

**Osteonecrosis of the Hip  
EVIDENCE TABLE**

| Reference   | Study Type      | Patients/<br>Events | Study Objective<br>(Purpose of Study)   | Study Results  | Study<br>Quality |
|---|-----------------|---------------------|---|--|------------------|
| 1. Murphey MD, Foreman KL, Klassen-Fischer MK, Fox MG, Chung EM, Kransdorf MJ. From the radiologic pathology archives imaging of osteonecrosis: radiologic-pathologic correlation. <i>Radiographics</i> . 2014;34(4):1003-1028.                                     | Review/Other-Dx | N/A                 | To review the underlying pathology of osteonecrosis.  | No results stated in abstract.   | 4                |
| 2. Lavernia CJ, Sierra RJ, Grieco FR. Osteonecrosis of the femoral head. <i>J Am Acad Orthop Surg</i> . 1999;7(4):250-261.  | Review/Other-Dx | N/A                 | To review ONFH.   | New cases of ONFH in the United States number between 10,000 and 20,000 per year. This disease usually affects patients in their late 30s and early 40s. Although a number of authors have related specific risk factors to this disease, its etiology, pathogenesis, and treatment remain a source of considerable controversy. This disorder has been associated with corticosteroid use, substance abuse, and various systemic medical conditions. Either direct damage to osteocytes (eg, by toxin production) or indirect damage (eg, due to disorders in fat metabolism or hypoxia) may lead to osteonecrosis. | 4                |
| 3. Kim HK. Legg-Calve-Perthes disease. <i>J Am Acad Orthop Surg</i> . 2010;18(11):676-686.  | Review/Other-Dx | N/A                 | To review Legg-Calve-Perthes disease.   | No results stated in abstract.   | 4                |
| 4. Beltran J, Opsha O. MR imaging of the hip: osseous lesions. <i>Magn Reson Imaging Clin N Am</i> . 2005;13(4):665-676, vi.  | Review/Other-Dx | N/A                 | To discuss the imaging techniques and MRI manifestations of the osseous entities.   | No results stated in abstract.   | 4                |
| 5. Demant AW, Kocovic L, Henschkowski J, et al. Hip pain in renal transplant recipients: symptomatic gluteus minimus and gluteus medius tendon abnormality as an alternative MRI diagnosis to avascular necrosis. <i>AJR Am J Roentgenol</i> . 2007;188(2):515-519. | Review/Other-Dx | 24 patients         | To review the diagnosis on MRI and radiography of 24 renal transplant recipients with hip pain suspicious for AVN and to investigate whether there is an association between kidney transplant patients with end-stage renal disease and symptomatic gluteus minimus and medius tendon abnormality. | Symptomatic gluteus minimus and medius tendon lesions and abnormalities can occur in renal allograft recipients. The MRI findings of this entity allow an alternative diagnosis in this patient population.  | 4                |

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| 6. Hauzeur JP, Pasteels JL, Schoutens A, et al. The diagnostic value of magnetic resonance imaging in non-traumatic osteonecrosis of the femoral head. <i>J Bone Joint Surg Am.</i> 1989;71(5):641-649.               | Review/Other-Dx  | 25 patients         | To assess the effectiveness of nuclear MRI in the detection of ONFH.   | Of the 49 hips, 33 had histological proof of osteonecrosis. 22 (67%) of these hips showed definite necrosis on the plain radiographs; 18 (62%), on the 29 available CT scans; 24 (77%), on the 31 available radionuclide bone scans; and all of the hips, on the MRI studies. In 6 additional hips, there were histological changes (marrow necrosis, edema, hemorrhage, and fibrosis) in the medullary spaces without detectable osteonecrosis. The plain radiographs and CT scans of these 6 hips were normal except for the CT scan of 1, and the radionuclide uptake on bone-scanning was abnormal in 4 of the 6, as were the MRI studies. In the 2 hips that had normal MRI studies, the biopsies showed only destruction of fat cells in the medullary spaces, with no edema or fibroblastic reaction. | 4                |
| 7. Stevens K, Tao C, Lee SU, et al. Subchondral fractures in osteonecrosis of the femoral head: comparison of radiography, CT, and MR imaging. <i>AJR Am J Roentgenol.</i> 2003;180(2):363-368.                       | Observational-Dx | 45 patients         | To compare the sensitivity of unenhanced radiography, CT, and MRI in revealing subchondral fractures.  | At 6 months, 18 fractures were shown on CT scans, but only 12 were detected on radiographs, and 6 on MRIs. At 12 months, 20 subchondral fractures were detected on CT scans, but only 17 were seen on radiographs and 11, on MRIs. Compared with CT, MRI has a sensitivity and specificity of 38% and 100%, and unenhanced radiography has a sensitivity and specificity of 71% and 97%, respectively. On T2-weighted MRIs, the subchondral fractures were visualized as crescentic high-signal-intensity lines, and in all patients, on the corresponding CT scans, the fracture clearly breached the femoral cortex.   | 2                |
| 8. Yeh LR, Chen CK, Huang YL, Pan HB, Yang CF. Diagnostic performance of MR imaging in the assessment of subchondral fractures in avascular necrosis of the femoral head. <i>Skeletal Radiol.</i> 2009;38(6):559-564. | Observational-Dx | 25 patients         | To determine the accuracy of routine MRI in correctly identifying subchondral fracture in AVN of the femoral head without apparent focal collapse on standard radiographs. | When the diagnoses of the 2 readers were compared with each other, only 16/28 diagnoses (57.5%) agreed. 17 of the 28 MRI readings (60.7%) made by the musculoskeletal radiologist and 15/28 (53.5%) made by the general radiologist agreed with those of the CT standard. False-positive diagnosis (that is, diagnosis of fracture when no fracture could be seen on CT) was more common than false-negative diagnosis.  | 2                |

\* See Last Page for Key

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| 9. Beckmann J, Matsuura M, Grassel S, Kock F, Grifka J, Tingart M. A muCT analysis of the femoral bone stock in osteonecrosis of the femoral head compared to osteoarthritis. <i>Arch Orthop Trauma Surg.</i> 2009;129(4):501-505. | Observational-Dx | 20 total patients   | To analyze the bone quality and 3-D microarchitecture of the femoral head and neck in patients with ONFH compared to a group of patients with primary OA. | No statistical significant differences were found for bone volume and the bone volume fraction, the connectivity density and the structure model index in patients with ONFH and those with OA ( $P>0.05$ ). Patients with ONFH and those with OA had a similar trabecular number, thickness and separation ( $P>0.05$ ).  | 3                |
| 10. Yoon TR, Abbas AA, Hur CI, Cho SG, Lee JH. Modified transtrochanteric rotational osteotomy for femoral head osteonecrosis. <i>Clin Orthop Relat Res.</i> 2008;466(5):1110-1116.  | Review/Other-Tx  | 39 patients         | To retrospectively review patients in whom a modified transtrochanteric rotational osteotomy was performed for osteonecrosis.                             | The minimum follow-up was 24 months. Based on the ARCO classification, 17 hips were classified as stage II and 26 as stage III. We performed rotational osteotomy alone in 15 cases, in combination with simple bone grafting in 3, and in combination with muscle-pedicle-bone grafting in 25. 16/17 ARCO stage II cases and 24/26 ARCO stage III cases had no progression of collapse or lesion size; 3 hips progressively collapsed. Of the 40 hips without progression, the Harris hip score improved from a mean 70 to 92 points at final follow-up, as did the range of motion of the hip. Modified transtrochanteric rotational osteotomy is an effective method for delaying the progression of collapse in the treatment of selected cases of ONFH. | 4                |
| 11. Sugioka Y, Yamamoto T. Transtrochanteric posterior rotational osteotomy for osteonecrosis. <i>Clin Orthop Relat Res.</i> 2008;466(5):1104-1109.  | Observational-Dx | 43 total patients   | To retrospectively review the clinical and radiographic results in patients in whom posterior rotational osteotomies were performed.                      | There were 30 male and 17 female patients. 36 hips were ARCO stage III, and 15 were stage IV. Conversion to THA was defined as the failure end point. 3 patients died and 1 was lost to follow-up. There were 43 patients assessed (46/51 hips, or 90%) a minimum of 1.2 years (average, 12 years; range, 1.2–21 years). The Harris hip score for preoperative and most recent follow-up was used. The average preoperative Harris hip score of 52 points improved to an average of 84 at the latest follow-up. Radiographically, the osteonecrosis in 30 hips (65%) had no progressive collapse, and 13 (28%) showed osteoarthritic changes, but no patients underwent THA.   | 3                |

