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Research article

Reliability of hip range of motion measurement among experienced arthroscopic hip preservation surgeons

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ABSTRACT

The aim of this study was to determine (i) the reliability of hip range of motion measurement among experienced arthroscopic hip preservation surgeons and (ii) the magnitude of hip flexion change with posterior pelvic tilt. Five experienced arthroscopic hip preservation surgeons (5–18 years of hip surgery experience) performed passive hip range of motion (internal and external rotation), flexion (contralateral hip extended) and flexion with posterior pelvic tilt (contralateral hip maximally flexed) on five young healthy asymptomatic volunteers (three males, two females; 34.4 ± 10.7 years of age). Motion was measured via digital photography and goniometry. Inter-observer reliability was calculated via two-way mixed, single measures, intra-class correlation coefficient. Paired *t*-test was utilized to compare hip flexion (with contralateral hip extended) to hip flexion with posterior pelvic tilt (with contralateral hip in forced flexion). The reliabilities of measurements of hip flexion with posterior pelvic tilt and external rotation were excellent, that of hip flexion was fair, and that of hip internal rotation was poor. The magnitude of hip flexion increase with posterior pelvic tilt was $17.0^\circ \pm 3.0^\circ$ ($P < 0.001$). The reliability of hip range of motion measurement by five experienced arthroscopic hip preservation surgeons was excellent for measures of hip flexion with posterior pelvic tilt and external rotation. Contralateral maximal hip flexion significantly increased ipsilateral hip flexion (approximately 17°).

Level of Evidence: Diagnostic, level III (without consistently applied reference standard)

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INTRODUCTION

Assessment of hip range of motion is a critical physical examination component for individuals with hip pain. Femoroacetabular impingement (FAI) syndrome is a common cause of hip pain and loss of motion [1]. Individuals with hip dysplasia may also report pain, but may exhibit excessive motion, rather than restricted motion [2]. Measures of spinopelvic alignment (pelvic incidence, pelvic tilt) have been shown to be significant predictors of hip pain and motion (proximal kinetic chain) [3]. Similarly, evidence has illustrated a significant relationship between hip motion and anterior cruciate ligament tear (distal kinetic chain) [4]. However, the association of hip motion with pain, strength, injury risk and osseous morphology is incompletely understood (Table I). Due to the prevalence of cam, pincer and dysplasia in asymptomatic individuals, identification of predictors of pain, loss of function and degenerative change is necessary [5]. Structurally speaking, those with FAI syndrome (cam morphology) and/or dysplasia are the two most common groups at increased risk of hip osteoarthritis [6, 7]. Thus, hip motion analysis is an essential element in understanding the link between arthritic and non-arthritic hip pain.

Despite the significant recent growth in hip preservation research, specifically hip motion, there has been very little on methods of measurement. Measurement of hip motion has been performed using visual estimation, goniometry, digital photography, digital inclinometry, surface-based motion analysis and osseous-based motion analysis [8–11]. Diagnostic accuracy, precision, reliability, reproducibility and validity must be balanced with cost of measurement. Previous investigations comparing motion capture (used as the gold standard comparison) with visual estimation, goniometry and digital photography have demonstrated optimal accuracy and precision of hip flexion, internal rotation and external rotation measured by attending orthopedic surgeons [12]. The influence of spinopelvic alignment and dynamic pelvic tilt on hip motion is less well understood [3].

Therefore, the purpose of this investigation was to determine (i) the reliability of hip range of motion measurement among experienced arthroscopic hip preservation surgeons; and (ii) the magnitude of hip flexion change with posterior pelvic tilt. The authors hypothesized that reliability of measurement of hip motion would be excellent and that hip flexion would increase significantly (approximately 15°) with posterior pelvic tilt.

