



Osteonecrosis: The perils of steroids. A review of the literature and case report

PDF (Size: 262KB) PP. 26-37 DOI: 10.4236/crcm.2012.12008

Author(s)

Ben J. Brooker, Prue P. A. Keith

ABSTRACT

Non-traumatic osteonecrosis is a cause of joint pain and deformity, not uncommonly caused by corticosteroid use. Despite this, corticosteroid induced osteonecrosis is poorly represented in the literature. We performed a detailed review of corticosteroid induced osteonecrosis, including aetiology, prevention, screening, clinical presentation, investigations, staging systems and treatment. We present this in the context of a patient at our institution who developed bilateral hip, shoulder and knee osteonecrosis following high dose corticosteroid therapy for dermatomyositis.

KEYWORDS

Osteonecrosis; Corticosteroids; Steroids; Avascular Necrosis of Bone

Cite this paper

Brooker, B. and Keith, P. (2012) Osteonecrosis: The perils of steroids. A review of the literature and case report. *Case Reports in Clinical Medicine*, 1, 26-37. doi: 10.4236/crcm.2012.12008.

References

- [1] Arlet, J. (1992) Nontraumatic avascular necrosis of the femoral head past, present, and future. *Clinical Orthopaedics and Related Research*, 277, 12-21.
- [2] Sarris, I., Weiser, R. and Sotereanos, D.G. (2004) Pathogenesis and treatment of osteonecrosis of the shoulder. *Orthopedic Clinics of North America*, 35, 397-404. doi:10.1016/j.ocl.2004.03.004
- [3] LaPorte, D.M., Mont, M.A., Mohan, V., Jones, L.C. and Hungerford, D.S. (1998) Multifocal osteonecrosis. *The Journal of Rheumatology*, 25, 1968-1974.
- [4] Drescher, W., Schneider, T., Becker, C., Hobolth, J., Ruther, W., Hansen, E. and Bunger, C. (2001) Selective reduction of bone blood flow by short-term treatment with high-dose methylprednisolone an experimental study in pigs. *The Journal of Bone & Joint Surgery*, 83-B, 274- 277. doi:10.1302/0301-620X.83B2.10323
- [5] Wang, G., Zhang, C.Q., Sun, Y., Feng, Y., Chen, S.B., Cheng, X.G. and Zeng, B.F. (2010) Changes in the femoral head blood supply and vascular endothelial growth factor in rabbits with steroid-induced osteonecrosis. *The Journal of International Medical Research*, 38, 1060-1069.
- [6] Cui, Q., Wang, G.J. and Balian, G. (1997) Steroid-induced adipogenesis in a pluripotential cell line from bone marrow. *The Journal of Bone & Joint Surgery*, 79-A, 1054-1063.
- [7] Jones, J.P. (1993) Fat embolism, intravascular coagulation, and osteonecrosis. *Clinical Orthopaedics and Related Research*, 292, 294-308.
- [8] Kerachian, M.A., Séguin, C. and Harvey, E.J. (2009) Glucocorticoids in osteonecrosis of the femoral head: A new understanding of the mechanisms of action. *The Journal of Steroid Biochemistry and Molecular Biology*, 114, 121-128. doi:10.1016/j.jsbmb.2009.02.007
- [9] Powell, C., Chang, C. and Gershwin, M.E. (2011) Current concepts on the pathogenesis and natural history of steroid-induced osteonecrosis. *Clinical Reviews in Allergy and Immunology*, 41, 102-113.

