larger than that for either single-limb landing ($p<0.01$, respectively). The rates of excursion for knee abduction among three tasks were not significantly different. The excursion for internal tibial rotation in plant and cutting was significantly larger than for either single-limb landing or both-limb jump landing ($p<0.01$, respectively), whereas that in single-limb landing was significantly larger than that of both-limb jump landing ($p<0.01$). The rate of excursion for internal tibial rotation in plant and cutting was significantly faster than that for either single-limb landing or both-limb jump landing ($p<0.01$, respectively).

4. Discussion

The primary purpose of this study was to analyze the biomechanical characteristics of the knee joint during several athletic tasks, and to examine what tasks present a risk for ACL injury. A plant and cutting manoeuvre is a movement that commonly causes ACL injury, of which most situations were single-foot push-offs [5]. However, biomechanical characteristics of plant and cutting and several athletic tasks are unknown. Therefore, to compare a plant and cutting and normal single-limb landing as well as both limb landing, we can understand these athletic tasks and examine what tasks are risky for ACL injury. The results of this study showed that greater excursion and more rapid knee abduction occur in plant and cutting than that which occurs in single-limb landing, in addition to greater internal tibial rotation. Furthermore, compared to similar single-limb tasks, both-limb jump landing knee flexion and knee abduction were greater; external tibial rotation at the foot contact was smaller.

4.1. Plant and cutting versus single-limb landing

Some recent studies have compared biomechanical characteristics across different athletic tasks [8,15,20]. Nevertheless, these studies present some limitations. Although Chappell et al. [8] compared knee kinematics of forward, vertical, and backward stop-jump tasks, they did not examine lateral movement. Sell et al. [15] compared two-legged stop-jump tasks in three different directions. Although their results indicate that lateral jumps are the most dangerous of the stop-jumps, all tasks were two-legged tasks, not single-leg tasks. Besier et al. [20] compared the joint load during running, sidestep cutting, and crossover cutting. They inferred that external moments applied to the knee joint during the stance phase of the cutting tasks place the ACL and collateral ligaments at risk of injury, but they did not analyze joint kinematics and the frequency of the motion analysis system was too slow to support examination of high-speed athletic tasks. Therefore, the results of this study, along with those of the prior study, provide some implications of mechanisms causing ACL injury.

The results of this study showed that, during plant and cutting, external tibial rotation at the foot contact and peak internal tibial rotation were greater than during single-limb landing. During plant and cutting, from foot contact, subjects rotated the tibia more rapidly and to a greater degree toward internal tibial rotation than during single-limb landing. Previous studies [8,15,16] that examined the mechanism of ACL injury have not analyzed tibial rotation during high-risk movement, probably because of technical issues. In this study, we analyzed tibial rotation using PCT. An anatomical study has demonstrated that internal tibial rotation increases the strain of ACL [21]. Therefore, biomechanically and anatomically, plant and cutting presents a high risk for ACL injury.

During plant and cutting, subjects demonstrated more increased knee adduction at foot contact than during single-limb landing. After foot contact, during single-limb landing, subjects showed twin peaks of knee abduction. During plant and cutting, subjects moved toward knee abduction with time, although subjects did not exhibit a great magnitude of knee abduction. Consequently, during plant and cutting, excursion of knee abduction was greater than during single-limb landing. Therefore, during plant and cutting, greater excursion of knee abduction occurred than during single-limb landing combined with greater internal tibial rotation to push off their body to the other side and change direction.

4.2. Both-limb jump landing versus single-limb tasks

Some studies have analyzed kinematics or kinetics during bilateral landing to examine ACL injury mechanisms [11,12,22]; other studies have screened risks for ACL injury [13] or lower limb injury [23,24]. However, few studies have examined the characteristics of bilateral landing in comparison to single-limb landing. Only Pappas et al. [16] compared bilateral and unilateral landings. Their results indicated that, in unilateral landings, subjects performed high-risk kinematics with increased knee valgus, decreased knee flexion, and decreased relative hip adduction. However, they showed no peak knee valgus or tibial rotation during landing.