METHODS

Institutional review board approval was obtained for this cross-sectional investigation, which took place at the International Society of Hip Arthroscopy 2016 Annual Scientific Meeting in San Francisco, CA, USA. Eligible participants in the study were Orthopedic Surgeons, specializing in hip arthroscopy, with formal training in hip arthroscopy via Sports Medicine fellowship and/or Hip Preservation surgery fellowship, who had performed over 150 arthroscopic hip preservation surgeries per year for a minimum of 3 years. All surgeons' practices were in the United States. Five participating surgeons (Group A; 5–18 years of hip surgery experience) performed the range of motion physical examination. Passive motion was assessed. Active motion was not assessed. Five healthy volunteers (Group B; three males; two females) were recruited at the meeting. Five separate individuals were recruited to be photographers (Group C). All photographs were taken with cellular phone cameras. Inclusion criteria were willingness to participate (hip motion assessed and photographed), greater than 18 years of age, no previous hip surgery, and no previous hip pain for greater than 6 weeks. Exclusion criteria were those unwilling to participate, with current pain, previous hip pain for more than 6 weeks, previous hip surgery and under 18 years of age. All healthy volunteers signed a written and gave verbal informed consent.

Hip range of motion was measured on a yoga mat (72 inches length; 30 inches width; $^1/_4$-inch thickness), which was placed on a thin carpeted hardwood floor. No significant cushion effect occurred with either the mat or the carpet. Participating volunteers were supine on the mat. No seated, lateral or prone examinations were performed. Four motions were assessed: (i) hip flexion with permissive contralateral hip extension (meaning the contralateral hip was allowed to remain flat on the examination surface yoga mat on the floor); (ii) hip flexion with forced contralateral maximal hip flexion; (iii) hip internal rotation with the hip at 90° flexion; (iv) hip external rotation with the hip at 90° flexion. While the surgeons (Group A) placed the volunteer's hip (Group B) into the maximal passive motion for each position, the photographer (Group C) took the photograph of the hip motion. Digital photographs were taken perpendicular to the axis of motion for each position (Fig. 1). For hip flexion, the camera was approximately three feet from the hip, aimed lateral to medial. The camera was aimed anterior to posterior, looking down the long axis of the femur, from the knee through to the hip, approximately three feet above the knee for internal and external rotation. All measurements were performed bilaterally.

All photographs were checked after each one was taken to ensure perpendicularity. If the photograph was off by an estimate of more than 5°, then the photograph was

Table I. Selected recent publications evaluating the association of hip motion with pain, strength, injury risk and osseous morphology

Authors	*Year*	*Participants*	*Influence of hip motion—relevant outcomes*
Wyles *et al.* [6]	2017	226 athletes (12–18 years of age)	• Young athletes with <10° IR showed increased degenerative changes on MRI and radiographs versus controls (>10° IR) • Over 5 years, 27% of those with <10° IR progressed from Tonnis 0 to Tonnis 1 (0% in controls) • 50% of those with <10° IR had a positive anterior impingement test (0% in controls) • Baseline variables associated with increased risk of degenerative changes: decreased hip IR, decreased hip flexion
Kraeutler *et al.* [23]	2018	220 patients (440 hips) with hip pain	• Cam morphology (>50° on radial CT) significantly decreased hip flexion, irrespective of femoral version • Femoral version abnormalities significantly outweighed the effect of cam morphology on hip IR
Mosler *et al.* [24]	2018	Male professional soccer players in Qatar—two seasons	• Asymptomatic hip with cam and large cam morphology associated with lower hip IR and bent knee fall out, higher pain • Dysplasia had higher degrees of abduction; pincer had lower degrees of abduction
Tak *et al.* [25]	2017	Systematic review, 11 studies	• Total rotation of both hips <85° was risk factor for groin pain development—strong evidence • IR, abduction, extension not associated with risk or presence of groin pain
Larson *et al.* [26]	2017	59 NHL players (118 hips)	• Higher AP, Dunn lateral, and maximal alpha angles correlated with lower hip IR • Higher AP alpha angle correlated with lower extension, abduction; higher Dunn correlated with lower hip flexion, abduction • Lower hip ER and total arc of motion correlated with increased risk of current or prior symptoms or surgery
Agnvall *et al.* [27]	2017	102 adolescent elite skiers	• Cam morphology (>55° alpha angle MRI) correlated with reduced IR in both supine and sitting, passive supine hip flexion • Cam morphology also correlated with positive impingement test

IR, internal rotation; ER, external rotation; MRI, magnetic resonance imaging; CT, computed tomography; NHL, National Hockey League.