CRCM Subscription

Most popular papers in CRCM

About CRCM News

Frequently Asked Questions

Recommend to Peers

Recommend to Library

Contact Us

Downloads: 1,242

Visits: 26,099

Sponsors >>

- [10] Asano, T., Takahashi, K.A., Fujioka, M., Inoue, S., Satomi, Y., Nishino, H., et al. (2003) Genetic analysis of steroid-induced osteonecrosis of the femoral head. *Journal of Orthopaedic Science*, 8, 329-333. doi:10.1007/s10776-003-0646-7
- [11] Li, Y., Yue-Bai, L. and Yi-Sheng, W. (2006) Dexamethasone-induced adipogenesis in primary marrow stromal cell cultures, mechanism of steroid-induced osteonecrosis. *Chinese Medical Journal*, 119, 581-588.
- [12] Vande Berg, B.C., Gilon, R., Malghema, J., Lecouvet, F., Depresseux, G. and Houssiau, F.A. (2006) Correlation between baseline femoral neck marrow status and the development of femoral head osteonecrosis in corticosteroid-treated patients: A longitudinal study by MR imaging. *European Journal of Radiology*, 58, 444-449. doi:10.1016/j.ejrad.2006.01.009
- [13] Zaidi, M., Sun, L., Robinson, L.J., Tourkova, I., Liu, L., Wang, Y., et al. (2010) ACTH protects against glucocorticoid-induced osteonecrosis of bone. *Proceedings of the National Academy of Sciences*, 107, 8782-8787. doi:10.1073/pnas.0912176107
- [14] Colwell, C.W. Jr., Robinson, C.A., Stevenson, D.D., Vint, V.C. and Morris, B.A. (1996) Osteonecrosis of the femoral head in patients with inflammatory arthritis or asthma receiving corticosteroid therapy. *Orthopedics*, 19, 941-946.
- [15] Lopez-Bena, R., Mikulsb, T.R., Moorec, D.S., Julian, B.A., Bernreuter, W.K., Ekins, M. and Saag, K.G. (2004) Incidence of hip osteonecrosis among renal transplantation recipients: A prospective study. *Clinical Radiology*, 59, 431-438. doi:10.1016/j.crad.2003.11.001
- [16] Lieberman, J.R., Roth, K.M., Elsissy, P., Dorey, F.J. and Kobashigwa, J.A. (2008) Symptomatic osteonecrosis of the hip and knee after cardiac transplantation. *Journal of Arthroplasty*, 23, 90-96. doi:10.1016/j.arth.2007.01.006
- [17] Metselaar, H.J., van Steenberge, E.J.P., Bijnen, A.B., Jeeke, J.J., van Linge, B., Weimar, W. (1985) Incidence of osteonecrosis after renal transplantation. *Acta Orthopaedica Scandinavica*, 56, 413-415. doi:10.3109/17453678508994360
- [18] Cruess, R.L., Blennerhassett, J., Macdonald, F., Maclean, L.D. and Dossetor, J. (1968) Aseptic necrosis following renal transplantation. *The Journal of Bone & Joint Surgery*, 50-A, 1577-1590.
- [19] Wong, G.K.C., Poon, W.S. and Chiu, K.H. (2005) Steroid-induced avascular necrosis of the hip in neurosurgical patients: Epidemiological study. *ANZ Journal of Surgery*, 75, 409-410. doi:10.1111/j.1445-2197.2005.03389.x
- [20] Shabatani, M., Fujioka, M., Arai, Y., Takahashi, K., Ueshima, K., Okamoto, M., et al. (2008) Degree of corticosteroid treatment within the first 2 months of renal transplantation has a strong influence on the incidence of osteonecrosis of the femoral head. *Acta Orthopaedica*, 79, 631-636. doi:10.1080/17453670810016641
- [21] Zhang, N.F., Li, Z.R., Wei, H.Y., Liu, Z.H. and Hernigou, P. (2008) Steroid-induced osteonecrosis the number of lesions is related to the dosage. *The Journal of Bone & Joint Surgery*, 90, 1239-1243.
- [22] Griffith, J.F., Antonio, G.E., Kumata, S.M., Hui, D.S., Wong, J.K.T., Joynt, G.M., et al. (2005) Osteonecrosis of hip and knee in patients with severe acute respiratory syndrome treated with steroids. *Radiology*, 235, 168-175. doi:10.1148/radiol.2351040100
- [23] Bradbury, G., Benjamin, J., Thompson, J., Kiees, E. and Copeland, J. (1994) Avascular necrosis of bone after cardiac transplantation prevalence and relationship to administration and dosage of steroids. *The Journal of Bone & Joint Surgery*, 76-A, 1385-1388.
- [24] Lv, H., de Vlas, S.J., Liu, W., Wang, T., Cao, Z., Li, C., et al. (2009) Avascular osteonecrosis after treatment of SARS: A 3-year longitudinal study. *Tropical Medicine and International Health*, 14, 79-84. doi:10.1111/j.1365-3156.2008.02187.x
- [25] McAvoy, S., Baker, K.S., Mulrooney, D., Blaes, A., Arora, M., Burns, L.J. and Majhail, N.S. (2010) Corticosteroid dose as a risk factor for avascular necrosis of the bone after hematopoietic cell transplantation. *Biology of Blood and Marrow Transplantation*, 16, 1231-1236. doi:10.1016/j.bbmt.2010.03.008
- [26] Motomura, G., Yamamoto, T., Irisa, T., Miyanishi, K., Nishida, K. and Iwamoto Y. (2008) Dose effects of corticosteroids on the development of osteonecrosis in rabbits. *The Journal of Rheumatology*, 35,

