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Universitat Autònoma
de Barcelona

Departament de Cirurgia

LA COXARTROSI EN L'ADULT JOVE: ESTUDI DE CRITERIS DIAGNÒSTICS I FACTORS BIOMECÀNICS.

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1

INTRODUCCIÓ

1.1. Background

L'artrosi de maluc (coxartrosi) compromet majoritàriament a pacients a partir de la sisena dècada de vida. És un trastorn que afecta entre el 3 i 6% de la població europea i que segons algunes prediccions, en la propera dècada pot arribar a afectar a més del 7% de la població, amb un cost econòmic i social creixent [1-3]. La solució clàssica pel seu estadi final és una de les intervencions de més èxit de l'ortopèdia : l'artroplàstia total de maluc [4]. En adults joves, però, el plantejament terapèutic d'aquesta patologia pot canviar degut a la seva supervivència limitada la implantació d'una pròtesi en subjectes joves i, en conseqüència, obligar potencialment a una o múltiples reintervencions de revisió en el futur, amb resultats molt menys predictibles. És per això que, en l'última dècada, l'anomenada "cirurgia de preservació de maluc" s'ha afermat com alternativa terapèutica per mirar d'oferir tractament a aquest grup de pacients típicament joves (>55 anys), amb malucs simptomàtics i en estadis inicials de la malaltia degenerativa o, fins i tot, amb condicions anatòmiques considerades preartrosiques. En aquest context, s'han desenvolupat i/o perfeccionat noves tècniques terapèutiques (principalment artroscòpia i osteotomies periacetabulars) amb l'objectiu d'alleujar el dolor, millorar l'activitat i la funció, i prevenir o retardar la degeneració articular.

Aquest nou escenari ha provocat un augment en l'interès per aprofundir en la patogènia de les primeres etapes de la coxartrosi , atès que, en bona part, la indicació i resultats de la cirurgia de preservació depenen, de manera determinant, d'una adequada selecció de pacients per destriar quins casos se'n poden beneficiar i quins no. Aquesta selecció, deixant de banda criteris clínics, es basa en dos principis. En primer lloc l'estadi de la malaltia degenerativa en el moment del diagnòstic: una cirurgia conservadora només té sentit si la malaltia es troba en un estadi inicial que justifiqui una aposta per conservar l'articulació nativa del pacient. En segon lloc, l'anàlisi de factors anatòmics que es consideren predictors de la degeneració articular. En aquest sentit, la descripció de mecanismes o condicions anatòmiques amb potencial lesional, entre els qual cal assenyalar, l'*impingement femoroacetabular*, ha contribuït a tipificar morfològicament un grup de malucs "en risc" de desenvolupar malaltia degenerativa i a mirar de sistematitzar-ne el tractament. Malgrat aquests avenços, persisteix un ampli marge d'incertesa en la identificació i el pronòstic d'aquest grup de pacients.

1.2. Etiologia de la coxartrosi.

Es considera que l'artrosi no és una malaltia sinó el fracàs d'un òrgan originat inicialment per causes mecàniques, per tant els canvis biològics són secundaris [5]. Existeix evidència que els canvis degeneratius s'inicien per l'existència de magnituds hiperfisiològiques

d'estrès a nivell del cartílag articular, o bé per alteracions en el patró de càrrega que originen canvis en les magnituds de la tensió normal a nivell de la interlínia articular com passa en articulacions amb problemes d'inestabilitat, deformitat o fractures. Els mecanismes biomecànics i biològics implicats en la transducció de les càrregues mecàniques a una resposta intracel·lular encara no s'han dilucidat. Tot i això, s'ha demostrat que l'estrès mecànic pot influir en la producció dels mediadors pro-inflamatoris com NO i PGE2, IL-1 β i el TNF- α entre d'altres i actuar així com un potent regulador de metabolisme de la matriu i la viabilitat cel·lular [6].

Seguint aquests principis, s'accepta que els factors mecànics juguen un paper fonamental també en l'etiopatogènia de la coxartrosi [7,8]. De fet, en el pacient jove, deixant de banda entitats específiques, com ara la necrosi isquèmica del cap femoral, aquest procés es relaciona gairebé de manera universal amb un trastorn mecànic subjacent i, en general, s'atribueix a una sobrecàrrega concèntrica o excèntrica de l'articulació coxofemoral [9]. És ben sabut que els canvis importants en la relació normal entre el fèmur i l'acetàbul, com passa a la displàsia, distorsionen la mecànica del maluc, provocant una malaltia degenerativa precoç. Aquesta degeneració és tan previsible que, en pacients joves amb displàsia de maluc, s'indiquen agressives intervencions quirúrgiques per tal de retardar l'aparició de coxartrosi. En absència de grans deformitats anatòmiques, però, la predictibilitat de la degeneració articular és molt més incerta i el coneixement de factors que la desencadenen o la fan progressar és incomplet.

1.3. Anatomia funcional del maluc.

El maluc actua com una articulació del tipus enartrosi sobre la qual el tronc s'equilibra durant la bipedestació i la marxa. L'estabilitat d'aquesta articulació és crítica per permetre al mateix temps el moviment i el suport de les forces derivades de l'activitat diària. L'alt grau de congruència de les superfícies articulars fa que gairebé tot el moviment entre el cap femoral i l'acetàbul sigui rotacional, sense cap translació detectable. Per tant, el rang de moviment requerit al maluc durant les tasques quotidianes es pot descriure amb un moviment rotacional en tres eixos .

L'alt grau de congruència articular és degut a la suma de diversos elements: l'arquitectura òssia, el làbrum acetabular, el cartílag articular, la càpsula articular i la musculatura circumdant [10, 11].

L'estabilitat intrínseca deriva de l'**anatomia òssia** de l'articulació femoro-acetabular determinada per la profunditat de l'acetàbul. En absència de càrrega existeix certa asime-

tria entre el cap femoral i l'acetàbul la qual es compensa amb la capacitat que té l'os de la làmina subcondral per dissipar les forces mitjançant la deformació (*FIGURA 1*).

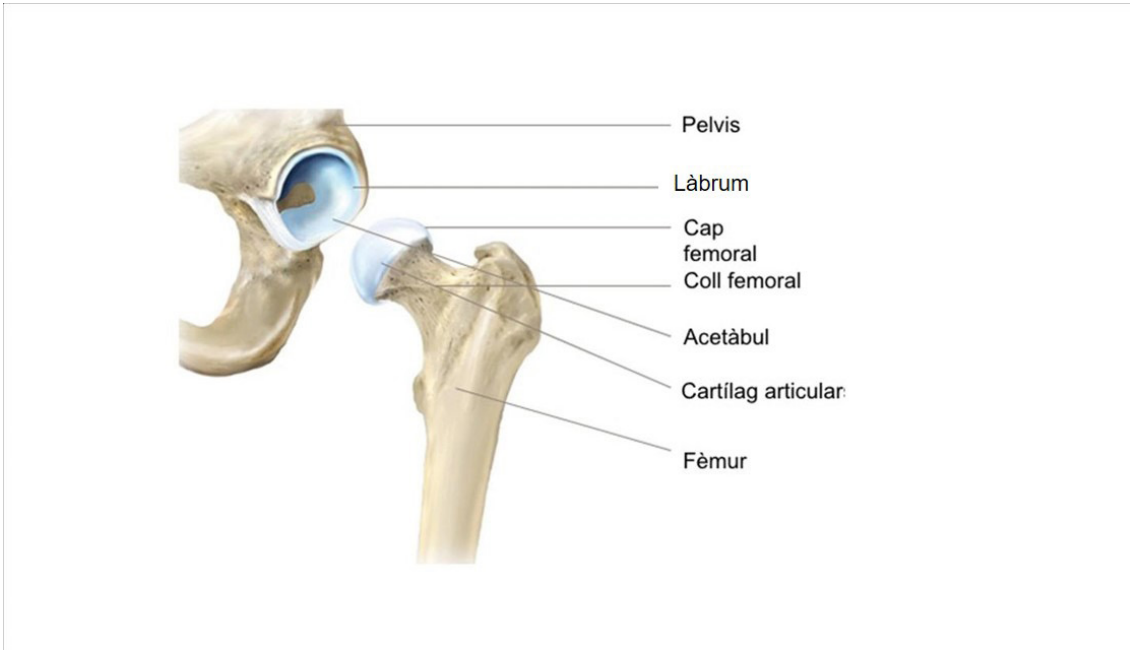


FIGURA 1. Articulació del maluc

L'arquitectura trabecular del fèmur proximal també facilita una transmissió adequada de càrrega a través de la formació de 3 arcades diferents disposades en angles de 60° per gestionar les forces de tensió i compressió experimentades pel cap i el coll femoral. Com a adaptació addicional a aquestes càrregues, l'estructura cortical del coll femoral és més gruixuda al marge inferior [12,13] (*FIGURA 2*).

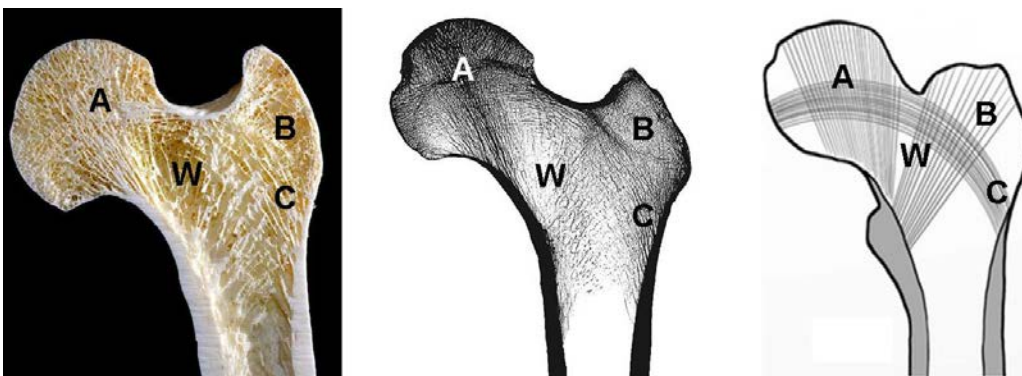


FIGURA 2. Arquitectura trabecular del fèmur proximal. La imatge mostra els diversos grups de trabècules en espècimen, en radiografia i en esquema. A: Grup de compressió principal; B: grup de compressió secundària; C :grup de tensió principal; W: triangle de Ward (definit pels tres grups trabeculars).

L'orientació espacial dels 2 components articulars juga una paper cabdal en la distribució de forces i en el rang de moviment: en condicions normals tant l'acetàbul com el coll

femoral presenten un cert angle d'anteversió la qual cosa facilita un moviment molt més ampli en flexió que en extensió. Encara que la variabilitat interindividual és molt àmplia s'accepten com normals valors de 10° d'anteversió femoral i 15° d'anteversió acetabular (FIGURA 3).

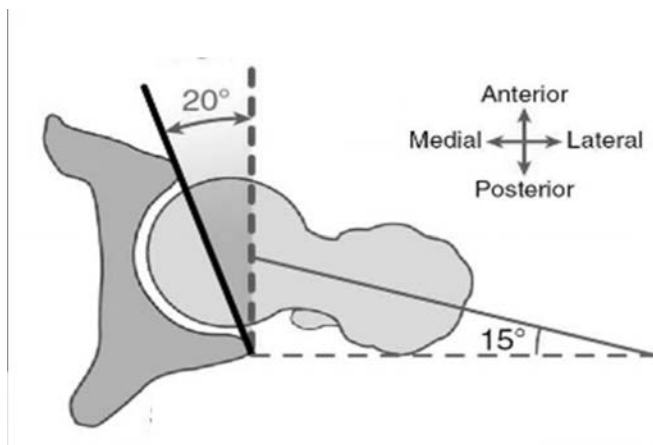


FIGURA 3. Esquema d'una vista superior de l'articulació del maluc mostrant l'anteversió femoral i acetabular.

La profunditat de l'acetàbul determina els límits absoluts del rang de moviment de l'articulació abans que tingui lloc el contacte entre fèmur i pelvis. Aquests límits tenen uns valors mitjans de 120° de flexió, 10° d'extensió, 45° d'abducció, 25° d'adducció, i 15° de rotació interna i externa [14].

Les superfícies articulars estan formades per múltiples capes altament organitzades de cartílag hialí per gestionar adequadament les forces a les quals se sotmet l'articulació. El màxim gruix es distribueix en el pla craniocaudal de l'acetàbul i en el pla ventrolateral de la superfície del cap femoral i decreix concèntricament des d'aquests punts. Aquest cartílag està compost per col·lagen tipus II i una alta concentració de glicosaminoglicans de gran capacitat hidròfila que permet absorbir impactes i dissipar les forces excessives generades en la superfície articular i protegir contra l'*stress shielding*. Aquesta característica actua sinèrgicament amb la funció de l'os subcondral per proporcionar una base sòlida per a la transmissió de les càrregues transarticulars [15,16].

El **làbrum** acetabular és una estructura complexa que consta d'una vora cartilaginosa composta de fibres circumferencials de col·lagen que circumden la totalitat de l'acetàbul en continuïtat anatòmica amb el lligament transvers. La funció fisiològica del làbrum no es coneix completament, però sembla clar que millora l'estabilitat coxofemoral (contribueix en un 22% en el total de la superfície articular i augmenta el volum acetabular en un 33%). El làbrum també proporciona un efecte de segellat al voltant de l'articulació, conservant una pressió hidrostàtica del líquid sinovial que facilita la lubricació i dificulta la

distracció articular. La seva continuïtat amb el lligament transvers proporciona una elasticitat inherent que permet una excel·lent congruència articular i, alhora, compensa incongruències menors de l'articulació. Tot això permet al làbrum dur a terme el seu paper més important: dissipar les altes forces de contacte que potencialment poden ocórrer durant l'activitat i el suport de pes per a qualsevol angle de flexió [17,18,19] (FIGURA 4).

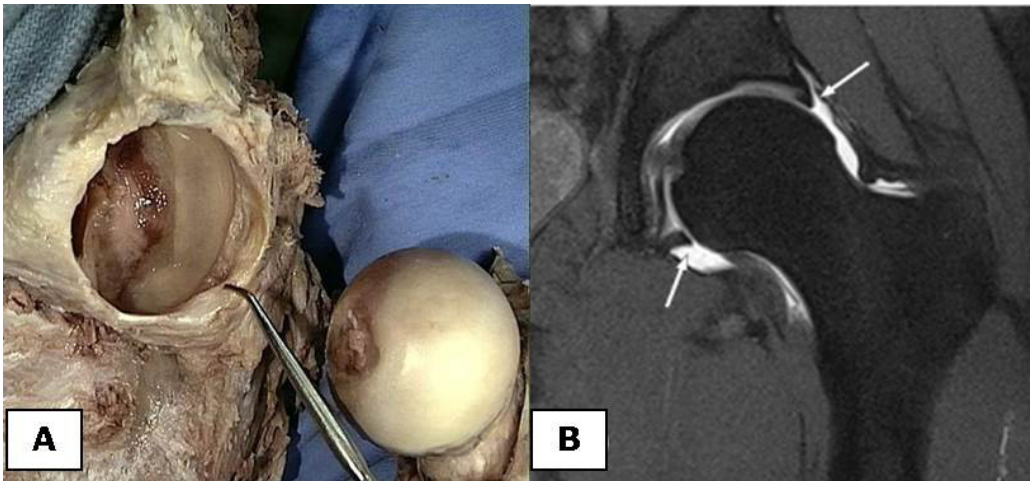


FIGURA 4: Imatge anatòmica (A) i en RMN (B) del làbrum acetabular.

L'estabilitat del maluc augmenta encara més per la forta **càpsula i lligaments** que l'envolten. La càpsula es divideix en tres bandes diferents que funcionen com a restrictors externs al moviment extrem. Especialment important és el lligament ilio-femoral medial o lligament en Y de Bigelow (que s'estén en dues bandes des de l'ili supraacetabular fins a la línia intertrocanteriana) limita l'extensió i la rotació externa i contribueix al manteniment d'una postura estàtica erecta amb una activitat muscular mínima [20,21] (FIGURA 5).

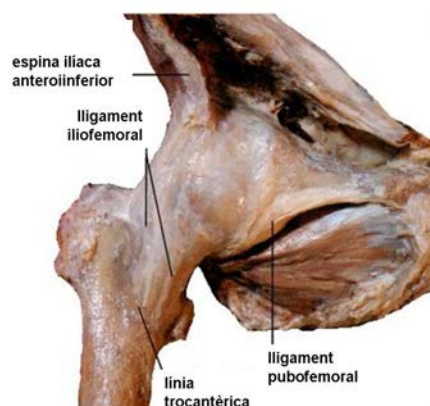


FIGURA 5. Vista anterior dels lligaments de l'articulació coxofemoral

1.4. Biomecànica.

L'articulació coxo-femoral és singular en el fet que mai no està en descàrrega completa durant les activitats diàries: sempre existeix una força de compressió residual a través de l'articulació amb una magnitud mitjana aproximada igual al pes del cos [22].

Pauwels va definir la forces que actuen al voltant del maluc i els moments angulars necessaris per mantenir l'equilibri de la pelvis en tot moment. La força de reacció articular és la força de compressió resultant de l'equilibri entre el moment angular generat pel pes corporal per una banda i el de la tracció de la musculatura pelvitrocantèria per l'altra. El contribuïdor principal a la força reactiva articular són les forces musculars de la musculatura abductora, amb una contribució menor del pes del cos. La magnitud d'aquesta força varia segons l'activitat i la posició del cos (recolzament mono- o bipodal, etc, ...) i s'ha quantificat entre 2 i 4 vegades el pes corporal durant la pujada d'escaleres i lleugerament més durant la baixada. En determinades activitats atlètiques la magnitud d'aquestes forces pot augmentar considerablement i situen les seves orientacions en els límits de l'articulació. Això requerirà la participació d'estructures musculars, lligamentoses i cartilaginoses adjacents per contribuir a la transferència de càrrega. La geometria i l'anteversió del fèmur proximal, fan que durant aquestes activitats s'originin forces de torsió també sobre el coll femoral, que ha de ser suportades per l'estructura òssia [9,23,24] (FIGURA 5).

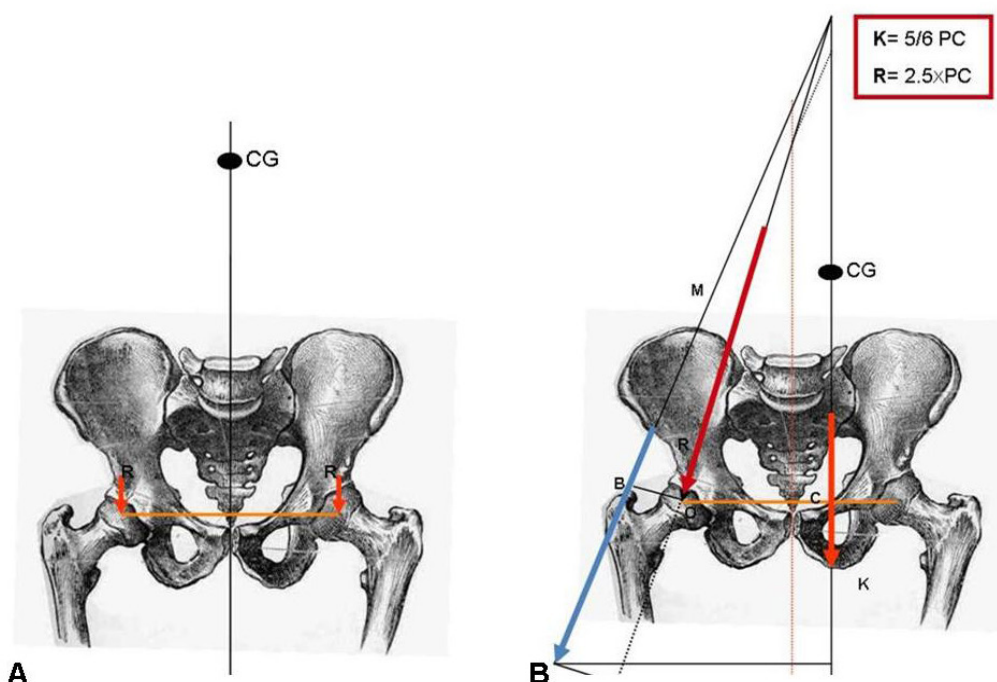


FIGURA 5. Esquema de les forces exercides sobre l'articulació del maluc en bipedestació (A) i en recolzament monopodal (B). En recolzament bipodal el pes corporal es reparteix simètricament i verticalment sobre ambdues articulacions amb una resultant aproximadament d'1/3 del pes corporal. En el moment exercit pel pes corporal (fletxa taronja) és contrarestat pel que exerceix la musculatura abductora (fletxa blava) originant una força resultant de compressió a nivell de l'articulació (fletxa vermella).

La marxa normal requereix d'un rang de moviment del maluc de 40° a 50° de rotació, 35° de flexió màxima i 10° d'extensió màxima. La mecànica de la marxa es basa en una sèrie ben sincronitzada de contraccions musculars concèntriques i excèntriques per facilitar un pas equilibrat. La posició adequada entre el cap femoral i acetàbul es manté mitjançant una coordinada activitat muscular, tant voluntària com involuntària, regulada per un complex bucle neuromuscular [25] .

