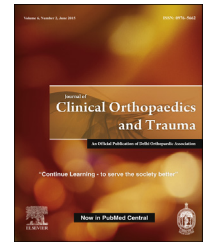
JOURNAL OF CLINICAL ORTHOPAEDICS AND TRAUMA 6 (2015) 108–112

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/jcot



Review Article

Polyethylene in knee arthroplasty: A review

Gautam Chakrabarty MBBS, D Orth, MS Orth, MCh Orth, FRCS (Ed), FRCS (Trauma & Orth)[a,*], Mayank Vashishtha MBBS, MRCS (Glas)[b], Daniel Leeder MBChB[c]

[a] Consultant Orthopaedic Surgeon, Huddersfield Royal Infirmary, Huddersfield, West Yorkshire HD3 3EA, United Kingdom

[b] Specialty Registrar Trauma & Orthopaedics, Yorkshire Deanery, Huddersfield Royal Infirmary, Huddersfield, West Yorkshire HD3 3EA, United Kingdom

[c] Core Surgical Trainee Trauma & Orthopaedics, Yorkshire Deanery, Huddersfield Royal Infirmary, Huddersfield, West Yorkshire HD3 3EA, United Kingdom

ARTICLE INFO

Article history:
Received 2 December 2014
Accepted 22 January 2015
Available online 19 February 2015

Keywords:
Highly cross linked
Polyethylene
Total knee replacement

ABSTRACT

Polyethylene (PE) has been used extensively in knee arthroplasty since the mid 20th century. Progress in material manufacturing and processing has led to newer polyethylenes over last few decades with different material properties. It has been established that PE wear in knee arthroplasty causes particle induced osteolysis which is the main reason for late failure and requires revision surgery. Although there are various causes of wear, the properties of PE have long been a matter of investigation as a contributory factor. The advent of newer highly cross linked PE has been shown to improve wear rates in hip arthroplasty but the benefits have not been shown to be of the same degree in knee arthroplasty. The laboratory and clinical studies so far are limited and slightly conflicting in their conclusions. The risks of using highly cross linked PE in knee arthroplasty include tibial post fracture, disruption of locking mechanism, liner fracture which can lead to increased wear and osteolysis. The current evidence suggests that highly cross linked polyethylenes should be used with caution and only considered in younger active patients. The results of a recently completed randomized trial to compare the conventional with high molecular weight PE in knee arthroplasty are awaited.

1. History of polyethylene

Polyethylene is a commonly used plastic with millions of tonnes produced annually.[1] The generic chemical composition of PE is denoted by the formula $(C_2H_4)n$. The value of 'n' can differ depending on the molecular size. The history of PE dates back to 1898 when German scientist Hans von Pechman prepared it serendipitously while heating diazomethane.[2] This new waxy substance was highly unstable and therefore not used industrially. It was in Northwich, England in 1933 that Eric Fawcett and Reginald Gibson synthesized the first

* *Corresponding author*. Department of Trauma & Orthopaedics, Lower Ground Floor, Huddersfield Royal Infirmary, Huddersfield, West Yorkshire HD3 3EA, United Kingdom. Tel.: +44 7971 432 185.
E-mail address: gautamchakrabarty@msn.com (G. Chakrabarty).
http://dx.doi.org/10.1016/j.jcot.2015.01.096

industrially useful PE, again serendipitously when they applied extremely high pressure to a mixture of ethylene and benzaldehyde.[3] Unfortunately, their accidental discovery was not easily reproducible due to initiation of reaction by trace oxygen contamination. Later in 1935, Michael Perrin developed a reproducible method to synthesize PE.[4] This laid the foundation of industrial scale production of PE in subsequent years.