- [27] Saisu, T., Sakamoto, K., Yamada, K., Kashiwabara, H., Yokoyama, T., Lida, S., et al. (1996) High incidence of osteonecrosis of femoral head in patients receiving more than 2 g of intravenous methylprednisolone after renal transplantation. *Transplantation Proceedings*, 28, 1559-1560.
- [28] Powell, C., Chang, C., Naguwa, S.M., Cheema, G. and Gershwin, M.E. (2010) Steroid induced osteonecrosis: An analysis of steroid dosing risk. *Autoimmunity Reviews*, 9, 721-743. doi:10.1016/j.autrev.2010.06.007
- [29] Wolverton, S.E. (2009) Can short courses of systemic corticosteroids truly cause osteonecrosis? *Dermatology and Therapy*, 22, 458-64. doi:10.1111/j.1529-8019.2009.01262.x
- [30] Zizic, T.M., Marcoux, C., Hungerford, D.S., Dansereau, J.V. and Stevens, M.B. (1985) Corticosteroid therapy associated with ischaemic necrosis of bone in systemic lupus erythematosus. *American Journal of Medicine*, 79, 596-604. doi:10.1016/0002-9343(85)90057-9
- [31] Miyanishi, K., Yamamoto, T., Irisa, T., Motomura, G., Jingushi, S., Sueishi, K. and Iwamoto, Y. (2005) Effects of different corticosteroids on the development of osteonecrosis in rabbits. *Rheumatology*, 44, 332-336. doi:10.1093/rheumatology/keh505
- [32] Niinimaki, R.A., Harila-Saari, A.H., Jartti, A.E., Seuri, R.M., Riikinen, P.V., Paakko, E.L., et al. (2007) High body mass index increases the risk for osteonecrosis in children with acute lymphoblastic leukemia. *Journal of Clinical Oncology*, 25, 1498-1504. doi:10.1200/JCO.2006.06.2539
- [33] Karkoulias, K., Charokopos, N., Kaparianos, A., Sampsonas, F., Tsiamita, M. and Spiropoulos, K. (2007) Aseptic femoral head necrosis in a patient receiving long term courses of inhaled and intranasal corticosteroids. *Tüberküloz ve Toraks Dergisi*, 55, 182-185.
- [34] Gunal, I. and Karatosun, V. (2006) Avascular necrosis of the femoral heads after single corticosteroid injection. *Canadian Medical Association Journal*, 175, 33. doi:10.1503/cmaj.051638
- [35] Juéry, P. Avascular necrosis after a steroid injection (Commentary). *Canadian Medical Association Journal*, 2007, 176, 814. doi:10.1503/cmaj.1060165
- [36] Kelman, G.J., Williams, G.W., Colwell, C.W. Jr. and Walker, R.H. (1990) Steroid-related osteonecrosis of the knee two case reports and a literature review. *Clinical Orthopaedics and Related Research*, 257, 171-176.
- [37] Yoshioka, T., Mishima, H., Akaogi, H., Sakai, S., Li, M. and Ochiai, N. (2011) Concentrated autologous bone marrow aspirate transplantation treatment for corticosteroid-induced osteonecrosis of the femoral head in systemic lupus erythematosus. *International Orthopaedics*, 35, 823-829. doi:10.1007/s00264-010-1048-y
- [38] Marston, S.B., Gillingham, K., Bailey, R.F. and Cheng, E.Y. (2002) Osteonecrosis of the femoral head after solid organ transplantation: A prospective study. *The Journal of Bone & Joint Surgery*, 84-A, 2145-2151.
- [39] Vakil, N. and Sparberg, M. (1989) Steroid-related osteonecrosis in inflammatory bowel disease. *Gastroenterology*, 96, 62-67.
- [40] Pritchett, J.W. (2001) Statin therapy decreases the risk of osteonecrosis in patients receiving steroids. *Clinical Orthopaedics and Related Research*, 386, 173-178. doi:10.1097/00003086-200105000-00022
- [41] Wang, G., Cui, Q. and Balian, G. (2000) The pathogenesis and prevention of steroid induced osteonecrosis. *Clinical Orthopaedics and Related Research*, 370, 295-310. doi:10.1097/00003086-200001000-00030
- [42] Iwakiri, K., Oda, Y., Kaneshiro, Y., Iwaki, H., Masada, T., Kobayashi, A., et al. (2008) Effect of simvastatin on steroid induced osteonecrosis evidenced by the serum lipid level and hepatic cytochrome P4503A in a rabbit model. *Journal of Orthopaedic Science*, 13, 463-468. doi:10.1007/s00776-008-1257-z
- [43] Pengde, K., Fuxing, P., Bin, S., Jing, Y. and Jingqiu, C. (2008) Lovastatin inhibits adipogenesis and prevents osteonecrosis in steroid-treated rabbits. *Joint Bone Spine*, 75, 696-701. doi:10.1016/j.jbspin.2007.12.008
- [44] Ajmal, M., Matas, A.J., Kuskowski, M. and Cheng, E.Y. (2009) Does statin usage reduce the risk of corticosteroid-related osteonecrosis in renal transplant population? *Orthopedic Clinics of North America*, 40, 33-40. doi:10.1016/j.ocl.2008.10.003

