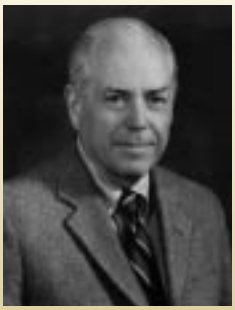
My First 50 Years of Orthopaedic Surgery

William H. Harris, MD



My career has spanned not only one half century, but more specifically and more importantly, the most spectacular half century in the history of medicine. Following World War II, an astonishing confluence of remarkable resources created a unique environment for progress in medicine that had never occurred before. These resources included the flowering of scientific capabilities and personnel in remarkable ways, the influx of massive funding for both patient care and research and a social environment that placed major emphasis on medicine in Western Civilization.

The high expectations have not been disappointed. Extraordinary progress has been made in these five decades — more, by far, than during the entire history of medicine prior to that era. And more importantly, the platform or base from which medicine will progress from here will dwarf the successes of the past five decades.

So, too, has the nature of practice of orthopaedics changed drastically. Consider, for a moment, that early in my career, I did the orthopaedic surgery of the first successful human limb replantation (May, 1962) and continued to design techniques and performed all the orthopaedic surgery for the limb replantations at the MGH for years.(19, 20) While this was occurring, I also did the tumor surgery such as the hemipelvectomies for chondrosarcoma, etc. and in addition wrote a book on the management of fracture cases.(21)

During that same early period, my research work focused on the effects of growth hormone on skeletal tissues and the interaction of calcium and phosphate metabolism on skeletal mass, bone turnover and osteoporosis.(1, 6, 7, 8, 11, 15, 17, 18) It was also in that era that we concentrated our work on the prevention of venous thromboembolic disease.

Think of the width of that experience in musculoskeletal disease. Such a panoply of interests is unheard of today. During that time, I also began to work on new ideas in reconstructive hip surgery, ideas in those days which emphasized ways to improve the surgery of and the results of cup arthroplasty.(2, 9, 12) Now, fast forward to the present time when our major effort is the decade long project of the development of electron beam, crosslinked, melted ultra high molecular weight polyethylene, with its high potential to revolutionize another type of hip reconstruction, total hip replacement surgery.

The range, depth, scope, and extent of this odyssey is, in major part, a reflection of this remarkable period of time. It is also a reflection of a decision I made from the start of my career to weave research into an academic clinical career. And indeed, it has been varied and fascinating.

If you will, permit me to reflect on what I consider to be, perhaps, the three most lasting areas of my activities, those perhaps that are the most influential on the current and future practice of orthopaedics.

Among the most satisfying areas of progress in our work during this half century have been the contributions to the conquest (or near conquest) of fatal pulmonary embolism following major hip surgery in the adult. Consider the fact that in 1959, when I was Chief Resident at the MGH, ignorance was massive in all five major aspects of venous thromboembolic disease (VTED):

1) the nature of the disease,
2) its true incidence;
3) the ability to diagnose the condition in vivo;
4) the prevention of venous thromboembolic disease;
5) the treatment of this condition.

In those days, fatal emboli were considered to be “acts of God” or “bolts out of the blue”. The incidence of deep venous thrombosis following surgery of the lower extremities in adults was felt to be about 12%, and this diagnosis was based mainly on the Homan’s sign! There were no widely used diagnostic tools, no preventative measures and no effective treatment. Along with Ed Salzman and Roman DeSanctis, we did the first study of the use of Coumadin in the prophylaxis against VTED following hip fractures.(3) Imagine, voluntarily using an anticoagulant in elderly patients with a fracture and a large hip wound.

When that proved to be effective, we initiated studies of a similar nature for prevention of VTED following elective hip

surgery.(4, 13, 16, 22, 24, 30, 36, 37, 40, 42, 50) This was done to refute the "accumulated wisdom" of our elders that the unilateral massive swelling of the extremity following cup arthroplasty was "the postoperative swelling of hip surgery." The results of this work plus the huge contributions of so many, many outstanding investigators can be estimated in three different forms:

1) the adoption of effective prophylaxis is extremely wide and in some areas nearly universal in high risk cases;
2) the major discussions about prevention of VTED now are no longer focused on "how", "if", or "why" but rather are focused on making choices over the uses of safer and safer and more and more effective modalities of prophylaxis.
3) the last fatal pulmonary embolism following hip surgery in a patient of mine was 42 years and 3,000 cases ago;