The results of this study demonstrated that, during both-limb jump landing, knee flexion at foot contact was greater than for single-limb landing and plant and cutting, and that peak knee flexion was greater than plant and cutting. These results were consistent with those of a previous study [16]. Pappas et al. [16] speculated that subjects might attempt to prevent falls by limiting excessive knee flexion during unilateral landing compared to bilateral landing, while simultaneously increasing the forces in ACL. Additionally, in slight knee flexion, i.e. less than 30, contraction of the quadriceps strains the ACL [21,25,26]. For that reason, slight knee flexion is inferred as a risk factor of ACL injury. During a process of prevention training leading athletes to increased knee flexion can decrease the incidence of ACL injury. On the other hand, during both-limb landing, external tibial rotation at the foot contact was less than that during single-limb landing and plant and cutting, while peak internal tibial rotation was not significantly different with plant and cutting. Unilateral landing has a greater excursion of tibial internal rotation than bilateral landing. As described above, an anatomical study has demonstrated that internal tibial rotation increases the ACL strain [21]. Consequently, characteristics of unilateral landing that have less knee flexion and greater internal tibial rotation present a higher risk for ACL injury than bilateral landings.

During both-limb jump landing, peak knee abduction was greater than for either single-limb landing or plant and cutting, while knee adduction at foot contact was smaller. These results did not support our hypothesis. We speculate that knee abduction was limited compensatory for greater internal tibial rotation and smaller knee flexion to prevent ACL injury during single-limb tasks. The possibility of ACL injury arose when subjects allowed greater knee abduction during single-limb tasks. Another reason might be that, because ACL injury occurs not only in single-limb situations but also in both-limb jump landing, the latter also poses a risk for ACL injury. Krosshaug et al. [27] analyzed videos of ACL injury situations and reported that ACL injury occurred during two-legged landing in 9 of 22 cases of female player situations, although it occurred in only four cases of one-legged landing. Therefore, it is thought that both-limb landing with greater knee abduction might also pose a risk for ACL injury.

Greater knee abduction was apparent during a both-limb jump landing task. For screening of ACL injuries, we detected knee abduction well in this task. It is difficult to detect a risk demonstrating greater knee abduction during single-limb tasks because of these characteristics, which demonstrate limited knee abduction. Moreover, knee abduction during both-limb landing can be evaluated using a two-dimensional approach, which uses a video recorder and analyzes a frontal projected knee valgus angle [17]. Some studies have been conducted using comparable methods [23,28]. Consequently, considering convenience and efficiency, both-limb jump landing is thought to be valuable for screening the risk of ACL injury.

4.3. Limitations

This study has important limitations. Influences of the hip and ankle have recently been suggested [9,29]. However, the present study analyzed the kinematics of the knee only. Additionally, although joint kinetics holds great importance for analyses of athletic tasks and for examination of the mechanisms of injuries, we only analyzed knee kinematics because we have not developed a joint-moment calculation system corresponding to PCT. Future studies should examine the relation between kinematic data and kinetics data to assess the ACL injury mechanism.

5. Conclusion

We compare the biomechanical characteristics of the knee joint for several athletic tasks to elucidate the characteristics of single-limb landing, plant and cutting and both-limb landing, and to examine what tasks present a risk for ACL injury. The results indicate that, in plant and cutting, knee abduction combined with internal tibial rotation poses a risk of causing ACL injury. Both-limb landing with greater knee abduction might also pose risks for ACL injury.

6. Conflict of Interest

No author of this manuscript has any conflict of interst.

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Original article

The effect of geometry of the tibial polyethylene insert on the tibiofemoral contact kinematics in Advance Medial Pivot total knee arthroplasty

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Abstract

Background. In modern total knee arthroplasty (TKA), it is important to reproduce both medial pivot motion and posterior femoral rollback to obtain greater postoperative knee flexion. Several studies have reported the factors affecting knee motion and range of motion after TKA. The purpose of this study was to evaluate the effect of the tibial insert geometry on the tibiofemoral contact kinematics, especially focusing on the medial pivot motion and posterior femoral rollback.