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| <p>12. Hsieh MS, Tsai MD, Yeh YD. Three-dimensional hip morphology analysis using CT transverse sections to automate diagnoses and surgery managements. <i>Comput Biol Med.</i> 2005;35(4):347-371.</p> | <p>Review/Other-Dx</p> | <p>N/A</p>          | <p>To describe an image analysis method that evaluates bone morphology of hip structures including the femur stem, trochanter, neck and head, acetabulum, and pelvis to automate hip diagnoses and surgical managements.</p> | <p>On every CT transverse section, radial B-spline curves are used to approximate the ellipse-like acetabulum and femur head and stem. The femur neck is approximated as trapezoid-like and the pelvis horizontally symmetrical structure. The centers of the ellipse-like structures from transverse sections are used to determine 3-D axes of the femur stem, head, and acetabulum. The centerlines of the neck or the pelvis on the sections are used to determine the neck axis or pelvis centerplane. Boundary changes of these structures are recognized as concave, convex and hole features that are then identified as fractures, tumors, and spurs. Based on the geometric evaluations of these structures and features, hip surgeries including tumor dissect and bone graft, open reduction using plates, screws and nails, and arthroplasty are automatically managed to achieve the normal hip function including dissection of tumors and reduction of dislocations and angular deviations between the hip structures.</p> | <p>4</p>         |

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| <p>13. Theodorou DJ, Malizos KN, Beris AE, Theodorou SJ, Soucacos PN. Multimodal imaging quantitation of the lesion size in osteonecrosis of the femoral head. <i>Clin Orthop Relat Res.</i> 2001(386):54-63.</p> | <p>Review/Other-Dx</p> | <p>45 patients<br/>(77 hips)</p> | <p>To assess multimodal imaging quantitation of the lesion size in ONFH.</p> | <p>Patients with ONFH were evaluated using a multimodal imaging approach that included conventional radiography, bone scintigraphy, and MRI. A computerized image analysis program that allowed quantification of the lesion size on radiographs and MRIs was used. Measurements of the extent of involvement on radiographs and selected serial MRIs were compared in 33 hips (42.9%) before collapse vs 44 hips (57.1%) after collapse. The size of the necrotic lesion varied significantly according to the specific stage of disease. Quantification of the lesion during the course of the disease provided a record of the progression of osteonecrosis, despite a spurious stability in staging. In general, conventional radiography closely approximated measurements of the lesion size obtained by MRI. Bone scintigraphy and MRI were well suited for detection of osteonecrosis at an early stage. Finally, precise quantification of the lesion size was an optimal preoperative means for evaluating the extent of involvement of the femoral head in the early and advanced stages of osteonecrosis.</p> | <p>4</p>         |

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| 14. Ryu JS, Kim JS, Moon DH, et al. Bone SPECT is more sensitive than MRI in the detection of early osteonecrosis of the femoral head after renal transplantation. <i>J Nucl Med.</i> 2002;43(8):1006-1011. | Observational-Dx | 24 patients         | To compare the diagnostic sensitivity of Tc99m-MDP bone SPECT and MRI in the early detection of femoral head osteonecrosis after renal transplantation. | A total of 32 femoral heads, including 24/29 painful hips and 8/19 asymptomatic contralateral hips, were confirmed as having osteonecrosis. SPECT detected osteonecrosis in all 32 of the femoral heads, resulting in a sensitivity of 100% (32/32), whereas MRI detected osteonecrosis in 21 femoral heads, for a sensitivity of 66% (21/32, $P<0.005$ ). SPECT showed the type 1 pattern in 13 and the type 2 in 19. 10/13 femoral heads with the type 1 pattern were false-negative on MRI, whereas only 1 of 19 with the type 2 pattern was normal on MRI ( $P<0.001$ ). There were 6 femoral heads with normal MRI findings and abnormal SPECT findings (type 1 pattern) in 3 patients, for whom hip pain decreased and radiographic findings were normal during follow-up. Follow-up bone SPECT showed a decreasing area of cold defect in 4 femoral heads. | 1                |
| 15. Luk WH, Au-Yeung AW, Yang MK. Diagnostic value of SPECT versus SPECT/CT in femoral avascular necrosis: preliminary results. <i>Nucl Med Commun.</i> 2010;31(11):958-961.                                | Observational-Dx | 22 patients         | To investigate the clinical value of conventional Tc99m-MDP SPECT against SPECT/CT in diagnosing hip AVN.   | A total of 22 patients and 24 symptomatic hips were analyzed. 7 hips (29%) were confirmed to have AVN. The AUCs obtained from receiver operator characteristic for trainee radiologist for SPECT vs SPECT/CT were 0.828 and 0.916, respectively. The AUC for specialist radiologist increased from 0.916 to 0.941 with CT.  | 2                |

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| 16. Scheiber C, Meyer ME, Dumitresco B, et al. The pitfalls of planar three-phase bone scintigraphy in nontraumatic hip avascular osteonecrosis. <i>Clin Nucl Med.</i> 1999;24(7):488-494.   | Observational-Dx | 143 patients        | To document the previously reported lower sensitivity of routine planar three-phase bone scintigraphy performed using a high-resolution parallel-hole collimator compared with MRI to diagnose nontraumatic AVN of the hip. | For the 6 observers, the A(z) values were 0.65, 0.67, 0.66, 0.67, 0.73, and 0.79, respectively, and 0.66, 0.71, 0.75, 0.81, 0.81, 0.82, and 0.84 after removing hip diseases other than AVN through data manipulation. Bone marrow edema, as seen on MRI, was the most frequently reported misleading sign in false-positive diagnoses, especially in the early or late phases of the disease. False-negative diagnoses misclassified the scans as “asymptomatic hips” in 28/30 cases. 22/30 scans appeared normal, but these AVN lesions were small (<25%) and were discovered by chance on MRIs that displayed bilateral involvement associated with radiographic evidence (stage 0 or 1). 13/20 patients were followed for 3 or more years, and only 1 worsened. | 3             |
| 17. Kamata N, Oshitani N, Sogawa M, et al. Usefulness of magnetic resonance imaging for detection of asymptomatic osteonecrosis of the femoral head in patients with inflammatory bowel disease on long-term corticosteroid treatment. <i>Scand J Gastroenterol.</i> 2008;43(3):308-313. | Observational-Dx | 20 patients         | To assess the usefulness of MRI in diagnosing early osteonecrotic change and to determine whether corticosteroid administration is related to the development of osteonecrosis.   | Osteonecrosis was diagnosed in 5 male patients including 4 in the asymptomatic stage. Cumulative lifetime dose of corticosteroid, duration of corticosteroid treatment, and steroid pulse therapy did not appear to be associated with the development of osteonecrosis. Maximum daily corticosteroid dose was significantly higher for patients with osteonecrosis than for those without it. Administration of 50 mg prednisolone for at least 14 days was a risk factor for osteonecrosis. Development of osteoporosis appeared not to be related to osteonecrosis.  | 4             |

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| 18. Piyakunmala K, Sangkomkamhang T, Chareonchonvanitch K. Is magnetic resonance imaging necessary for normal plain radiography evaluation of contralateral non-traumatic asymptomatic femoral head in high osteonecrosis risk patient. <i>J Med Assoc Thai.</i> 2009;92 Suppl 6:S147-151.            | Review/Other-Dx  | 32 patients                        | To examine the incidence rate and extension of nontraumatic asymptomatic ONFH in high-risk patient groups.   | 32 patients with index femoral head osteonecrosis and nontraumatic asymptomatic contralateral femoral head were studied. Average age of these patients was 46.38 years. The most common risk factors were alcohol (78.12%) and corticosteroid use (18.75%). ONFH was found in 22 patients (68.75%). These hips were in stage VI (87.5%) with 99.05% extension area of osteonecrosis, large extension, C-location, and mix intensity of MRI on index side. We found stage I in all patients (100%), 80.62% extension area of osteonecrosis, large extension, C-location and mix intensity of MRI on ONFH at contralateral side with normal plain radiographic. | 4                |
| 19. Balakrishnan A, Schemitsch EH, Pearce D, McKee MD. Distinguishing transient osteoporosis of the hip from avascular necrosis. <i>Can J Surg.</i> 2003;46(3):187-192.   | Review/Other-Dx  | 10 men                             | To review the circumstances surrounding the misdiagnosis of TOH as AVN and to increase physician awareness of the prevalence and diagnosis of this condition in young men. | 12 hips in 10 young men (mean age 41 years, range from 32–55 years) were identified. 9 men underwent MRI before referral, which showed characteristic changes of TOH. All 10 patients were referred for surgical intervention for a diagnosis of AVN. The correct diagnosis was made after reviewing patients' charts and the scans and was confirmed by spontaneous resolution of both symptoms and MRI findings an average of 5.5 months and 7.5 months, respectively, after consultation.  | 4                |
| 20. Ikemura S, Yamamoto T, Motomura G, Nakashima Y, Mawatari T, Iwamoto Y. MRI evaluation of collapsed femoral heads in patients 60 years old or older: Differentiation of subchondral insufficiency fracture from osteonecrosis of the femoral head. <i>AJR Am J Roentgenol.</i> 2010;195(1):W63-68. | Observational-Dx | 30 consecutive hips in 30 patients | To verify the hypothesis that osteonecrosis and subchondral insufficiency fracture of the femoral head can be differentiated on the basis of their appearance on MRI.      | 16 hips (53.3%) showed evidence of osteonecrosis and 14 (46.7%) showed evidence of subchondral insufficiency fracture, which was consistent with the corresponding histopathologic diagnoses. In all cases of osteonecrosis, the patient had a history of either corticosteroid intake or alcohol abuse. Among patients with subchondral insufficiency fracture, the proportion of women was significantly higher than that among patients with osteonecrosis. A crescent sign (subchondral fracture) was present radiographically in about half of all cases in both groups.   | 3                |