The second overarching theme of my work has dealt with concepts, designs, techniques and instruments to further the efficacy of reconstructive surgery of the hip. These efforts ranged from new incisions (5, 10, 23) and new approaches regardless of incision (14, 29, 31, 32), through many instruments, many implants to innovative concepts. (26-28, 31, 32, 35, 57, 69, 73, 74) We were the first to use a cement gun to deliver bone cement; the use is now world-wide. We designed the first modular acetabular component and the first metal-backed acetabular component. In North America, the vast majority of acetabular components are modular. We did the first femoral head autograft and first femoral head allograft for acetabular augmentation for total hip replacement and designed the first special components for and performed the first total hip replacement on a hip that had a congenital total dislocation. (34, 38, 41, 52, 59, 63, 67, 68) Later on, we developed the hybrid total hip replacement concept, recognized as the state of the art at the last consensus report of the NIH. (51, 75-77, 79) We also developed the Harris Hip Score in 1967.(9, 78)

Our work was active in the design of both cemented and cementless total hip replacement, with special emphasis on improved fixation. Perhaps one of the most lasting efforts in this realm is the work with Jorge Galante that culminated in the design of the hemispherical, porous acetabular component transfixed with screws (or press fit) that has so drastically changed total hip surgery. (43, 49, 62, 67) It has played a major role in solving many of the problems of acetabular revision surgery, has greatly improved acetabular reconstruction surgery in young patients and is now gaining increasing scientific backing as the best acetabular component in primary total hip replacement in the older age group as well. This implant also is very valuable in the "high hip center" concept (45, 55, 61, 64) and the "Jumbo" socket concept.(80)

These efforts continue apace with major work now aimed at reducing dislocation, increasing range of motion, and augmenting the quality of life by creating more normal and more anatomic total hip replacement.

Thirdly, a most exciting avenue of research has been the role we played in the identification, definition and hopefully the cure of a world-wide disease. That disease is periprosthetic osteolysis. (25, 33, 39, 44, 46-48, 50, 53, 54, 56, 60)

Many, many excellent investigators have played major roles in this effort. Our particular pathway began with the publication in 1976 of four cases of periprosthetic osteolysis. (25) Many others had seen this affliction, including Charnley, McKee and Willert. Charnley had felt it most likely due to infection but could not identify bacteria. (70) McKee felt it was secondary to the motion of loose components. (71) Willert advanced the idea of the concept of particle migration. (72)

From this small start (the publication of four cases), for us the next step was work with Steve Goldring and Al Schiller (33, 39) that was the first demonstration that, indeed, the periprosthetic membrane which people had been discarding for over 20 years as "fibrous tissue" had the capacity to elaborate PGE_2 and collagenase and to resorb bone. All of the work identifying the many cytokines and enzymes involved in the lysis that constitutes periprosthetic osteolysis followed rapidly thereafter.

We also identified the role of this lytic process in acetabular loosening and femoral loosening. (44, 46) Since the submicron particulate debris, primarily particulate ultra high molecular weight polyethylene (UHMWP) generated at the metal to polyethylene articulation, is the offending agent that initiates periprosthetic lysis, we initiated in 1990 a program to see if we could decrease such debris by creating a better articulation for artificial joints.

But, rather than starting our research on materials, we began by inventing a new hip simulator, driven by the belief that without such a device which could quantify the efficacy of any proposed new articulation in terms of reduced wear, any proposed new material would long remain a hypothetical possibility.

The effort to design a better hip simulator also drove us to define, for the first time, the actual pathways that individual points on the femoral head must take inside the hip joint during the gait cycle.(58) Once the hip simulator was established, in collaboration with Professor Ed Merrill at MIT, our group has invented a new material, electron-beam irradiated, melted, highly crosslinked ultra high molecular weight polyethylene.(65, 66, 81). Massive in vitro experiments have shown it to be remarkable, not only in wear resistance and oxidation resistance, but in physical properties as used in an acetabular component. This material has been FDA approved for use in hips and knees. Should it prove to be as effective in vivo as its behavior is in vitro, a new age of total hip replacement will be with us. The duration of success, reduction of complications, decrease in revisions, improvements in functional outcomes, decrease in cost, improved ADL and extended indications would all follow. More importantly, should this material demonstrate long term success, it would close the loop in the story of the world-wide disease of periprosthetic osteolysis. That is to say, periprosthetic osteolysis

is a man-made disease, never seen before in the history of mankind. It is the direct result of the invention of total joint surgery. If the improved polyethylene works over the long term, this disease may have been fully cycled, that is to say, introduced, identified, defined, explained and cured, all in one generation. Were that to occur, it would be a remarkable feat.