Methods. Seven cadaveric knees were replaced with the Advance Medial Pivot TKA, and two different geometries of polyethylene tibial insert, the standard medial pivot design (MP-design) and double high design (DH-design), were biomechanically compared. Four experimental configurations were evaluated in each specimen in this order: (1) the MP-design with posterior cruciate ligament (PCL) retaining, (2) the DH-design with PCL retaining, (3) the MP-design with PCL sacrificing, and (4) the DH-design with PCL sacrificing.

Results. Under the PCL-retaining condition, both designs showed no medial pivot but bicondylar femoral rollback more than 60° of knee flexion. In the MP-design, tibiofemoral contact point (estimated contact point, ECP) of the medial compartment was located on the posterior lip of the ball-in-socket structure while demonstrating greater than 120° of knee flexion. The posterior translation was also the same in both designs. On the other hand, ECP of the MP-design and the DH-design showed only medial pivot pattern under the PCL-sacrificing condition. In the DH-design, ECP of the lateral compartment showed paradoxical anterior translation from 0° to 60° of knee flexion. Total posterior translation was significantly greater in the lateral compartment than that in the medial compartment.

Conclusions. The results of this study suggest that in this type of TKA system the ball-in-socket geometry in the MP-design has an advantage for reproducing medial pivot motion in the PCL-sacrificing condition, and the flexion path structure in the DH-design is considered to be both effective and safe for femoral rollback in the PCL-retaining condition. However, neither design is sufficient to reproduce medial pivot motion and posterior femoral rollback. Therefore, a different design of tibial insert is needed for more physiological kinematics after TKA.

Introduction

An important aim of total knee arthroplasty (TKA) is to return the arthritic knee to as close to normal function as possible. The physiological motion of the knee joint has both medial pivot motion and femoral rollback.[1–3] This motion pattern is seen not only in the midflexion area but also in a deep flexion range of more than 100°.[4] Therefore, the combination of a medial pivot motion and femoral rollback is thought to be the key motion for high flexion of the knee joint. There are several factors that influence the three-dimensional knee motion after TKA: these include the geometry of the femoral and tibial component, the setting alignment of these implants to the bone, changes in the level of the joint line, soft tissue balance and tension, and retention or sacrifice of the posterior cruciate ligament (PCL).[5–8] Fluoroscopic studies of modern TKA have not yet demonstrated expected knee motion close to normal conditions but rather a nonphysiological motion such as paradoxical sliding forward or paradoxical rolling forward.[8–10] Furthermore, these studies have analyzed the knee motion during normal gait, up/down stairs, and rising from/sitting in a chair. In these activities, the maximum flexion of the knee joint is never greater than 90°; therefore, precisely how the knee joint moves after TKA thus remains unclear, especially in deep flexion.

Recently, an asymmetrical tibial polyethylene insert, a ball-in-socket on the medial side and an arcuate

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groove on the lateral side, was introduced to reproduce the medial pivot motion during knee extension-flexion.[11] In this type of TKA system, the typical medial pivot motion was observed by an in vivo kinematic study using fluoroscopy.[12] However, it is not clearly demonstrated whether we should preserve or sacrifice the PCL at surgery. Furthermore, it is unknown whether posterior femoral rollback is reproduced in this type of TKA system. The purpose of the current study was to evaluate the effect of polyethylene tibial insert geometry in the medial pivot TKA on the tibiofemoral contact kinematics in relationship to retaining or sacrificing PCL, especially focusing on the medial pivot motion and posterior femoral rollback in deep knee flexion.

Materials and methods

Seven fresh-frozen cadaveric knee joints were used in this study. Consent for the design of this study was obtained from the Institutinal Review Board and the ethical committee of our institute. X-ray examination was previously performed to select knee joints of almost the same size. None of the knees had any evidence of skeletal deformity, and it was confirmed that the PCL was in an intact condition.