repeated. Photographs were then stored in a password-protected drive, without any identifying information for any individual involved in the study. Screen Protractor (Iconico, New York, NY) was utilized to perform on-screen motion measurements by a single study author (J.H.) [11, 12]. For hip flexion, the limb axis was placed down the mechanical axis of the femur and the reference axis 180° from the trunk with the contralateral limb permissively extended on the mat. For hip flexion with posterior pelvic tilt, the limb axis was again placed down the mechanical axis of the femur and the reference axis again 180° from the trunk. However, this time the contralateral limb was forced into maximal hip flexion while the volunteer held the hip there. The examiner ensured that

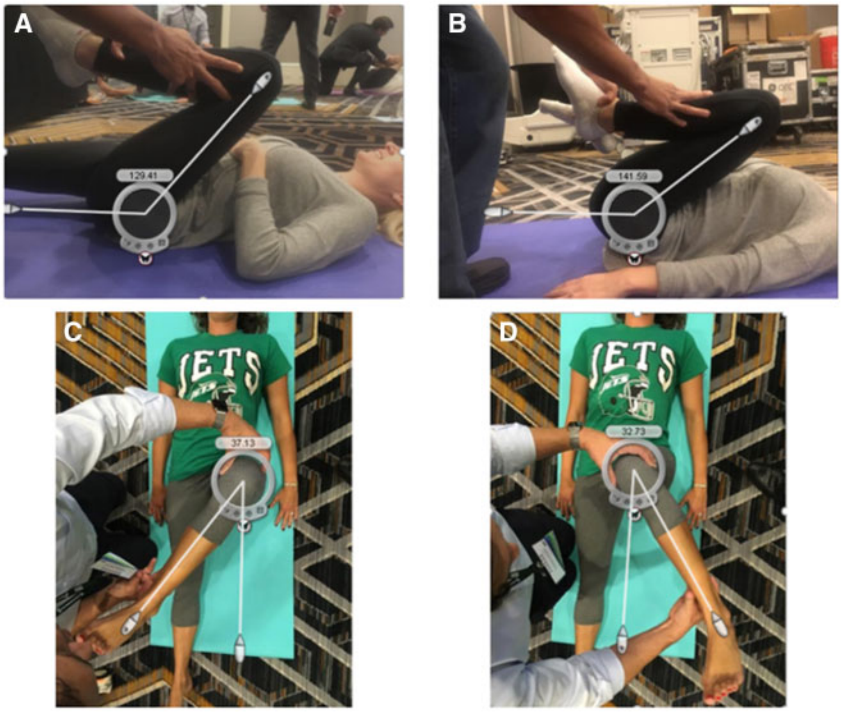

Fig. 1. (**A**) Photograph of left hip flexion with right hip in permissive extension. (**B**) Photograph of left hip flexion with forced right hip maximal flexion, while keeping the lumbosacral spine on the mat surface as much as possible. (**C**) Photograph of left hip external rotation. (**D**) Photograph of left hip internal rotation. All motions demonstrate on-screen goniometer measurement.

the lumbosacral spine did not lift off the mat. For hip internal and external rotation, the vertex of the angle of measurement was down the center of the femur while looking from above the knee. The limb axis was down the mechanical axis of the tibia. The reference axis was parallel to the spinal column, straight in the sagittal plane.

Study design was intended to measure the actual examiner's assessment of passive hip motion, not the volunteer's ability to achieve more or less motion and not the photographer's ability to take the photograph. The dependent variable was the actual hip motion, based on the examiners' techniques. Examiners were instructed to perform passive motion assessment as they would in the clinical office setting, with the end point of motion assessed by a subjective 'stop'.

Descriptive statistics were calculated. Continuous data were described using mean ± standard deviation. Categorical data was described using frequency with percentages. For calculation of inter-observer reliability, two-way mixed, single measures, intra-class correlation coefficient (ICC) was used. ICC between 0.75 and 1.00 was defined as excellent reliability; 0.60–0.74 as good; 0.40–0.59 as fair; and less than 0.40 as poor. The normative value of hip flexion utilized for this study was 115° ± 11.5° [13–15]. Based on the latter, using beta of 0.2 (power 80%) and an expected difference from hip flexion (with contralateral hip extended) to hip flexion with posterior pelvic tilt (with contralateral hip in forced flexion) of 15°, the calculated sample was five individuals. A paired *t*-test was utilized to compare hip flexion (with contralateral hip extended) to hip flexion with posterior pelvic tilt (with contralateral hip in forced flexion). A *P*-value less than 0.05 was defined as statistically significant. IBM SPSS Statistics (Version 22.0.0.0) (Armonk, NY, USA) was used for all statistical analysis.