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| 21. Lee YK, Yoo JJ, Koo KH, Yoon KS, Min BW, Kim HJ. Collapsed subchondral fatigue fracture of the femoral head. <i>Orthop Clin North Am.</i> 2009;40(2):259-265.                | Review/Other-Dx  | 9 patients          | To evaluate the follow-up results of subchondral fatigue fractures of the femoral head in which femoral head collapse occurred.  | Collapsed subchondral fatigue fractures of the femoral head have a benign clinical course quite unlike that of collapsed ONFH.   | 4                |
| 22. Kim YM, Oh HC, Kim HJ. The pattern of bone marrow oedema on MRI in osteonecrosis of the femoral head. <i>J Bone Joint Surg Br.</i> 2000;82(6):837-841.                       | Review/Other-Dx  | 200 patients        | To evaluate the MRI of ONFH with particular attention to the bone marrow oedema pattern, to determine if there is any evidence to support the concept of a continuum between transient osteoporosis and osteonecrosis. | The MRIs of consecutive patients with ONFH in respect of the bone marrow oedema pattern were assessed. This pattern was not observed in the early stage of ONFH. The initial abnormal finding detected on the MRIs was an abnormal band of intensity at the junction between the necrotic area and the normal bone. Structural damage of the head seems to result in the appearance of the bone marrow oedema pattern and the development of pain in ONFH. There was no finding to support the existence of a continuum between bone marrow oedemas and ONFH.  | 4                |
| 23. Malizos KN, Zibis AH, Dailiana Z, Hantes M, Karachalios T, Karantanas AH. MR imaging findings in transient osteoporosis of the hip. <i>Eur J Radiol.</i> 2004;50(3):238-244. | Observational-Dx | 42 patients         | To describe the MRI findings including perfusion imaging, in association with the course of acute bone marrow oedema syndrome, in a group of patients with acute hip pain and a final diagnosis of TOH.                | Osteopenia was present on plain radiographs in 87% of cases. The most common pattern of bone marrow oedema was extending to the femoral head and neck. Acetabulum was involved in 16.6%. In 22.6% the bone marrow oedema spared the subchondral region of the femoral head. There were 2 cases (4.7%) with subchondral changes. A joint effusion was noted in 33/42 patients. On perfusion imaging, a delayed peak enhancement was noted in 20 patients between 40 and 65 s after the first pass of contrast. No patient had any evidence of femoral head collapse or change in sphericity on follow-up MRI. None of the patients developed AVN in a time frame of 18 months from the onset of the acute hip pain. | 4                |

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| 24. Vande Berg BC, Malghem JJ, Lecouvet FE, Jamart J, Maldague BE. Idiopathic bone marrow edema lesions of the femoral head: predictive value of MR imaging findings. <i>Radiology</i> . 1999;212(2):527-535. | Observational-Dx | 72 femoral head lesions in 42 men and 25 women | To determine the frequency of several subchondral MRI features observed in bone marrow edema lesions of the femoral head and to determine their value for differentiation of irreversible from transient lesions. | Lack of any additional subchondral change on T2-weighted or contrast-enhanced T1-weighted images had 100% positive predictive value for transient lesions. For irreversible lesions, presence of a subchondral area of low signal intensity at least 4 mm thick or 12.5 mm long had positive predictive values of 85% and 73%, respectively, on T2-weighted images and 87% and 86%, respectively, on contrast-enhanced T1-weighted images.   | 1                |
| 25. Korompilias AV, Karantanas AH, Lykissas MG, Beris AE. Bone marrow edema syndrome. <i>Skeletal Radiol</i> . 2009;38(5):425-436.  | Review/Other-Dx  | N/A  | To review bone marrow edema syndrome.   | Bone marrow edema syndrome is primarily characterized by bone marrow edema pattern. The disease mainly affects the hip, the knee, and the ankle of middle-aged males. Many hypotheses have been proposed to explain the pathogenesis of the disease. Unfortunately, the etiology of bone marrow edema syndrome remains obscure. The hallmark that separates bone marrow edema syndrome from other conditions presented with bone marrow edema pattern is its self-limited nature. Laboratory tests usually do not contribute to the diagnosis. Histological examination of the lesion is unnecessary. Plain radiographs may reveal regional osseous demineralization. MRI is mainly used for the early diagnosis and monitoring the progression of the disease. Early differentiation from other aggressive conditions with long-term sequelae is essential in order to avoid unnecessary treatment. Clinical entities, such as TOH, migratory osteoporosis, and reflex sympathetic dystrophy are spontaneously resolving, and surgical treatment is not needed. On the other hand, early differential diagnosis and surgical treatment in case of osteonecrosis is of crucial importance. | 4                |

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| 26. Miyanishi K, Hara T, Kaminomachi S, Maeda H, Watanabe H, Torisu T. Contrast-enhanced MR imaging of subchondral insufficiency fracture of the femoral head: a preliminary comparison with that of osteonecrosis of the femoral head. <i>Arch Orthop Trauma Surg.</i> 2009;129(5):583-589. | Review/Other-Dx  | 10 hips in 10 patients  | To retrospectively review contrast-enhanced MRIs in patients with subchondral insufficiency fracture and osteonecrosis.  | Low-signal intensity bands on T1-weighted images were present within the femoral head in all hips examined. The segment proximal to the band was contrast-enhanced following intravenous Gd administration in 9 of 10 hips (90%) with subchondral insufficiency fracture and in none of the 10 hips with osteonecrosis.  | 4                |
| 27. Khanna AJ, Yoon TR, Mont MA, Hungerford DS, Bluemke DA. Femoral head osteonecrosis: detection and grading by using a rapid MR imaging protocol. <i>Radiology.</i> 2000;217(1):188-192.   | Observational-Dx | 179 hips in 92 patients | To design and evaluate a limited MRI examination that can be performed rapidly and potentially inexpensively in patients with clinical suspicion of osteonecrosis. | Both examinations were performed successfully in all cases. Agreement between the limited and full examinations for presence of osteonecrosis was 98.9% (177/179 cases; kappa, 0.97). 46 (92%) of 50 patients with femoral head osteonecrosis at both examinations were placed in the appropriate quartile of percentage of femoral head weight-bearing surface involvement by both readers (weighted kappa, 0.94). Incidental findings were made at the full examination that could not be made or were difficult to make at the limited examination.   | 2                |
| 28. May DA, Disler DG. Screening for avascular necrosis of the hip with rapid MRI: preliminary experience. <i>J Comput Assist Tomogr.</i> 2000;24(2):284-287.  | Review/Other-Dx  | 12 patients             | To compare rapidly acquired MRIs with routinely employed spin echo and turbo spin echo images in screening for hip AVN.  | The rapidly acquired MRIs were judged to be similar to the routine protocol in demonstrating marrow edema, irregular lines within the femoral head characteristic of AVN and OA.   | 4                |
| 29. Kim HK, Kaste S, Dempsey M, Wilkes D. A comparison of non-contrast and contrast-enhanced MRI in the initial stage of Legg-Calve-Perthes disease. <i>Pediatr Radiol.</i> 2013;43(9):1166-1173.  | Observational-Dx | 30 children             | To investigate pre- and post-contrast MRI in depicting stage I femoral head involvement.   | Interobserver reliability of percent head involvement using noncontrasted MRIs had intraclass correlation coefficient of 0.72. Post-contrast MRI improved interobserver reliability (intraclass correlation coefficient 0.82). Qualitatively, the area of involvement was more clearly visible on contrast-enhanced MRI. A comparison of results obtained by each observer using the 2 MRI techniques showed no correlation. Intraclass correlation coefficient ranged from -0.08 to 0.03 for each observer. Generally, greater head involvement was depicted by contrast compared with noncontrast MRI (Pearson $r = -0.37$ , $P=0.04$ ). | 3                |