- [45] Kang, P., Gao, H., Pei, F., Shen, B., Yang, J. and Zhou, Z. (2010) Effects of an anticoagulant and a lipid-lowering agent on the prevention of steroid-induced osteonecrosis in rabbits. International Journal of Experimental Pathology, 91, 235-243. doi:10.1111/j.1365-2613.2010.00705.x
- [46] Motomura, G., Yamamoto, T., Miyanishi, K., Jingushi, S. and Iwamoto, Y. (2004) Combined effects of an anticoagulant and a lipid-lowering agent on the prevention of steroid-induced osteonecrosis in rabbits. Arthritis & Rheumatism, 50, 3387-3391. doi:10.1002/art.20517
- [47] Motomura, G., Yamamoto, T., Miyanishi, K., Kondo, K., Hirota, Y. and Iwamoto, Y. (2008) Risk factors for developing osteonecrosis after prophylaxis in steroid-treated rabbits. The Journal of Rheumatology, 35, 2391-2394. doi:10.3899/jrheum.080416
- [48] Drescher, W., Beckmann, R., Kasch, R., Pufe, M., Knobe, M., Kweider, N., et al. (2011) Nitrate patch prevents steroid related bone necrosis. Journal of Orthopaedic Research, 29, 1517-1520. doi:10.1002/jor.21420
- [49] Hasan, S.S. and Romeo, A.A. (2002) Nontraumatic osteonecrosis of the humeral head. Journal of Shoulder and Elbow Surgery, 11, 281-298. doi:10.1067/mse.2002.124347
- [50] Castro, T.C.M., Lederman, H., Terreri, M.T.A., Kaste, S.C. and Hilario, M.O.E. (2010) Detection of multifocal osteonecrosis in an adolescent with dermatomyositis using whole-body MRI. Pediatric Radiology, 40, 1566-1568. doi:10.1007/s00247-010-1636-4
- [51] Mont, M.A. and Hungerford, D. (1995) Current concepts review non-traumatic avascular necrosis of the femoral head. The Journal of Bone & Joint Surgery, 77-A, 459- 474.
- [52] Cruess, R.L. (1978) Experience with steroid-induced avascular necrosis of the shoulder and etiologic considerations regarding csteonecrosis of the hip. Clinical Orthopaedics and Related Research, 130, 86-93.
- [53] Ficat, R.P. (1985) Idiopathic bone necrosis of the femoral head early diagnosis and treatment. The Journal of Bone & Joint Surgery, 67-B, 3-9.
- [54] Drescher, W., Schlieper, G., Floege, J. and Eitner, F. (2011) Steroid-related osteonecrosis—An update. Nephrology Dialysis Transplantation, 26, 2728-2731. doi:10.1093/ndt/gfr212
- [55] Lavernia, C.J., Sierra, R.J. and Grieco, F.R. (1999) Osteonecrosis of the femoral head. Journal of the American Academy of Orthopaedic Surgeons, 7, 250-261.
- [56] D' Aubigne, R.M., Postel, M., Mazabraud, A., Massias, P. and Gueguen, J. (1965) Idiopathic necrosis of the femoral head in adults. The Journal of Bone & Joint Surgery, 47B, 612-633.
- [57] Cruess, R.L. (1976) Steroid-induced avascular necrosis of the head of the humerus natural history and management The Journal of Bone & Joint Surgery, 58-B, 313-317.
- [58] Cruess, R.L. (1998) Osteonecrosis of bone current con- cepts as to etiology and pathogenesis. Clinical Orthopaedics and Related Research, 208, 30-39.
- [59] Cruess, R.L. (1985) Corticosteroid-induced osteonecrosis of the humeral head. Orthopedic Clinics of North America, 16, 789-796.
- [60] Harrelid, K.L., Marker, D.R., Wiesler, E.R., Shafiq, B. and Mont, M.A. (2009) Osteonecrosis of the humeral head. Journal of the American Academy of Orthopaedic Surgeons, 17, 345-355.
- [61] Mitchell, D.G., Rao, V.M., Dalinka, M.K., Spritzer, C.E., Alavi, A., Steinberg, M.E., et al. (1987) Femoral head avascular necrosis, correlation of MR imaging, radiographic staging, radionuclide imaging, and clinical findings. Radiology, 162, 709-715.
- [62] Steinberg, M.E., Hayken, G.D. and Steinberg, D.R. (1995) A quantitative system for staging avascular necrosis The Journal of Bone & Joint Surgery, 77-B, 34-41.
- [63] Nam, K.W., Kim, Y.L., Yoo, J.J., Koo, K., Yoon, K.S. and Kim, H.J. (2008) Fate of untreated asymptomatic osteonecrosis of the femoral head. The Journal of Bone & Joint Surgery, 90, 477-484. doi:10.2106/JBJS.F.01582
- [64] Hernigou, P., Poignard, A., Nogier, A. and Manicom, O. (2004) Fate of very small asymptomatic stage- 1 osteonecrotic lesions of the hip. The Journal of Bone & Joint Surgery, 86-A, 2589-2593.
- [65] Kerboul, M., Thomine, J., Postel, M. and D' Aubigene, R.M. (1974) The conservative surgical