After the skin and subcutaneous tissue were stripped, leaving the capsule, ligaments, and muscles intact, each knee was replaced with the Advance Medial Pivot Prosthesis (Wright Medical Technology, Arlington, TN, USA). The distal femur was cut in 5° of valgus and 3° of external rotation. The proximal tibia was cut at a right angle to the tibial axis in the coronal plane and 3° of posterior slope in the sagittal plane. The PCL was preserved, and the patella was not resurfaced. After bone cutting was completed, a size 2 femoral and tibial component with a 10-mm-thick polyethylene insert was placed. The metal rods were inserted into the intramedullary space of the femur and tibia, and the femoral rod was rigidly fixed to the motion frame. The tibial rod was fixed to the clamp that allows 6-degrees-of-freedom motion. The knee joint was moved from 0° to 150° of flexion by a load cell under the loading condition of 40 N on the quadriceps tendon and 20 N on each medial and lateral hamstring muscle through the semitendinosus and biceps femoris tendon. The load ratio of quadriceps and hamstring was according to previous reports; however, the actual amount of load was less than that of the physiological condition as a result of the strength of the motion frame and load cell.[13,14]

The tibiofemoral contact kinematics was then evaluated using the photostereometric knee motion analysis system (KKN/1B), which was basically developed at our institute (Faculty Engineering, Niigata University). This system consists of eight LEDs (BR 3371X; Stanley Denshi, Tokyo, Japan) with marker devices mounted onto the femoral and tibial bone, two sets of three linear high resolution CCD cameras (TCD141C; Toshiba, Tokyo, Japan) for tracking the LED position, and a PC for data analysis. The spatial resolution was designed to be 0.06 mm when the LEDs were located on the focal plane of the CCD cameras, and overall accuracy of the measuring system was within 0.52 and 0.11 mm at any point on the femoral component. Three-dimensional computer-aided design (CAD) solid models of the femoral component, tibial tray, and polyethylene insert were obtained, and the positional relationship between these models was also measured. Intersurface distance between the femoral component and polyethylene insert was quantitatively assessed, and the area where the value of the intersurface distance was less than or equal to 0.75 mm was defined as the estimated contact area. The center of the estimated contact area was finally defined as the estimated contact point (ECP), and the contact kinematics was evaluated by changing the ECP.[15–17]

In the current study, two different designs of the polyethylene tibial insert were compared: one was the standard medial pivot design (MP-design) and the other was the double high design (DH-design). In the MP-design, a medial socket exactly conformed to the sphere of the femoral component, thus providing the medial ball-in-socket kinematics, and the lateral part was an arcuate groove centered on the medial socket. The basic geometry of the DH design was the same as the MP-design: the main difference between the MP-design and the DH-design was the geometry of the posterior lip. In the MP-design, the geometry of the posterior lip was part of the ball-in-socket and arcuate groove design; on the other hand, the posterior lip of the DH-design was 3 mm lower than that of the MP-design, which resulted in a posterior slope (Fig. 1a–c). The concept of posterior slope was that this slope will act as a "flexion path" when femoral rollback occurs. The medial pivot femoral component was used for both the MP-design and the DH-design. Both medial and lateral condyles of the medial pivot femoral component had a sphere and C-curve design with a single radius in all three planes. Both types of polyethylene inserts were exchanged on the same metal tibial component, so that the difference of the design was directly comparable using the same cadaveric knee joint.

Four experimental configurations were evaluated in each specimen in this order: (1) the MP-design with PCL retaining, (2) the DH-design with PCL retaining, (3) the MP-design with PCL sacrificing, and (4) the DH-design with PCL sacrificing.

At the time of measurement under the PCL-sacrificing condition, the extension gap and the flexion gap were evaluated and a polyethylene insert 2 mm thicker was used.