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| 30. Du J, Lu A, Dempsey M, Herring JA, Kim HK. MR perfusion index as a quantitative method of evaluating epiphyseal perfusion in Legg-Calve-Perthes disease and correlation with short-term radiographic outcome: a preliminary study. <i>J Pediatr Orthop</i> . 2013;33(7):707-713. | Observational-Dx | 20 patients                       | To develop a reliable method to quantify femoral head perfusion using this MRI technique and to determine whether the perfusion at early stages of Perthes disease correlates with radiographic deformity after a 2-year follow-up. | The intraobserver agreement assessed by the intraclass correlation coefficient was 0.96 for observer 1 and 0.97 for observer 2. The interobserver agreement of the MR perfusion index was 0.90 for trials 1 and 2. MR perfusion index in the early stages of Perthes disease was highly variable, ranging from 0 to 0.70. After a minimum of 2 years following MRI acquisition, radiographs were obtained and evaluated using the deformity index, a continuous measure of femoral head deformity, by 2 blinded observers. Deformity index at 2-year follow-up showed moderate correlation with predeformity MR perfusion index ( $r=-0.56$ , $P=0.01$ , $R=0.31$ ). In those patients who were treated nonoperatively, the correlation was stronger ( $r=-0.79$ , $P=0.006$ , $R=0.63$ ). | 3                |
| 31. Chan WP, Liu YJ, Huang GS, et al. Relationship of idiopathic osteonecrosis of the femoral head to perfusion changes in the proximal femur by dynamic contrast-enhanced MRI. <i>AJR Am J Roentgenol</i> . 2011;196(3):637-643.  | Observational-Dx | 12 patients (14 symptomatic hips) | To relate intramedullary perfusion of the proximal femur to severity of ONFH by using dynamic contrast-enhanced MRI.  | Compared with control hips, there was significantly greater peak enhancement in the femoral head in hips of all grades ( $P<0.001$ ) and in the femoral neck ( $P=0.001$ ) and intertrochanteric area ( $P=0.001$ ) in grade 2 hips. The time to peak was significantly delayed in the femoral head in grade 0 hips ( $P=0.02$ ) and in the intertrochanteric area in grade 2 hips ( $P=0.003$ ) compared with the controls.   | 2                |

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|---|------------------|--------------------------|---|---|------------------|
| 32. Kaushik A, Sankaran B, Varghese M. Prognostic value of dynamic MRI in assessing post-traumatic femoral head vascularity. <i>Skeletal Radiol.</i> 2009;38(6):565-569.                      | Observational-Dx | 30 patients with 31 hips | To evaluate the role of dynamic MRI in predicting femoral head vascularity and thereby AVN after intracapsular femoral neck fractures.            | Fractures were divided into 3 types (Type A, B, or C) based on the femoral head vascularity shown by dynamic curve patterns on MRI evaluation. Type A was preserved vascularity, Type B was some decrease in vascularity but still viable while Type C was significantly reduced vascularity. Type A curves correlate well with vascular status and Type C curves correlate well with poor vascularity of the femoral heads. No AVN was seen in any of Type A (13/31) or Type B (8/31). 5 cases showed AVN and all of them were of Type C dynamic curves. Dynamic MRI is a reliable tool to evaluate vascularity of femoral heads and thus reduces the uncertainty of outcome of treatment of intracapsular femoral neck fractures. Dynamic MRI can be a useful tool to formulate a treatment algorithm in management of intracapsular femoral neck fracture. | 3                |
| 33. Lee JH, Dyke JP, Ballon D, Ciombor DM, Tung G, Aaron RK. Assessment of bone perfusion with contrast-enhanced magnetic resonance imaging. <i>Orthop Clin North Am.</i> 2009;40(2):249-257. | Observational-Dx | 22 patients; 24 animals  | To discuss the use of novel noninvasive imaging techniques as a means of assessing bone perfusion and quantifying differences seen in OA and AVN. | Review of the human data suggests that the MRI contrast dye is retained for longer periods of time, suggesting decreased perfusion out of regions of OA and AVN. Use of such a noninvasive measure of assessing bone perfusion could be useful in the diagnosis, prevention, and treatment of not only OA and AVN but also other entities that affect the musculoskeletal system.   | 4                |

**Osteonecrosis of the Hip  
EVIDENCE TABLE**

| Reference   | Study Type       | Patients/<br>Events | Study Objective<br>(Purpose of Study)  | Study Results   | Study<br>Quality |
|---|------------------|---------------------|--|---|------------------|
| 34. Camporesi EM, Vezzani G, Bosco G, Mangar D, Bernasek TL. Hyperbaric oxygen therapy in femoral head necrosis. <i>J Arthroplasty</i> . 2010;25(6 Suppl):118-123.  | Experimental-Tx  | 20 patients         | To evaluate hyperbaric oxygen therapy on a cohort of patients with femoral head necrosis.                                    | Each patient received 30 treatments of hyperbaric oxygen or hyperbaric air for 6 weeks. Range of motion, stabilometry, and pain were assessed at the beginning of the study and after 10, 20, and 30 treatments by a blinded physician. After the initial 6-week treatment, the blind was broken; and all hyperbaric air patients were offered hyperbaric oxygen treatment. At this point, the study becomes observational. Pretreatment, 12-month and 7 year-follow-up MRIs were obtained. Statistical comparisons were obtained with nonparametric Mann-Whitney U test. Significant pain improvement for hyperbaric oxygen was demonstrated after 20 treatments. Range of motion improved significantly during hyperbaric oxygen for all parameters between 20 and 30 treatments. All patients remain substantially pain-free 7 years later: none required hip arthroplasty. Substantial radiographic healing of the osteonecrosis was observed in 7 of 9 hips. | 1                |
| 35. Mackenzie JD, Hernandez A, Pena A, et al. Magnetic resonance imaging in children with sickle cell disease--detecting alterations in the apparent diffusion coefficient in hips with avascular necrosis. <i>Pediatr Radiol</i> . 2012;42(6):706-713. | Observational-Dx | 44 children         | To examine the ability of ADC measurements on diffusion-weighted imaging to detect AVN in children with sickle cell disease. | The ADC values were elevated in the hips of children with AVN (median ADC = 1.57 x 10 <sup>-3</sup> mm <sup>2</sup> /s [95% CI = 0.86–2.10]) and differed significantly in pairwise comparisons (all P<0.05) from normal children (0.74 [0.46–0.98]), asymptomatic children with sickle cell disease (0.55 [0.25–0.85]), and sickle cell disease children who had symptoms referable to their hips but did not show findings of hip AVN on conventional MRI or radiographs (0.46 [0.18–0.72]).  | 3                |

**Osteonecrosis of the Hip  
EVIDENCE TABLE**

| Reference  | Study Type       | Patients/<br>Events  | Study Objective<br>(Purpose of Study)   | Study Results   | Study<br>Quality |
|--|------------------|--|---|---|------------------|
| 36. Oner AY, Aggunlu L, Akpek S, et al. Staging of hip avascular necrosis: is there a need for DWI? <i>Acta Radiol.</i> 2011;52(1):111-114.  | Observational-Dx | 35 femoral heads of 21 cases affected by AVN; 10 as control group                  | To determine ADC alterations in hip AVN and to determine variations of ADC values according to stages of disease.   | The median ADC value of normal bone measured in control group was 185.5 +/- 133.2 x 10 <sup>(-6)</sup> mm <sup>(2)</sup> /s. The median ADC value measured in hip AVN lesions was 988.0 +/- 332.7 x 10 <sup>(-6)</sup> mm <sup>(2)</sup> /s. ADC values in hip AVN lesions were statistically significantly higher than normal bone marrow ( $P < 0.01$ ). The median ADC values of hips with AVN at stage I, II, III, IV were 817.5 +/- 172.1 x 10 <sup>(-6)</sup> mm <sup>(2)</sup> /s, 902.0 +/- 181.0 x 10 <sup>(-6)</sup> mm <sup>(2)</sup> /s, 1200.0 +/- 363.2 x 10 <sup>(-6)</sup> mm <sup>(2)</sup> /s and 1024.0 +/- 324.0 x 10 <sup>(-6)</sup> mm <sup>(2)</sup> /s, respectively. There was no statistically significant difference among AVN lesions at stages I, II, III and IV ( $P > 0.05$ ). | 3                |
| 37. Yamamoto S, Watanabe A, Nakamura J, et al. Quantitative T2 mapping of femoral head cartilage in systemic lupus erythematosus patients with noncollapsed osteonecrosis of the femoral head associated with corticosteroid therapy. <i>J Magn Reson Imaging.</i> 2011;34(5):1151-1158. | Observational-Dx | 14 healthy volunteers (control group) and 10 systemic lupus erythematosus patients | To evaluate articular cartilage degeneration with transverse relaxation time (T2) mapping in systemic lupus erythematosus patients with noncollapsed and asymptomatic ONFH associated with corticosteroids. | T2 values of the femoral head cartilage were significantly higher in the osteonecrosis group than in the control group (34.4 msec vs 30.8 msec, $P = 0.001$ ). Multiple regression analysis revealed that the osteonecrosis group and decreased center-edge angle was significantly associated with high T2 values (T2 value = 34.6 + 3.6 x [osteonecrosis] - 0.14 x center-edge angle, $R(2) = 0.52$ , $P = 0.003$ ).  | 3                |
| 38. Min BW, Song KS, Cho CH, Lee SM, Lee KJ. Untreated asymptomatic hips in patients with osteonecrosis of the femoral head. <i>Clin Orthop Relat Res.</i> 2008;466(5):1087-1092.  | Observational-Dx | 152 patients   | To use MRI to confirm asymptomatic ONFH in patients whose other hip had nontraumatic symptomatic osteonecrosis.   | The minimum follow-up was 5 years (mean, 8.3 years; range, 5–16 years). At the latest follow-up, 31 hips (38%) were symptomatic and 26 hips (32%) had collapsed. The mean interval between diagnosis and collapse was 4.1 years. We observed no correlation between femoral head collapse and patients' age, gender, weight, presumed cause of osteonecrosis, or length of follow-up. With combined factors, only extent of large necrotic lesion (hazard ratio, 4.06; 95% CI, 1.29–12.77) and location of Type C2 necrotic lesion (hazard ratio, 6.35; 95% CI, 1.18–34.11) predicted collapse.   | 2                |