RESULTS

Bilateral hip range of motion was successfully measured in all five participants (three males: 23, 40 and 50 years of age; two females: 28 and 31 years of age) (Table II). The reliability of the measurement of hip range of motion is listed in Table III. The reliability of measurements of hip flexion with posterior pelvic tilt and external rotation were excellent, hip flexion fair and hip internal rotation poor. The magnitude of hip flexion increase with posterior pelvic tilt was 17.0° ± 3.0° ($P < 0.001$).

DISCUSSION

The primary outcome of this investigation was that the reliability of measurement of hip range of motion of five

Table II. Measurements of hip range of motion (mean of all five raters)

	Motion (°)
Hip flexion	123.9 ± 6.4
Hip flexion[a]	141.0 ± 4.0
Internal rotation	32.3 ± 6.8
External rotation	42.4 ± 6.1

[a] Hip flexion with posterior pelvic tilt (contralateral hip forced maximal flexion).

Table III. Reliability of measurements of hip range of motion (for all five raters)

	ICC	*95% CI*
Hip flexion	0.51	0.233 to 0.809
Hip flexion[a]	0.77	0.551 to 0.925
Internal rotation	0.22	−0.0079 to 0.599
External rotation	0.82	0.637 to 0.944

CI, confidence interval.

[a] Hip flexion with posterior pelvic tilt (contralateral hip forced maximal flexion).

young healthy volunteers via digital photography by five experienced arthroscopic hip preservation surgeons was excellent for measures of hip flexion with posterior pelvic tilt and external rotation, partially confirming the primary hypothesis. However, reliability of hip flexion was fair, and internal rotation was poor. The magnitude of hip flexion increase was, as hypothesized (∼15°) at 17°.

Previous investigations of hip motion measurements in both symptomatic and asymptomatic individuals have yielded variable conclusions (Table IV). The rapid recent growth and evolution of the hip preservation literature have underscored the importance of the accuracy of determination of hip motion. The literature is replete with investigations of non-arthritic conditions like FAI syndrome, dysplasia and labral tears [2, 3]. These all require a thorough assessment of hip and pelvis motion. However, the literature is quite limited in its method of evaluation of that motion. The studies that do exist are in relative concordance with the findings of the current investigation with regard to the magnitude of hip flexion and internal and external rotation. Where the current study differs is in its reliability [16, 17]. Excellent inter-observer reliability of measurement of hip flexion with posterior pelvic tilt and external rotation is a key point for future hip preservation studies. A limitation is that inter-observer reliability for hip flexion (a common supine measurement in nearly all studies of hip surgery) was fair and internal rotation (a common supine measurement in nearly all studies of hip surgery) was poor. Both hip flexion and internal rotation are frequently utilized as measures of ‘success’ or ‘quality’ in paired comparisons of pre- and post-operative hip surgeries. A potential reason for the fair reliability (as opposed to excellent or good) of hip flexion is the variability in magnitude of dynamic posterior pelvic tilt induced by the examiner’s push to the ‘endpoint’ of flexion. A potential reason for the poor reliability of internal rotation is statistical—given the similar standard deviations of measurement of all four ROM techniques, but the smaller absolute magnitude of the internal rotation values, the variability in measurement lowers the reliability via ICC for internal rotation. It does not affect hip flexion with posterior pelvic tilt and external rotation as much given their higher magnitude values.