Les magnituds de les forces experimentades pel maluc durant la passa presenten un patró bifàsic amb dos pics màxims en la fase de contacte del taló i durant la fase final del cicle. L'àrea de la superfície articular sotmesa a càrrega varia amb la posició relativa de fèmur i l'acetàbul i amb la magnitud de la càrrega. En un maluc sa, durant activitats com caminar, la càrrega es reparteix sobre una àmplia part de la superfície articular. Això implica els sectors anterior, superior i posterior del cap femoral. A l'acetàbul la força es transmet a través de 2 columnes des de la perifèria fins l'aspecte superior de la fosa acetabular. Queden així excloses de càrrega una zona de cartílag articular a la regió foveal i la part inferior del cap femoral. En els extrems del rang de moviment la càrrega es distribueix per la perifèria articular incloent el marge acetabular i el làbrum [26,27] .

Les forces experimentades pel fèmur proximal es transmeten distalment a través de la combinació trabècules de tensió i compressió disposades en la direcció del eix llarg del coll femoral descrites prèviament [28]. La quantitat i proporció de trabècules de tracció i compressió varia amb l'angle de l'eix del coll del fèmur per satisfer millor les demandes mecàniques específiques: un coll valg presenta més trabècules de compressió mentre que un coll var en tindrà més tensió [9]. L'orientació geomètrica del cartílag articular també està optimitzada per a la transferència de càrrega, perquè les porcions més gruixudes es troben a les zones més freqüentment implicades en la càrrega durant la marxa [29]. Els moviments cíclics del malucs poden fer fluctuar ràpidament la força i direcció del vector aplicat i ocasionar una discordança entre el requeriment mecànic i la capacitat de sol·licitació del cartílag d'una determinada àrea. Aquest *missmatching* entre anatomia i mecànica ha estat proposat com explicació de determinats patrons degeneratius observats perquè les capacitats compressives del cartílag articular varien segons la seva ubicació [30].

Aquests principis generals de biomecànica de maluc tenen rellevància clínica significativa pel que fa la funció de l'articulació del maluc en absència de patologia i s'ha de tenir en compte quan s'està avaluant a pacient. La rehabilitació després d'una lesió o intervenció quirúrgica del maluc han de tenir en compte també aquests principis per restaurar la funció i minimitzar el canvi patològic o degeneratiu.

1.5. Etiopatogènia. Paper del pinçament femoroacetabular.

L'etiopatogènia de la coxartrosi s'ha reinterpretat en la última dècada a partir dels treballs de Ganz i col·laboradors amb l'encunyament del concepte de **pinçament femoroacetabular** (FAI a partir d'ara, per l'acrònim en anglès *Femoroacetabular Impingement*¹). Aquest concepte, de manera directa o indirecta, estarà present en els estudis que presentarem a continuació. Es tracta d'un mecanisme dinàmic que produeix un contacte anòmal entre el marge acetabular i coll femoral bé per una sobrecobertura acetabular (anomenat tipus pincer) bé per una deformitat en la zona de transició cap-coll (anomenat tipus cam). Aquestes dues condicions anatòmiques s'han postulat com a precursoras de la coxartrosi i s'ha definit per a cadascuna d'elles un mecanisme lesional i un patró anatomopatològic característic (*FIGURA 6*).

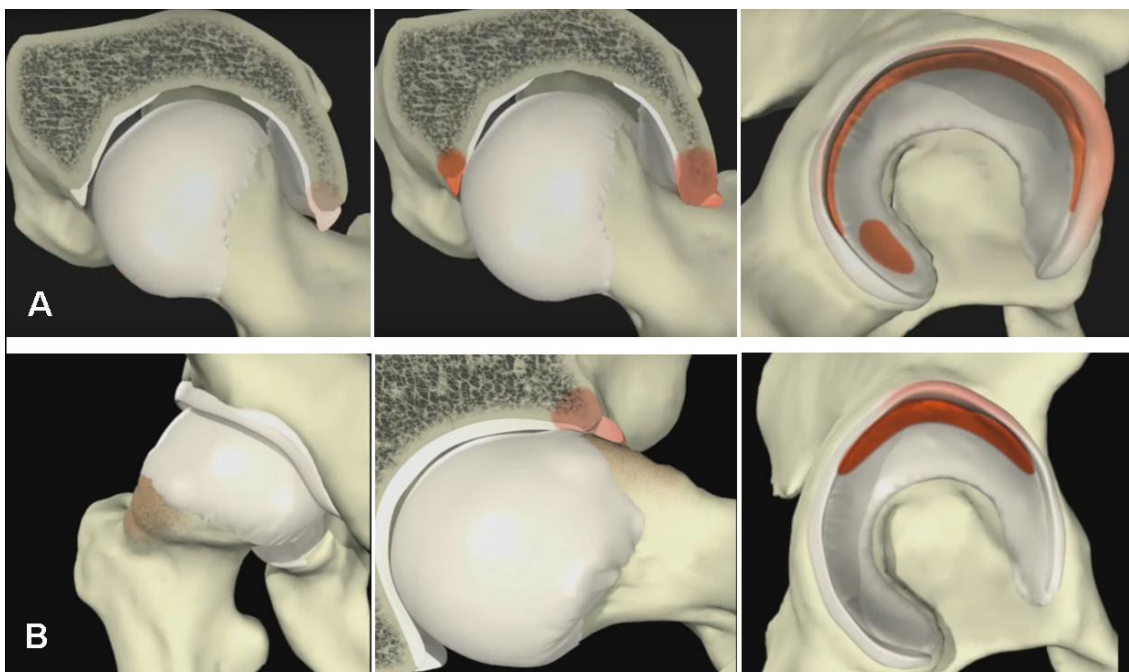


FIGURA 6. Esquema que mostra el patró lesional de les dos configuracions de FAI .A (tipus pincer):La causant del contacte anòmal és la sobrecobertura acetabular. El patró de lesió es caracteritza per una lesió del làbrum per compressió directe amb una estreta franja de cartílag acetabular i amb lesió de contra cop. B (tipus cam): La causant del contacte anòmal és la deformitat en la unió cervicocefàlica del fèmur. El patró de lesió es caracteritza per una lesió localitzada a nivell de la unió condrolabral, amb una franja més profunda d'afectació del cartílag acetabular perifèric.

La relació causa-efecte entre FAI i coxartrosi, abans de la seva definició moderna, va ser proposada per primera vegada en 1936 per Smith-Petersen [32], que va tractar al seu

¹ La consulta cursada al Departament de Lingüística de la Generalitat de Catalunya, va resoldre que l'expressió "pinçament femoroacetabular" es podia acceptar com la traducció normativa del terme anglosaxó "femoroacetabular impingement". Malgrat això, aquest concepte no apareix encara al diccionari Enciclopèdic de Medicina (DEMCAT). Així doncs, s'ha triat l'ús de l'acrònim anglès FAI, acceptat i utilitzat universalment, per tal d'agilitzar la lectura i, sobre tot, per evitar la confusió derivada de l'ús d'una expressió poc consolidada en la comunitat científica en el moment actual.

pacients amb un acetabuloplàstia i van observar la millora del dolor. Stulberg va identificar una associació entre la deformitat en la unió cap-coll femoral, que va anomenar “pistol grip deformity”, i el desenvolupament de coxartrosi idiopàtica [33](FIGURA 7). Això va ser recolzat per Harris al 1986 [34]. El renovat interès en aquest concepte va sorgir més tard, quan Ganz descriu una sèrie de pacients que tenien dolor progressiu després de ser sotmesos a osteotomia periacetabular. En aquests pacients, tot i haver restaurat una anteversió normal de l’acetàbul, es va descobrir que persistia un contacte anormal entre el coll femoral i la perifèria acetabular en moviments de flexió i la rotació interna [34] .

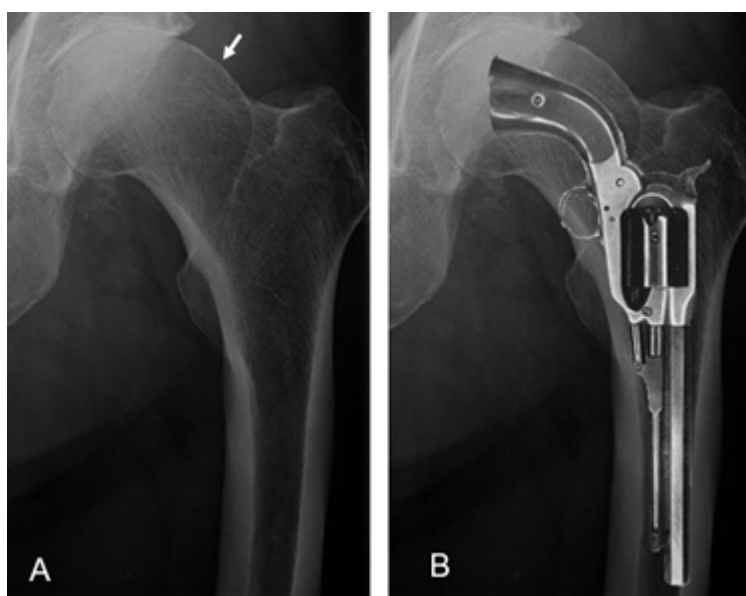


FIGURA 7. A: Imatge radiogràfica (fletxa) de la “pistol grip deformity”(de l’article original de Stulberg”) que més endavant es definirà com deformitat tipus cam. B: Superposició de una pistola en el extrem proximal de fèmur on es mostra la gran similitud del contorn en la unió cap-coll femoral amb la culata de la pistola.

Per definir aquestes dues condicions anatòmiques s’utilitzen paràmetres morfològics (bé de nova definició o bé definits prèviament). La taules i esquemes següents descriuen alguns dels més utilitzats (TAULA 1, FIGURA 8, FIGURA 9).

| | PARAMETRE | SIGNIFICAT | VALORS NORMALS |
|------------|-------------------------|---|-----------------------|
| CAM | Angle Alfa | Mesura l’anesfericitat del cap femoral | <55° |
| | PINCER | CEA | Sobrecobertura global |
| | Signe Cross-over | Sobrecobertura focal (retroversió acetabular) | negatiu |
| | Signe paret posterior | Sobrecobertura focal (retroversió acetabular) | negatiu |
| | Signe espina isquiàtica | Sobrecobertura focal (retroversió acetabular) | negatiu |

TAULA 1 . Alguns dels paràmetres més freqüentment utilitzats per definir el FAI.

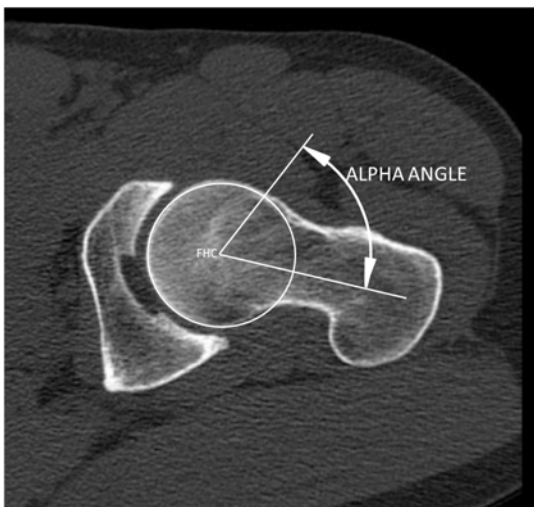


FIGURA 8. Angle Alfa : L'angle alfa és el principal paràmetre que s'utilitza per definir la anesfèricitat del cap femoral i per tant quantificar la deformitat tipus cam. Es pot mesurar en projeccions radiològiques axials en radiologia convencional o, més fiablement, mitjançant TAC o RMN utilitzant talls obtinguts en el pla axial oblic. Tot i un cert debat sobre el límit de la normalitat, es considera normal una angle inferior a 55° [35] .

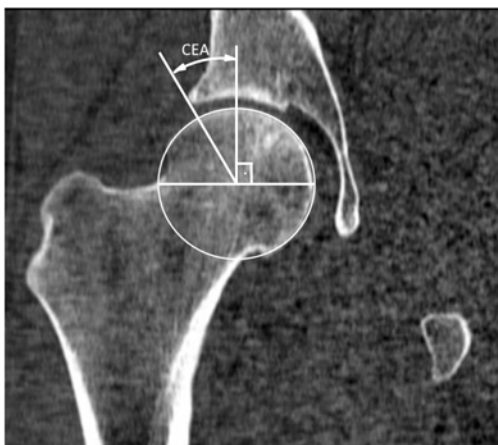


FIGURA 9. Center Edge Angle (CEA) que mesura la cobertura lateral . Per sota de 25° defineix una displàsia, i per sobre de 35° és considerat un indicador de sobrecobertura de l'acetàbul.



FIGURA 10 . Signe del Cross-over (línia contínua): un acetàbul normal presenta anteversió i per tant la línia de la projecció de paret acetabular anterior en una radiografia anteroposterior de pelvis se situa medialment a la de la paret posterior en tota la seva longitud [36]. Un creuament entre les línies de la paret anterior i posterior a nivell cranial, defineix un signe C-O positiu implica una sobrecobertura acetabular focal per retroversió de la part superior de l'acetàbul i es considera indicatiu de pincer. **Signe de la paret posterior (punt):** indicador d'una paret posterior prominent. Això pot provocar un impacte posterior. En un maluc normal, el contorn visible de la vora posterior descendeix aproximadament a través del punt central del cap femoral (punt). Si la línia posterior es troba lateralment al centre femoral, hi ha una paret posterior més prominent. **Signe de la espina isquiàtica (línia discontinua):** Es positiu si en la RX de pelvis apareix la tuberositat isquiàtica medial a la línia iliopúbica.

La retroversió o manca relativa d'anteversió acetabular, es considera indicadora de pincer perquè ocasiona una restricció en el moviment del maluc en flexió. Per això molts dels signes indicatius de pincer es relacionen amb la manca d'anteversió acetabular. Cal ressaltar els diferents graus de fiabilitat en la quantificació dels diferents paràmetres. La deformitat cam es pot quantificar amb fiabilitat amb l'angle alfa tant en rx, RMN o TAC [37,38]. La sobrecobertura acetabular es pot quantificar fiablement en el pla frontal mitjançant el CEA tant en Rx, TAC o RMN [39]. En el pla horitzontal, però, la definició de sobrecobertura es basa habitualment en signes no paramètrics i amb dubtosa reproductibilitat [40].

1.6. Diagnòstic de la coxartrosi.

Diverses escales basades en la radiologia simple s'ha utilitzat històricament per estadiar la coxartrosi: algunes de elles no específiques com la proposada per Kellgren and Lawrence en 1957 [41] o la de Croft en 1990 [42], i d'altres específiques com Joint

Space Width (JSW) [43]. D'entre aquestes últimes, la més universalment utilitzada en la pràctica clínica de la cirurgia conservadora de maluc és la descrita per Tönnis l'any 1972 [44].

En pacients candidats a cirurgia de preservació del maluc, la necessitat de detectar patologies preartròsiques (com lesions del làbrum o lesions incipients del cartílag articular) han fet guanyar protagonisme a proves molt específiques com ara l'artro- RMN o, més recentment la DGEMRIC (Delayed Gadolinium Enhanced Magnetic Resonance Imaging of Cartilage). Aquestes proves, però, són costoses en termes de recursos temporals i econòmics i el seu ús no pot considerar-se generalitzat. És per això que la radiologia simple continua sent la pedra angular pel diagnòstic de canvis estructurals coxofemorals en la població general.



2

OBJECTIUS

El coneixement de l'etiopatogènia de la coxartrosi primària, especialment en adults joves, ha experimentat un avenç definitiu en la última dècada. El plantejament clàssic d'abstenció terapèutica en pacients joves amb malucs simptomàtics i amb mínims o inexistents canvis degeneratius, tot esperant un empitjorament clínic i radiològic suficient que justifiqui una substitució protètica articular, s'ha invertit definitivament. Les noves tècniques de cirurgia conservadora de maluc lluiten per oferir a aquest grup de pacients una millora clínica immediata i el retard de la degeneració articular a llarg termini.

Per altra banda aquest nou cos de coneixement científic, al mateix temps que ha canviat la percepció d'una realitat llargament assumida i n'ha millorat la comprensió, es veu qüestionat per noves incògnites que el mateix coneixement revela en el seu avenç.

El conjunt de treballs que aquí es presenten s'han desenvolupat amb l'objectiu de trobar respostes a algunes d'aquestes qüestions no resoltes sobre l'etiopatogènia i diagnòstic de la coxartrosi primària en l'adult jove. Entre els múltiples abordatges possibles, els tres treballs que segueixen n'incideixen en tres àmbits diferents i, en bona mesura, complementaris: el de la biomecànica, el de l'anatomia (mitjançant imatges radiològiques) i el del diagnòstic. A continuació s'exposa la justificació i els objectius específics de cadascun d'ells.

2.1. Treball 1: Biomecànica.

"Impact of hip anatomical variations on the cartilage stress: A finite element analysis towards the biomechanical exploration of the factors that may explain primary hip arthritis in morphologically normal subjects".

El FAI descriu un conflicte estrictament dinàmic relacionat amb la manca d'espai lliure (o *clearance*) articular i que, per tant, es manifesta tan sols amb el moviment. Així doncs, negligeix qualsevol consideració relacionada amb l'estàtica o distribució de forces a nivell de les superfícies articulars del maluc. Ja hem esmentat que tenim la certesa que alteracions extremes de l'anatomia condicionen una estàtica sobrefisiològica inassumible per la supervivència del cartílag articular del maluc.

Objectiu: determinar com variacions anatòmiques menors, és a dir, que considerem dins del rang de la normalitat, influeixen en la distribució de càrregues i estressos a nivell de la interlínia articular coxofemoral, i si aquest canvis són de magnitud suficient per ser clínicament rellevants.

2.2. Treball 2: Anatomia.

“Acetabular overcoverage in the horizontal plane: an underdiagnosed trigger of early hip arthritis. A CT scan study in young adults”

El FAI, com a configuració anatòmica (tant el tipus pincer com el cam), s’ha revelat com un factor promotor de la degeneració articular. La prevalença, però, d’aquestes dues condicions anatòmiques en població asimptomàtica és notable. En una metanàlisi recent, que inclou 26 estudis i 2114 malucs de pacients asimptomàtics, la prevalença mitja de deformitats tipus cam va ser del 37% (rang 7% a 100%) i del tipus pincer del 67% (rang 61% a 76%) [45]. Aquestes dades evidencien que existeix un cavalcament morfològic evident entre la població asimptomàtica i la que presenta patologia degenerativa derivada d’aquestes condicions anatòmiques. Per tant, el FAI, tal i com es descriu en l’actualitat, pot ser una condició necessària però no sembla suficient pel desenvolupament de la coxartrosi.

Objectiu: determinar diferències anatòmiques, mitjançant l’estudi amb TAC, entre subjectes amb coxartrosi en estadis inicials i subjectes sans per tal de poders definir amb més predictibilitat els paràmetres promotors de malaltia degenerativa.

2.3. Treball 3:Diagnòstic.

“Reliability of Tönnis classification in early hip arthritis: a useless reference for hip-preserving surgery”.

L’èxit de la cirurgia conservadora de maluc depèn en gran mesura de la selecció adequada de pacients. S’ha demostrat que l’existència de canvis degeneratius significatius previs a la cirurgia n’empitjoren proporcionalment els resultats [46]. És cert que s’usen sistemàticament tècniques d’imatge avançades (TAC, RMN, artro-RMN, etc...) tan per definir paràmetres de FAI com pel diagnòstic de lesions artròsiques molt incipients o preartròsiques (patologia del làbrum). Però és cert també que la quantificació d’aquests canvis estructurals degeneratius continuen descansant sobre l’aplicació de escales clàssiques de radiologia simple. Cal advertir, però, que el paper d’aquestes escales ha variat dràsticament amb el nou escenari de la cirurgia conservadora. Fins ara, tenien un rol purament acadèmic, atès que la solució final de la coxartrosi era l’artroplàstia, i la seva indicació depèn, gairebé exclusivament, de la clínica del pacient. Ara, però, aquestes escales (la més usada és la de Tönnis) s’han incorporat als algorismes de tractament en la cirurgia conservadora de maluc de manera que influeixen, de vegades de manera

definitiva, en la indicació quirúrgica i en són eina fonamental en el seguiment i avaluació de resultats [47-48]. En aquest canvi de rol però es troba a faltar un pas necessari: no s'ha testat suficientment la fiabilitat d'aquestes escales per ser aplicades a un grup de pacients amb un espectre de malaltia degenerativa molt més restringit que aquell per al qual van ser creades. En altres paraules, no sabem si aquestes escales són capaces de discriminar de manera reproduïble entre pacients on els canvis degeneratius són incipients o inexistents.

Objectiu: avaluar la reproductibilitat, intra- i interobservador, de l'escala de Tönnis com a referència en pacients candidats a cirurgia conservadora del maluc.

3

HIPÒTESIS DE TREBALL

3.1. TREBALL 1.

Les petites variacions en l'anatomia del maluc poden influir de manera rellevant en la magnitud i distribució de càrregues a nivell de la interlínia articular coxofemoral i, per tant, ser causa de degeneració articular precoç.

3.2. TREBALL 2.

Una definició del FAI més acurada, utilitzant la TAC, pot ajudar a definir millor la morfologia dels malucs en risc de desenvolupar coxartrosi precoç.

3.3. TREBALL 3.

L'escala de coxartrosi de Tönnis, aplicada a pacients candidats de cirurgia conservadora de maluc, té una reproductibilitat suficient com per ser-ne referència fiable.