**Osteonecrosis of the Hip  
EVIDENCE TABLE**

| Reference  | Study Type       | Patients/<br>Events | Study Objective<br>(Purpose of Study)  | Study Results   | Study<br>Quality |
|--|------------------|---------------------|--|---|------------------|
| 39. Nam KW, Kim YL, Yoo JJ, Koo KH, Yoon KS, Kim HJ. Fate of untreated asymptomatic osteonecrosis of the femoral head. <i>J Bone Joint Surg Am.</i> 2008;90(3):477-484.  | Review/Other-Dx  | 105 hips            | To evaluate the fate of untreated asymptomatic ONFH with an emphasis on the size of the lesion.                        | 62 hips became symptomatic, and 43 hips remained asymptomatic for more than 5 years (average, 8 years and 7 months). Of the 21 hips with a small necrotic lesion (<30% of the area of the femoral head), 1 became painful; of the 24 hips with a medium-sized necrotic lesion (30% to 50% of the area of the femoral head), 11 became painful; and of the 60 hips with a large necrotic lesion (>50% of the area of the femoral head), 50 became painful. 46/62 hips that became symptomatic required surgery. Pain developed within 5 years after the diagnosis in 58 (94%) of the 62 symptomatic hips.  | 4                |
| 40. Ha AS, Wells L, Jaramillo D. Importance of sagittal MR imaging in nontraumatic femoral head osteonecrosis in children. <i>Pediatr Radiol.</i> 2008;38(11):1195-1200. | Observational-Dx | 34 patients         | To hypothesize that sagittal MRIs show a greater degree and angular span of femoral head collapse than coronal images. | Sagittal MRIs showed 29% maximal femoral head radius collapse, whereas coronal images showed 16% collapse ( $P<0.001$ ). Sagittal images showed a larger angular span of collapse (115 degrees) than coronal images (55 degrees, $P<0.001$ ). Sagittal images showed greater epiphyseal bone loss in the anterior than in the posterior portion ( $P<0.001$ ), whereas coronal images did not show a significant difference in bone loss between the medial and lateral portion ( $P=0.32$ ).   | 2                |
| 41. Liu B, Yi H, Zhang Z, Li Z, Yue D, Sun W. Association of hip joint effusion volume with early osteonecrosis of the femoral head. <i>Hip Int.</i> 2012;22(2):179-183. | Observational-Dx | 109 patients        | To examine the association between hip joint effusion volume and ONFH using the ARCO classification.                   | Out of 109 patients included in this study, 185 hip joints were involved (unilateral disease in 33 patients and bilateral diseases in 76 patients). The patients had a mean age of 39 +/- 11 years (range, 13–70). All the affected hip joints exhibited effusion, classified as grade 1 (n = 70, 37.8%), grade 2 (n = 62, 33.5%), and grade 3 (n = 53, 28.7%). The volume of joint effusion varied significantly among stage I, II, and III ( $X^2 = 29.210$ , $P<0.05$ ). The effusion volume did not differ significantly among stage IIA, IIB, and IIC ( $X^2 = 0.103$ , $P>0.05$ ), whereas it differed significantly among stage IIIA, IIIB, and IIIC ( $X^2 = 11.556$ , $P<0.05$ ). The volume of hip joint effusion was associated with the ARCO stage, and increased over the staging. | 3                |

\* See Last Page for Key



**Osteonecrosis of the Hip  
EVIDENCE TABLE**

| Reference   | Study Type       | Patients/<br>Events | Study Objective<br>(Purpose of Study)   | Study Results  | Study<br>Quality |
|---|------------------|---------------------|---|--|------------------|
| 42. Schmitt-Sody M, Kirchhoff C, Mayer W, Goebel M, Jansson V. Avascular necrosis of the femoral head: inter- and intraobserver variations of Ficat and ARCO classifications. <i>Int Orthop</i> . 2008;32(3):283-287. | Observational-Dx | 38 patients         | To evaluate interobserver as well as intraobserver reliability and variability of commonly used parameters of Ficat and ARCO on plain radiographs and MRIs for the classification of femoral head necrosis. | In all, 38 patients (54 hips) were enrolled. There were 10 patients who presented with radiographs and 28 patients with radiographs and MR scans. Paired comparisons revealed a mean interobserver kappa reliability coefficient of 0.39 for the first and of 0.32 for the second review using the Ficat classification for radiographs, whereas for the MRIs a mean of 0.39 in the first and of 0.34 in the second reading resulted. The MRI evaluation using the ARCO classification resulted in a mean interobserver reliability coefficient of 0.37 in the first and of 0.31 in the second reading. The mean kappa value for intraobserver reproducibility using the Ficat classification was 0.52 for radiographs and 0.50 for MRIs, whereas a reproducibility of 0.43 resulted for the ARCO classification.  | 2                |
| 43. Zhao FC, Li ZR, Zhang NF, et al. Lesion size changes in osteonecrosis of the femoral head: a long-term prospective study using MRI. <i>Int Orthop</i> . 2010;34(6):799-804.                                       | Observational-Dx | 51 patients         | To use MRI to observe the lesion size changes of ONFH induced by corticosteroid administration in severe acute respiratory syndrome patients.   | The study included 51 severe acute respiratory syndrome patients (84 hips) with early-stage ONFH who did not receive any operative treatment and were diagnosed by MRI. All of the patients underwent MRI follow-ups. Each patient was evaluated on the basis of the lesion volume on MRI at every follow-up for further comparisons. At the first MRI scan, the mean lesion volume was 10.12 +/- 8.05 cm(3) (range: 0.39–41.62 cm(3)). At the mid-term follow-up (2.5 years), the mean lesion volume was 7.82 +/- 7.59 cm(3) (range: 0.11–39.65 cm(3)). At the final follow-up (5 years), complete regression of the lesion was observed in 6 hips, and the mean lesion volume was 5.67 +/- 6.58 cm(3) (range: 0.00–31.47 cm(3)). Overall, the lesion volume was reduced by >15% in 80 hips, and only 4 hips with relatively larger lesion volumes showed no apparent reductions. The reduction in lesion size of ONFH observed on MRI is a slow, discontinuous and time-dependent process. | 3                |