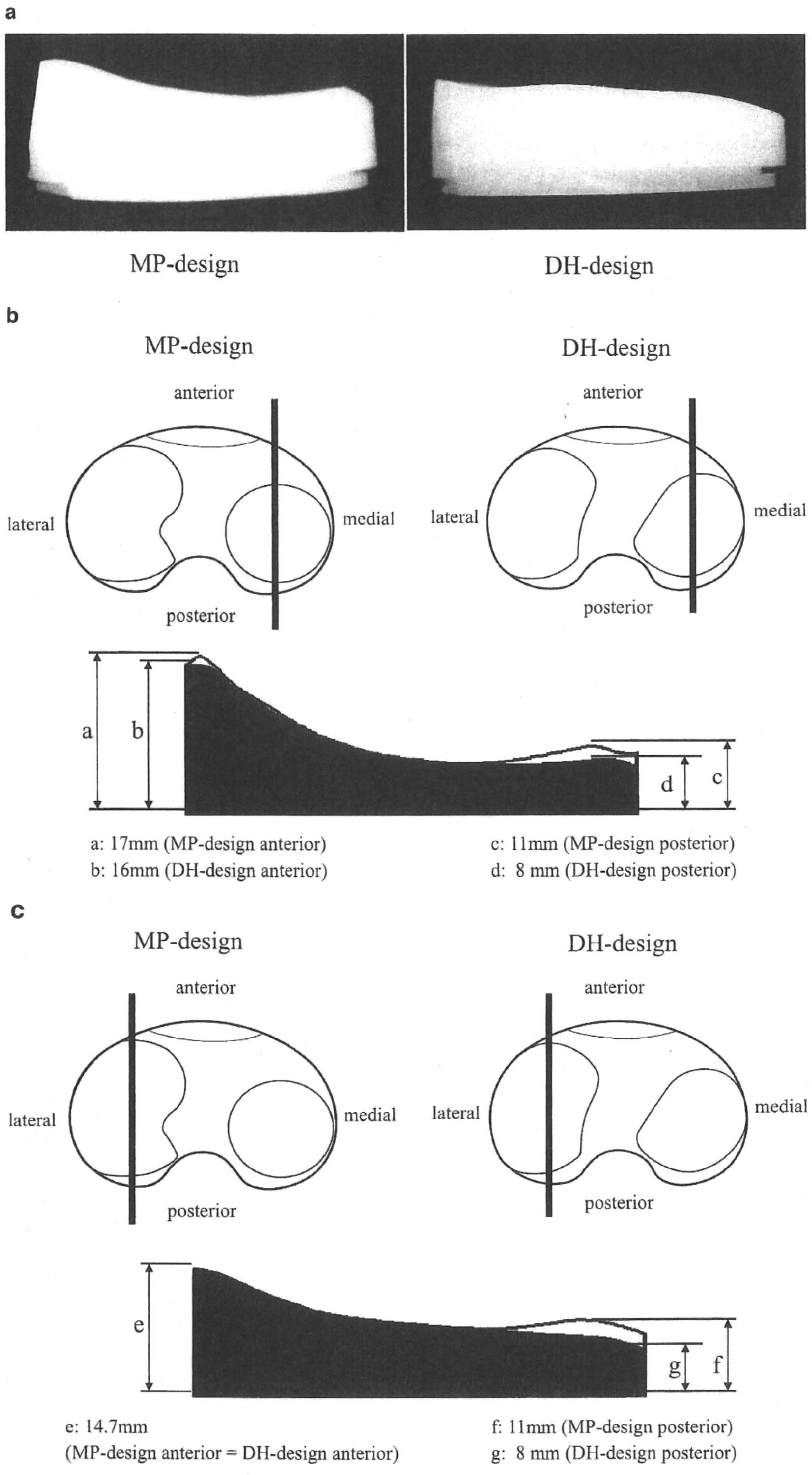

Fig. 1. Geometric characteristics of medial pivot design (DH-design) and double high design (DH-design). **a** Lateral view. **b** Cross-sectional geometry of the medial compartment. **c** Cross-sectional geometry of the lateral compartment

In this study, the anteroposterior motion of the ECP in the medial and lateral condyles was analyzed. Two-way analysis of variance (ANOVA) with within factors was used to analyze the effect of tibial insert geometry on the contact kinematics. The within factors were the aforementioned four different configurations. The significance level was set at a probability value less than 0.05.