It must be said that in everything I have described there have been many powerful and massive, major contributing forces. These include but are not limited to, the giants in our field who built the platform that made any such effort possible, the large number of remarkably bright, dedicated and inventive colleagues and co-workers who were a constant source of solace, inspiration and renewal throughout the five decades and in particular, the Fellows. As a source of renewal, challenge, excitement and inspiration, the Fellows are unequaled and, almost without question, they are my most impressive legacy. To all these people, I owe an incalculable debt. Many thanks.

References

1. **Harris, W.H.**, *A microscopic method of determining rates of bone growth.* Nature, 1960 **188**: p. 1038-1039.
2. **Harris, W. and O. Aufranc**, *Mold arthroplasty in the treatment of hip fractures complicated by sepsis.* J Bone Joint Surg, 1965. **47A**: p. 31-41.
3. **Salzman, E., W. Harris, and R. DeSanctis**, *Anticoagulation for prevention of thromboembolism following fractures of the hip.* N. Eng. J. Med., 1966. **275**: p. 122-130.
4. **Harris, W., E. Salzman, and R. DeSanctis**, *The prevention of thromboembolic disease by prophylactic anticoagulation. A controlled study in elective hip surgery.* J Bone Joint Surg, 1967. **49A**: p. 81-89.
5. **Harris, W.**, *A new lateral approach to the hip joint.* J Bone Joint Surg, 1967. **49A**: p. 891-898.
6. **Harris, W., R.H. Jackson, and J. Jowsey**, *The in vivo distribution of tetracyclines in canine bone.* J. Bone and Joint Surg, 1962. **44A:**1308-1320.
7. **Harris, W., et al.**, *Spatial and Temporal Variations in Cortical Bone Formation in Dogs.* J Bone Joint Surg, 1968. **50A**: p. 1118-1128.
8. **Harris, W. and R. Heaney**, *Skeletal renewal and metabolic bone disease.* N. Eng. J. Med., 1969. **280**: p. 193-202,253-59,303-11.
9. **Harris, W.**, *Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation.* J Bone Joint Surg, 1969. **51A**: p. 737-755.
10. **Harris, W.**, *Surgical approach and technique of cup arthroplasty.* Surgical Clinics of North America, 1969. **49**: p. 763-774.
11. **Harris, W. and R. Heaney**, *Effect of growth hormone on skeletal mass in adult dogs.* Nature, 1969. **223**: p. 403-404.
12. **Harris, W.**, *Power instrumentation for cup arthroplasty.* Clin Orthop, 1970. **72**: p. 219-223.
13. **Salzman, E., W. Harris, and R. DeSanctis**, *Reduction in venous thromboembolism by agents affecting platelet function.* N. Eng. J. Med., 1971. **284**: p. 1287-1292.
14. **Harris, W.**, *A new total hip implant.* Clin Orthop, 1971. **81**: p. 105-113.
15. **Harris, W. and E. Weinberg**, *Microscopic method of measuring increases in cortical bone volume and mass.* Calcified Tissue Research, 1972. **8**: p. 190-196.
16. **Harris, W., et al.**, *Prevention of venous thromboembolism following total hip replacement. Warfarin vs dextran 40.* JAMA, 1972. **220**: p. 1319-1322.
17. **Harris, W.H., et al.**, *The effect on skeletal renewal in the adult dog. Part I. Morphometric studies.* Calcif Tissue Res, 1972. **10**: p. 1-13.
18. **Heaney, R., et al.**, *Growth hormone: the effect on skeletal renewal in the adult dog. II. Mineral kinetic studies.* Calcified Tissue Research, 1972. **10**: p. 14-22.
19. **Malt, R., J. Remensnyder, and W. Harris**, *Long-term utility of replanted arms.* Annals of Surgery, 1972. **176**: p. 334-342.
20. **Harris, W. and R. Malt**, *Late results of human limb replantation: eleven-year and six-year follow-up of two cases with description of a new tendon transfer.* Journal of Trauma, 1974. **14**: p. 44-52.