Hip range of motion must be recognized to co-exist with lumbopelvic (spinopelvic) biomechanics [17]. Anterior pelvic tilt has been shown to decrease cranial and central acetabular version, subsequently decreasing hip internal rotation (at 90° of flexion) and internal rotation (at 90° of flexion and 15° of adduction) [18]. Similarly, posterior pelvic tilt increases internal rotation (at 90° of flexion) and internal rotation (at 90° of flexion and 15° of adduction) [18]. Previous studies have also implicated a standard overestimation of hip motion in the literature on account of pelvic tilt falsely permitting ‘extra’ motion [17, 19]. Using ultrasound, which is more sensitive than physical examination for detection of femur-acetabular labrum contact, dynamic ‘impingement-free’ hip motion in asymptomatic young adult males was shown (via initiation of labral deflection and maximal flexion when femur impinged on acetabular rim) to be 68° ± 17° and 96° ± 6°, respectively [19]. These values are significantly less than typically quoted in the literature [20]. The reason is likely secondary to posterior pelvic tilt permitting further hip flexion and a false sense of ‘hip motion’ [17]. An examiner’s physical examination is not sensitive enough to detect femur–labrum contact, as the examiner is feeling for an ‘endpoint’ which includes: (i) the amount of flexion at the moment of femur–labrum contact and, (ii) the amount of flexion that occurs with posterior pelvic tilt occurring with flexion beyond this contact. The influence of pelvic incidence, a fixed spinopelvic parameter, has demonstrated a significant role in hip motion measurement. In subjects with FAI syndrome due to cam morphology, a higher pelvic incidence was associated with more limited sagittal hip mobility [3]. However, in patients with pincer morphology, a smaller pelvic incidence has been observed [21]. The mechanism for the latter is possibly secondary to the need to maintain

Table IV. Selected publications on measurement of normal hip range of motion

	Year	*Participants*	*Number of hips*	*Flexion*	*Internal rotation*	*External rotation*
Roaas and Andersson [13]	1982	Healthy males, 30–40 years age, Sweden	210	120.4	32.6	33.7
AAOS [15]	1974	n/r	n/r	113	35	48
Boone and Azen [14]	1979	Healthy males, 20–50 years age	56	121.3	44.4	44.2
Roach and Miles [28]	1991	Healthy males, females, 25–74 years age, USA	1313	123 M (25–39 yo) 121 M (40–59 yo) 118 M (60–74 yo) 123 F (25–39 yo) 121 F (40–59 yo) 119 F (60–74 yo)	34 M (25–39 yo) 33 M (40–59 yo) 31 M (60–74 yo) 33 F (25–39 yo) 30 F (40–59 yo) 29 F (60–74 yo)	33 M (25–39 yo) 31 M (40–59 yo) 27 M (60–74 yo) 36 F (25–39 yo) 34 F (40–59 yo) 32 F (60–74 yo)
Hallaceli *et al.* [29]	2014	Healthy males, females; 19–32 years age, Turkey	1974	128.2	43.3	41.9
Kumar *et al.* [30]	2011	Healthy males, females; 1–75 years age, India	648	138.5 (15–25 yo) 137.0 (25–75 yo)	31.2 (15–25 yo; sitting) 23.7 (15–25 yo; supine) 38.3 (15–25 yo; prone) 27.2 (25–75 yo; sitting) 20.5 (25–75 yo; supine) 32.2 (25–75 yo; prone)	35.8 (15–25 yo; sitting) 30.7 (15–25 yo; supine) 44.7 (15–25 yo; prone) 30.5 (25–75 yo; sitting) 25.9 (25–75 yo; supine) 38.1 (25–75 yo; prone)

M, male; F, female; yo, years old; n/r, not reported.

sagittal balance forces anterior pelvic tilt (due to the low pelvic incidence). Nonetheless, the evidence on the role of spinopelvic alignment, hip motion and hip symptoms is inconclusive [22].

When supine, if the contralateral hip is not held maximally flexed while trying to extend the ipsilateral hip (the Thomas Test), then this allows the ipsilateral femur to continue to drop because of anterior pelvic tilt [10]. In this position, the iliopsoas and rectus femoris are under less tension, so achieving 0° of hip flexion and 90° of knee flexion is easier. When supine, as the examiner is flexing (and measuring) the hip, maximal flexion of the contralateral hip posteriorly tilts the pelvis, with greater acetabular uncovering, and resultant increased hip flexion. Despite the knowledge of the importance of contralateral maximal hip flexion, it is seldom observed in the literature, but should be, based on the results of the current investigation.

Limitations

There are minor limitations in this investigation. Selection bias of a small number of young healthy individuals limits study external validity and generalizability. Nonetheless, *a priori* sample size calculation was performed. Further, the difference between hip flexion with contralateral hip extended and hip flexion with posterior pelvic tilt (contralateral hip in forced flexion) was statistically significant. In addition, the magnitude of motion difference (17°) is likely clinically important. Although a minimal clinically importance difference for hip motion has not been established, this magnitude of motion difference is more than 10% of the total arc of motion for hip flexion. Measurement of motion was via an on-screen goniometer. Several other methods of motion measurement exist and were not used in this investigation. Only hip preservation surgeons were used for measurement and no other clinicians (hip arthroplasty surgeons, hip trauma surgeons, pediatric hip surgeons, spine surgeons, fellows, residents, student, physical therapists, nurses, research assistants, athletic trainers, among others).