Results

The MP-design showed bicondylar posterior translation under the PCL-retaining condition and medial pivot motion under the PCL-sacrificing condition. When the PCL was retained, the ECP of the medial compartment shifted posteriorly mainly more than 60° of knee flexion, and the ECP of the lateral compartment showed continuous posterior translation along knee flexion. The ECP of the medial compartment was located on the posterior lip of the ball-in-socket structure while demonstrating greater than 120° of knee flexion (Fig. 2a). The posterior translation of the ECP was 15.1 ± 3.1 mm (mean ± SD) in the lateral compartment and 11.6 ± 2.9 mm in the medial, and no statistical difference was seen between either compartment (Fig. 3). After the PCL was sacrificed, the MP-design showed a typical medial pivot motion. The ECP of the medial compartment was located at almost the same point from 0° to 90° of knee flexion followed by a slight posterior translation of greater than 100° of flexion. On the other hand, the ECP of the lateral compartment showed continuous posterior translation along knee flexion (Fig. 2a). The posterior translation of the ECP was significantly greater in the lateral compartment (11.1 ± 3.8 mm) than that in the medial compartment (3.3 ± 2.5 mm) ($P = 0.022$) (Fig. 3).

The DH-design had basically the similar tracking pattern of the ECP as the MP-design under PCL-retaining conditions, which included a posterior shift of the medial ECP of greater than 60° of knee flexion and a continuous posterior translation of the lateral ECP. Both medial and lateral ECP shifted posteriorly on the posterior slope of the flexion path more than 120° of knee flexion (Fig. 2b). The posterior translation of the ECP was 14.5 ± 4.2 mm in the lateral compartment and 10.7 ± 3.8 mm in the medial compartment, and no statistical difference was found according to these results