21. **Harris, W., W. Jones, and O. Aufranc**. *Fracture Problems*. 1965: C.V. Mosby,Inc, St Louis.
22. **Harris, W., et al.**, *Comparison of warfarin, low-molecular-weight dextran, aspirin, and subcutaneous heparin in prevention of venous thromboembolism following total hip replacement.* J Bone Joint Surg, 1974. **56A**: p. 1552-1562.
23. **Harris, W.**, *A new approach to total hip replacement without osteotomy of the greater trochanter.* Clin Orthop, 1975. **106**: p. 19-26.
24. **Harris, W., et al.**, *Comparison of 125I fibrinogen count scanning with phlebography for detection of venous thrombi after elective hip surgery.* N. Eng. J. Med., 1975. **292**: p. 665-667.
25. **Harris, W., et al.**, *Extensive localized bone resorption in the femur following total hip replacement.* J.Bone Joint Surg, 1976. **58A**: p. 612-618.
27. **Rushfeldt, P., R. Mann, and W. Harris**, *Improved techniques for measuring in vitro the geometry and pressure distribution in the human acetabulum--I. Ultrasonic measurement of acetabular surfaces, sphericity and cartilage thickness.* Journal of Biomechanics, 1981. **14**: p. 253-260.
28. **Rushfeldt, P., R. Mann, and W. Harris**, *Improved techniques for measuring in vitro the geometry and pressure distribution in the human acetabulum. II. Instrumented endoprosthesis measurement of articular surface pressure distribution.* Journal of Biomechanics, 1981. **14**: p. 315-323.
29. **WH, H. and A. JR**, *The calcar replacement femoral component for total hip arthroplasty: design, uses and surgical technique.* Clin. Orthop., 1981. **157**: p. 215-224.
30. **Harris, W., et al.**, *High and low-dose aspirin prophylaxis against venous thromboembolic disease in total hip replacement.* J Bone Joint Surg, 1982. **64A**: p. 63-66.
31. **Oh, I. and Harris, WH**, *Indications and surgical technique for use of the protrusio shell.* Clin. Orthop., 1982. **162**: p. 175-184.
32. **Harris, W. and R. White**, *Socket fixation using a metal-backed acetabular component for total hip replacement. A minimum five-year follow-up.* J Bone Joint Surg, 1982. **64A**: p. 745-748.
33. **Goldring, S., et al.**, *The synovial-like membrane at the bone-cement interface in loose total hip replacements and its proposed role in bone lysis.* J Bone Joint Surg, 1983. **65A**: p. 575-584.
34. **Woolson, W. and W. Harris**, *Complex total hip replacement for dysplastic or hypoplastic hips using miniature or microminiature components..* J Bone Joint Surg, 1983. **65A**: p. 1099-1108.
35. **Burke, D., E. Gates, and W. Harris**, *Centrifugation as a method of improving tensile and fatigue properties of acrylic bone cement.* J Bone Joint Surg, 1984. **66A**: p. 1265-1273.
36. **Harris, W., et al.**, *Detection of pulmonary emboli after total hip replacement using serial C15O2 pulmonary scans.* J Bone Joint Sur, 1984. **66-A**: p. 1388-1393.
37. **Harris, W., et al.**, *Prophylaxis of deep-vein thrombosis after total hip replacement. Dextran and external pneumatic compression compared with 1.2 or 0.3 gram of aspirin daily.* J Bone Joint Surg, 1985. **67A**: p. 57-62.
38. **Gerber, S. and W. Harris**, *Femoral head autografting to augment acetabular deficiency in patients requiring total hip replacement. A minimum five-year and an average seven-year follow-up study.* J Bone Joint Surg, 1986. **68A**: p. 1241-1248.
39. **Goldring, S., et al.**, *Formation of a synovial-like membrane at the bone-cement interface. Its role in bone resorption and implant loosening after total hip replacement.* Arthritis and Rheumatism, 1986. **29**: p. 836-842.