4

MATERIAL I MÈTODES

4.1. TREBALL 1.

Per a l'estudi biomecànic de l'estàtica de l'articulació del maluc es va triar el **mètode d'elements finits, (EF)** un mètode numèric per resoldre problemes d'enginyeria i física matemàtica. Aquest mètode suposa una aproximació al comportament d'un cos físic mitjançant la seva divisió en una malla de petits cossos geomètrics per a cada un dels quals es defineixen equacions relativament simples que defineixen el seu comportament i el relacionen amb el dels cossos confrontants. El càlcul integrat de totes aquestes equacions defineixen el comportament del cos en la seva totalitat. La seva aplicació a la medicina, i més concretament a l'anàlisi de qüestions biomecàniques, ha estat creixent durant les últimes dècades [49] .

El model de EF construït *ad hoc* per a aquest estudi, pretén avançar cap a una descripció realista del maluc en termes de geometria i propietats dels teixits i es va concebre per definir els successos mecànics a nivell de la superfície articular. Des del punt de vista morfològic i, en contrast amb altres models similars utilitzats prèviament, el model creat per aquest estudi considera el làbrum com a component fonamental atribuint-li funcions biomecàniques específiques [50]. També es va modelar la anatomia d'una superfície articular femoral i acetabular (*fascies lunata*) inèdita fins al moment per tal d'obtenir una topografia més realista dels estressos i forces exercides. Per optimitzar la precisió de la detecció de contactes, es va modelar la capa del cartílag amb una malla quatre vegades més fines que les del teixit ossi . Aquest refinament va permetre també establir un gradient de gruix de cartílag del cap femoral com el que existeix en l'anatomia real (més gruixut al centre i més prim a la perifèria). Per altra banda, la clàssica consideració del cartílag com a teixit de comportament elàstic lineal va ser substituït al nostre model pel comportament hiperelàstic, el qual tot i suposar un augment molt important de la complexitat matemàtica, també millora dramàticament la descripció del comportament del cartílag sota grans tensions.

Amb la utilització d'aquest model es va analitzar el comportament estàtic de diferents configuracions anatòmiques de l'articulació del maluc en diverses activitats quotidianes i la repercussió en forma d'estressos articulars que això suposava en el cartílag del cap femoral i de l'acetàbul. (*FIGURA 11*).

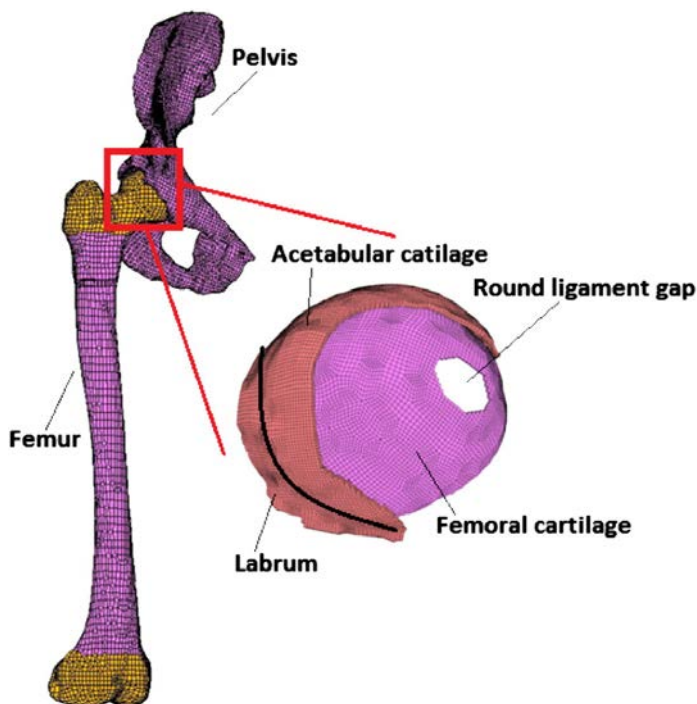


FIGURA 11. Model d'EF utilitzat per aquest estudi.

Aquestes diferents configuracions anatòmiques suposen variacions dels angles anatòmics dins del rang dels que es consideren malucs no patològics. Aquest són els models proposats

angle cervicodiafisial (CD): 110° - 120° - 130°

angle d'anteversió femoral (AF): 0° - 10° - 20°

angle d'anteversió acetabular(AA): 0° - 10° - 20° ° (**FIGURA 12**).

A efectes d'anàlisi, es va prendre com a configuració de referència la formada per aquestes angles CD: 120° , AF: 10° i AA: 10° .

Es van analitzar les forces a nivell de la interlínia per a cadascuna de les diverses combinacions a anatòmiques modelades. Les condicions de càrrega es van aplicar en dos casos: el primer representava la força de reacció del sòl aplicada al cap femoral i dirigit a acomodar el cap femoral dins del maluc, i el segon, la càrrega derivada de les forces musculars més les forces de reacció, per tal de simular l'activitat normal de caminar. La pressió hidrostàtica i les àrees de contacte en el cartílag i làbrum es van calcular en el pic màxim de càrrega.

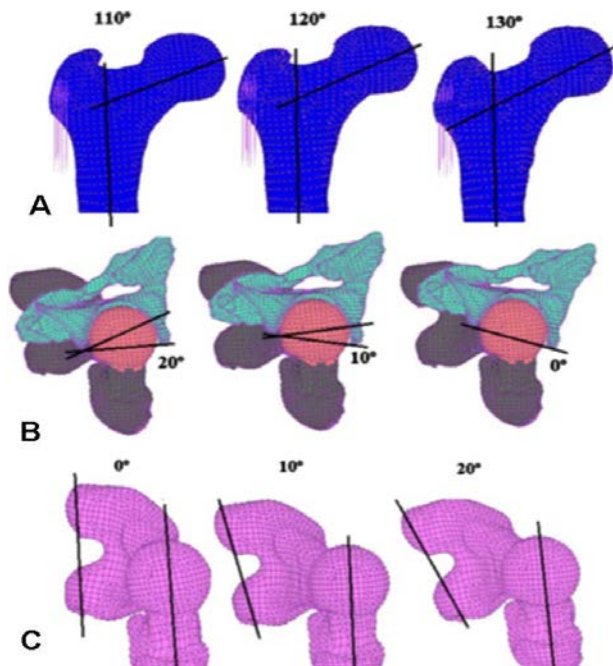


FIGURA 12: Variacions anatòmiques d'angle simulades . A: angle cervicodisfival B: anteversió acetabular ; a C: anteversió femoral.

4.2. TREBALL 2.

Es tracta d'un estudi prospectiu observacional, comparatiu entre els dos grups de subjectes amb els següents criteris d'inclusió:

Grup Pacients:

- adults de 55 anys o menys
- consulta a la nostra unitat de maluc per clínica de coxàlgia
- presència de signes de coxartrosi incipient (Tönnis graus 1 o 2) i absència de criteris de displàsia en la radiologia simple (CEA $\geq 25^\circ$).

Grup Controls:

- adults de 55 anys o menys
- amb malucs asimptomàtics
- radiologia simple sense signes de coxartrosi ni criteris de displàsia

El motiu de restringir els graus de coxartrosi a graus inicials (I i II) en el grup pacients era avaluar els diversos paràmetres anatòmics en pacients en els quals el procés degeneratiu ja s'ha iniciat però no ha modificat encara substancialment les referències radiològiques, com podria passar en estadis més avançats.

A tots ells se'ls va practicar un estudi d'imatge dels malucs consistent en radiologia simple (Rx) simple i tomografia axial computeritzada (TAC): als del grup de pacients, dins

del protocol habitual d'estudi del maluc dolorós de l'adult jove establert al nostre centre, i als del grup control per causes no relacionades amb els malucs. Abans de la seva inclusió a l'estudi, un consultor independent va descartar semiologia actual o història prèvia de patologia relacionada amb el maluc en tots els subjectes del grup control. Finalment, 60 malucs del grup de pacients i 57 del grup de control (un total de 117 malucs) es van incloure en l'estudi. L'estudi va ser aprovat pel comitè d'ètica de recerca clínica de la nostra institució.

En aquest estudi, la radiologia simple tan sols va ser utilitzada per aplicar els criteris d'inclusió/exclusió (absència/presència de signes degeneratius o de criteris de displàsia), de manera que la comparació entre grups es va dur a terme entre els TACs. Mitjançant reconstruccions multiplanars es van definir plans específics que permeten la mesura dels següents angles i índex que defineixen l'anatomia radiològica del maluc segons mètodes prèviament descrits (tots els acrònims corresponen a la denominació en anglès d'aquests paràmetres) (*FIGURA 13*):

- Pla axial mig: l'angle d'anteversió acetabular (AAA); l'angle del sector acetabular anterior (AASA); l'angle del sector acetabular posterior (PASA); i l'angle del sector acetabular horitzontal (HASA), que és el resultat de la suma AASA + PASA [51,52]; l'angle de anteversió femoral (FAVA), [53], en aquest cas utilitzant la línia condil·lar posterior, tangencial a ambdós còndils femorals posteriors en una tall axial (*FIGURA 14*), i l'índex d'instabilitat de Mckibbin (MI) [54] que s'obté de la suma AA + FAVA.
- Pla axial oblic: l'angle Alpha (AA) [35].
- Pla frontal mig: l'angle centre-marge de Wisberg (CEA) [39] (*FIGURA 9*).

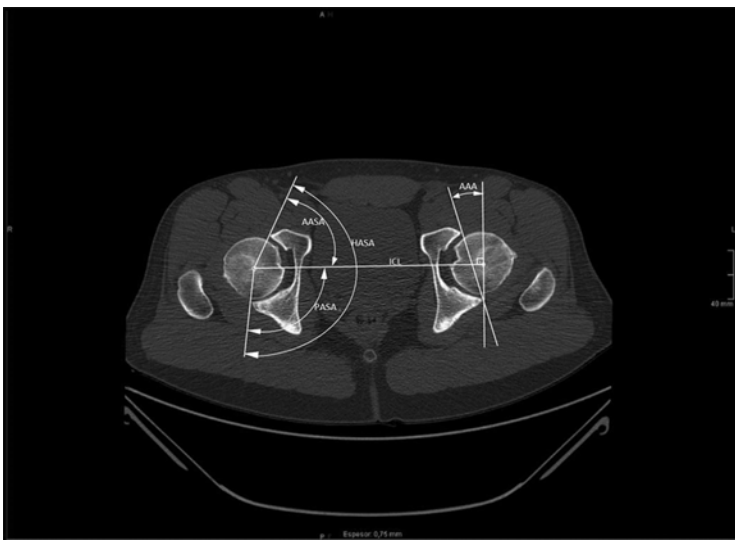


FIGURA 13: esquema de mètode de determinació dels diversos angles utilitzats a l'estudi en el pla mig axial.

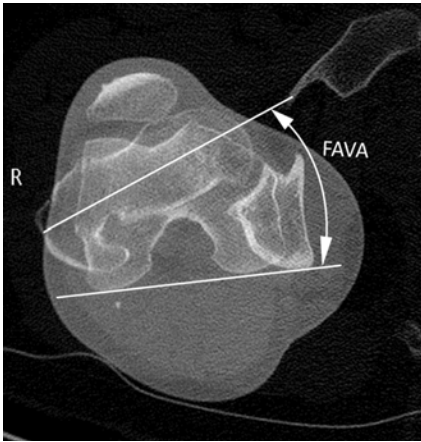


FIGURA 14: esquema de mètode de determinació l'angle d'anteversió femoral

Dos observadors independents van realitzar totes les mesures sobre imatges digitals i per a l'anàlisi estadística es van utilitzar els valors mitjans de les dues mesures.

4.3. TREBALL 3.

Aquest estudi utilitza les mateixes cohorts d'estudi del treball anterior. En aquest cas es van utilitzar les radiografies simples anteroposterior de pelvis obtingudes segons una tècnica radiològica prèviament protocol·litzada [55]. Un total de 117 malucs (60 del grup de pacients i 57 del grup de control) van ser inclosos per a l'avaluació.

Tres observadors independents, amb diversos graus d'experiència (A: cirurgià expert; B: cirurgià expert; C: metge resident) van avaluar separatament les radiografies de tots els subjectes dels dos grups, anonimitzades i aleatoritzades, estadiant l'artrosi de cada maluc segons la classificació de Tönnis (TAULA 2). L'avaluació es va repetir dos mesos més tard, després d'una nova aleatorització i sense informació sobre el resultat de l'avaluació prèvia. Els observadors no van establir cap consens previ a l'aplicació dels criteris de la classificació de Tönnis als casos de l'estudi.

Es va avaluar la reproductibilitat intra- i interobservador utilitzant els coeficients kappa de Cohen i es van classificar segons els graus de Landis i Koch en pobre, discret, moderat i bo [56].

| GRAU | DESCRIPCIÓ |
|-------------|--|
| 0 | Sense signes d'artrosi |
| 1 | Esclerosi augmentada, lleuger pinçament de l'espai articular, no o pèrdua lleu de l'esfericitat del cap o osteofits als marges de l'articulació. |
| 2 | Quistos petits, pinçament moderat de l'espai articular, pèrdua moderada d'esfericitat del cap. |
| 3 | Quistos grans, pinçament greu o obliteració de l'espai articular, deformitat greu del cap. |

TAULA 2: Classificació de Tönnis.



5

RESULTATS

5.1. TREBALL 1.

Els resultats van mostrar que una variació de $\pm 10^\circ$ en els angles estudiats respecte al model de referència (CD120°, AF10° i AA10°) van causar importants diferències en la pressió hidrostàtica a nivell del cartílag articular i làbrum.

Al model de referència, en el cartílag femoral va mostrar un patró característic de distribució de la pressió que s'estén des del centre en direcció postero-inferior amb valors de 2,5 MPa, de manera similar al que passa en el cartílag acetabular. En aquest model de referència el làbrum va mostrar pressions hidrostàtiques de baixa magnitud.

En models on l'anteversió del fèmur o l'acetàbul disminuïa (models amb AF=0° o AA=0°), però, la distribució dels màxims de càrrega al cartílag acetabular i femoral es desplaçava des de la regió posterior del cap femoral i l'acetàbul a la superior i perifèrica arribant a la unió condrolabral. De manera homòloga, en aquest mateixos models, els màxims d'estrès hidrostàtic a nivell del làbrum es desplaçaven també cap al segment superior. Les magnituds, d'aquets pics de pressió tant a nivell dels cartíl·lacs femoral i acetabular com del làbrum van ser de 5 MPa (cinc vegades superior a la mitjana de la resta de models) (FIGURA 15).

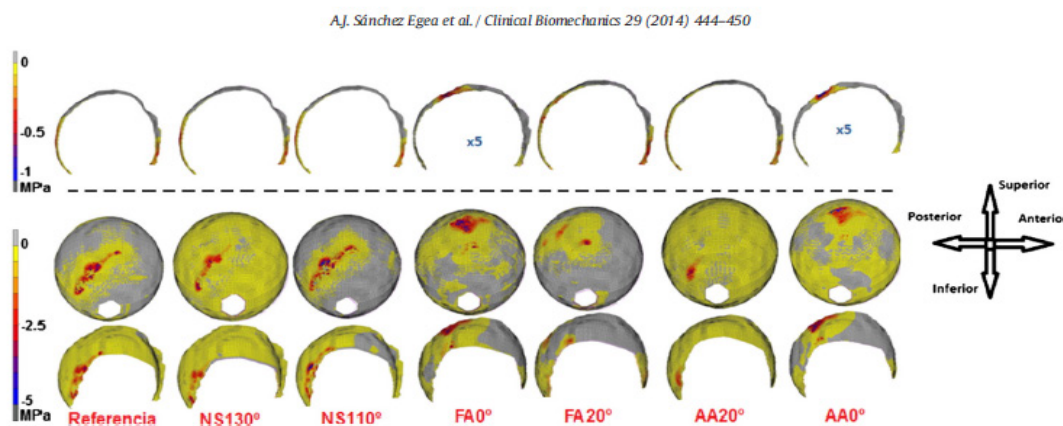


FIGURA 15. Distribució de la pressió hidrostàtica per als diferent models. Fila superior: làbrum; filera del mig: cartílag femoral; fila inferior: cartílag acetabular. Les zones de teixits de color groc corresponen a valors de pressió hidrostàtica d' 1 MPa i aquesta magnitud es considera no patològica (Responte et al., 2012)

Es van trobar grans diferències en les àrees de contacte entre models. D'una banda, els NS130° i AA20° eren els models amb les àrees de contacte més grans i els valors HS més petits. D'altra banda, el NS110° i AF0° tenien zones de contacte més petites en comparació amb altres geometries.

L'àrea de contacte mitjana calculada per als valors de pressió hidrostàtica superiors a 1 MPa va ser de 243 mm² en el model de referència, mostrant resultats similars a altres models anatòmics publicats a la literatura [57]. Per tal de relacionar les dues variables (àrees i pressions) es van calcular les àrees de contacte normalitzades pels diferents rangs de pressió amb els següents resultats. Pel cartílag femoral i acetabular, les àrees

de contacte van disminuir a mesura que augmentava el rang de valors de pressió hidrostàtica: el model AF20° tenia les àrees de contacte més baixes d'alta tensió i el AF0° mostrava les zones de contacte més grans d'alta pressió. Només quatre configuracions anatòmiques (NS110°, AF0°, AA20° i AA0°) van produir zones de contacte amb valors de més de 5 MPa i, entre elles, les que presentaven retroversió, són les que van produir les àrees més grans de d'estrès elevat (FIGURA 16).

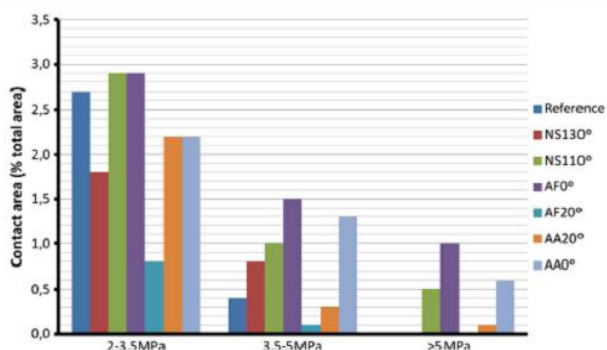


FIGURA 16. Àrees de contacte normalitzades pels diferents rangs de pressió hidrostàtica al cartílag dels diferents models.

Al làbrum, també el model AF0° va presentar les àrees més grans amb pressions superiors a 3,5 MPa. De nou, només els models de retroversió (AF0° i AA0°) van mostrar valors de pressió hidrostàtica superiors a 5 MPa. (FIGURA 17).

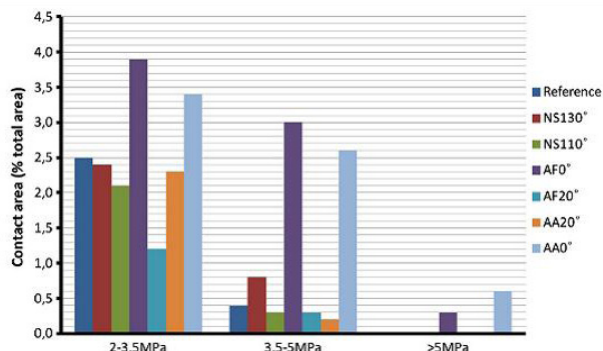


FIGURA 17. Àrees de contacte normalitzades pels diferents rangs de pressió hidrostàtica al làbrum dels diferents models.

5.2. TREBALL 2.

El resultat més rellevant d'aquest estudi és la constatació que tots els angles que mesuren la cobertura acetabular en el pla horitzontal (AASA, PASA i HASA) van resultar significativament més grans en el grup de pacients que en el grup de controls ($p < 0,001$, $p = 0,03$ i $p < 0,001$, respectivament). També es va observar que en el grup de pacients hi havia una associació significativa ($p = 0,024$) entre un CEA elevat (sobrecobertura frontal) i una HASA elevat (sobrecobertura horitzontal), fet que no es donava en el grup de controls ($p = 0.121$).

L'AA va ser significativament més gran ($p < 0,001$) en el grup de pacients ($79,63^\circ$) que en el grup control ($67,24^\circ$). Altres angles com AAA, FAVA i CEA van ser més alts en el grup de control que en el de pacients però sense diferències significatives.

No es va detectar cap associació significativa entre un angle alfa elevat ($> 60^\circ$) i un CEA elevat ($> 35^\circ$) ni en pacients ni en controls ($p = 0,51$ i $p = 0,18$, respectivament).

També es va trobar una associació significativa entre un IM elevat i un HASA elevat en el grup control ($p = 0,05$) però no en el de pacients ($p = 0,393$).

L'anàlisi de regressió multivariant va mostrar que els únics predictors significatius de malaltia degenerativa van ser HASA (OR 1.07, $p = 0.008$) i angle alfa (OR = 1.05, $p = 0,048$) quan es van incloure tots els angles. Un segon anàlisi es va realitzar exclouent l'HASA per tal de discriminar entre ASAA i PASA com a factors predictius. En aquesta cas l'ASAA (OR = 1.15, $p = 0.004$) i l'AAA (OR = 1,12, $p = 0,05$) van ser els únics predictors significatius de malaltia degenerativa.