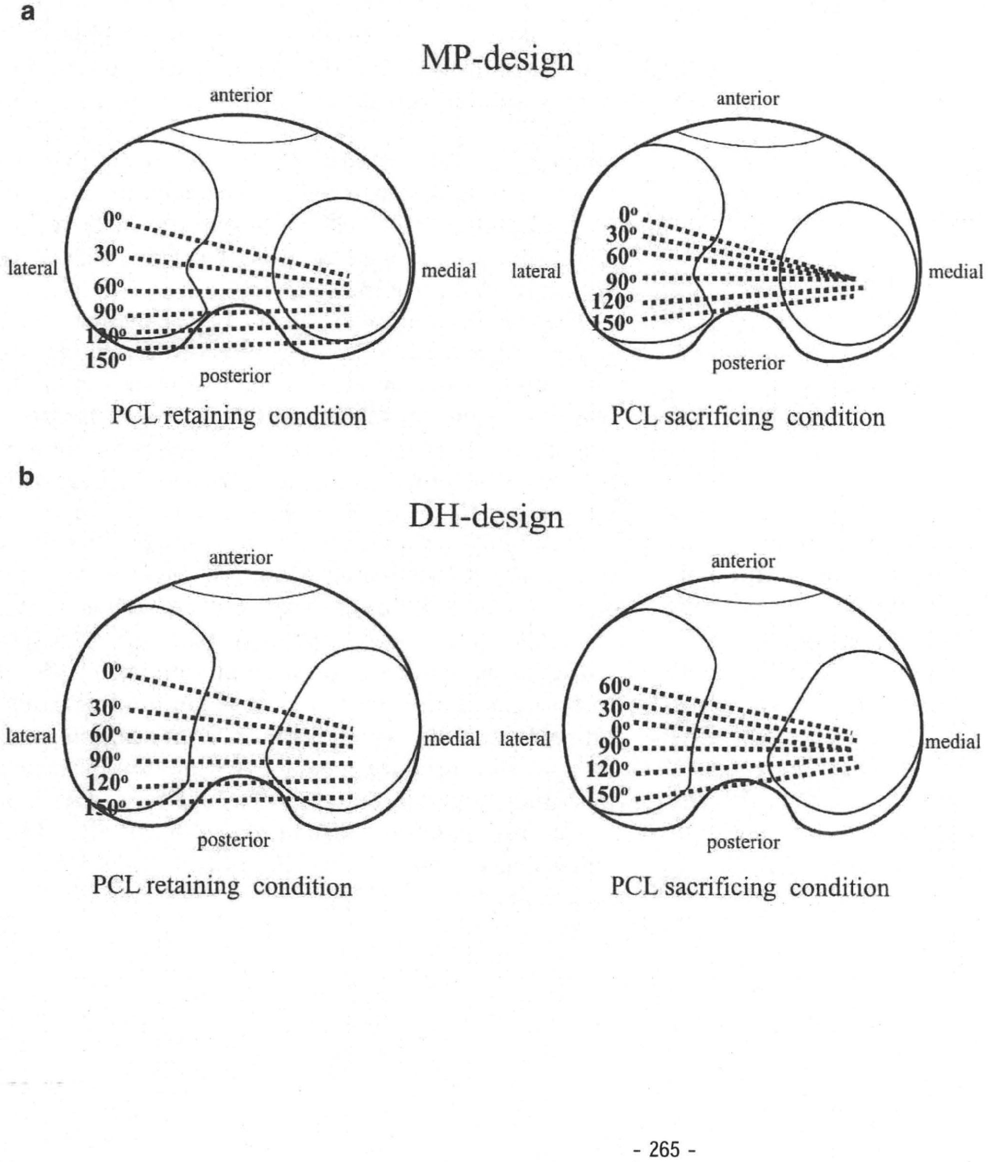

Fig. 2. Position movement of the estimated contact point (ECP). **a** MP-design. ECP of the medial compartment located the posterior lip of the ball-in-socket structure greater than 120° of knee flexion under posterior cruciate ligament (PCL)-retaining condition. **b** DH-design. ECP of the lateral compartment showed paradoxical anterior translation from 0° to 60° of knee flexion