40. **Paiement, G., et. al.**, Low-dose warfarin versus external pneumatic compression for prophylaxis against venous thromboembolism following total hip replacement. J. Arthroplasty 1987. **2**:23-26.
41. **Jasty, M. and W. Harris**, *Total hip reconstruction using frozen femoral head allografts in patients with acetabular bone loss.* Orthopaedic Clinics of North America, 1987. **18**: p. 291-299.
42. **Paiement, G., S. Wessinger, and W. Harris**, *Survey of prophylaxis against venous thromboembolism in adults undergoing hip surgery.* Clin Orthop, 1987. **223**: p. 188-193.
43. **Harris, W., R. Krushell, and J. Galante**, *Results of cementless revisions of total hip arthroplasties using the Harris-Galante prosthesis.* Clin Orthop, 1988. **235**: p. 120-126.
44. **Maloney, W., et al**., *Biomechanical and histologic investigation of cemented total hip arthroplasties. A study of autopsy-retrieved femurs after in vivo cycling.* Clin Orthop, 1989. **249**: p. 129-140.
45. **Russotti, G.M., and W.H. Harris**, *Proximal placement of the acetabular component in total hip arthroplasty. A long-term study.* J Bone and Joint Surg 1991. **73A**:587-592.
46. **Schmalzried, T.P., et al.**, *The mechanism of loosening of cemented acetabular components in total hip arthroplasty. Analysis of specimens retrieved at autopsy.* Clinical Orthopaedics & Related Research, 1992(274): p. 60-78.
47. **Schmalzried, T., M. Jasty, and W. Harris**, *Periprosthetic bone loss in total hip arthroplasty. Polyethylene wear debris and the concept of the effective joint space.* J Bone Joint Surg [Am], 1992. **74**: p. 849-863.
48. **Tanzer, M., et al.**, *Revision of the acetabular component with an uncemented Harris- Galante porous-coated prosthesis.* J Bone Joint Surg [Am], 1992. **74**: p. 987-994.
49. **Schmalzried, T. and W. Harris**, *The Harris-Galante porous-coated acetabular component with screw fixation. Radiographic analysis of eighty-three primary hip replacements at a minimum of five years.* J Bone Joint Surg [Am], 1992. **74**: p. 1130-1139.
50. **Jiranek, W., et al.**, *Production of cytokines around loosened cemented acetabular components. Analysis with immunohistochemical techniques and in situ hybridization [see comments].* J Bone Joint Surg, 1993. **75A**: p. 863-879.
51. **Schmalzried, T. and W. Harris**, *Hybrid total hip replacement. A 6.5 year follow-up study.* J Bone and Joint Surg 1993. **75B**:p. 608-615.
52. **Kwong, L. and W. Harris**, *High failure rate of bulk femoral head allograft in acetabular reconstructions at 10 years.* Orthop Trans, 1991. **15**: p. 788.
53. **Jasty, M. and W. Harris**, *Particle disease associated with cementless total hip arthroplasty.* Seminars in Arthroplasty, 1994. **5 (1)**: p. 12-19.
54. **Harris, W.**, *Osteolysis and particle disease in hip replacement. A review.* Acta Orthop Scandinavica, 1994. **65**: p. 113-123.
55. **Schutzer, S. and W. Harris**, *High placement of porous-coated acetabular components in complex total hip arthroplasty.* J Arthroplasty, 1994. **9**: p. 359-367.
56. **Jiranek, W., et al.**, *Tissue response to particulate polymethylmacrylate in mice with various immune deficiencies.* J Bone Joint Surg, 1995. **77A**: p. 1650-1661.
57. **Mulroy, W., D. Estok, and W.Harris**, *Total hip arthroplasty with use of so-called second-generation cementing techniques. A fifteen-year average follow-up study.* J Bone and Joint Surg Am, 1995. **77**: p. 1845-1852.
58. **Ramamurti, B., et al.**, *Loci of movement of selected points on the femoral head during normal gait. Three-dimensional computer simulation.* J Arthroplasty, 1996. **11**: p. 845-852.
59. **Shinar, A. and W. Harris**, *Bulk structural autogenous grafts and allografts for reconstruction of the acetabulum in total hip arthroplasty. Sixteen-year-average follow-up.* J Bone Joint Surg Am, 1997. **79**: p. 159-168.
60. **Harris, W.H., R.P. Heaney, et. al.**, *Stimulation of bone formation in vivo by phosphate supplementation.* Calcif Tissue Res, 1976. **22**: p. 85-98.