5.3. TREBALL 3.

Els resultats es resumeixen en la següent taula (TAULA 3):

| | | INTRA-OBSERVADOR | | | INTER-OBSERVADOR | | | | | |
|----------------|-----|------------------|-------|-------|------------------|-------|-------|-------|-------|-------|
| Tots els casos | | A1_A2 | B1_B2 | C1_C2 | A1-B1 | A2_B2 | B1_C1 | B2_C2 | A1-C1 | A2_C2 |
| | | OA% | 65 | 60.6 | 66.6 | 50.4 | 56.4 | 65 | 55.6 | 63.2 |
| | K | 0.389 | 0.364 | 0.397 | 0.173 | 0,271 | 0.397 | 0.261 | 0.339 | 0.325 |
| Pacients | | A1_A2 | B1_B2 | C1_C2 | A1-B1 | A2_B2 | B1_C1 | B2_C2 | A1-C1 | A2_C2 |
| | OA% | 67.4 | 60 | 66.7 | 51.7 | 56.7 | 65 | 55.1 | 68.3 | 61.7 |
| | K | 0.383 | 0.387 | 0.391 | 0.259 | 0.252 | 0.44 | 0.249 | 0.362 | 0.320 |
| Controls | | A1_A2 | B1_B2 | C1_C2 | A1-B1 | A2_B2 | B1_C1 | B2_C2 | A1-C1 | A2_C2 |
| | OA | 61.4 | 61.4 | 66.7 | 49.1 | 56.2 | 64.9 | 56.2 | 57.9 | 61.4 |
| | K | 0.1 | 0.316 | 0.351 | 0.021 | 0.166 | 0.327 | 0.261 | 0.158 | 0.225 |

TAULA 3. Paràmetres de concordança intra- i interobservador per a tots els casos (dues línies superiors) i per a pacients i controls per separat (línies inferiors). K: valors kappa. OA%: percentatge d'acord observat. A: primer cirurgia sènior; B: segon cirurgia sènior; C: resident. Els números següents a les lletres (1 o 2) fan referència a la primera i segona observació, respectivament.

Fiabilitat intraobservador.

Els valors de Kappa en un rang comprès entre 0,364 i 0,397 indiquen una fiabilitat intraobservador de caràcter pobre. Tots els percentatges de concordança intraobservador observats van ser inferiors al 70%. Les avaluacions discordants es van distribuir de la següent manera: el 94,6% va mostrar una diferència d'un grau en la classificació de Tönnis (95, 86,6 i 100% per a l'observador A, B i C, respectivament). La resta corresponia a observacions amb una diferència de dos graus. La distinció entre els graus 0 (absència de coxartrosi) i el grau 1 van ser, amb diferència, la major causa de discordança intraobservador i van representar el 76,3% del total (73,1% , 73,8% i 82% per als observadors A, B i C, respectivament).

Fiabilitat interobservador.

Tots els valors kappa, excepte un, van variar entre 0.173 i 0.339, indicant una fiabilitat intraobservador de caràcter pobre o discret. Tots els percentatges de concordança observats intraobservador van ser inferiors al 70%. De les avaluacions discordants el 94,4% van mostrar diferència d'un grau (92.4, 95.5 i 95.3% entre A-B, B-C i A-C, respectivament). La resta corresponia a observacions amb diferències de dos graus. De nou, la distinció entre els graus 0 i 1 van ser la major causa de discordança intraobservador representant el 73,01% de les avaluacions discordant (72,6, 71,5 i 74,9% entre A-B, B-C, i A-C, respectivament) (FIGURA 17).

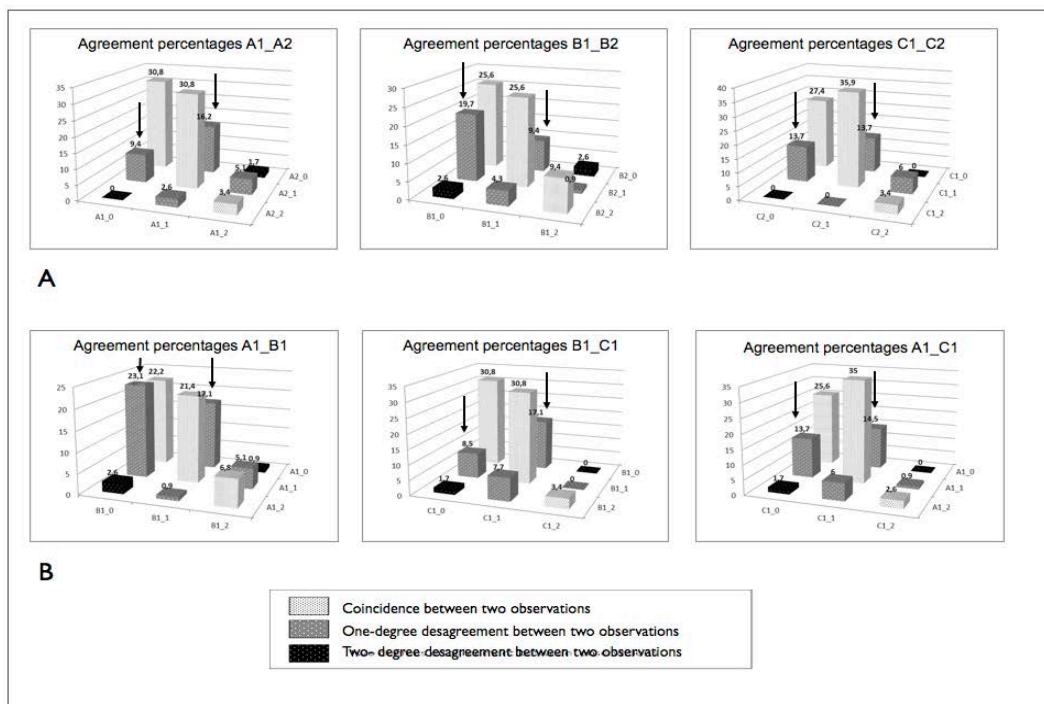


FIGURA 17. Percentatges d'acord intraobservador (a) i interobservador (b) per a tots els observadors i combinacions. Es mostren els gràfics corresponents a la primera observació. Els valors s'expressen en percentatges. En tots els gràfics, la majoria dels desacords van ser causats per no poder distingir entre els graus 0 i 1 (fletxes)

Un altre resultat rellevant és la constatació que l'experiència dels observadors no va tenir cap influència en els paràmetres de concordança: els valors de kappa i els intervals de confiança per l'observador C, no diferien dels dels observadors A i B tant en l'anàlisi intra- com interobservador (FIGURA 18).

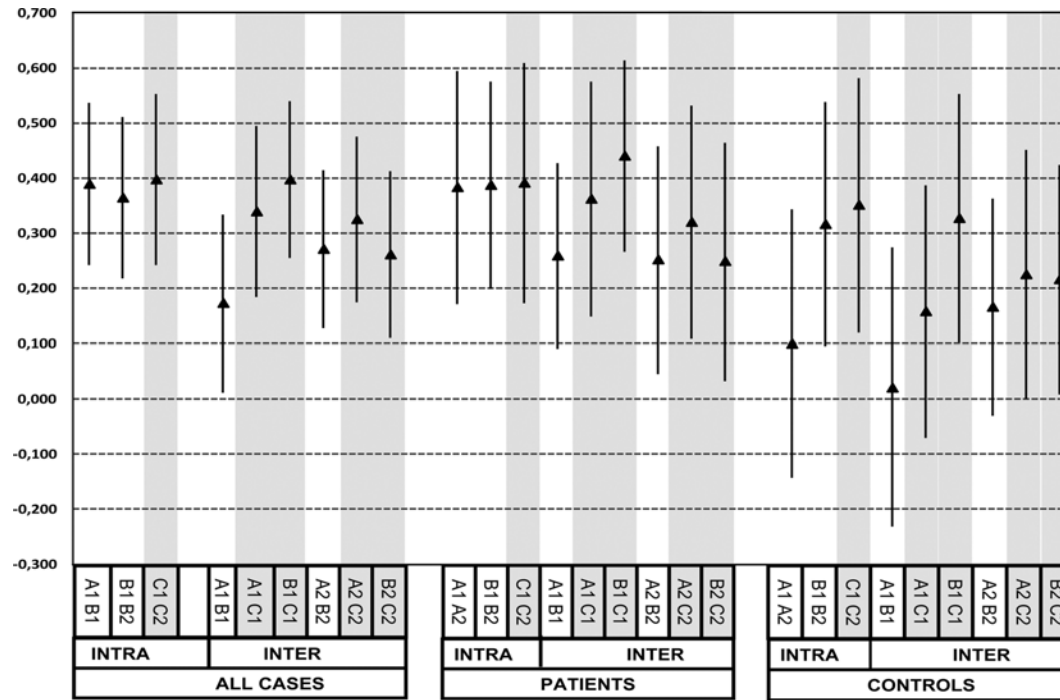


FIGURA 18. Gràfic que representa els valors de Kappa i intervals de confiança del 95% per a totes les combinacions intra- i interobservador. Es mostra la dispersió de dades i la superposicions en els intervals de confiança. No es van trobar diferències quan l'observador C (menys experimentat) estava involucrat (barres grises).

6

DISCUSSIÓ

6.1. TREBALL 1.

Aquest estudi demostra que petites variacions anatòmiques, considerades dins del rang de normalitat anatòmica, poden provocar significatius canvis en les càrregues mecàniques a les superfícies de les articulacions de maluc durant activitats diàries. En concret l'anteversió femoral i/o acetabular semblen tenir una influència molt important: els resultats suggereixen que les anatomies acetabulars i femorals relativament retroverses (o amb anteversió reduïda) són les condicions més desfavorables mecànicament tant pel cartílag acetabular com pel làbrum. En aquests models la distribució de càrregues es va desplaçar des de la part posterior de l'acetàbul fins a una zona més anterior i perifèrica. De manera similar, el làbrum va registrar màxims de pressió hidrostàtica en els models amb retroversió femoral o acetabular. En aquests models, l'estrès hidrostàtic va assolir valors cinc vegades més grans que els registrats al model de referència arribant als 5MPa. S'ha demostrat que pics de pressió hidrostàtica d'aquesta magnitud, aplicats de manera repetida en el temps, són un estímul mecànic per a la secreció de MMP3 (metaloproteïnasa 3 de la matriu), responsable de la degradació dels proteoglicans en el cartílag articular [58]. És remarcable la coincidència topogràfica d'aquestes zones de màxim estrès amb les descrites en els treballs de Ganz i col·laboradors, com a zones *trigger* de la degeneració articular causada pel FAI [31].

La retroversió acetabular i femoral, de manera aïllada o combinada, ja havien estat relacionades clínicament amb trastorns degeneratius de maluc [59,60]. No obstant això, aquesta relació causa-efecte era de naturalesa dinàmica: es basava en la restricció de moviments que aquestes condicions anatòmiques provocaven pel contacte entre fèmur i acetàbul principalment en moviments de flexió i de rotació interna, és a dir en el mecanisme que coneixem per FAI. Cap de les condicions anatòmiques que defineixen FAI (sobrecobertura acetabular o deformitat en la unió cervicocefàlica) estaven presents a la nostra modelització del maluc, on per tant, no hi havia zones de contacte anòmal. Al nostre estudi, l'efecte dinàmic es va negligir i es van analitzar només les forces màximes registrades durant la deambulació normal com a càrrega quasi-estàtica. Així doncs, la disminució de l'anteversió femoral i/o acetabular semblen condicions mecànicament hostils per al maluc, no només perquè des d'un punt de vista dinàmic poden restringir el moviment, sinó perquè també, des del punt de vista estàtic, augmenten fins a magnituds hiperfisiològiques les càrregues de cartílag articular en àrees crítiques durant activitat de mínima demanda on la rotació femoral és relativament baixa.

La modelització matemàtica del maluc utilitzada en aquest estudi, tot i aportar les significatives millores esmentades respecte a estudis similars, presenta limitacions susceptibles de consideració/millora. Per exemple, els models avançats de cartílag, com els models osmoporoviscoelàstics utilitzats en alguns estudis per explorar la patogènesi de l'artrosi, serien especialment adequats per a una millor extrapolació dels nostres

resultats a la regulació biofísica alterada del cartílag malalt [61,62]. Per altra banda, l'ús generalitzat de models d'elements finits amb dissenys pacient-específics sembla un pas obligatori per a una transferència més fiable dels resultats de la simulació a la pràctica clínica, cosa que els nostres resultats semblen indicar.

6.2. TREBALL 2.

Els resultats més rellevants del present estudi apunten a la importància del que podríem definir com “pincer horitzontal” en l'aparició d'artrosi precoç de maluc. Tots els paràmetres que defineixen la cobertura acetabular al pla horitzontal (ASA, PASA i HASA) van mostrar valors significativament més alts en pacients que en controls ($p < 0,001$, $p = 0,03$ i $p < 0,001$, respectivament). La cobertura frontal, expressada per la CEA, també va ser més alta en el grup de pacients, però no significativament ($p = 0,13$). No obstant això, es va objectivar una relació positiva entre sobrecobertura en el pla frontal I ($CEA > 35^\circ$) i en al pla horitzontal ($HASA > 160^\circ$) en el grup de pacients ($p = 0,024$), però no en els controls ($p = 0,21$). Aquesta troballa suggereix que la sobrecobertura acetabular només és promotora de la coxartrosi, si existeix simultàniament en els plans frontal i horitzontal, mentre que si es dona en un sol pla no ho és. Considerem molt significatius aquest resultat, atès que aquest paràmetres que defineixen la cobertura acetabular en el pla horitzontal són rutinàriament ignorats, tant en el diagnòstic de pacients amb FAI, com en els algoritmes de presa de decisió terapèutica en cirurgia conservadora de maluc.

Altres aspectes a considerar són el resultat en relació a l'angle alfa i l'anteversió acetabular. La coxartrosi s'ha associat de manera repetida a uns valors elevats d'angle alfa [63,64]. Al nostre estudi, els valors significativament més alts d'angle alfa en el grup de pacients ($p < 0,001$) donen suport ferm al rol prevalent de la deformitat tipus cam com a desencadenant de la coxartrosi. Pel que fa a l'anteversió acetabular, tot i que els pacients presentaven uns valors més baixos que els controls, la diferència no era significativa ($p = 0,49$). No obstant això, l'anteversió acetabular sí apareix amb significació estadística com un dels factors predictors de l'artritis del maluc en l'anàlisi multivariant ($p = 0,05$). D'altra banda, l'anteversió acetabular també està inclosa en el MI (suma d'anteversió acetabular i femoral), que era més gran en el grup control sense significació estadística ($p = 0,17$). Tot i això, un MI elevat (> 50) va mostrar una associació positiva amb un alt HASA en el grup de control ($p = 0,05$), però no en pacients ($p = 0,393$). Aquestes troballes són coherents amb la idea generalment acceptada que una disminució de l'anteversió acetabular està relacionada amb l'aparició de la coxartrosi [65,66] i suggereixen que un MI alt juga una paper protector contra la malaltia degenerativa.

Molts malucs amb diagnòstic de FAI es consideren de “tipus mixt”, és a dir, que combinen característiques de cam i pincer. Els nostres resultats, no donen suport a aquesta

idea: no es va objectivar cap associació significativa entre sobrecobertura frontal (CEA elevat) o horitzontal (HASA elevat) i l'existència de deformitat tipus cam (angle alfa elevat) ni en pacients ni en controls. Per tant, l'estudi de la nostra sèrie suggereix que cam i pincersón entitats patoanatòmiques diferents com alguns autors ja havien defensat [67].

El disseny prospectiu i els criteris d'inclusió restrictiu, que proporcionen una mostra d'estudi homogènia en termes d'estadi de malaltia i edat, són les principals fortaleses d'aquest estudi. Les principals limitacions es relacionen amb el tamany de la mostra estudiada, que pot ser insuficient per ser representatiu de la població i que pot limitar també el valor estadístic d'alguns resultats. No obstant això, la major part dels resultats, fins i tot en casos amb diferències no significatives, van ser coherents amb els resultats generalment reportats (per exemple, major anteversió acetabular i femoral en els controls que en pacients o CEA superior en pacients que en controls). Això suggereix que una mostra més gran podria haver proporcionat més evidència, però no resultats contraposats als generalment acceptats.

El paper de FAI com a causa de coxartrosi precoç ja no es qüestiona. Malgrat això, definir, avaluar i quantificar un mecanisme dinàmic que depèn de complexes condicions anatòmiques tridimensionals utilitzant imatges estàtiques bidimensionals segueix sent un repte sense resoldre. Aquesta dificultat podria ser una de les principals causes de la indefinició de la frontera morfològica més enllà de la qual un maluc pot ser considerat de manera fiable en risc de desenvolupar artrosi precoç.

6.3. TREBALL 3.

Els nostres resultats qüestionen seriosament la fiabilitat de la classificació de Tönnis en els estadis inicials de la coxartrosi. Els paràmetres d'acord tant intra- com interobservador (amb valors de l'índex kappa entre 0.1 i 0.4) demostren una fiabilitat inacceptable quan s'aplica a pacients amb signes degeneratius incipients o absents.

L'estadiatge precís de la coxartrosi en les seves primeres etapes és de vital importància per a la cirurgia de preservació de maluc, tant pel que fa a les indicacions com per a l'avaluació de resultats. Encara que la classificació Tönnis no es va crear amb aquesta finalitat s'ha convertit en la referència radiològica més àmpliament utilitzada entre els cirurgians de maluc.

A la literatura trobem escassos exemples d'anàlisi de la fiabilitat de la classificació de Tönnis, i sempre formant part d'estudis amb altres objectius [68,69]. En aquests treballs els paràmetres de concordança són millors que els del nostre estudi. Aquesta disparitat és explicable per dos factors. El primer és l'existència o mida del grup control. Al nostre estudi el grup control suposa el 50% dels casos mentre que en els altres estudis no n'hi

ha o representa només el 30% dels casos. Considerant que el principal contingent de discordances (tant intra- com interobservador) es van donar a l'hora de discriminar entre els graus 0 i 1 de la classificació, l'augment de la proporció de subjectes, a priori, sense patologia degenerativa (Tönnis grau 0) afavoreix una disminució en la fiabilitat al conjunt de l'estudi. El segon factor és l'existència d'un entrenament dels avaluadors previ a l'aplicació de la classificació. El nostre estudi, a diferència dels altres, va ser dissenyat excloent explícitament qualsevol consens/entrenament previ entre avaluadors per aplicar els criteris de la classificació. Aquest fet, tot i actuar en detriment de la concordança entre observadors, reproduceix, al nostre parer, molt millor les condicions d'aplicació real de la classificació en la comunitat internacional de cirurgians de maluc.

La reproductibilitat d'una classificació depèn de que els paràmetres estiguin clarament definits i permetin classificar subjectes sense superposició entre graus. El fracàs de la classificació de Tönnis en aconseguir aquests objectius es deu a dos factors principals. En primer lloc, la pobra definició dels paràmetres radiològics, degut a la utilització d'adjectius massa interpretables que n'impedeixen una quantificació fiable (TAULA). En segon lloc, la revisió de la literatura demostra aquests paràmetres, considerats per separat, bé estan mancats de reproductibilitat o bé poden conduir fàcilment a la confusió entre patologia i troballes anatòmiques sense transcendència clínica [68-70] .

7

CONCLUSIONS

7.1. TREBALL 1.

Variacions relativament petites en l'angle cervicodiafisial, en el d'anteversió femoral o en el d'anteversió acetabular originen variacions molt importants de les càrregues mecàniques a nivell del cartílag de l'articulació del maluc en activitats quotidianes. En particular, les retroversions relatives tant acetabulars com femorals, generen pics hiperfisiològics de pressió hidrostàtica afectant al làbrum i al cartílag pròxim a la unió condrolabral. Per tant, aquestes condicions anatòmiques, més enllà de la seva implicació dinàmica amb el mecanisme del FAI, són també altament desfavorables des del punt de vista estàtic pel maluc i, per tant, reforcen el seu paper en l'etiologia de la coxartrosi precoç.

7.2. TREBALL 2.

La sobrecobertura acetabular en el pla horitzontal té un paper etiopatogènic important en l'inici de la coxartrosi i suporten la idea que una definició més precisa del que podríem anomenar el "pincer horitzontal" podria ajudar a identificar millor els malucs en risc de desenvolupar una coxartrosi precoç. Per tant, recomanem incloure paràmetres com ASA, PASA i HASA en els algorismes de presa de decisions en cirurgia conservadora de maluc.

7.3. TREBALL 3.

La reproductibilitat de la classificació Tönnis per estadiar la coxartrosi és limitada, especialment quan s'aplica en les primeres etapes de la malaltia. Per tant, l'ús d'aquesta classificació com a referència en la cirurgia conservadora de maluc hauria de ser reconsiderada.



8

**TREBALLS
INCLOSOS**

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Impact of hip anatomical variations on the cartilage stress: A finite element analysis towards the biomechanical exploration of the factors that may explain primary hip arthritis in morphologically normal subjects



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ABSTRACT

Background: Hip arthritis is a pathology linked to hip–cartilage degeneration. Although the etiology of this disease is not well defined, it is known that age is a determinant risk factor. However, hip arthritis in young patients could be largely promoted by biomechanical factors. The objective of this paper is to analyze the impact of some normal anatomical variations on the cartilage stress distributions numerically predicted at the hip joint during walking. **Methods:** A three-dimensional finite element model of the femur and the pelvis with the most relevant axial components of muscle forces was used to simulate normal walking activity. The hip anatomical condition was defined by: neck shaft angle, femoral anteversion angle, and acetabular anteversion angle with a range of 110–130°, 0–20°, and 0–20°, respectively. The direct boundary method was used to simulate the hip contact. **Findings:** The hydrostatic stress found at the cartilage and labrum showed that a $\pm 10^\circ$ variation with respect to the reference brings significant differences between the anatomic models. Acetabular anteversion angle of 0° and femoral anteversion angle of 0° were the most affected anatomical conditions with values of hydrostatic stress in the cartilage near 5 MPa under compression.