**Osteonecrosis of the Hip  
EVIDENCE TABLE**

| Reference   | Study Type       | Patients/<br>Events                      | Study Objective<br>(Purpose of Study)   | Study Results   | Study<br>Quality |
|---|------------------|--|---|---|------------------|
| 44. Aldridge JM, 3rd, Urbaniak JR. Vascularized fibular grafting for osteonecrosis of the femoral head with unusual indications. <i>Clin Orthop Relat Res.</i> 2008;466(5):1117-1124.                               | Review/Other-Dx  | 154 patients                             | To retrospectively review the charts of patients of various subgroups treated with the free vascularized fibular graft procedure for ONFH, evaluating pre- and postoperative Harris hip scores, hip range of motion, radiographs, and number of conversions to THA. | Patients were followed a minimum of 1 year (mean, 6.8 years, range, 1 to 19 years). Athletes and patients with pyarthrosis-related osteonecrosis had high Harris hip scores at final review with scores of 94 and 97, respectively. Patients with ONFH after a slipped capital femoral epiphysis or following pregnancy had a low conversion rate to THA at 6% and 8%, respectively. 25% of patients with transplant-related ONFH were converted to THA at an average of 2.7 years.   | 4                |
| 45. Chen JM, Hsu SL, Wong T, Chou WY, Wang CJ, Wang FS. Functional outcomes of bilateral hip necrosis: total hip arthroplasty versus extracorporeal shockwave. <i>Arch Orthop Trauma Surg.</i> 2009;129(6):837-841. | Observational-Dx | 17 patients                              | To compare the functional outcomes of THA in 1 and ESWT in the other in 17 patients with bilateral hip necrosis.  | The evaluations included pain score and Harris hip score, radiographs and MRIs. The magnitudes of improvement in pain and function favored the ESWT side. 13 patients rated ESWT better than THA; 4 patients reported comparable results between THA and ESWT, and none graded THA better than ESWT. Better functional outcomes were observed after ESWT for early hip necrosis than THA for late cases in patients with bilateral hip disease.   | 3                |
| 46. Hofstaetter JG, Wang J, Yan J, Glimcher MJ. The effects of alendronate in the treatment of experimental osteonecrosis of the hip in adult rabbits. <i>Osteoarthritis Cartilage.</i> 2009;17(3):362-370.         | Observational-Tx | 60 adult, male New Zealand white rabbits | To characterize the effects of alendronate on the repair process of the osteonecrotic femoral head as well as the development of secondary OA in the ipsilateral hip in an established experimental model of osteonecrosis.   | Repair in the osteonecrotic femoral head in the placebo group led to a significantly increased bone volume fraction and volumetric bone mineral density in the trabecular region and to an increase in porosity in the cortical and subchondral region when compared to the normal femoral head on the contralateral side. Alendronate treatment significantly further increased bone volume fraction and volumetric bone mineral density in the trabecular region, and significantly reduced porosity and increased volumetric bone mineral density in the necrotic subchondral and cortical bone when compared to placebo. Alendronate led to a significant increase in volumetric bone mineral density in the subchondral region of the osteoarthritic acetabulum as well as to a significant reduction in articular cartilage degeneration. | 1                |

**Osteonecrosis of the Hip  
EVIDENCE TABLE**

| Reference   | Study Type              | Patients/<br>Events | Study Objective<br>(Purpose of Study)  | Study Results   | Study<br>Quality |
|---|-------------------------|---------------------|--|---|------------------|
| <p>47. Hsu JE, Wihbey T, Shah RP, Garino JP, Lee GC. Prophylactic decompression and bone grafting for small asymptomatic osteonecrotic lesions of the femoral head. <i>Hip Int.</i> 2011;21(6):672-677.</p> | <p>Observational-Tx</p> | <p>37 patients</p>  | <p>To evaluate the outcome of core decompression in the asymptomatic hip with osteonecrosis.</p> | <p>37 consecutive patients with MRI confirmed osteonecrosis of the hips that underwent simultaneous bilateral core decompression and bone grafting were followed. Prior to surgery, only 1 of the hips was symptomatic, and the main indication for surgical decompression of the asymptomatic side was to prevent disease progression. No hip on the asymptomatic side was staged greater than Steinberg IIB classification. Serial radiographs were followed for evidence of disease progression. 6 patients were lost to follow-up prior to 2 years. The remaining 31 patients were followed for an average of 32.6 months. There were 20 men and 11 women with an average age of 40.6 years. 10 patients with asymptomatic hips at the time of surgical decompression had disease progression requiring THA. The mean time to arthroplasty in this group was 15.1 months. Meanwhile, 13 symptomatic hips at the initial surgery progressed to THA at an average of 12.9 months following core decompression. The proportion of hips requiring conversion to THA was similar between the 2 groups (<math>P=0.30</math>), and the rate of progression to THA was not significantly faster compared to patients with symptomatic hips who subsequently required THA (<math>P=0.18</math>).</p> | <p>1</p>         |

**Osteonecrosis of the Hip  
EVIDENCE TABLE**

| Reference   | Study Type       | Patients/<br>Events  | Study Objective<br>(Purpose of Study)   | Study Results  | Study<br>Quality |
|---|------------------|--|---|--|------------------|
| 48. Sen RK, Tripathy SK, Aggarwal S, Marwaha N, Sharma RR, Khandelwal N. Early results of core decompression and autologous bone marrow mononuclear cells instillation in femoral head osteonecrosis: a randomized control study. <i>J Arthroplasty</i> . 2012;27(5):679-686. | Experimental-Tx  | 40 patients  | To evaluate the early results of bone marrow mononuclear cells instillation into the femur head after multiple small drill holes in ARCO stage I/II osteonecrotic hips. | 51 osteonecrotic hips in 40 patients were randomly divided into 2 treatment groups. Patients in group A (25 hips) were treated with core decompression, and those in group B (26 hips) received autologous bone marrow mononuclear cell instillation into the core tract after core decompression. Outcome between the 2 groups were compared clinically (Harris Hip score), radiographically (x-ray and MRI), and by Kaplan-Meier hip survival analysis after 12 and 24 months of surgical intervention. The clinical score and mean hip survival were significantly better in group B than in group A ( $P < .05$ ). Patients with adverse prognostic features at initial presentation, that is, poor Harris Hip score, x-ray changes, edema, and/or effusion on MRI had significantly better clinical outcome and hip survival in group B than in group A.  | 1                |
| 49. Tetik C, Basar H, Bezer M, Erol B, Agir I, Esemeli T. Comparison of early results of vascularized and non-vascularized fibular grafting in the treatment of osteonecrosis of the femoral head. <i>Acta Orthop Traumatol Turc</i> . 2011;45(5):326-334.                    | Observational-Tx | 11 osteonecrotic hips of 8 patients who underwent vascularized fibular grafting; 15 osteonecrotic hips of 13 patients who underwent nonvascularized fibular grafting | To compare the results of vascularized fibular grafting with that of nonvascularized fibular grafting in the treatment of femoral head osteonecrosis.                   | Steroid use was the most common etiologic factor, found in 26 hips of 21 patients in the entire patient population. There was no significant difference between the 2 groups according to their age, sex and preoperative Harris hip scores ( $P > 0.05$ ). According to the Ficat staging system for radiological evaluation, 4 hips were Grade 2A, 4 hips were Grade 2B, and 3 hips were Grade 3 in the vascularized group and 8 hips were Grade 2A, 3 hips Grade 2B, 3 hips Grade 3 and 1 hip was identified as Grade 4 in the nonvascularized group. When the Harris hip and VAS scores of both groups were evaluated, the group treated by vascularized fibular grafting had significantly higher scores than the ones treated by nonvascularized fibular grafting in the other group ( $P < 0.05$ ). Furthermore, when the Harris hip and VAS scores of preoperative and postoperative first year of vascularized fibular grafting patients were compared, there were significantly higher scores after the surgery. | 1                |

**Osteonecrosis of the Hip  
EVIDENCE TABLE**

| Reference  | Study Type       | Patients/<br>Events      | Study Objective<br>(Purpose of Study)   | Study Results  | Study<br>Quality |
|--|------------------|--------------------------|---|--|------------------|
| 50. Wang CJ, Wang FS, Yang KD, et al. Treatment of osteonecrosis of the hip: comparison of extracorporeal shockwave with shockwave and alendronate. <i>Arch Orthop Trauma Surg.</i> 2008;128(9):901-908. | Experimental-Tx  | 48 patients with 60 hips | To compare the results of ESWT and alendronate with that of ESWT without alendronate in early ONFH. | The overall clinical outcomes were improved in 83%, unchanged in 7% and worsened in 10% for group A; and improved in 77%, unchanged in 13% and worsened in 10% for group B. THA was performed in 10% of group A and 10% of group B ( $P=1.000$ ). Significant improvements in pain and function of the hip were noted in both groups ( $P<0.001$ ), however, the differences between the 2 groups were not significant ( $P=0.400$ , 0.313). On MRIs, the lesions showed progression in 10%, regression in 47% and unchanged in 43% in group A, and progression in 7%, regression in 53% and unchanged in 40% in group B ( $P=0.830$ ).                      | 1                |
| 51. Wong T, Wang CJ, Hsu SL, Chou WY, Lin PC, Huang CC. Cocktail therapy for hip necrosis in SARS patients. <i>Chang Gung Med J.</i> 2008;31(6):546-553.   | Observational-Tx | 4 patients               | To evaluate the outcomes of cocktail therapy with a 4-year follow-up.                               | At the 4-year follow-up, significant improvements in pain score and Harris hip score were observed in all cases ( $P<0.001$ ). All patients returned to work as healthcare providers. None required surgical intervention including hip replacement. MRI showed a trend of reduction in bone marrow edema and the size of the lesion, but no changes in the stage of the lesion.   | 1                |
| 52. Aigner N, Schneider W, Eberl V, Knahr K. Core decompression in early stages of femoral head osteonecrosis--an MRI-controlled study. <i>Int Orthop.</i> 2002;26(1):31-35.                             | Review/Other-Dx  | 39 patients              | To assess the efficacy of core decompression in early stages of ONFH.                               | Average age of patients was 41 (27–68) years and average follow-up 68.9 (31–120) months. In 30 hip joints in stage I, 29 showed no radiographic progression and a complete remission of the changes consistent with necrosis on MRI at the last follow-up. In 27 patients the clinical result based on the Harris hip score assessment was excellent (average 91.9 points). Of 9 hips in stage II, 4 had received a THA, 1 had deteriorated to stage IV, and 4 were still classified as stage II (average Harris hip score 95 points). Of 6 hips in stage III, 3 had received a THA and 3 had deteriorated to stage IV (average Harris hip score 73 points). | 4                |