treatment of idiopathic avascular necrosis of the femoral head. The Journal of Bone & Joint Surgery, 56B, 291-296.

- [66] Ohzono, K., Saito, M., Sugano, N., Takaoka, K. and Ono, K. (1992) The fate of nontraumatic avascular necrosis of the femoral head a radiologic classification to formulate prognosis. Clinical Orthopaedics and Related Research, 277, 73-78.
- [67] ARCO (Association Research Circulation Osseous) (1992) Committee on terminology and classification. ARCO News, 4, 41-46.
- [68] Sakai, T., Sugano, N., Nishii, T., Hananouchi, T. and Yoshikawa, H. (2008) Extent of osteonecrosis on MRI pre- dicts humeral head collapse. Clinical Orthopaedics and Related Research, 466, 1074-1080. doi:10.1007/s11999-008-0179-6
- [69] Urbaniak, J.R. and Harvey, E.J. (1998) Revascularization of the femoral head in osteonecrosis. Journal of the American Academy of Orthopaedic Surgeons, 6, 44-54.
- [70] Takao, M., Sugano, N., Nishii, T., Miki, H. and Yoshikawa, H. (2006) Spontaneous regression of steroid-re- lated osteonecrosis of the knee. Clinical Orthopaedics and Related Research, 452, 210-215. doi:10.1097/01.blo.0000229278.51323.08
- [71] Sun, Y., Feng, Y. and Zhang, C. (2009) The effect of bone marrow mononuclear cells on vascularization and bone regeneration in steroid-induced osteonecrosis of the femoral head. Joint Bone Spine, 76, 685-690. doi:10.1016/j.jbspin.2009.04.002
- [72] Takano-Murakami, R., Tokunaga, K., Kondo, N., Ito, T., Kitahara, H., Ito, M. and Endo, N. (2009) Glucocorticoid inhibits bone regeneration after osteonecrosis of the fe- moral head in aged female rats. The Journal of Experi- mental Medicine, 217, 51-58.
- [73] Sakamoto, M., Shimuzu, K., Iida, S., Akita, T., Moriya, H. and Nawata, Y. (1997) Osteonecrosis of the femoral head: A prospective study with MRI. The Journal of Bone & Joint Surgery, 79-B, 213-219. doi:10.1302/0301-620X.79B2.7179
- [74] Cheng, E., Thongrangan, I., Laoor, A. and Saleh, K.J. (2004) Spontaneous resolution of osteonecrosis of the femoral head. The Journal of Bone & Joint Surgery, 86-A, 2594-2599.
- [75] Agarwala, S., Shah, S. and Joshi, V.R. (2009) The use of alendronate in the treatment of avascular necrosis of the femoral head follow-up to eight years. The Journal of Bone & Joint Surgery, 91-B, 1013-1018.
- [76] Kotecha, R.S., Powers, N., Lee, S.J., Murray, K.J., Carter, T. and Cole, C. (2010) Use of bisphosphonates for the treatment of osteonecrosis as a complication of therapy for childhood acute lymphoblastic leukaemia (ALL). Pediatric Blood & Cancer, 54, 934-940.
- [77] Nguyen, T. and Zacharin, M.R. (2006) Pamidronate treatment of steroid associated osteonecrosis in young patients treated for acute lymphoblastic leukaemia: Two-year outcomes. Journal of Pediatric Endocrinology and Metabolism, 19, 161-167. doi:10.1515/JPEM.2006.19.2.161