Interpretation: Cartilage stresses and contact areas were equivalent to the results found in literature and the most critical anatomical regions in terms of tissue loads were in a good accordance with clinical evidence. Altogether, results showed that decreasing femoral or acetabular anteversion angles isolatedly causes a dramatic increase in cartilage loads.

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1. Introduction

Primary hip arthritis is a non-inflammatory pathology linked to hip–cartilage degeneration, and characterized by joint pain and loss of mobility. Hip arthritis disease is estimated to affect 3% of adults over the age of 30 in the United States (Felson and Zhang, 1998). The clinical classification of this disease can be divided into: idiopathic arthritis, primary arthritis, rheumatic arthritis and post-traumatic arthritis. Duart et al. (2008) focused on primary arthritis, which was shown to affect 22% of patients under 50 years old who suffered arthritis in a cohort of 121 patients registered between 1995 and 2000. Though the etiology of this disease is not well defined due to the large amount of factors involved, age is commonly accepted as a determinant risk factor (Martin and Buckwalter, 2001). However, aging cannot explain the development of primary hip arthritis in the young population. Mechanical loads are also known to play a role in the onset and progression of early

hip arthritis. The anatomy of the hip, including morphology and relative orientation of both acetabulum and proximal femur, can modify pressure distribution within the joint, thus promoting cartilage damage. Some anatomical conditions have been identified as hip osteoarthritis promoters. In the last decade the role of a motion-induced degeneration known as femoroacetabular impingement (FAI) has been proposed and largely discussed as a cause of early osteoarthritic changes (Ganz et al., 2003, 2008). In particular, D.E. Anderson et al. (2010) showed that increased extensions of the acetabulum over the femoral head or non-spherical head–neck junctions can cause acetabular impingements between both sides of the joint, eventually leading to peripheral cartilage damage. This pathogenic sequence has been demonstrated to be responsible for the onset of early hip osteoarthritis in a patient cohort group of 121 patients (Duart et al., 2008). However, FAI radiological signs have been found in a maximum amount of 30% of the general asymptomatic population (Hack et al., 2010), suggesting that no direct cause–effect relationship can be established between FAI and the development of hip arthritis.

The hip is a biomechanically complex organ where the loads acting on the cartilage can be up to four times the body weight during routine daily activities such as walking, stair or ramp climbing and descending,

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among others (Bergmann et al., 2001). Depending on the physical activity, the pressure distribution and contact areas can be found in different regions of the cartilage (Anderson et al., 2008). Clinical evidence shows that cartilage degeneration starts at the periphery of the acetabulum and at the chondrolabral junction (Austin et al., 2008; Greaves et al., 2010). Thereby, knowledge of maximum pressure values in this area is critical.

The geometry of the hip is defined mainly by the neck shaft angle (NS), the femoral anteversion angle (AF), and the acetabular anteversion angle (AA). Such angles can have large inter-individual variations. Large alteration of these angles can be found in pathologies such as hip dysplasia, coxa vara, and coxa valga, where anatomical hip geometry falls out of the normal range (Tai et al., 2003). In those cases, the altered hip joint morphology has significant consequences on the forces and contact areas experienced at the joint surface (Tibor and Leunig, 2012). The mechanism of degeneration in the dysplastic hip is well understood, but determining the pathogenesis for idiopathic osteoarthritis remains elusive. The assessment of contact areas within the hip joint during activities of daily living is of critical importance to understand early degeneration mechanisms.

As such, this study aims to address the lack of biomechanical explorations about the influence of acetabular or femoral angle variations on cartilage loads, within the normal radiological range of hip anatomies in young adults. We hypothesize that small anatomical angle variations with respect to a reference hip geometry can cause significant variations in cartilage loads at the hip joint during daily activities, contributing to initiate arthritic changes. To test this hypothesis, we developed and explored a geometrically parameterized hip joint finite element (FE) model able to calculate the mechanical response of the articular cartilage layers included under specific load conditions.

2. Methods

A matching set of pelvis and femur FE models were obtained from computerized tomography images of the VAKHUM database (<http://www.ulb.ac.be/project/vakhum/>). The subject (0006) was a 99 year-old female with height of 155 cm and weight of 55 kg. The models were made of hexahedral elements and their respective optimal mesh densities were assessed against mesh convergence studies. Both models were then assembled in a single hip joint model where soft tissues were reconstructed manually (Fig. 1). The three-dimensional femoral and acetabular cartilage layers were expanded from the underlying bone surface until their geometric meshes match with real geometry. The procedure was done to keep the real morphology of the cartilage surface, which is an important requirement directly related with the final stresses calculated in the cartilage (A.E. Anderson et al., 2010). Experimental analyses (Shepherd and Seedhom, 1999) and MRI studies (Li et al., 2008; Naish et al., 2006) reported cartilage thickness range from 0.9 to 2.3 mm. In this study, the mean cartilage thickness was about 1.5 mm, except at the periphery where it was about 1 mm thick in order to avoid any mesh penetration. The complex geometry of the acetabular cartilage was rebuilt according to both the area and the aperture radius measured for the lunata surface (Salamon et al., 2004). The final acetabular cartilage model had a characteristic horseshoe shape (Fig. 1). The femoral cartilage covered the entire femoral head with a small area for the fovea capitis where the round ligament is located. The labrum was defined as an extension of the acetabular cartilage. At the interface region, it could not be differentiated from the acetabular cartilage, and its geometry was defined as an irregular area all along the acetabular surface edge and connected to the acetabular cartilage.

Three major extracapsular ligaments were considered, i.e. the iliofemoral ligament, the femoral arcuate ligament, and the ischiofemoral ligament. They all link together the pelvic and femoral bones and they were modeled as unidirectional elements. Insertion points, orientations and cross sectional areas were derived from anatomical descriptions (Hewitt et al., 2001). Also three different muscles were accounted for

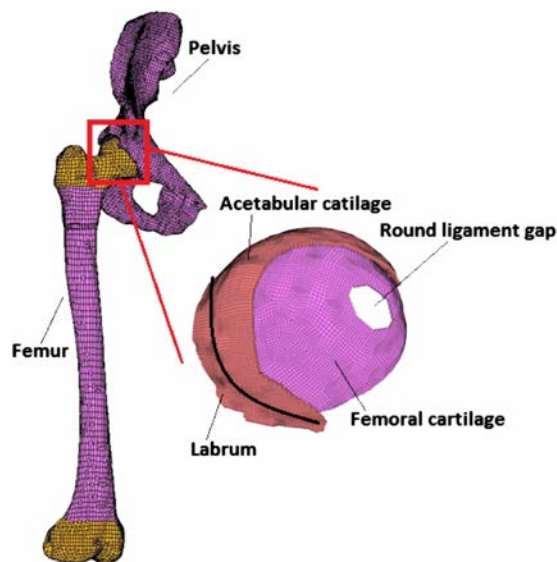


Fig. 1. Hip anatomical geometry of the hip finite element model.

and modeled as unidirectional elements: psoas iliacus, gluteus medius and obturator externus. All the material properties of the tissues are given in Table 1. The ligaments and muscles were implemented with cable elements, accounting for a linear elastic behavior and working only under traction with maximum force values obtained from the literature (Hewitt et al., 2001; Stolk et al., 2001). The femoral cartilage, the acetabular cartilage, and the labrum were considered as hyperelastic materials: a Mooney–Rivlin constitutive model was used with coefficient values that allow realistic simulations of cartilage behavior under compression efforts (Noailly et al., 2011). Sliding contact between the cartilage layers was modeled through a direct boundary constraint method, and node penetration was prevented between the contacting deformable meshes. To optimize the accuracy of contact detection, the mesh of the cartilage layers was four times more refined than that of the bone. Subchondral bone elements were refined as well to ensure mesh continuity with the cartilage, and connection to the rest of the bony structure was ensured by a rigid contact model.

The femur–pelvis junction was defined by three angles: the neck shaft (NS) angle, the femoral anteversion (FA) angle, and the acetabular anteversion (AA) angle, which varied between 110–130°, 0–20°, and 0–20°, respectively (Fig. 2). The configuration NS120°, AF10° and AA10° was taken as reference anatomy (Isaac et al., 1997; Toogood et al., 2009). Only one angle was varied at a time giving a total of seven anatomical configurations. The pelvis was fully constrained at both the ischium and the iliac crest (Phillips et al., 2007), and the femur had flexible constraints imposed by both the muscles and the ligaments. Boundary force values and insertion points of these forces were derived from the literature (Heller et al., 2005). The ground reaction force was applied all along the internal femoral head surface. Also the most relevant axial components of muscle forces were applied on the femur in order to simulate the normal walking activity, and we considered the action of both the vastus lateralis and the proximal and distal parts of the abductor tensor fasciae latae. Peak force values registered along normal walking were applied quasi-statically (Fig. 3).

The load conditions were applied in two load cases: the first load case represented the ground reaction force applied on the femoral head and aimed at accommodating the femoral head within the hip cavity. The second load case consisted of the muscle forces plus the reaction force to simulate a normal walking activity. Analyses were

Table 1
Material and geometrical properties of the tissues used in the FE model.

| Anatomical region | Material/sub-region | Young's moduli (MPa) | Poisson's ratio | Geometrical values | Reference |
|----------------------|---|---|-------------------|--|--|
| Femur | Cortical bone | E _{xx} = 9600 | $\nu_{xy} = 0.38$ | Model was reconstructed from the computerized tomography images obtained from the VAKHUM database | Dong and Guo (2004) Ohman et al. (2007) Rho et al. (1999) |
| | | E _{yy} = 9600 | $\nu_{xz} = 0.17$ | | |
| | | E _{zz} = 15,000 | $\nu_{zx} = 0.26$ | | |
| | | G _{xx} = 3800 | | | |
| | | G _{yy} = 3800 | | | |
| Pelvis | Cancellous bone | G _{zz} = 5400 | $\nu = 0.3$ | Cross section area 107 mm ² Cross section area 89 mm ² Cross section area 73 mm ² Cross section area 14 mm ² Thickness 1 mm each tissue, Cartilage femoral = 1690 mm ² , Cartilage acetabular = 4780 mm ² , Labrum = 420 mm ² | Hewitt et al. (2002) Hewitt et al. (2001) |
| | | E = 160 | $\nu = 0.3$ | | |
| | | E = 13,600 | $\nu = 0.3$ | | |
| | | E = 160 | | | |
| | | E = 350 | | | |
| Ligaments | Superior iliofemoral | E = 320 | | Cross section area 826 mm ² Cross section area 4613 mm ² Cross section area 484 mm ² | Noailly et al. (2011) Shepherd and Seedhom (1999) Naish et al. (2006) Li et al. (2008) Salamon et al. (2004) Bergmann et al. (2001) Heller et al. (2005) Masuda et al. (2003) |
| | | E = 130 | | | |
| | | E = 80 | | | |
| | | E = 0.227, C01 = 0.0007, C11 = 1.824, C20 = 0.111 | | | |
| | | E = 80 | | | |
| Cartilage and labrum | C10 = 0.227, C01 = 0.0007, C11 = 1.824, C20 = 0.111 | | | | |
| | | | | | |
| | | | | | |
| Muscles | Psoas iliacus Gluteus medius Obturator externus | E = 75 | | | |
| | | E = 60 | | | |
| | | E = 50 | | | |

performed using Marc-Mentat® 2007r1 (MSC Software, Newport Beach, CA, USA). The hydrostatic stress (HS) and contact areas within the cartilage and labrum were calculated at maximum load.

3. Results

Results showed that a $\pm 10^\circ$ variation with respect to the reference (CD120°, AF10° and AA10°) gave significant HS differences among the numerical models (Fig. 4). The femoral cartilage of the reference model showed a characteristic pattern of pressure that spread postero-caudally from the center of the cartilage with values of 2.5 MPa. On the acetabular cartilage, such contact pattern corresponded to the inferior posterior rim of the cartilage. The labrum of the reference model showed polarized HS values of small magnitude.

The HS distribution followed different patterns depending on the model geometry. The acetabular cartilage had higher pressure distribution in the posterior regions, but in some cases, like AF0° and AA0°, it was displaced to the superior region. At the femoral cartilage, HS distributions were comparable to those given by the anatomical variation models of the NS angle variation group. Different patterns with more localized peak loads were found for the AA and AF variation groups. As for the labrum, HS distributions showed that almost all models had the maximum HS values concentrated in the postero-anterior part with maximum magnitudes around 1 MPa. Only the retroverted anatomical models, i.e. AF0° and AA0° had the maximum HS along the superior part of the tissue. Also, the highest contact pressures were found in these two retroverted models, with values about five times higher (around 5 MPa) than those computed in the other models. These high HS values were found at the peripheral region where the acetabular cartilage joins to the chondrolabral junction.

Large differences in contact areas were found between models (Fig. 4). On one hand, the NS130° and AA20° were the models with the largest contact areas and smaller HS values. On the other hand, the NS110° and the AF0° had smaller contact areas compared to other geometries. The average contact area calculated for HS values over 1 MPa was found to be 243 mm² in the reference model. Similar areas were predicted for other anatomical models published in the literature (Anderson et al., 2008). In order to compare HS and contact area values for each anatomy, the percentages of cartilage area associated to different ranges of pressure are shown in Fig. 5. For the femoral and acetabular cartilage layers, all tissue areas colored in yellow in Fig. 4 were bearing compressive stresses of 1 MPa, and such a magnitude is considered as non-pathologic (Responte et al., 2012). Interestingly, the contact areas in the cartilage decreased as the HS range of values increased: the AF20° model had the lowest contact areas of high stress and the AF0° showed the largest contact areas of high stress (Fig. 5). Only four anatomical configurations, i.e. NS110°, AF0°, AA20°, and AA0°, produced contact areas with values of HS over 5 MPa, among which retroversion always led to the highest area of high stress. In the labrum, the AF0° model also had the largest areas with HS higher than 3.5 MPa (Fig. 6). Only the retroversion anatomies (AF0° and AA0°) showed HS values over 5 MPa.

4. Discussion

This study demonstrated that small anatomical variations in terms of both femoral and acetabular anteversion angles can cause significant changes in mechanical loads at the cartilage hip joint surfaces during walking activity. In our model, load alterations especially affected the periphery of the acetabular cartilage and the chondrolabral junction. To the best of the authors' knowledge, this is the first attempt to show the influence of such variations on idiopathic hip arthritis onset. The results suggest that relatively retroverted acetabular and femoral anatomies are the most mechanically unfavorable conditions in terms of both HS peaks in the acetabular cartilage and in the labrum. Interestingly, the load distribution moved from the posterior part of the acetabulum to a more anterior and peripheral area as the anteversion of the femur

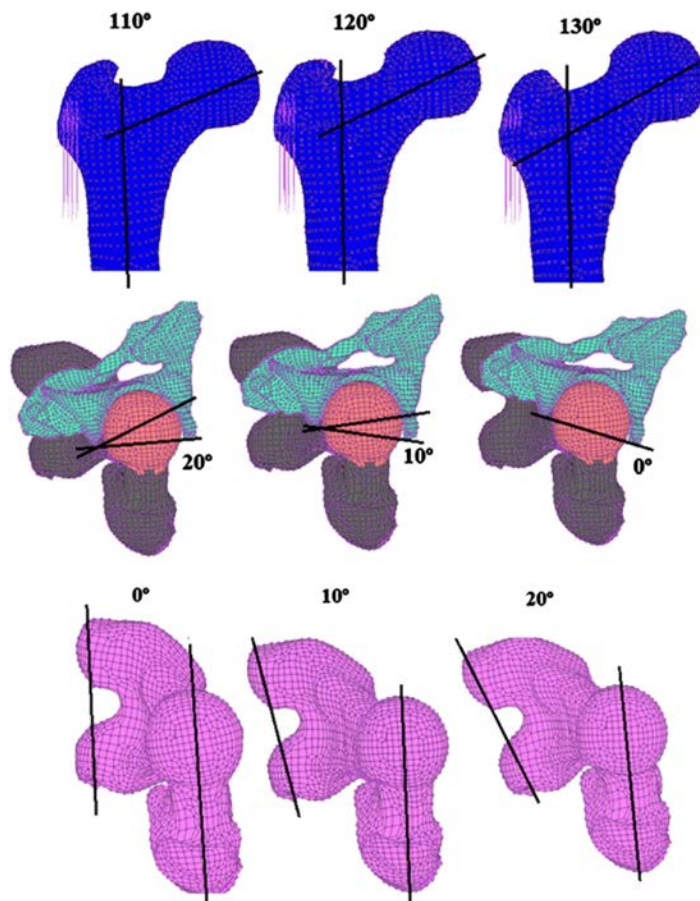


Fig. 2. Anatomical angle variations simulated (first: neck shaft angle, second: acetabular anteversion and third: femoral anteversion).

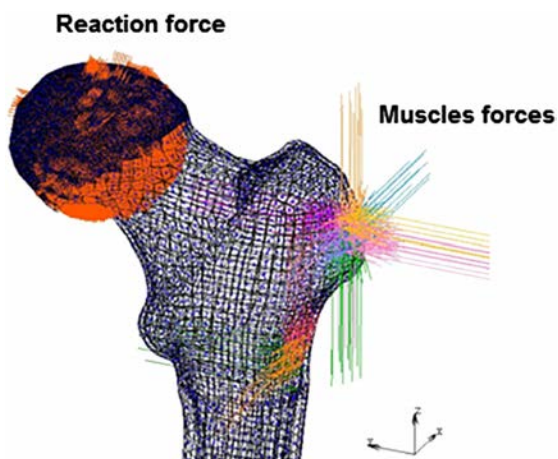


Fig. 3. Boundary conditions applied to the femur to simulate normal walking activity, (Heller et al., 2005). (The resultant force is collinear to the femoral neck axis).

or of the acetabulum decreased. In a similar way, the labrum reached HS maxima in configurations with femoral or acetabular retroversion. In these relatively anterior areas, HS reached values five times higher than those given by the reference model, covering a contact area that was less than 1% of the total contact area.

Ganz and co-workers (Beck et al., 2005; Ganz et al., 2008) described an etiopathogenic mechanism for hip arthritis based on anatomopathological findings in patients with femoroacetabular impingement (FAI). FAI is a motion-induced disorder that consists in an abnormal contact between femur head and acetabulum due to a too deep acetabulum or to a non-spherical femoral head. Data from the surgical procedures of such patients revealed how the degeneration process begins at the acetabulum periphery (involving the labrum and chondrolabral junction), and advances later to the rest of the joint (Beck et al., 2005; Ganz et al., 2008; McCarthy et al., 2001). It is in our opinion remarkable that our study reveals that maximum HS were highly concentrated in the same area in models with femoral or acetabular retroversion. Although acting through a different mechanism, it can be hypothesized that acetabular or femoral relative retroversion may be hip arthritic promoters by injuring the same trigger area described by Ganz.

Acetabular retroversion has been clinically related to hip disorders: significant correlation was reported between acetabular retroversion and joint space narrowing (Kim et al., 2006), and acetabular retroversion has also been described as a minor form of hip dysplasia associated with a high incidence of hip pain (Reynolds et al., 1999). The acetabular

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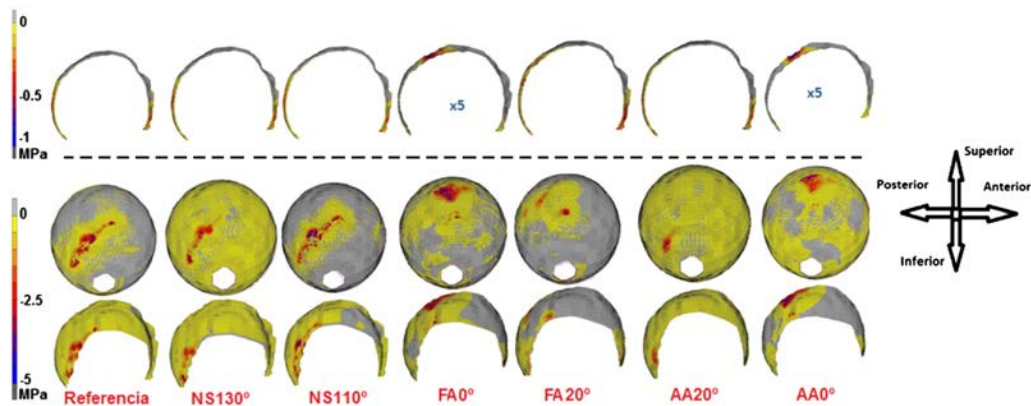
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Fig. 4. HS distribution in cartilage and labrum for the different anatomic models: upper row: labrum; middle row: femoral cartilage; lower row: acetabular cartilage.

retroversion has also been described as the major factor that causes pincer-type impingement: retroversion generally acts as an obstacle to the flexion and internal rotation of the hip by creating impingement of the antero-superior part of the femoral head and neck against the proximal-medial part of the acetabular rim (Siebenrock et al., 2003).