**Osteonecrosis of the Hip  
EVIDENCE TABLE**

| Reference  | Study Type       | Patients/<br>Events | Study Objective<br>(Purpose of Study)  | Study Results  | Study<br>Quality |
|--|------------------|---------------------|--|--|------------------|
| 53. Yoshida T, Kanayama Y, Okamura M, Negoro N, Inoue T, Yoshikawa J. Long-term observation of avascular necrosis of the femoral head in systemic lupus erythematosus: an MRI study. <i>Clin Exp Rheumatol</i> . 2002;20(4):525-530. | Observational-Dx | 13 patients         | To assess long-term prognosis of clinically silent, early-stage AVN of the femoral head in patients with systemic lupus erythematosus. | 15 hips improved (more than 15% reduction in the volume of necrosis), 5 did not change and 4 worsened during the observation period. All hips with a volume of necrotic area less than 25% showed improvement. All but 1 Type A hip and 1 Type B hip improved, while the mean volume of necrosis did not change in Type C. The volume of the necrotic area was smaller in Type A & B than in Type C hips ( $P<0.001$ ).  | 3                |
| 54. Joseph B, Rao N, Mulpuri K, Varghese G, Nair S. How does a femoral varus osteotomy alter the natural evolution of Perthes' disease? <i>J Pediatr Orthop B</i> . 2005;14(1):10-15.  | Review/Other-Dx  | 314 patients        | To study how a femoral osteotomy alters the natural evolution of Perthes' disease, records and radiographs.                            | It was observed that a varus osteotomy clearly alters the natural evolution of Perthes' disease. Of patients who were operated in the stage of AVN, 34% bypassed the stage of fragmentation. The duration of the disease was shorter in these patients. The duration of the stage of fragmentation was reduced in operated children who passed through the stage of fragmentation. The extent of femoral head extrusion was minimized at the stage when it was most vulnerable for deformation. Metaphyseal widening and subsequent femoral head enlargement were also minimized in children who underwent a femoral osteotomy. The chances of retaining the sphericity of the femoral head were much higher in those children who had a femoral osteotomy. These beneficial effects of a varus osteotomy, were most evident when the operation was performed either in the stage of AVN or in the early stage of fragmentation. | 4                |

**Osteonecrosis of the Hip  
EVIDENCE TABLE**

| Reference   | Study Type       | Patients/<br>Events | Study Objective<br>(Purpose of Study)  | Study Results   | Study<br>Quality |
|---|------------------|---------------------|--|---|------------------|
| 55. Hernigou P, Habibi A, Bachir D, Galacteros F. The natural history of asymptomatic osteonecrosis of the femoral head in adults with sickle cell disease. <i>J Bone Joint Surg Am.</i> 2006;88(12):2565-2572.   | Review/Other-Dx  | 121 patients        | To review the natural history of asymptomatic osteonecrosis of the femoral head.   | At the time of the initial evaluation, 56 hips were classified as Steinberg stage 0, 42 hips were classified as Steinberg stage I, and 23 hips were classified as Steinberg stage II. At the time of the most recent follow-up, pain had developed in 110 previously asymptomatic hips (91%) and collapse had occurred in 93 hips (77%). Symptoms always preceded collapse. Of the 56 hips that were classified as Steinberg stage 0 at the time of the initial evaluation, 47 (84%) had symptomatic osteonecrosis and 34 (61%) had collapse at the time of the most recent follow-up. Of the 42 asymptomatic stage-I hips, 40 (95%) became symptomatic within 3 years and 36 (86%) had collapse of the femoral head. Of the 23 asymptomatic stage-II hips, all became symptomatic within 2 years and all collapsed; the mean interval between the onset of pain and collapse was 11 months. At the time of the final follow-up, 91 one hips (75%) had intractable pain and required surgery. | 4                |
| 56. Nagasawa K, Tada Y, Koarada S, et al. Very early development of steroid-associated osteonecrosis of femoral head in systemic lupus erythematosus: prospective study by MRI. <i>Lupus.</i> 2005;14(5):385-390. | Observational-Dx | 45 patients         | To define prospectively the early development of corticosteroid-induced ONFH in patients with systemic lupus erythematosus and to identify the association of initial steroid treatment with the development of early (silent) ONFH. | Of 45 patients, 15 (33%) developed silent ONFH and 5 (11%) symptomatic ONFH. It was of interest that MRI detected silent ONFH very early (by 3 months) in 14 patients (93%). It should be noted that pulse therapy with 1000 mg/day methylprednisolone was found to be done very frequently (13/15, 87%) in the silent ONFH group compared to non-ONFH group (11/30, 37%) ( $P<0.01$ ) although other clinical features were not significantly different between both groups. High dose corticosteroids caused elevation of serum levels of total cholesterol, albumin, and leukocyte count in most of patients. The degree of elevation of those parameters at 1 or 3 months was more prominent in the silent ONFH group. In particular, the change ratio of total cholesterol at 1 month was outstanding in the silent ONFH group compared to non-ONFH group (0.551 vs 0.374, $P<0.05$ ).   | 2                |

**Osteonecrosis of the Hip  
EVIDENCE TABLE**

| Reference   | Study Type       | Patients/<br>Events | Study Objective<br>(Purpose of Study)   | Study Results  | Study<br>Quality |
|---|------------------|---------------------|---|--|------------------|
| 57. Nadel SN, Debatin JF, Richardson WJ, et al. Detection of acute avascular necrosis of the femoral head in dogs: dynamic contrast-enhanced MR imaging vs spin-echo and STIR sequences. <i>AJR Am J Roentgenol.</i> 1992;159(6):1255-1261. | Observational-Dx | 5 dogs              | To compare dynamic contrast-enhanced MRI with conventional spin-echo and short TI inversion-recovery sequences for detecting acute osteonecrosis in an animal model.                                      | Spin-echo and spin-echo and short TI inversion-recovery images did not show any acute changes in the ischemic femoral heads. In contrast, significant differences were present in the enhancement profiles of the marrow spaces in the normal and ischemic femoral heads ( $P=.005$ ). Normal marrow was characterized by rapid enhancement, with an average signal intensity increase of 83% peaking at 36 sec; no measurable enhancement was seen in the marrow of the ischemic femoral head. Spin-echo images, obtained 7 days after devascularization ( $n = 2$ ), showed changes characteristic of AVN. Dynamic contrast-enhanced MRIs showed persistent lack of enhancement in the avascular marrow of the ischemic femoral head. A junctional zone, characterized by rapid contrast enhancement in excess of 120% without early washout, was identified at the interface between normal and avascular marrow. | 3                |
| 58. Catto M. A histological study of avascular necrosis of the femoral head after transcervical fracture. <i>J Bone Joint Surg Br.</i> 1965;47(4):749-776.  | Review/Other-Dx  | N/A                 | To review AVN of the femoral head after transcervical fracture.   | No results stated in abstract.   | 4                |
| 59. Lang P, Mauz M, Schorner W, et al. Acute fracture of the femoral neck: assessment of femoral head perfusion with gadopentetate dimeglumine-enhanced MR imaging. <i>AJR Am J Roentgenol.</i> 1993;160(2):335-341.                        | Review/Other-Dx  | 13 patients         | To evaluate the use of MRI, before and after intravenous administration of gadopentetate dimeglumine, for assessing perfusion of the femoral head in 13 patients with acute fracture of the femoral neck. | Digital subtraction angiography showed impaired blood supply to the femoral head in 5 patients. On contrast-enhanced MRIs of these patients, the femoral head did not enhance and was lower in signal intensity than were the enhancing femoral shaft and neck distal to the fracture and the enhancing femoral head on the unaffected side. In the patients with persistent perfusion, contrast-enhanced MRIs showed a uniform increase in signal intensity in the femoral shaft and neck as well as the femoral head; the femoral head on the fractured side showed contrast enhancement similar to that on the healthy side.  | 4                |