2. Polyethylene manufacturing processes

Polyethylene components are manufactured by either machining or compression molding. Machined components are made from either a sheet or bar whereas compression moulded ones are made by powder compressed into the desired shape.[5] Arthroplasty components manufactured from compression moulded polyethylene have been shown to exhibit less wear and may be preferable for clinical use.[6]

The manufacturing processes directly affect the material characteristics and include irradiation dose, types of post irradiation thermal processing and end point sterilization.[7] Ultra high molecular weight polyethylene (UHMWPE) is a subset of polyethylene materials with extremely long chains and a molecular weight between 2 and 6 million units. In order to manufacture highly cross linked polyethylene (HXLPE), UHMWPE is irradiated with gamma or electron beam to break the carbon–hydrogen chains. This produces free radicals, which in the presence of oxygen facilitate degradation of the polymer. These free radicals also help to form cross-links. An increase in the radiation dose, increases the cross linking which confers an increase in wear resistance.[7,8] It is therefore expected that this would lead to improved clinical performance. However this does not seem to be the case because there is a corresponding decrease in mechanical properties like tensile strength and resistance to fatigue crack propagation.[9] In order to reduce the concentration of free radicals in irradiated PE, a process of post irradiated melting or annealing is performed. The melting point of PE is 135 °C. Melting changes PE structure from a crystalline to an amorphous solid and allows access to free radicals by unfolding polymer chains while the cross links act as molecular constraints. This reduction in crystallinity reduces mechanical properties like crack resistance and fracture toughness.[7,9,10] In contrast to melting, annealing involves heating the PE to below its melting point. This leads to less efficient removal of free radicals but preserves more mechanical properties.[8] Overall, a method which would not reduce the crystallinity and remove free radicals would be ideal. This has led to the development of 2nd generation highly cross linked polyethylenes.[7] Their manufacture uses other methods to extinguish free radicals which include soaking in vitamin E (alpha tocopherol, an antioxidant) or irradiating in 3 sequential doses with annealing after each radiation dose to reduce free radicals. Preliminary in vitro testing indicates good wear and improved mechanical and fatigue properties[7] in this group.

3. Sterilization of polyethylene

The type of sterilization process is also reported to affect the characteristics of PE and its shelf life.[11] Sterilization using gamma radiation in air makes PE susceptible to oxygenation. Ethylene oxide or gas plasma are used for sterilization without radiation to avoid free radical production, but this produces no cross linking directly affecting the mechanical properties.[11] In the second generation HXLPE, sterilization is performed with ethylene oxide or gas plasma to avoid reintroduction of free radicals.[7]

4. Polyethylene in arthroplasty

UHMWPE was introduced by Sir John Charnley in 1960s in hip replacement surgery.[12] His development of a low friction arthroplasty with a metallic femoral head and an all PE cup was a milestone in orthopaedic surgery. This was achieved after an in depth research into cemented implant fixation and bearing surfaces. After an unhappy experience with teflon cups, he used a high density PE cup. Since then, PE has been used for almost half a century and remains a frequent bearing surface in total joint replacement.

The earliest attempt at a knee replacement dates back to 1890s and is accredited to Theophilus Gluck who used an ivory hinge prosthesis.[13] The early condylar designs came in vogue in 1960s which used PE tibial component.[13]

5. Wear and osteolysis in arthroplasty

While PE has been an indispensable part of the evolution of joint arthroplasty surgery, its wear has been of as much interest. It has been established that PE wear in arthroplasty causes particle induced osteolysis which is the main reason for late failure and requires revision surgery.[14] Although there are various causes of wear, the properties of the PE have long been a matter of investigation as a contributory factor. Other factors include implant design, surgical technique and patient factors. The conventional PE used in hip arthroplasty was sterilized by gamma radiation in air, which offered the benefit of cross linking.[11] But at the same time, this process produced free radicals that oxidize in air and thus decrease resistance of this biomaterial leading to increased wear.[11] The need for improved implant durability stemmed from the fact that in the past decade, the indications for hip arthroplasty have changed to include younger, higher demand patients with increased life expectancy.[7,15] The subsequent development of new highly cross linked polyethylene (HXLPE) in 1990s was aimed at decreasing wear resistance whilst not compromising on material properties.[16] The basis of HXLPE production process has been cross linking, heat treatment and sterilization with avoidance of oxygen exposure.[16] The preclinical laboratory testing demonstrated the newer cross linked polyethylenes to have significantly less wear than conventional PE.[7] In published literature, there is evidence that these first generation HXLPE have decreased wear rates in vivo with reduction in the prevalence and severity of osteolysis. However, it has been shown that these HXLPEs may be more susceptible to fatigue fracture.[7] Currently, second generation HXLPEs have been developed as discussed previously in the manufacturing process. Mid term results of new HXLPEs indicate that it is one of the materials of choice in hip