Decreased femoral anteversion has also been related to hip arthritis (Tönnis and Heinecke, 1999): although no significant difference was found in femoral anteversion among specimens with and without hip arthritis (Wedge et al., 1989), decreased anteversion has been involved in the cam-type femoro-acetabular impingement pathogenesis. Indeed, the head-neck junction deformity is not the only one responsible for cam-type femoro-acetabular impingements. Reduced femoral anteversion may increase or even cause impingements through the generation of a joint geometry less adapted to flexion, and especially to flexion and internal rotation movements (Ito et al., 1998).

Accordingly, variations in either proximal femur or acetabulum orientations or a combination of both have been proposed as hip damage promoters. However the cause-to-effect relationship has always been related to a motion-induced mechanism, where femoro-acetabular mismatch is revealed mainly for flexion and internal rotation movements. None of the anatomical conditions defining FAI were present in our model, where the contact force calculations were done in a common anatomy, without abnormal areas of contact. The dynamic effect has been overlooked by applying only the maximum forces registered during

the normal walking activity as a quasi-static load. Thus, decreased femoral or acetabular anteversions appear as mechanically hostile for the hip, not only because they can restrict the movement, but because they also increase dramatically joint cartilage loads in critical areas during a low demand activity where the femoral rotation is relatively low. Truly, the predicted HS of 5 MPa in the retroverted models under compression matches with the magnitudes estimated by Anderson et al. (2008). Nonetheless, according to the data reported by Blain (2007), such a stress magnitude has been proven to be a mechanical stimulus for MMP3 (Matrix Metalloproteinase 3 responsible for proteoglycan degradation in articular cartilage) secretion, when repeatedly applied over time.

The influence of neck shaft angle variations on the joint cartilage loads was not found to be critical in this study. Although the 110° configuration (coxa vara) showed higher HS values than the reference configuration, its clinical implication is unclear if we consider that the areas of maximum load are in the central part of head and acetabulum cartilage, leaving the periphery and the chondrolabral junction undamaged. A range between 110° and 130° was analyzed. This range could be considered as a limitation since extending the study to the highest values of normal range (up to 140°) may have shown a more significant influence of the neck-shaft angle on the cartilage loads. A predictable anatomic relationship between femoral and acetabular anteversions has been described (Buller et al., 2012), suggesting that the anatomical variations on each side of the joint can compensate the unfavorable

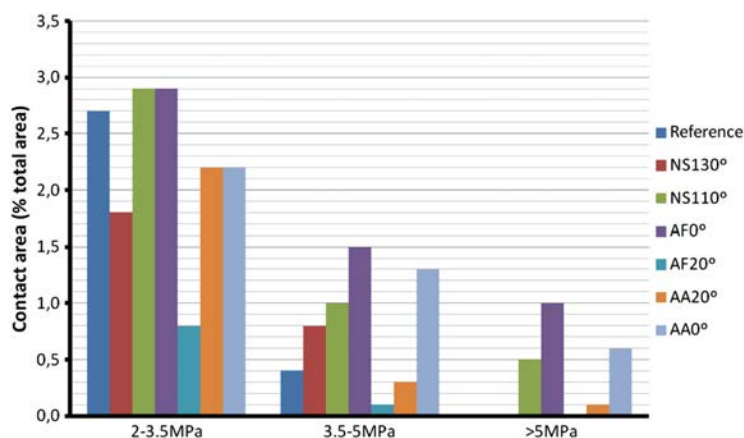


Fig. 5. Normalized contact areas for different ranges of HS in the cartilages of the different anatomic models.

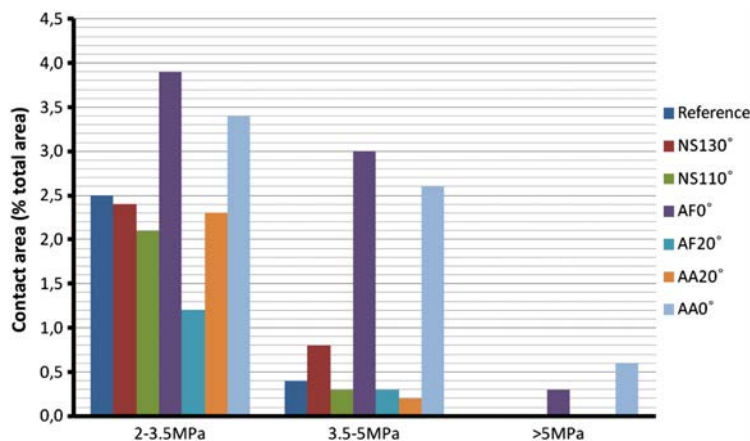


Fig. 6. Normalized contact areas for different ranges of HS in the labrum of the different anatomic models.

configuration of one specific side, especially the retroversion of the acetabulum. Since in our study, only one of the anatomical angles was varied at a time, further studies should focus on the combination of different configurations, especially to test the relative behavior between femoral and acetabular anteversions: larger angle variations or a combination of angles can be expected to produce even larger changes in cartilage loads.

The FE model built in this study, which included muscles, ligaments, bone structures and soft tissues, aims to progress towards a realistic description of the hip in terms of geometry and tissue entities. In particular, our model is taking into account the labrum, being a fundamental entity with specific biomechanical functions, in contrast to other similar FE models used to study the cartilage contact stresses (Jorge et al., 2012; Yoshida et al., 2006). Also, these studies considered the cartilaginous tissues as linear elastic materials, while hyperelastic behavior was used in the present study to better describe the cartilage behavior under large strains. Truly, important modeling limitations remain. For example, advanced cartilage models might allow more accurate description of the tissue mechanical model. For example, the osmoporoviscoelastic models used by van Donkelaar and colleagues (Hosseini et al., 2013; van Donkelaar and Wilson, 2012) to explore the pathogenesis of osteoarthritis would be particularly suitable to better extrapolate our result to the altered biophysical regulation of the hip cartilage in disease. Also, the use of patient-specific model geometries appears mandatory for a thorough transfer of the simulation results to clinics, which is indeed clearly highlighted by our results. Though the above-cited developments should be part of the next steps towards the clinical exploitation of our models, the present numerical study aimed to serve as a first proof-of-concept prior to these developments. Importantly, the controlled model parameterizations and the comparative exploration of the resulting models indicate that extra modeling efforts deserve to be invested for more quantitative and personalized explorations of the clinical hypothesis tackled.

Only three muscles were considered in order to stabilize the FE model. Deeper explorations of the muscle effects would be useful to implement more realistic load boundary conditions (Phillips et al., 2007). Also, simulations represented only the load conditions at the point of maximum effort of the gait cycle. Dynamic boundary conditions could be introduced to capture the cyclic behavior of the cartilage all along the gait cycle. In spite of these limitations, the FE model let us explore the influence of the hip angle variation as a cause of juvenile coxarthrosis.

In the last decade conservative hip surgery has become a common practice in the orthopedic community. Its goals are to improve symptoms like pain or limitation of movements and, eventually, slow down cartilage degeneration in patients with hip arthritis in the early stages.

Most algorithms used to treat such patients consider FAI anatomic conditions, detected with the aid of clinical imaging, as a main factor to indicate or disregard surgery. Furthermore surgical procedures are specifically planned to correct such deformities (Bedi et al., 2008). Since acetabular and femoral relative retroversions might be considered as risk factors for hip arthritis progression, regardless of any other anatomic consideration, as shown in this study, it should be seriously taken into account for surgical treatment strategy planning.

5. Conclusion

This study showed that relatively small variations in the neck shaft angle, in the femoral anteversion angle, or in the acetabular anteversion could increase the mechanical loads supported by the hip joint cartilage at the chondrolabral union. In particular, results strongly suggest that both acetabular and femoral relative retroversions (AA0° and AF0°) can play a significant role in the etiology of young adult hip arthritis. As such, indications of hip primary arthritis should be monitored closely in young patients, especially for those patients with retroverted anatomy.

The results achieved in this study, and their correlations to clinical outcomes revealed that personalized *in silico* study would be highly useful for the educated prevention of degenerative progressions in young patients presenting indications of retroversion. Such advanced diagnostic and prognostic tools could be followed by specific physiotherapy to reduce overloading of the hip/pelvis joint cartilage.

Conflict of interest

There are no professional and financial affiliations of the author that may have biased the article.

Acknowledgments

Access to the VAKHUM database (<http://www.ulb.ac.be/project/vakhum/>) is acknowledged. There are no author's professional and financial affiliations that may have biased the article.

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Acetabular overcoverage in the horizontal plane: an underdiagnosed trigger of early hip arthritis. A CT scan study in young adults

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Abstract

Introduction Acetabular overcoverage promotes hip osteoarthritis causing a pincer-type femoroacetabular impingement. Acetabular coverage in the horizontal plane is usually poorly defined in imaging studies and may be misdiagnosed. The goal of this study was to analyze the role of acetabular overcoverage measured in the frontal plane and in the horizontal plane by CT scan and to determine its relationship with other anatomic features in the onset of hip arthritis in young adults.

Materials and methods We compared prospectively CT scans from two groups of adults of 55 years or younger: the patient group ($n = 30$) consisted of subjects with diagnosis

of early hip arthritis (Tönnis Grade I or II) and the control group ($n = 31$) consisted of subjects with healthy hips. Two independent observers analyzed centre edge angle (CEA), acetabular anteversion angle (AAA), anterior sector acetabular angle (AASA), posterior sector acetabular angle (PASA), horizontal acetabular sector angle (HASA), femoral anteversion angle (FAVA), alpha angle (AA), and Mckibbin Instability Index (MI).

Results Angles measuring the acetabular coverage on the horizontal plane (AASA, PASA and, HASA) were significantly higher in the patient group ($p < 0.001$, $p = 0.03$ and $p < 0.001$, respectively). Pearson's correlation coefficient showed a positive correlation between CEA and HASA in patients ($r = 0.628$) and in controls ($r = 0.660$). However, a high CEA ($> 35^\circ$) was strongly associated with a high HASA ($> 160^\circ$) in patients ($p = 0.024$) but not in controls ($p = 0.21$), suggesting that pincer should be simultaneously present in the horizontal and frontal plane to trigger hip degeneration. No significant association was detected between a high alpha angle ($> 60^\circ$) and a high CEA ($> 35^\circ$) suggesting that a mixed pincer-cam aetiology was not prevalent in our series. Multivariate regression analysis showed the most significant predictors of degenerative joint disease were HASA ($p = 0.008$), AA ($p = 0.048$) and ASAA ($p = 0.004$).

Conclusions Acetabular overcoverage in the horizontal plane plays an important role in the onset of early hip arthritis. Considering that this condition is usually underdiagnosed, we suggest the anterior sector acetabular angle, the posterior sector acetabular angle, and the horizontal acetabular sector angles be routinely included in decision-making algorithms in hip conservative surgery to better define hips-at-risk of developing early hip osteoarthritis.

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Keywords Hip osteoarthritis · Femoroacetabular impingement · Pincer · Acetabular overcoverage · Hip conservative surgery

Introduction

The aetiology of primary osteoarthritis (OA) of the hip is not fully understood. Despite its recognized multifactorial character, it is accepted that mechanical factors play a fundamental role [1, 2]. It is well known that major changes in the normal relationship between the femur and the acetabulum, such as dysplasia, distort hip mechanics, leading to early degenerative joint disease [3]. However, knowledge of factors triggering hip OA in non-dysplastic hips is limited.

Joint-preserving surgery of the hip in young adults has increased interest in the mechanisms involved in the early stages of hip arthritis and its pathogenesis. Ganz and co-workers [4, 5] described an etiopathogenic mechanism based on anatomopathological findings in patients with femoroacetabular impingement (FAI). FAI is a motion-induced disorder involving abnormal contact between the femoral head and the acetabulum. It may be caused by focal or general acetabular overcoverage (pincer type) or by an anterior abutment in the femoral head–neck junction (cam type). However, such anatomical conditions have been found to be relatively prevalent among the asymptomatic [6–8]. Therefore, the consideration of these two mechanisms alone—as currently defined—fails to fully explain the aetiology of primary hip arthritis.

Cam-type FAI is quantified by measuring the alpha angle (AA), which is frequently studied by CT scan or MRI. Many studies have evaluated different methods to measure the alpha angle on CT scan and MRI and compared findings with plain X-ray measurements [9–12]. However, CT or MRI is less commonly used to evaluate acetabular overcoverage in pincer-type hips. Diagnosis of this condition thus continues to rely on X-ray parameters. The most commonly used reference to measure coverage in the frontal plane is the centre edge angle of Wiberg (CEA) that has shown similar reliability whether measured in CT or X-ray [13]. Coverage in the horizontal plane is usually defined using parameters such as the cross-over sign or the posterior wall sign. These signs are non-parametric and have shown poor interrater reliability [14]. Interestingly, CT scan and MRI axial views provide more reliable parameters concerning horizontal coverage but they are routinely ignored. This imprecision can lead to misdiagnosis of horizontal acetabular overcoverage. As pincer-type parameters are routinely included in treatment algorithms and hip OA studies [15, 16], such misdiagnosis can induce erroneous decision in hip conservative surgery.

Another factor that should be taken into consideration when studying the arthritic hip is that small variations in anatomic hip angles can cause dramatic changes in mechanical stress distribution on the cartilage in the acetabulum and in the femoral head [17]. Measuring these angles in cases with advanced hip arthritis can lead to a bias due to secondary deformity and/or bone apposition caused by the progression of the degenerative disease itself. Thus, we hypothesized that if a more exact definition of overcoverage could improve the etiologic understanding of hip arthritis, it should be based on subjects with early stages of hip OA. It may otherwise be difficult to determine whether a difference is the cause or the consequence of the degeneration.

Our objective was to obtain a simple, complete measure of acetabular coverage and use this to analyze its role, along with other anatomic features, in the onset of hip arthritis in young adults. We quantified acetabular overcoverage both in the frontal plane and in the horizontal plane by means of CT scans.

Patients and methods

In a prospective observational study, we compared a group of young adults with early hip arthritis with a group of young adults with healthy hips. The study was approved by the clinical research ethics committee at our institution. Our aim was to assess the presence of anatomical features which can be considered OA promoters in patients in whom the degeneration process had not substantially modified radiologic landmarks. Between January 2012 and December 2012, we consecutively recruited subjects aged 55 or younger from two population groups. The patient group was made up of subjects who visited our outpatient hip unit and who met the following inclusion criteria: groin pain, early arthritic changes on plain X-rays (Tönnis grade 1 or 2) and non-dysplastic radiological criteria (CEA $\geq 25^\circ$). Thirty from 34 subjects gave their informed consent to participate in the study. All of them underwent plain AP pelvic X-rays and a CT scan as a part of our routine protocol for young adult hip OA. Five subjects in the patient group had bilateral pain. Subjects of the control group were prospectively recruited among patients of the same age who underwent a pelvic X-ray and CT scan as study of sacroiliac pain. Forty-three from 62 subjects gave their informed consent to participate in the study. By doing this, they authorized the CT scan to be extended to the knee to measure femoral anteversion. Before inclusion in the study, all subjects in the control group were evaluated by the same independent consultant to rule out any physical sign of hip pathology or any previous history of hip pain or disease. 12 of the CT scans showed suggestive images of sacroiliac pathology and patients were excluded to avoid any bias caused by an inflammatory disease. Finally, 31 subjects were included. Five hips in this

group were excluded due to a previous history of unilateral hip pathology (3 acetabular fractures, one subcapital fracture and one unilateral Perthes disease).

We, therefore, finally included 60 hips from the patient group and 57 hips from the control group (a total of 117 hips) (Table 1). There were no statistical differences between both groups in terms of age ($p = 0.12$), gender ($p = 0.23$) or body mass index ($p = 0.41$). Considering the number of hips included and the coefficient of variation stated on the literature (between 10 and 20%), the power of the study was found to be higher than 80% for all variables. [10, 18–21].

Imaging study

AP pelvis X-rays were obtained using a standard radiographic technique as previously described [22]. Subjects were placed in a supine position with the legs positioned in 15° internal rotation. The X-ray-to-film distance was 120 cm. The beam was directed perpendicularly to the table and centered on the point midway between the superior border of the pubic symphysis. A line was drawn connecting the anterior superior iliac spines.

For CT examinations, patients were placed in supine position on the CT gantry and a square pelvis relative to the table was assured. The feet were placed in neutral rotation with the hips and knees in extension and secured with a plastic foot binder. All CT scans (patients and control) were performed according to hospital protocol for sacroiliac pain study to have comparable imaging studies. An anteroposterior scout view of the bilateral hips and knees was obtained. Guided by the scout view, we obtained continuous 5-mm axial slices through both hip joints and femoral necks, and two 10-mm sections through the femoral condyles with 110 kV, 50 mA, 2 s exposure parameters, using a 16-slice Philips CT (Philips Brilliance, Eindhoven, The Netherlands) high-resolution scanner with a 512 matrix.

All images were processed using a digitized IMPAX Client 6.4 system (©2008 Agfa-Gevaert N.V). AP pelvic plain X-rays were used to rule out hip dysplasia ($CEA < 25^\circ$) or radiological evidence of any other previous hip pathology.

On CT scan, we used a mid-axial plane (intersecting both femoral head centers) to evaluate all acetabular axial angles. We defined a reference line on this plane between the centers

of both femoral heads (intercapital center line). To define femoral neck axis, we used a “four-point-reference” tool (IMPAX ES Orthopaedic Application, ©2008 Agfa-Gevaert N.V). For the femoral anteversion measurement, we defined a posterior condylar line, tangential to both posterior femoral condyles on a CT axial view. Using these references, we measured the following angles (Fig. 1): the acetabular anteversion angle (AAA), between a line through the anterior lip of the acetabulum and the lip of the posterior acetabulum and the intercapital center line; the anterior sector acetabular angle (AASA), between the anterior acetabular margin, the center of femoral head and the intercapital center line; the posterior sector acetabular angle (PASA) between the posterior acetabular margin, the center of femoral head and the intercapital center line; and the horizontal acetabular sector angle (HASA), which is the result of adding the AASA + PASA [23, 24]; femoral anteversion angle (FAVA), between the femoral neck axis and the posterior condylar line [25]. The alpha angle (AA) was calculated obtaining an angled axial plane parallel to the axis of the femoral neck and passing through the centre of the femoral head, on the basis of a coronal scout view. The femoral neck axis line was defined in this image (Fig. 2). The best matching circumference was then drawn over the femoral head contour. The angle was calculated between the axis, the center of the femoral head and the point where the femoral head outlines the circumference anteriorly [26]. The Mckibbin Instability Index (MI) was calculated adding AA + FAVA. To measure CEA, we obtained a mid-frontal plane image determined by a corresponding intercapital center line on axial reference images and orthogonal to the standard axial plane. The CEA was determined as the angle measured between a line perpendicular to the intercapital center line and a line extending from the center of the femoral head to the lateral margin of the acetabular roof (Fig. 3). For analytical purposes, normal and high values were established for some angles according to the literature. CEA values above 35° and HASA values above 160° were considered high [18, 24]. MI values below 20 were considered to have a low instability index, while values above 50 were considered to have a high instability index [27].

For the femoral anteversion angle (FAVA) measurement, we defined a posterior condylar line, tangential to both posterior femoral condyles on a CT axial view. We measured the angle in reference to the axial neck line defined on a overlaid axial image of the same series (Fig. 4).

Measurements were performed by two independent observers blinded to patients’ clinical data on digital images using IMPAX ES Orthopaedic Application (Agfa Healthcare, Mitra Imaging Inc., 2004). Both observers independently defined all the previously described reference lines and planes. Mean values of the two measurements were used for statistical analysis. Interrater reliability was evaluated

Table 1 Some demographic data of the series

| | Patients | <i>p</i> | Controls |
|-------------------------|----------------------|----------|------------|
| Male/female | 22/8 | 0.184 | 17/14 |
| Age—mean (SD) y.o. | 41.2 (3.4) | 0.623 | 42.9 (4.1) |
| BMI—mean (SD) | 25.3 (3.5) | 0.421 | 24.5 (3.6) |
| Laterality (left/right) | 21/14 (5 bilaterals) | | |

SD standard deviation

Fig. 1 Scheme showing the method used to measure all angles in the mid-axial views as described in the text. *ICL* inter-capital line, *AAA* anteversion acetabular angle, *ASAA* anterior sector acetabular angle, *PASA* posterior sector acetabular angle

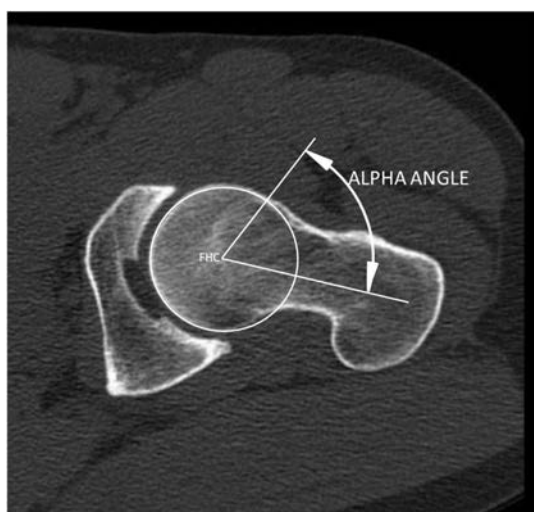
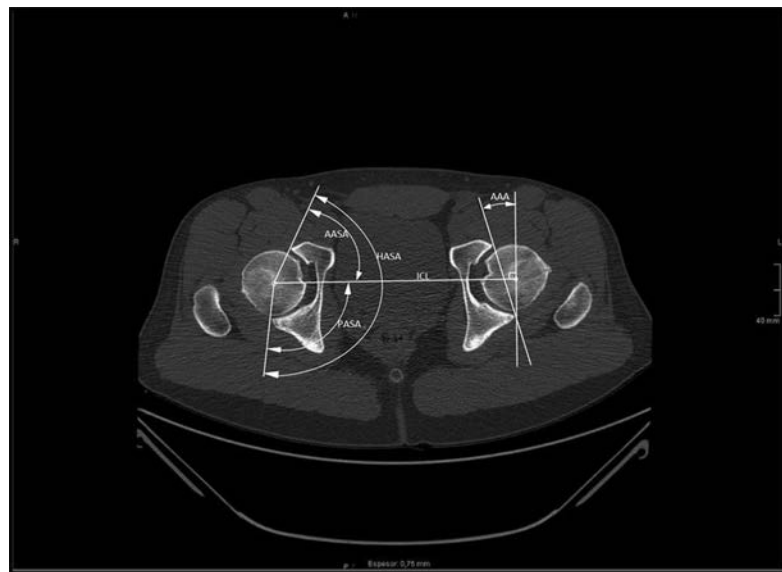


Fig. 2 Scheme showing the method used to measure the alpha angle



Fig. 3 Scheme showing the method used to measure the femoral anteversion angle (FAVA)

using Cronbach's alpha coefficient [28] and was within the good to perfect level of consistency for all angles except for the Alpha Angle, which was acceptable (Table 2).