**Osteonecrosis of the Hip  
EVIDENCE TABLE**

| Reference   | Study Type       | Patients/<br>Events | Study Objective<br>(Purpose of Study)   | Study Results  | Study<br>Quality |
|---|------------------|---------------------|---|--|------------------|
| 60. Lamer S, Dorgeret S, Khairouni A, et al. Femoral head vascularisation in Legg-Calve-Perthes disease: comparison of dynamic gadolinium-enhanced subtraction MRI with bone scintigraphy. <i>Pediatr Radiol.</i> 2002;32(8):580-585.         | Observational-Dx | 23 children         | To compare dynamic gadolinium-enhanced subtraction MRI and bone scintigraphy in the assessment of femoral head perfusion in Legg-Calve-Perthes disease.   | Total agreement between both techniques was noted in the depiction of epiphyseal necrosis (kappa=1), and metaphyseal abnormalities (kappa=0.9). Dynamic gadolinium-enhanced subtraction MRI demonstrated better revascularization in the lateral (kappa=0.62) and medial pillars (kappa=0.52). The presence of basal transphyseal reperfusion was more conspicuous with MRI.   | 3                |
| 61. Sebag G, Ducou Le Pointe H, Klein I, et al. Dynamic gadolinium-enhanced subtraction MR imaging--a simple technique for the early diagnosis of Legg-Calve-Perthes disease: preliminary results. <i>Pediatr Radiol.</i> 1997;27(3):216-220. | Review/Other-Dx  | 4 patients          | To determine whether the simple technique of dynamic gadolinium-enhanced subtraction MRI, which is available on standard MR units, can detect ischemia of the femoral head in children with early Legg-Calve-Perthes disease. | Subtraction MRI depicted ischemia as a widespread absence of enhancement and was in good agreement with bone scintigraphy. The subtraction technique improved the sensitivity and the specificity of MRI in 2 children. Furthermore, subtraction MRI allowed recognition of the pattern of early reperfusion.  | 4                |
| 62. Beltran J, Knight CT, Zuelzer WA, et al. Core decompression for avascular necrosis of the femoral head: correlation between long-term results and preoperative MR staging. <i>Radiology.</i> 1990;175(2):533-536.                         | Observational-Dx | 24 patients         | To assess the potential correlation between the extent of AVN, as determined with preoperative MRI, and development of collapse.  | The preoperative MR results were classified into 4 categories: group A, no AVN; group B, less than 25% involvement of the weight-bearing portion of the femoral head; group C, 25%–50% involvement; and group D, >50% involvement. Histologic evidence of AVN was found in all 34 hips. Collapse occurred in none of the hips in groups A and B (n = 12), in 3 of 7 hips (43%) in group C, and in 13 of 15 hips (87%) in group D.        | 2                |
| 63. Shimizu K, Moriya H, Akita T, Sakamoto M, Suguro T. Prediction of collapse with magnetic resonance imaging of avascular necrosis of the femoral head. <i>J Bone Joint Surg Am.</i> 1994;76(2):215-223.                                    | Review/Other-Dx  | 50 patients         | To predict the probability of collapse of a femoral head in which there is AVN.   | The hips were followed radiographically for an average of 49 months (range, 16 to 84 months), and with MRI for an average of 44 months (range, 12 to 73 months). 21 (32%) of the femoral heads had collapsed by 32 months. Of the 23 femoral heads in which necrosis involved at least one-fourth of the diameter of the head and encompassed at least two-thirds of the major weight-bearing area, 17 (74%) had collapsed by 32 months. | 4                |

**Osteonecrosis of the Hip  
EVIDENCE TABLE**

| Reference  | Study Type       | Patients/<br>Events | Study Objective<br>(Purpose of Study)   | Study Results  | Study<br>Quality |
|--|------------------|---------------------|---|--|------------------|
| 64. Merlini L, Combescure C, De Rosa V, Anooshiravani M, Hanquinet S. Diffusion-weighted imaging findings in Perthes disease with dynamic gadolinium-enhanced subtracted (DGS) MR correlation: a preliminary study. <i>Pediatr Radiol.</i> 2010;40(3):318-325. | Observational-Dx | 12 patients         | To assess the significance of signal alteration on diffusion-weighted MRI in Legg-Calve-Perthes disease.  | Femoral epiphysis increased diffusivity was observed in the affected hip in all cases. Increased metaphysis diffusivity in the affected side was observed in all cases with absent lateral pillar enhancement at dynamic gadolinium-enhanced subtraction MR.   | 2                |
| 65. de Sanctis N, Rega AN, Rondinella F. Prognostic evaluation of Legg-Calve-Perthes disease by MRI. Part I: the role of physeal involvement. <i>J Pediatr Orthop.</i> 2000;20(4):455-462.   | Observational-Dx | 24 patients         | To establish the reliability of 4 MRI parameters: extent of epiphyseal necrosis, lateral extrusion of the femoral head, physeal involvement, and metaphyseal changes. | An interobserver blind analysis was made to establish the reliability of 4 MRI parameters: extent of epiphyseal necrosis, lateral extrusion of the femoral head, physeal involvement, and metaphyseal changes. The interobserver analysis resulted in a good reliability for all MRI parameters (concordance, >80%; K index, >0.45). A statistical correlation study (Spearman test) was then done between each MRI parameter and the condition of the hips at follow-up evaluated by Stulberg class and a personal scored system (total score) of clinical-radiographic condition. All MRI parameters appeared well correlated to the Stulberg class and to the total score (S >0.66; P<0.05). Physeal involvement resulted the strongest correlated parameter (S = 0.84 for Stulberg class; S = 0.91 for total score). | 3                |
| 66. Dillman JR, Hernandez RJ. MRI of Legg-Calve-Perthes disease. <i>AJR Am J Roentgenol.</i> 2009;193(5):1394-1407.  | Review/Other-Dx  | N/A                 | To describe and illustrate the various MRI appearances of this condition.   | MRI may show proximal femoral abnormalities before radiography in the setting of Legg-Calve-Perthes disease, allowing appropriate diagnosis and prompt treatment. MRI can also assess for revascularization, healing, and multiple complications.  | 4                |

**Osteonecrosis of the Hip  
EVIDENCE TABLE**

| Reference  | Study Type       | Patients/<br>Events | Study Objective<br>(Purpose of Study)   | Study Results   | Study<br>Quality |
|--|------------------|---------------------|---|---|------------------|
| 67. Yoo WJ, Kim YJ, Menezes NM, Cheon JE, Jaramillo D. Diffusion-weighted MRI reveals epiphyseal and metaphyseal abnormalities in Legg-Calve-Perthes disease: a pilot study. <i>Clin Orthop Relat Res.</i> 2011;469(10):2881-2888. | Observational-Dx | 17 children         | To determine whether (1) there would be any age-related diffusion changes; (2) diffusion-weighted MRI would reveal ischemic damage; and (3) diffusion changes are correlated with prognostic MR findings in patients with Legg-Calve-Perthes disease. | Normal diffusion decreased with age. In Legg-Calve-Perthes disease hips, epiphyseal diffusion increased early and remained elevated through the healing stage. 6/17 patients who had a metaphyseal ADC greater than 50% over the normal side had 13 times greater odds of having an association with transphyseal reperfusion to the epiphysis. The increase of metaphyseal ADC also was associated with an increased T2-signal intensity in the metaphysis and presence of focal physeal irregularity. | 2                |

## Evidence Table Key

### Study Quality Category Definitions

- *Category 1* The study is well-designed and accounts for common biases.
- *Category 2* The study is moderately well-designed and accounts for most common biases.
- *Category 3* There are important study design limitations.
- *Category 4* The study is not useful as primary evidence. The article may not be a clinical study or the study design is invalid, or conclusions are based on expert consensus. For example:
  - a) the study does not meet the criteria for or is not a hypothesis-based clinical study (e.g., a book chapter or case report or case series description);
  - b) the study may synthesize and draw conclusions about several studies such as a literature review article or book chapter but is not primary evidence;
  - c) the study is an expert opinion or consensus document.
- M = Meta-analysis

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Dx = Diagnostic

Tx = Treatment

## Abbreviations Key

ADC = Apparent diffusion coefficient

AUC = Area under the curve

AVN = Avascular necrosis

CI = Confidence interval

CT = Computed tomography

ESWT = Extracorporeal shockwave therapy

MDP = Methylene diphosphate

MRI = Magnetic resonance imaging

OA = Osteoarthritis

ONFH = Osteonecrosis of the femoral head

SPECT = Single-photon-emission computed tomography

THA = Total hip arthroplasty

TOH = Transient osteoporosis of the hip