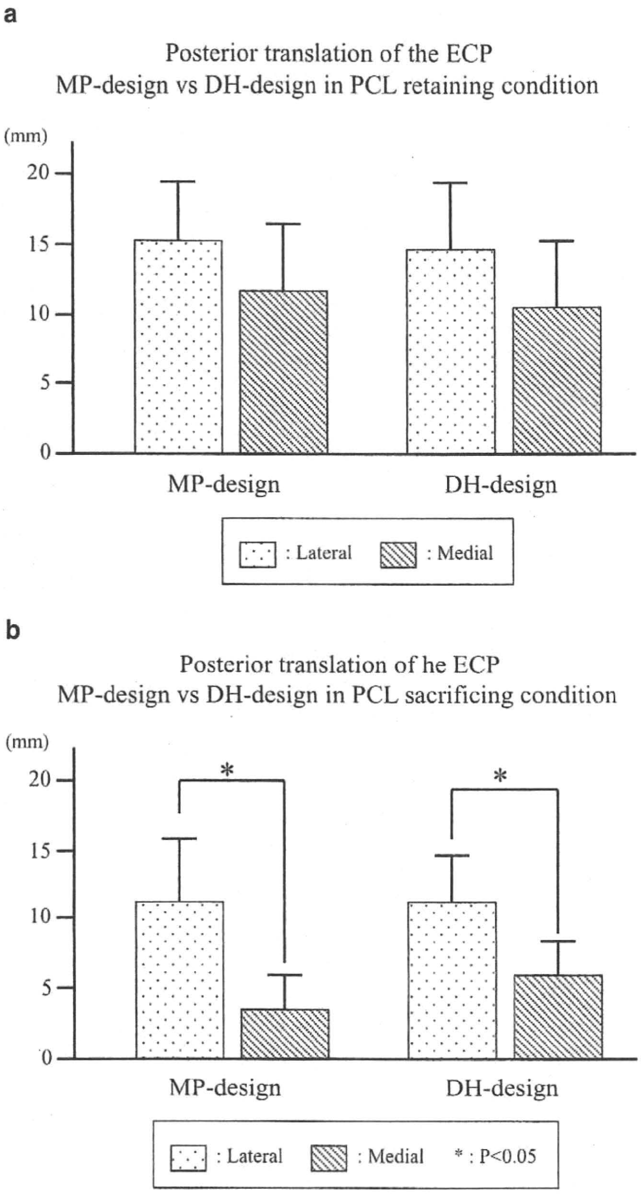

Fig. 3. Posterior translation of the ECP. **a** PCL-retaining condition. **b** PCL-sacrificing condition

(Fig. 3). The DH-design also showed a medial pivot motion after the PCL was sacrificed. The ECP of the medial compartment did not move from 0° to about 120° of knee flexion and then it slightly shifted to the posterior direction. In the lateral compartment, ECP showed paradoxical anterior translation from 0° to 60° of knee flexion followed by continuous posterior translation (Fig. 2b). The posterior translation of the ECP was 11.2 ± 3.6 mm in the lateral compartment and 5.5 ± 2.7 mm in the medial compartment, and then the posterior translation in the lateral ECP was significantly greater than that on the medial compartment ($P = 0.028$) (Fig. 3).

When comparing both designs, posterior translation of the ECP was not statistically different between the MP-design and DH-design under both PCL-retaining and PCL-sacrificing conditions.

Discussion

Currently, very few studies exist on the kinematic analysis of the medial pivot type TKA. Saari et al.[18] evaluated the Samuelson total knee prosthesis and described that the medial spherical condyle stabilized anteroposterior motion. Schmidt et al.[12] studied the Advance Medial Pivot prosthesis using fluoroscopy and showed medial pivot motion during the stance phase of the gait cycle. Moonot et al.[19] analyzed the Medial Rotation Knee with fluoroscopy and demonstrated medial pivot motion in a lunge motion.

In the present study, two different geometries of the polyethylene insert in the Advance Medial Pivot TKA were compared. The medial pivot geometry (MP-design) has a highly conformed "ball-in-socket" design to reproduce the medial pivot motion. On the other hand, the double high tibial insert (DH-design) is designed to achieve both medial pivot motion and posterior femoral rollback in deep knee flexion that will hopefully lead to more physiological kinematics and a better flexion angle. However, our data in the current study demonstrate that the contact kinematics by ECP did not substantially differ between the MP-design and the DH-design, especially in the deep flexion area greater than 120° of knee flexion. When the PCL was retained, both designs showed no medial pivot but did have bicondylar rollback, and, when the PCL was sacrificed, both designs showed no femoral rollback but typical medial pivot motion.

The first reason for this result is that medial ball-in-socket geometry is a highly conformed design and has an advantage in reproducing medial pivot motion, but it is insufficient for femoral rollback even if the posterior slope was made. The second reason is that femoral rollback is essentially controlled by the PCL, and this effect is stronger than that of the geometric conformity of the tibial insert as the MP-design and the DH-design under the PCL-retaining condition. Most et al.[20] analyzed femoral rollback after cruciate-retaining and stabilizing TKA and described that the cam-spine engagement structure played an important role in restoring posterior femoral rollback in the PCL-substituting TKA. However, the cam-post mechanism is not thought to reproduce medial pivot motion. Therefore, this study suggests that if we would reproduce both medial pivot motion and femoral rollback after TKA, a new concept and design of the tibial insert geometry will be needed.