Statistical study

Categorical variables are expressed as the number of cases and percentages. Quantitative variables were described using mean (m) and standard deviation (SD). When necessary,

confidence intervals (CI) were calculated at 95%. The level of significance was set at 5% ($\alpha = 0.005$). The relationship between categorical variables was calculated using the Chi-square test. The significance of differences in means of continuous variables between two groups was determined using the Student's *T* test. Bivariate correlations were determined using Pearson's correlation coefficients. Multivariate step-wise logistic regression was undertaken to identify factors predictive of hip OA. Statistical analyses were performed using IBM- SPSS (V 22.0).

Fig. 4 Scheme showing the method used to measure the centre edge angle (CEA)

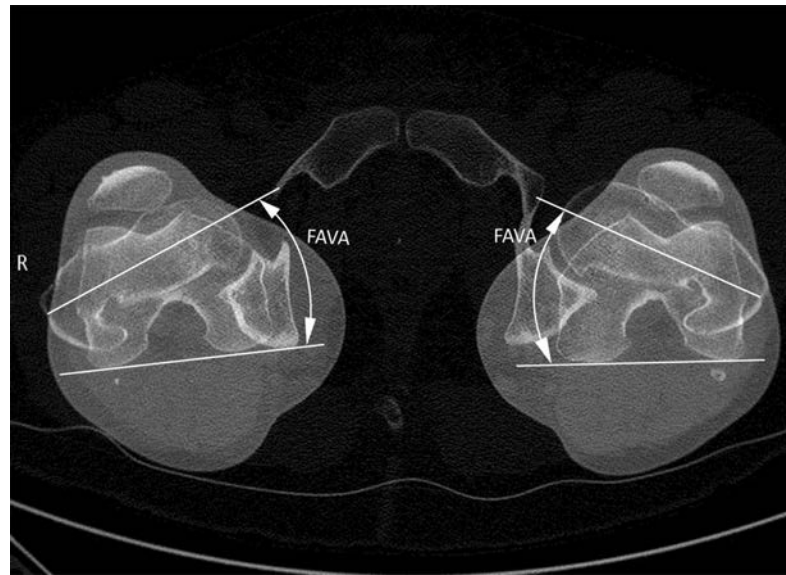


Table 2 Interrater reliability for all angles

| | Cronbach's α | 95 % CI | Sig. |
|------|---------------------|-----------|---------|
| AA | 0.71 | 0.67–0.82 | 0.003 |
| CEA | 0.83 | 0.74–0.88 | 0.006 |
| AAA | 0.97 | 0.96–0.98 | < 0.001 |
| FAVA | 0.75 | 0.60–0.85 | 0.021 |
| AASA | 0.87 | 0.70–0.93 | 0.031 |
| PASA | 0.81 | 0.74–0.87 | 0.001 |
| HASA | 0.85 | 0.71–0.84 | 0.020 |

AA alpha angle, CEA center edge angle, AAA anteversion acetabular angle, FAVA femoral anteversion angle, PASA posterior acetabular sector angle, AASA posterior acetabular sector angle, HASA horizontal acetabular sector angle

Results

Table 3 shows a summary of results. All mean values of the control group were within the normal anatomical range reported in the literature [10, 13, 18–21].

Laterality

Differences were analyzed on the basis of laterality for every patient and for every angle. Comparisons of right and left hips showed no significant differences in any angle in patients or in controls (Table 4).

A specific analysis was performed among unilaterally affected patients ($n = 25$) to compare affected and unaffected sides: the values of the symptomatic side did not differ significantly from those of the asymptomatic side (Table 5).

Table 3 Statistics of the series

| | Patients ($n = 60$) | | Controls ($n = 57$) | | Reference values Mean \pm SD [*] |
|----------------------|-----------------------|-------|-----------------------|-------|---------------------------------------|
| | Mean | SD | Mean | SD | |
| FAVA ($^{\circ}$) | 13.29 | 8.01 | 14.49 | 9.01 | 17 \pm 3 [20] |
| CEA ($^{\circ}$) | 38.28 | 7.75 | 34.00 | 7.34 | 35 \pm 6 [13] |
| AAA ($^{\circ}$) | 19.52 | 5.84 | 21.23 | 18.14 | 24 \pm 5 [10] |
| Alpha ($^{\circ}$) | 67.24 | 12.62 | 57.73 | 13.07 | 53.3 \pm 9.6 [21] |
| ASAA ($^{\circ}$) | 63.19 | 8.54 | 58.58 | 7.58 | 63 \pm 6 [18] |
| PASA ($^{\circ}$) | 99.79 | 10.30 | 96.06 | 8.17 | 103 \pm 9 [18] |
| HASA ($^{\circ}$) | 162.99 | 13.68 | 154.65 | 12.13 | 165 \pm 9 [18] |
| MI ($^{\circ}$) | 33.40 | 10.01 | 36.22 | 24.27 | 34.3 \pm 11 [10, 20] |

SD standard deviation, [*] reference

Accordingly, we performed a statistical comparison between patients and controls that included both hips from every subject in the patient group regardless of the unilaterality or bilaterality of clinical symptoms.

Male vs female

Significant differences were found when comparing male and female hips. Mean CEA, AAA and MI were significantly higher in female patients than in male patients ($p = 0.004$, $p = 0.01$ and $p = 0.03$, respectively). On the control group, the only significant difference was that females showed a higher CEA ($p = 0.04$). The rest of the values did not show any differences (Table 6).

Table 4 Analysis of differences between left and right hips for every patient

| | | $\Delta[r - l]$ | SD | 95% IC | | <i>p</i> |
|---------------------------|-----------|-----------------|--------|---------|-------|----------|
| | | | | Inf. | Sup. | |
| Cases (<i>n</i> = 30) | FAVA (°) | 2.65 | 6.91 | - 5.51 | 1.38 | 0.067 |
| | CEA (°) | 0.44 | 8.00 | - 3.43 | 1.46 | 0.761 |
| | AAA (°) | 0.26 | 2.87 | - 0.80 | 0.52 | 0.617 |
| | ALPHA (°) | 3.36 | 16.11 | - 9.37 | 2.94 | 0.263 |
| | ASAA (°) | 0.85 | 6.39 | - 3.23 | 1.16 | 0.472 |
| | PASA (°) | 0.19 | 6.03 | - 2.44 | 1.10 | 0.860 |
| | HASA (°) | 0.70 | 9.09 | - 4.09 | 1.66 | 0.677 |
| Controls (<i>n</i> = 26) | MI (°) | 2.33 | 7.53 | - 5.44 | 1.50 | 0.135 |
| | FAVA (°) | 0.84 | 6.87 | - 4.16 | 1.57 | 0.598 |
| | CEA (°) | 0.85 | 4.76 | - 3.22 | 1.12 | 0.458 |
| | AAA (°) | 0.29 | 2.46 | - 0.92 | 0.58 | 0.616 |
| | ALPHA (°) | 0.63 | 21.6 | - 14.07 | 4.97 | 0.474 |
| | ASAA (°) | 0.10 | 3.6 | - 2.02 | 0.91 | 0.907 |
| | PASA (°) | 0.22 | 8.42 | - 4.28 | 1.93 | 0.907 |
| HASA (°) | 0.38 | 7.57 | - 3.37 | 1.78 | 0.830 | |
| | MI (°) | 0.31 | 6.94 | - 4.72 | 2.00 | 0.879 |

None of the angles in patients or controls showed any significant difference between left and right sides. $\Delta[r - l]$ mean difference between left and right hips for every patient in absolute figures
SD standard deviation, 95% IC confidence interval of 95%

Table 5 Differences between left and right hips for every patient in the unilaterally affected cases

| | | $\Delta(R - L)$ | SD | IC 95% | | <i>p</i> |
|--|-----------|-----------------|-------|--------|-------|----------|
| | | | | Inf. | Sup. | |
| Unilaterally affected cases (<i>n</i> = 25) | FAVA (°) | 3.15 | 6.03 | - 5.46 | 1.55 | 0.067 |
| | CEA (°) | 0.22 | 8.66 | - 4.51 | 4.95 | 0.926 |
| | AAA (°) | 0.35 | 6.54 | - 3.14 | 3.85 | 0.838 |
| | Alpha (°) | 7.05 | 6.11 | - 9.50 | 11.99 | 0.488 |
| | ASAA (°) | 0.85 | 8.03 | - 5.73 | 3.28 | 0.587 |
| | PASA (°) | 0.11 | 13.70 | - 7.63 | 7.87 | 0.976 |
| | HASA (°) | 0.77 | 9.09 | - 4.09 | 1.66 | 0.81 |
| | MI (°) | 2.54 | 8.39 | - 5.44 | 1.50 | 0.431 |

None of the angles showed any significant difference between left and right sides. $\Delta[r - l]$ mean difference between left and right hips for every patient in absolute figures
SD standard deviation; IC 95% confidence interval of 95%; *p* T test significance

Patients vs controls

Table 7 compares all angles measured in patients and controls.

The AA was significantly higher ($p < 0.001$) in the patient group (79.63°) than in controls (67.24°). Mean AAA, FAVA and CEA were higher in the control group than in the patient group. However, none of these differences were statistically significant.

All angles measuring the acetabular coverage on the horizontal plane (AASA, PASA and HASA) were greater in the patient group than in controls and all these

differences were statistically significant ($p < 0.001$, $p = 0.03$ and $p < 0.001$, respectively).

Pearson's correlation coefficient showed a moderately positive correlation between CEA and HASA both in patients ($r = 0.628$) and controls ($r = 0.660$). However, only 27.9% of subjects in the control group showed a simultaneously high CEA (> 35°) and high HASA (> 160°) compared to 58% in the patient group. The Chi-square test showed that a high CEA was strongly associated with a high HASA in the patient group ($p = 0.024$) but not in control group ($p = 0.121$).

Table 6 Differences between males and females

| | Patients (<i>n</i> = 60) | | | | <i>p</i> (IC 95%) | Controls (<i>n</i> = 57) | | | | <i>p</i> (IC 95%) |
|----------|---------------------------|-------|-------------------------|-------|---------------------------|---------------------------|-------|-------------------------|-------|---------------------------|
| | Male (<i>n</i> = 43) | | Female (<i>n</i> = 17) | | | Male (<i>n</i> = 30) | | Female (<i>n</i> = 27) | | |
| | Mean | SD | Mean | SD | | Mean | SD | Mean | SD | |
| FAVA (°) | 11.96 | 6.66 | 15.64 | 9.75 | 0.121 [− 8.35, − 0.003] | 14.24 | 8.71 | 14.76 | 9.58 | 0.861 [− 6.539, 5.496] |
| CEA (°) | 36.77 | 8.14 | 41.30 | 6.89 | 0.044 [− 8.98, 0.128] | 34.68 | 7.96 | 38.24 | 5.68 | 0.164 [− 8.633, 1.523] |
| AAA (°) | 17.96 | 5.26 | 23.175 | 5.62 | 0.001 [− 8.242, − 0.183] | 16.86 | 4.96 | 22.77 | 4.21 | 0.048 [− 7.814, − 2.091] |
| ALFA (°) | 79.31 | 13.26 | 73.57 | 27.74 | 0.289 [− 5.00, 16.486] | 70.38 | 14.24 | 66.31 | 21.53 | 0.566 [− 10.357, 18.496] |
| ASAA (°) | 64.26 | 7.90 | 60.70 | 9.47 | 0.140 [− 1.199, 8.335] | 57.82 | 4.79 | 59.82 | 6.90 | 0.299 [− 5.852, 1.852] |
| PASA (°) | 92.11 | 13.69 | 100.46 | 9.46 | 0.02 [− 15.461, − 1.250] | 92.48 | 6.79 | 89.66 | 16.05 | 0.453 [− 4.727, 10.372] |
| HASA (°) | 156.38 | 16.49 | 161.16 | 11.25 | 0.266 [− 13.331, 3.754] | 150.30 | 8.88 | 149.48 | 20.80 | 0.866 [− 8.982, 10.628] |
| MI (°) | 30.36 | 7.40 | 38.81 | 11.85 | 0.003 [− 14.814, − 2.091] | 34.36 | 7.40 | 40.02 | 11.85 | 0.083 [− 12.814, − 3.451] |

SD standard deviation, *P* *T* test significance, IC 95% confidence interval of 95%

Table 7 Differences between patients and controls

| | Patients (<i>n</i> = 60) | | Controls (<i>n</i> = 57) | | <i>p</i> | IC 95% | |
|-----------|---------------------------|-------|---------------------------|-------|----------|--------|-------|
| | <i>m</i> | SD | <i>m</i> | SD | | Inf. | Sup. |
| | FAVA (°) | 13.29 | 80.14 | 14.49 | | 90.12 | 0.54 |
| CEA (°) | 19.52 | 5.84 | 21.23 | 18.14 | 0.49 | − 1.53 | 4.61 |
| AAA (°) | 38.28 | 77.95 | 34.00 | 73.41 | 0.37 | − 1.28 | 2.68 |
| Alpha (°) | 67.24 | 12.62 | 57.73 | 13.07 | 0.00 | 4.69 | 13.23 |
| ASA (°) | 63.19 | 8.54 | 58.58 | 7.58 | 0.00 | 1.06 | 7.88 |
| PASA (°) | 99.79 | 10.30 | 96.06 | 8.17 | 0.03 | 1.78 | 9.00 |
| HASA (°) | 162.99 | 13.68 | 154.65 | 12.13 | 0.00 | 4.42 | 15.32 |
| MI (°) | 33.40 | 10.01 | 36.22 | 24.27 | 0.46 | 2.27 | 7.72 |

m Mean, SD standard deviation, IC 95% confidence interval of 95%, *p* *T* test significance

No significant association was detected between a high alpha angle (> 60°) and a high CEA (> 35°) either in patients or in controls (*p* = 0.51 and *p* = 0.18, respectively). Similarly, no association was found between high alpha angle (> 60°) and a high HASA (< 160°) in patients or in controls (*p* = 0.22 and *p* = 0.35, respectively).

Mean MI was higher in controls (36.22°) than in patients (33.04°) but the difference was not significant. However, high MI was associated with high HASA in 25% of patients and in 34% of controls. The Chi-square test showed an association of high MI and high HASA in the control group (*p* = 0.05) but not in the patient group (*p* = 0.393).

A high instability index (> 30°) showed a positive association with a high HASA in the control group (*p* = 0.037) but not in the patient group (*p* = 0.21).

Multivariate regression analysis showed the most significant predictors of degenerative joint disease were HASA (OR 1.07, *p* = 0.008) and alpha angle (OR = 1.05, *p* = 0.048) when all angles were included. A second regression analysis was performed excluding HASA to try to discriminate between ASAA and PASA as predictive factors. In this setting, ASAA (OR = 1.15, *p* = 0.004) and AAA

(OR = 1.12, *p* = 0.05) were the only significant predictors for OA.

Discussion

The most relevant results of the present study point to the importance of what we could call the “horizontal pincer” in the onset of early hip arthritis. All parameters defining the acetabular coverage on the horizontal plane (ASA, PASA and HASA) showed significantly higher values in patients than in controls (*p* < 0.001, *p* = 0.03 and *p* < 0.001, respectively). Frontal coverage, expressed by the CEA, was also higher in the patient group, although the difference was not significant (*p* = 0.13). Nevertheless, a positive relation between frontal (CEA > 35°) and horizontal (HASA > 160°) overcoverage was found in the patient group (*p* = 0.024) but not in controls (*p* = 0.21). These results suggest that a combination of horizontal and frontal overcoverage may trigger hip OA, while isolated overcoverage in one plane does not. These findings argue against the concept that a Coxa profunda or “deep socket hip”—defined in AP X-ray views

by a high CEA—can be considered in isolation as sign of pincer impingement and thus a hip OA promoter [3, 22]. Conversely, our results are consistent with other authors who have questioned this idea and suggested that other overcoverage index should be added to cause impingement [29].

In our study, PASA in the patient group was significantly higher than in the control group, and so was HASA. This result contradicts that reported by Hapa et al. [30] in a similar study: they found a deficient posterior wall (lower PASA) was a potential hip OA promoter although they found no relation between the total horizontal coverage (HASA) and hip OA. These contradictory results could be explained in terms of the population target of each study; Hapa et al. included subject of all ages (range 19–79 years old) and all OA stages while we included only young patients with early degenerative changes. Thus, although a deficient posterior wall has been related with hip OA [31], our results suggest that this condition has a role in older patients but does not act as a trigger of OA in a young population with non-dysplastic hips.

In the present study, alpha angle was significantly higher ($p < 0.001$) in the patient group than in controls (67.24° vs 57.73°). The alpha angle measured on plain X-rays (using cross-table or lateral Dunn views) or on axial CT or MRI views quantifies cam deformity. Prior investigators used either a 50° or a 55° threshold value to distinguish normal and abnormal alpha angles depending on the study [6, 21, 32, 33]. However, there seems to be a consensus among authors in considering hips with an alpha angle higher than 65° to have a high risk of developing hip arthritis [16, 34]. Regardless of the reference values, our results strongly support a prevalent role of cam deformity in the onset of early hip arthritis.

Although patients showed lower acetabular anteversion (19.52°) than controls (21.23°), the difference was not significant ($p = 0.49$). However, acetabular anteversion appeared as one of the predictor factors for hip arthritis in the multivariate analysis ($p = 0.05$). Moreover, acetabular anteversion is among the factors that are added to the MI, which was higher in the control group. Although again this difference was not significant ($p = 0.17$), a high MI (> 50) showed a positive association with a high HASA in the control group ($p = 0.05$) but not in patients ($p = 0.393$). These findings are consistent with the generally accepted idea that a diminished acetabular anteversion is related to the onset of osteoarthritis [35, 36] and suggest that a high MI plays a protective role in degenerative joint disease when horizontal plane overcoverage is present.

Many hips with FAI diagnosis are considered “mixed-type FAI”, combining cam and pincer features. In our study, the alpha angle was significantly higher in the patient group, supporting its role in the onset of arthritis, as previously considered to occur through a cam-type FAI

mechanism, [4, 37–39]. However, no significant association was detected between a high alpha angle and a high CEA in patients or in controls ($p = 0.51$ and $p = 0.18$, respectively). Similarly, no association was found between high alpha angle and a high HASA in patients or in controls ($p = 0.22$ and $p = 0.35$, respectively). In view of this results, we can state that a “mixed-type” impingement was not prevalent in our series supporting the idea that cam and pincer hips are distinct pathoanatomic entities as previously reported [40].

The main strengths of this study are its prospective design and the restrictive inclusion criteria that provide a homogeneous group in terms of stage of disease and age. However, we acknowledge the following limitations. First, our cohort was small and may thus not be representative of patient populations. The sample size may also have limited the significance of some measurements. However, most of the non-significant differences between patients and controls were consistent with the results generally reported (i.e., higher acetabular and femoral anteversion in controls than in patients or higher CEA in patients than in controls). This suggests that a larger sample may have provided more evidence but that results would not have contradicted those most generally accepted. A second limitation is that we considered statistically independent the observations of different hips of the same patient. In our patient cohort, there were five with bilateral clinical involvement and the rest unilateral. The option to include hips of the same subject, with unilateral involvement, in different groups of the same study, is theoretically incorrect for morphological analysis, considering that the left and right hips have the same genetic basis. Our statistical comparison between both sides from our patients did not show significant differences (not even in the unilaterally affected subjects). Taking this into account, we included both hips of every affected subject in the patients group (regardless of the uni- or bilateral involvement), considering that the effect of this design can play on variables is equivalent in both groups and would not affect final outcomes. A third limitation is that did not consider pelvic tilt, which is considered to influence some pelvic parameters, such as acetabular version, either in plain X-rays [41] or in CT scan [42, 43]. However, its been reported that pelvic tilt changes significantly from lying to standing position considering that CT scan cannot be performed in standing position [42], authors decided not to include pelvic tilt in the analysis. The role of FAI as a cause of early hip OA is no longer questioned. However, defining, evaluating and quantifying such a dynamic mechanism that depends on complex three-dimensional anatomical conditions from static two-dimensional images remains an unresolved challenge. This difficulty could be a major cause of the poor definition of the morphological frontier beyond which a hip can be reliably considered at risk of developing early OA.