CONCLUSIONS

Reliability of hip range of motion measurement by five experienced arthroscopic hip preservation surgeons was excellent for measures of hip flexion with posterior pelvic tilt and external rotation. Contralateral maximal hip flexion significantly increased ipsilateral hip flexion (approximately 17°).

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CONFLICT OF INTEREST STATEMENT

J.D.H. AAOS: Board or committee member, American Journal of Orthopedics: Editorial or governing board, American Orthopaedic Society for Sports Medicine: Board or committee member, Arthroscopy: Editorial or governing board, Arthroscopy Association of North America: Board or committee member, DePuy, A Johnson & Johnson Company: Research support, Frontiers In Surgery: Editorial or governing board, International Society of Arthroscopy, Knee Surgery, and Orthopaedic Sports Medicine: Board or committee member, SLACK Incorporated: Publishing royalties, financial or material support, Smith & Nephew: Paid consultant; Paid presenter or speaker; Research support, Xodus Medical: Paid presenter or speaker; **R.C.M.** Arthroscopy Association of North America: Board or committee member, KNG Health Consulting: Paid consultant, North Carolina Orthopaedic Association: Board or committee member, Reflexion Health: Research support, Stryker: Paid consultant, Zimmer: Research support; **S.J.N.** Allosource: Research support, American Journal of Orthopedics: Editorial or governing board, American Orthopaedic Society for Sports Medicine: Board or committee member, Arthrex, Inc: Research support, Arthroscopy Association of North America: Board or committee member, Athletico: Research support, DJ Orthopaedics: Research support,Linvatec: Research support, Miomed: Research support, Ossur: IP royalties; Paid consultant, Smith & Nephew: Research support, Springer: Publishing royalties, financial or material support, Stryker: Paid consultant; Research support; **J.P.S.** AAOS: Board or committee member, American Orthopaedic Society for Sports Medicine: Board or committee member, Arthroscopy Association of North America: Board or committee member, Franklin BioScience: Stock or stock Options, Stryker: Paid consultant; **A.J.S.** AAOS: Board or committee member, American Board of Orthopaedic Surgery, Inc.: Board or committee member, American Orthopaedic Society for Sports Medicine: Board or committee member, Arthroscopy Association of North America: Board or committee member, International Society of Arthroscopy, Knee Surgery, and Orthopaedic Sports Medicine: Board or committee member, International Society of Hip Arthroscopy: Board or committee member, Journal of Hip Preservation Surgery: Editorial or governing board, MASH Group: Board or committee member, Thieme: Publishing royalties, financial or material support; **G.S.V.T.** Smith & Nephew: Paid consultant, Paid presenter or speaker, Trainer Rx: Paid consultant, Stock or stock Options, Vericel: Paid consultant, Paid presenter or speaker, Zimmer: IP royalties, Paid consultant, Paid presenter or speaker; **A.B.W.** Allosource: Paid consultant, Stryker: Paid consultant; **J.J.C.** Arthrex, Inc: IP royalties, Paid consultant, Paid presenter or speaker, Research support, Arthroscopy: Editorial or governing board, Breg: IP royalties, Paid consultant, Paid presenter or speaker, International Society for Hip Arthroscopy: Board or committee member; **T.J.E.** Acute Innovations: IP royalties, Medacta: Paid consultant, Research support; **D.K.M.** AAOS: Board or committee member, Arthrocare: IP royalties, Biomet: IP royalties, ISHA: Board or committee member, Orthopedics Overseas: Board or committee member, Orthopedics Today: Editorial or governing board, Smith & Nephew: IP royalties, Zimmer: IP royalties; Paid consultant; **B.R.K.** nothing to disclose; **D.S.C.** American Orthopaedic Foot and Ankle Society: Board or committee member, Biomet: Paid consultant; Paid presenter or speaker, CONMED Linvatec: IP royalties.

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