- [78] Kawate, K., Yajima, H., Sugimoto, K., Ono, H., Ohmura, T., Kobata, Y., et al. (2007) Indications for free vascularized fibular grafting for the treatment of osteonecrosis of the femoral head. BMC Musculoskeletal Disorders, 8, 78. doi:10.1186/1471-2474-8-78
- [79] Yoo, M., Kim, K., Hahn, C. and Parvizli, J. (2008) Long-term follow up of vascularized fibular grafting for femoral head necrosis. Clinical Orthopaedics and Related Research, 466, 1133-1140.
- [80] Chen, C., Lin, C., Chen, W., Shih, H., Wueng, S.W.N. and Lee, M.S. (2009) Vascularized iliac bone- grafting for osteonecrosis with segmental collapse of the femoral head. The Journal of Bone & Joint Surgery, 91, 2390-2394. doi:10.2106/JBJS.H.01814
- [81] Drescher, W., Fürst, M., Hahne, H.J., Helfenstein, A., Petersen, W. and Hassenpflug, J. (2003) Survival analysis of hips treated with flexion osteotomy for femoral head necrosis. The Journal of Bone & Joint Surgery, 85-B, 969-974. doi:10.1302/0301-620X.85B7.14155
- [82] Ugiokam, Y., Otokebuchmi, T. and Sutsuim, H. (1992) Transtrochanteric anterior rotational osteotomy for idiopathic and steroid-induced necrosis of the femoral head indications and long-term results. Clinical Orthopaedics and Related Research, 277, 111-120.
- [83] Stulberg, B.N., Singer, R.S., Goldner, J. and Stulberg, J. (1997) Uncemented total hip arthroplasty in osteonecrosis a 2 to 10 year evaluation. Clinical Orthopaedics and Related Research, 334, 116-123. doi:10.1097/00003086-199701000-00015

- [84] Garino, J.P. and Steinberg, M.E. (1997) Total hip arthroplasty in patients with avascular necrosis of the femoral head a 2 to 10 year follow up. Clinical Orthopaedics and Related Research, 334, 108-115.
- [85] Watanabe, R., Sato, K., Nakamura, T., Obara, Y., Toyama, Y. and Ikegami, H. (2011) Steroid-induced osteonecrosis of bilateral distal humerus treated by arthroplasty using costal osteochondral graft: Case report. John Hornby Skewes, 36A, 816-819.
- [86] Nakagawa, Y., Matsusue, Y. and Nakamura, T. (2003) Osteochondral graft transplantation for steroid-induced osteonecrosis of the femoral condyle. The Lancet, 362, 402. doi:10.1016/S0140-6736(03)14031-7
- [87] Gortz, S., De Young, A.J. and Bugbee, W.D. (2010) Fresh osteochondral allografting for steroid-associated osteonecrosis of the femoral condyles. Clinical Orthopaedics and Related Research, 468, 125-146.
- [88] Adachi, N., Ochi, M., Deie, M., Ishikawa, M. and Ito, Y. (2007) Osteonecrosis of the knee treated with a tissue-engineered cartilage and bone implant. The Journal of Bone & Joint Surgery, 89, 2757-2757.