Conclusions

Our results suggest acetabular overcoverage in the horizontal plane plays an important role in the onset of early hip arthritis, and support the idea that a more precise definition of what we could call the “horizontal pincer” may help to better identify hips-at-risk of developing early OA. We, therefore, recommend including parameters such as ASA, PASA and HASA in decision-making algorithms for hip-conservative surgery.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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Ethical approval The study was approved by the clinical research ethics committee at our institution (CODE: EBE-2011-74).

Informed consent Informed consent was obtained from all individual participants included in the study.

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Reliability of Tönnis classification in early hip arthritis: a useless reference for hip-preserving surgery

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Abstract

Introduction The Tönnis classification is widely accepted for grading hip arthritis, but its usefulness as a reference in hip-preserving surgery is yet to be demonstrated. We aimed to evaluate reproducibility of the Tönnis classification in early stages of hip osteoarthritis, and thus determine whether it is a reliable reference for hip-preserving surgery.

Materials and methods Three orthopaedic surgeons with different levels of experience examined 117 hip X-rays that were randomly mixed of two groups: a group of 31 candidates for hip-preserving surgery and a control group of 30 patients that were asymptomatic with respect to the hip joint. The surgeons were asked to rate an eventual osteoarthritis according to the Tönnis classification. After 2 months, the surgeons were asked to re-evaluate the X-rays in a random order. Intra- and interobserver reliabilities were calculated by comparing the observers' two estimations using Kappa statistics.

Results Kappa values for interobserver reliability were slight or fair (range 0.173–0.397). Kappa values for

intraobserver reproducibility were fair (range 0.364–0.397). Variance in grading no and slight osteoarthritis was the most frequent cause for intra- and interobserver disagreements (76.3 and 73.01 % of the non-concordant observations, respectively). The confidence interval analysis showed that the observers' experience did not affect reproducibility.

Conclusions The Tönnis classification is a poor method to assess early stages of hip osteoarthritis. These findings suggest that its routine use in therapeutic decision-making for conservative hip surgery should be reconsidered.

Keywords Hip osteoarthritis · Tönnis classification · Hip-preserving surgery · Interobserver reliability

Introduction

Hip-preserving surgery is performed in young symptomatic patients with early or pre-arthritis conditions usually related to femoroacetabular impingement or hip dysplasia. The goals of such surgical procedures are to relieve pain, enhance activity and function, and prevent or delay joint degeneration. The presence of significant osteoarthritis (OA) prior to surgery has been associated with poor outcomes and early conversion to total hip arthroplasty (THA) [1–9]. Adequate preoperative assessment of early hip OA is therefore necessary to optimize indications in hip-preserving surgery.

Despite the growing role of MRI and tomography to refine diagnosis, plain radiographs continue to be an essential tool in the diagnosis of structural hip disease. An ideal clinical classification system should allow to clearly classify patients, to choose therapeutic strategies rationally, and to reasonably estimate prognosis in every case. All users of a classification system should reach the same result

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if it is to be used universally for clinical and research purposes.

Although the Tönnis classification was created to evaluate hip OA in dysplastic patients [10, 11], it has become the most widely accepted reference in literature and in common clinical practice in hip-preserving surgery (Table 1). In this setting, it is commonly used in decision-making algorithms and to evaluate the postoperative course [1, 5, 7, 9, 12–15]. However, this new clinical scenario entails a change in the target population because it focuses in patients with no or early hip OA.

Despite its wide application, very few data have been published about the reliability of the Tönnis classification in such populations. We therefore aimed to assess, if the Tönnis classification is a reliable method for grading early stages of hip OA and thus, if it is a useful reference in hip-preserving surgery.

Patients and methods

This prospective observational study of 117 hips was approved by the clinical research ethics committee of the Hospital de la Santa Creu i Sant Pau. Our aim was to assess the reproducibility of the Tönnis classification in patients with early or no hip OA. To this end, between January 2012 and December 2012, we consecutively recruited patients aged between 18 and 55 years from two population groups. The first group (patient group) was made up of patients who visited the outpatient hip unit at our institution for groin pain (either unilateral or bilateral) and who were considered as candidates for hip-preserving surgery. The second group (control group) consisted of patients who underwent a pelvic X-ray at the outpatient orthopaedic department for reasons other than hip pain. All patients in the control group were evaluated by an independent consultant to discard any physical sign of hip pathology or any previous history of hip pain or hip disease. Anteroposterior pelvis X-rays were used for evaluation. All X-rays were obtained using a standard radiographic technique as previously described [16]. Subjects were placed in a supine position with the legs in 15° of internal rotation. The X-ray-to-film distance was 120 cm, and the beam was directed perpendicularly to the table and centered on the point midway between the superior border of

the pubic symphysis and a line drawn connecting the anterior superior iliac spines. All images were processed using a digitized IMPAX Client 6.4 system (©2008 Agfa-Gevaert N.V). Thirty anteroposterior pelvic X-rays from the patient group and 31 pelvic X-rays from the control group were initially selected. Seven patients complained bilateral pain. Five hips from the control group were excluded due to the previous history of unilateral hip pathology. Thus, 60 hips from patient group and 57 hips from control group (a total of 117 hips) were finally included for evaluation. The overall mean age was 42.1 years (42.9 years in the control group and 41.2 in the patient group). The overall male-to-female ratio was 1.54 (1.1 in the control group and 2.1 in the patient group).

The radiological appearance of each hip was evaluated by three independent observers with different levels of training: two experienced consultant hip surgeons (observers A and B), and one fourth year orthopaedic resident (observer C). The observers were not involved in patients' recruitment and were blinded to the patients' identity and clinical data.

X-rays from both groups were anonymized and randomized together in a single list. Each observer graded every hip according to the Tönnis classification [17]. All three observers repeated the evaluation 2 months later following a second randomization. They were blinded to the previous results. The observers did not undergo a training session before evaluating the X-rays, so no consensus was established to assess the presence or absence of the Tönnis classification parameters.

Intra- and interobserver reproducibilities were assessed using Cohen's kappa coefficients. According to Landis and Koch [18], the indicated agreement for kappa coefficients in the range between 0 and 0.2 was slight, between 0.21 and 0.4 was fair, between 0.41 and 0.6 was moderate, between 0.61 and 0.8 was substantial, and greater than 0.8 was almost perfect. Statistical analyses were performed with use of SPSS 16.0 (SPSS), with consultation of a statistician.

Results

Table 2 summarizes the intra- and interobserver agreement parameters.

Table 1 Tönnis Classification

| Grade | Description |
|-------|--|
| 0 | No signs of osteoarthritis |
| 1 | Increased sclerosis, slight narrowing of the joint space, no or slight loss of head sphericity or lipping at the joint margins |
| 2 | Small cysts, moderate narrowing of the joint space, moderate loss of head sphericity |
| 3 | Large cysts, severe narrowing or obliteration of the joint space, severe deformity of the head |

Table 2 Agreement parameters

| | Intraobserver | | | Interobserver | | | | | |
|----------|---------------|-------|-------|---------------|-------|-------|-------|-------|-------|
| | A1–A2 | B1–B2 | C1–C2 | A1–B1 | A2–B2 | B1–C1 | B2–C2 | A1–C1 | A2–C2 |
| All hips | | | | | | | | | |
| OA % | 65 | 60.6 | 66.6 | 50.4 | 56.4 | 65 | 55.6 | 63.2 | 61.6 |
| κ | 0.389 | 0.364 | 0.397 | 0.173 | 0.271 | 0.397 | 0.261 | 0.339 | 0.325 |
| Patients | | | | | | | | | |
| OA % | 67.4 | 60 | 66.7 | 51.7 | 56.7 | 65 | 55.1 | 68.3 | 61.7 |
| κ | 0.383 | 0.387 | 0.391 | 0.259 | 0.252 | 0.44 | 0.249 | 0.362 | 0.320 |
| Controls | | | | | | | | | |
| OA | 61.4 | 61.4 | 66.7 | 49.1 | 56.2 | 64.9 | 56.2 | 57.9 | 61.4 |
| κ | 0.1 | 0.316 | 0.351 | 0.021 | 0.166 | 0.327 | 0.261 | 0.158 | 0.225 |

Parameters for intra- and interobserver agreement for all cases (two top lines) and for patients and controls, separately (bottom lines)

Numbers following letters (1 or 2) refer to first and second observation, respectively

κ kappa values, OA % observed agreement percentage, A first senior surgeon, B second senior surgeon, C orthopaedic resident

Intraobserver reliability: Kappa values ranged from 0.364 to 0.397 indicating fair intraobserver reliability. All observed agreement percentages were under 70 % (Fig. 1a). Discordant observations were distributed as follows: 94.6 % showed a one-grade difference (95, 86.6 and 100 % for observer A, B and C, respectively). The rest corresponded to observations with a two-grade difference. Variance in grading no and slight osteoarthritis was by far the most frequent cause for intra- and interobserver disagreements for all observers, representing 76.3 % of the non-concordant observations (73.1, 73.8 and 82 % for observer A, B and C, respectively).

Interobserver reliability: all kappa values but one, showed slight or fair interobserver agreement. Kappa values ranged from 0.173 to 0.339. Observed agreement percentages were under 70 % (Fig. 1b). Discordant observations were distributed as follows: 94.4 % showed a one-degree difference (92.4, 95.5 and 95.3 % between A–B, B–C, and A–C, respectively). The rest corresponded to observations with two-degree difference. And again, variance in grading no and slight osteoarthritis was the most frequent cause of disagreement for all interobserver combinations, representing 73.01 % of the non-concordant observations (72.6, 71.5 and 74.9 % between A–B, B–C, and A–C, respectively).

Patients vs control: when analyzed separately, kappa coefficients were slightly higher for the patient group than for the control group: in the intraobserver analysis the kappa index average was 0.387 for the patient group vs 0.25 for the control group. Similarly, in the interobserver analysis, the average kappa indices were 0.313 for the patients group and 0.193 for the control group. However, these differences were not statistically significant (Fig. 2).

Observers' experience: the observers' experience did not affect agreement parameters. Kappa values and confidence intervals for Observer C (resident) did not differ from those for observers A and B, neither for intra- nor for interobserver reproducibility (Fig. 2). Instead, the worst kappa interobserver coefficient was found between the two most experienced observers (0.173).

Discussion

Accurate grading of hip arthritis in its earliest stages is of paramount importance for hip-preserving surgery, both for indications and to evaluate results. Although the Tönnis classification was not created for such purposes, it has become the most widely used radiographic reference among hip surgeons, though little has been reported about its reliability. Our study calls the reliability of Tönnis classification in early hip arthritis into question.

Our study has some limitations. The three observers were surgeons with different levels of experience, and they had not reached any previous consensus regarding the use of the classification. This may have caused some heterogeneity or bias in the observations outcomes. However, it more accurately reproduces conditions of current clinical practice. The applicability of a scale in clinical practice depends on its reproducibility between independent observers. The need for a previous consensus among observers prior to a scale application undermines its universal use. For this reason, we decided not to make a consensus prior to the observations.

The reproducibility of the Tönnis classification has been studied previously [9, 12, 19]. Two of these studies are comparable in size and methodology to the present study.

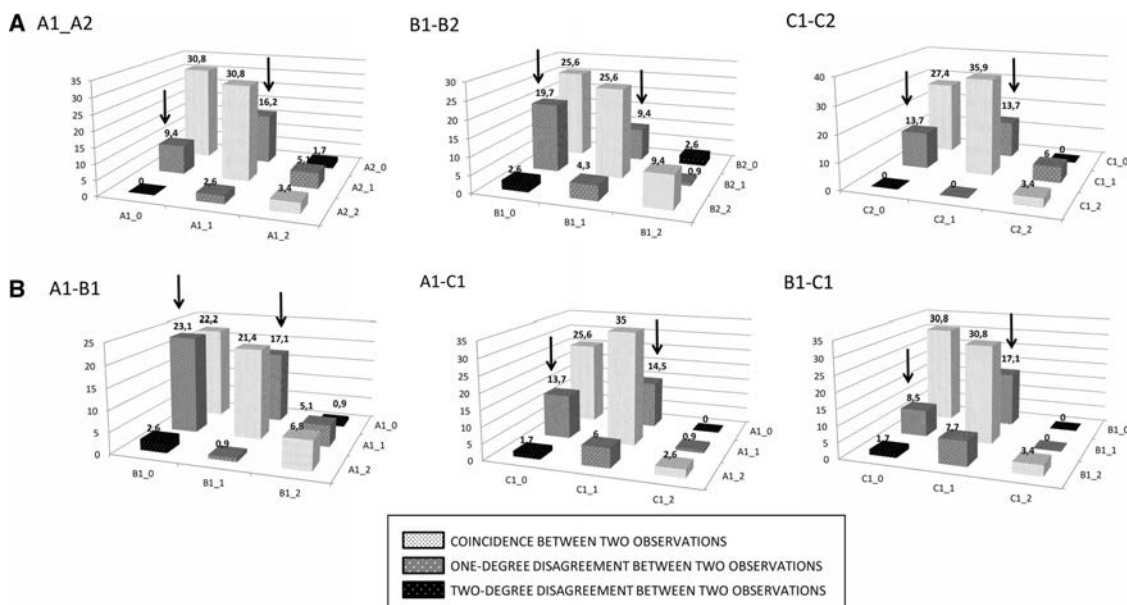


Fig. 1 The percentage of the intraobserver (a) and interobserver (b) agreement for all observers and combinations. Only graphics from the first observation are shown. Values are expressed in percentages.

Note how in all graphics most disagreements were caused by the failure to distinguish between grades 0 and 1 (arrows)

Steppacher et al. [9] used the Tönnis classification to grade 50 X-rays from a cohort of patients with hip dysplasia prior to periacetabular osteotomy. They found a substantial intraobserver (Kappa 0.73 and 0.76) and interobserver reliability (Kappa 0.74). Beside other radiographic parameters, Clohisy et al. [12] assessed the reproducibility of the Tönnis classification for 77 patients with acetabular dysplasia or femoroacetabular impingement and for 25 control patients. They reported an interobserver kappa of 0.59 and an intraobserver kappa of 0.60.

Agreement rates in both of these studies were higher than those in our study. This may have been caused by the influence of the control group in our study. Since the distinction between a completely healthy joint and a joint with slight osteoarthritic changes causes the most uncertainty, including more patients in the control group with no hip complaints—and thus presumably most of them to be classifiable as healthy joints—will increase the number of uncertain ratings. Our study contained the largest control group, whereas Clohisy et al. [12] included 25 control patients and Steppacher et al. [9] included no control patients at all.

Reproducibility of a classification system depends on clearly defined parameters, which allow grading without overlapping. The specific parameters of the Tönnis classification seem to fail to do so:

- Subchondral sclerosis: This parameter appears as increased in Grade 1. It correlates well with pain [20] and with progression of osteoarthritis [21, 22]. However, its assessment may be uncertain even if it is considered as a categorical variable. Reproducibility studies have reported unacceptable agreement values [21, 23]. Subchondral sclerosis can thus be considered one of the most confusing parameters in the Tönnis classification, especially when trying to distinguish grade 0 from 1 (Fig. 3).
- Subchondral cysts: This parameter appears as either small or large in grades 2 and 3, respectively. Although these cysts are a constant anatomopathological finding in arthritic femoral heads, they are frequently missed on X-ray [24]. The reported intra- and interobserver agreement rates are low for femoral cysts and moderate for combined femoral and acetabular cysts [21, 25]. Further confusion is caused by the presence of pit herniations, which some authors consider irrelevant with respect to osteoarthritis [26] (Fig. 4).
- Joint space narrowing: this is described slight, moderate or severe, for grades 1, 2 or 3, respectively. This parameter is the most frequently reported radiological sign in the literature. Some authors, however, found factors like weight, gender or patient position altering

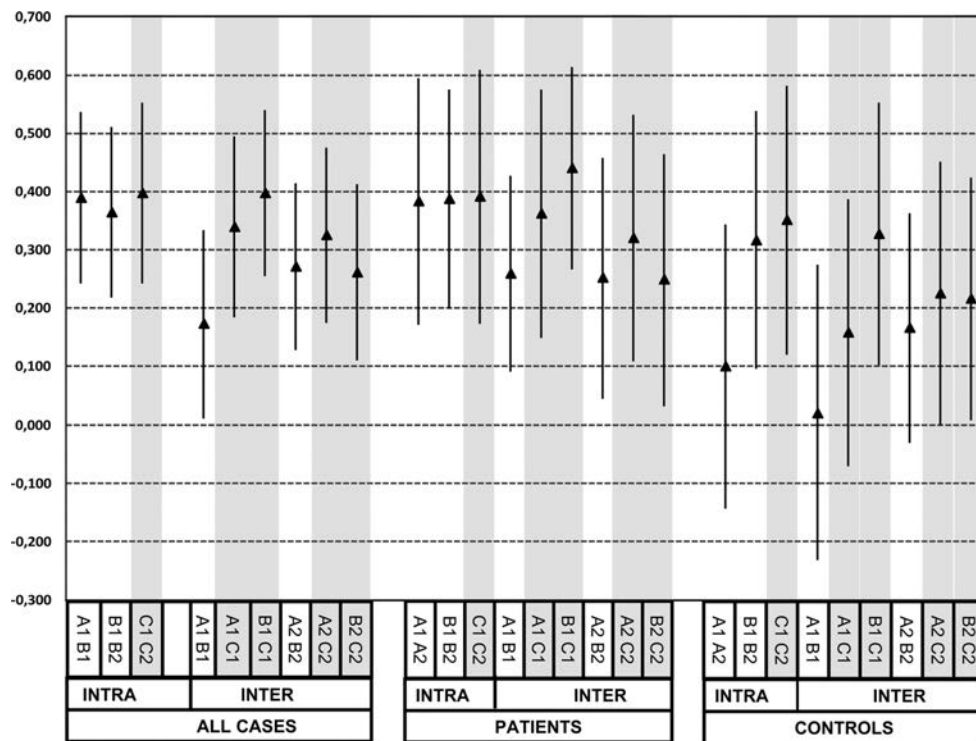


Fig. 2 Graph representing Kappa values and 95 % confidence intervals for all intra- and interobserver combinations. Data dispersion and overlapping in confidence intervals are shown. No differences were found when observer C (less experienced) was involved (grey bars)

joint space on X-rays [27, 28], others did not [29, 30]. Nevertheless, there is general agreement that this parameter is the most reproducible [25, 30] and that it is strongly linked to pain and disease progression [20, 31]. Lane et al. [21] found joint space values less than 1.7 mm on women and less than 2.5 mm in men as strongly associated with disease progression. Such measurements, however, require calibrated X-rays and accurate measure tools (Fig. 5).

- Sphericity of femoral head: this parameter is easily reproducible when taken as a categorical variable [16, 25]. However, according to Tönnis it is graded as slight (or lipping), moderate or severe for grades 1, 2 and 3, respectively. Again, confusion may arise among hip surgeons considering whether all anespheric hips showing the so-called CAM deformity should or should not be classified as Tönnis grade 1, even when no other degeneration signs are present (Fig. 3).
- Osteophytes: their presence indicate grade 1 (lipping). Their correlation with pain and progression is poor [20, 32]. Furthermore, acetabular osteophytes may be

difficult to distinguish from overcoverage in a pincer deformity [21] (Fig. 4).

In summary, it can be stated that the radiographic parameters that are relevant for the Tönnis classification are poorly defined and difficult to assess on plain X-rays. This is especially true when trying to classify the earliest stages such as patients with femoroacetabular impingement [33]. Parameters such as sclerosis, osteophytes or head sphericity can easily be over- or underestimated, thus, leading to unequal grading. Establishing a consensus or performing training sessions for observers prior to the evaluation of the X-rays may therefore improve agreement rates.

Certainly, a CT or Arthro-MRI would be able to refine diagnosis in young adult hip disorders. However, those techniques are not routinely used in every day practice. Instead, plain X-rays still are the gold standard for diagnosis as well as for post-op examinations in such patients. Therefore, a refined radiological classification system should be established, that allows a reliable grading in early stages of hip osteoarthritis.



Fig. 3 AP pelvis X-ray of a 35 year-old male from the control group. Subchondral sclerosis could be considered normal (grade 0) or increased (grade 1) in both hips. Lost of sphericity could be considered either absent (grade 0) in right hip and slight (grade 1) in left hip, or slight in both hips (grade 1), or slight in right hip and moderate (grade 2) in left hip



Fig. 4 AP pelvis X-ray of a 52 year-old female from the patient group with a left symptomatic hip. The presence of a small supracetabular cyst on the left hip can lead to a grade 2 classification if considered pathological; otherwise both hips should be considered in the same Tönnis grade. Left acetabular lipping can be difficult to distinguish from a pincer-type hip, especially when compared with the contralateral side

Conclusions

Reliability of grading hip osteoarthritis according to the Tönnis classification is limited. Since the poor definition of radiological parameters diminishes reproducibility



Fig. 5 AP pelvis X-ray of a 42 year-old male from the control group. Joint space narrowing can be considered slight (grade 1) or moderate (grade 2) on both sides

especially for the grading of early stages of osteoarthritis, the use of the Tönnis classification as reference in hip-preserving surgery should be reconsidered.

Compliance with ethical standards

Conflict of interest None.

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