61. **Harris, W.**, *Reconstruction at a high hip center in acetabular revision surgery using a cementless acetabular component.* Orthopedics, 1998. **21**: p. 991-992.
62. **Clohisy, J.C. and W.H. Harris**, *The Harris-Galante porous-coated acetabular component with screw fixation. An average ten-year follow-up study.* Journal of Bone & Joint Surgery - American Volume, 1999. **81**(1): p. 66-73.
63. **Anderson, M.J. and W.H. Harris**, *Total hip arthroplasty with insertion of the acetabular component without cement in hips with total congenital dislocation or marked congenital dysplasia.* Journal of Bone & Joint Surgery - American Volume, 1999. **81**(3): p. 347-54.
64. **Dearborn, J.T. and W.H. Harris**, *High placement of an acetabular component inserted without cement in a revision total hip arthroplasty. Results after a mean of ten years.* Journal of Bone & Joint Surgery - American Volume, 1999. **81**(4): p. 469-80.
65. **Kurtz, S.M., et al.**, *Advances in the processing, sterilization, and crosslinking of ultra-high molecular weight polyethylene for total joint arthroplasty.* Biomaterials, 1999. **20**(18): p. 1659-88.
66. **Muratoglu, O.K., et al.**, *Unified wear model for highly crosslinked ultra-high molecular weight polyethylenes (UHMWPE).* Biomaterials, 1999. **20**(16): p. 1463-70.
67. **Bal, B.S., T. Maurer, and W.H. Harris**, *Revision of the acetabular component without cement after a previous acetabular reconstruction with use of a bulk femoral head graft in patients who had congenital dislocation or dysplasia. A follow-up note.* Journal of Bone & Joint Surgery - American Volume, 1999. **81**(12): p. 1703-6.
68. **Dearborn, J.T.. and W.H Harris**, *Acetabular revision after failed total hip arthroplasty in patients with congenital hip dislocation and dysplasia: results after a mean of 8.6 years.* J. Bone and Joint Surg., 2000. **82A**: p. 1146-1153.
69. **Jensen, N.F. and W.H. Harris**, *A system for trochanteric osteotomy and reattachment for total hip arthroplasty with a ninety-nine percent union rate.* Clin. Orthop. 1986. **208**:p. 174-181.
70. **Charnley, J. F. Follacci, et. al.**, *The long-term reaction of bone to self-curing acrylic cement.* J. Bone Joint Surg. 1968. **50B**: p. 822-829.
71. **McKee, G. and J. Watson-Farrar**, *Replacement of arthritic hips by the McKee-Farrar prosthesis*. J. Bone Joint Surg. 1966. **48B**: p. 245-259.
72. **Willert, H. , J. Ludwig, et al.** *Reaction of bone to methacrylate after hip arthroplasty: a long-term gross, light microscopic, and scanning electron microscopic study.* J. Bone Joint Surg. 1974. **56A**: p. 1368-1382.
73. **Harris, W.H.**, *Etiology of osteoarthritis of the hip*. Clin. Orthop. 1986. **213**:p. 20-33.
74. **Barrack, RA.L., R.D. Mulroy, and W.H. Harris**, *Improved cementing techniques and femoral component loosening in young patients with hip arthroplasty: a 12 year radiographic review.* J. Bone Joint Surg. 1992. **74B**: p. 385-389.
75. **Davey, J., and W.H. Harris**, *A preliminary report of the use of a cementless acetabular component with a cemented femoral component.* Clin. Orthop. 1989. **245**: 150-155.
76. **Harris, W.H. and W.J. Maloney**, *Hybrid total hip arthroplasty.* Clin. Orthop. 1989. **249**: p. 21-29.
77. **Maloney, W.J. and W.H. Harris**, *Comparison of a hybrid with an uncemented total hip replacement.* J Bone and Joint Surg 1990. **72A**: p. 1349-1352.
78. **Johnston, R.C., R.H. Fitzgerald, et. al.**, *Clinical and radiographic evaluation of total hip replacement. A standard system of terminology for reporting results*. J. Bone Joint Surg 1990. 72A: p. 11-168.
79. **Harris, W.H.**, Hybrid total hip replacement: *Rationale and intermediate clinical results.* Clin. Orthop. 1996. **333**:115-164.
80. **Dearborn, J.T., and W.H. Harris**, *Acetabular revision arthroplasty using so-called jumbo cementless components: An average 7-year follow-up.* J. Arthroplasty 2000. **15**:p. 8-15.
81. **Muratoglu, O.K., C.R. Bragdon, et. al.**, *A novel method of crosslinking UHMWPE to improve wear, reduce oxidation and retain mechanical properties.* J. Arthroplasty 2001. **16(2)**: p. 149-160.