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Case report

Early failure of sequentially annealed polyethylene in total knee arthroplasty

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ABSTRACT

Improvements in the processing of polyethylene have led to a dramatic reduction in wear rates in total hip arthroplasty. This led to the adoption of modern highly cross-linked polyethylene in total knee arthroplasty (TKA). However, the differences in modes of wear and failure between total hip arthroplasty and TKA have tempered expectations regarding similar decreases in polyethylene-related complications in TKA. We present a case of early catastrophic failure of a modern sequentially irradiated and annealed highly cross-linked polyethylene insert only 5 years after contemporary cementless TKA.

Introduction

Historically, conventional polyethylene was irradiated in air, which resulted in the production of free radicals prone to oxidation and resultant high wear rates and revision due to osteolysis [1]. This has been heavily studied in total hip arthroplasty (THA) as it is felt that the differences in wear mechanisms between THA and total knee arthroplasty (TKA) result in more benefit of improved wear characteristics for THA bearings which primarily fail by head penetration and osteolysis [2]. Alternatively, TKA inserts are most susceptible to failure by pitting and delamination. Improvements in processing of polyethylene, mainly increased cross-linking, over the past 10-15 years have been translated into use in TKA and resulted in minimized failure rates because of polyethylene wear [3-5]. However, there remains concern that polyethylene failure mechanisms may not be solved by the modern highly cross-linked polyethylene (HXLPE). Furthermore, the more complex sliding, rolling, and pivoting motion of TKA may not translate into the substantial polyethylene wear reduction that has been observed in THA. In addition, when polyethylene wear does occur, it tends to be a late mode of failure, generally greater than 10 years after primary TKA [4,5]. We present a case of early catastrophic failure of a modern sequentially irradiated and annealed HXLPE insert only 5 years after contemporary cementless TKA.

Case history

This case involves a 51-year-old female who presented with right knee pain secondary to end-stage valgus osteoarthritis of the right knee (Fig. 1). She had failed nonoperative management and therefore elected to undergo TKA. This was performed with cementless components with an anterior-lipped sequentially irradiated and annealed polyethylene insert (X3; Stryker, Mahwah, NJ) with the patella left unresurfaced (Fig. 2). Her immediate postoperative course was uneventful. However, at 5 years post-operative, she presented complaining of minor stiffness. On examination, she demonstrated increased varus-valgus instability with firm endpoints throughout range of motion. Radiographically, posteromedial polyethylene wear was noted on successive

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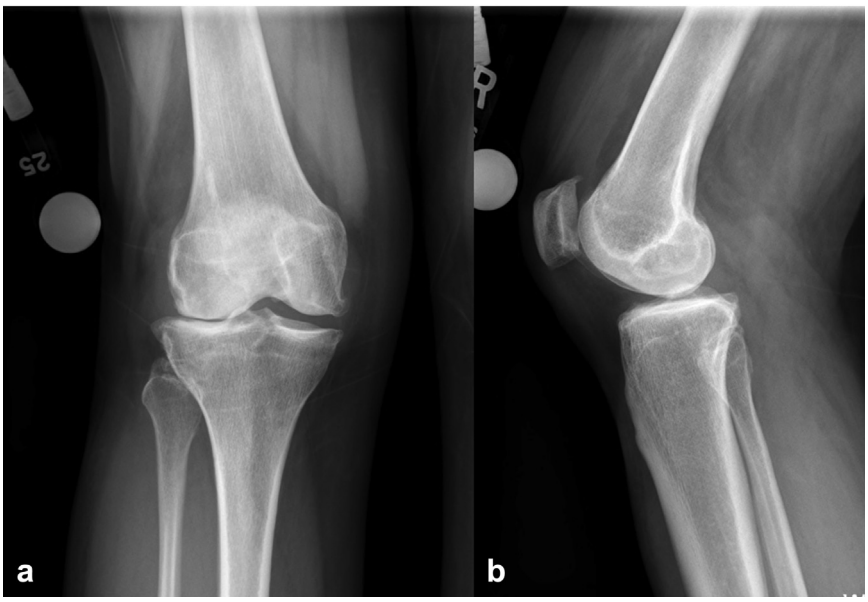

Figure 1. Preoperative standing (a) anteroposterior (AP) and (b) lateral right knee radiographs demonstrating valgus osteoarthritis.

radiographs (Fig. 3). At 5-1/2 years postoperative, she had developed increasing feelings of instability and pain. Radiographically she had completely worn through her polyethylene posteromedially and revision surgery was recommended (Fig. 3). At the time of revision, her cementless components were well ingrown, but posteromedial polyethylene wear was found to the point that the medial femoral condyle was articulating on the tibial tray causing intra-articular metallosis (Fig. 4). In addition, the entire polyethylene surface demonstrated yellow discoloration consistent with oxidation. Owing to the tibial component damage, total revision was performed, and at 1-month follow-up, the patient was recovering well without complication or complaints (Fig. 5).

Discussion

The preparation of polyethylene includes cross-linking with irradiation and subsequent remelting or annealing to reduce free radicals. Despite this, free radicals are never completely eliminated, and in vivo oxidation still occurs, resulting in wear and osteolysis. Remelting occurs above the polyethylene melting point while annealing heats the polyethylene below the melting point. Sequentially irradiated and annealed polyethylene (X3; Stryker, Mahwah, NJ) consists of 3 rounds of irradiating and annealing the polyethylene. It was developed with the goal of further reducing free radicals without substantially affecting the mechanical

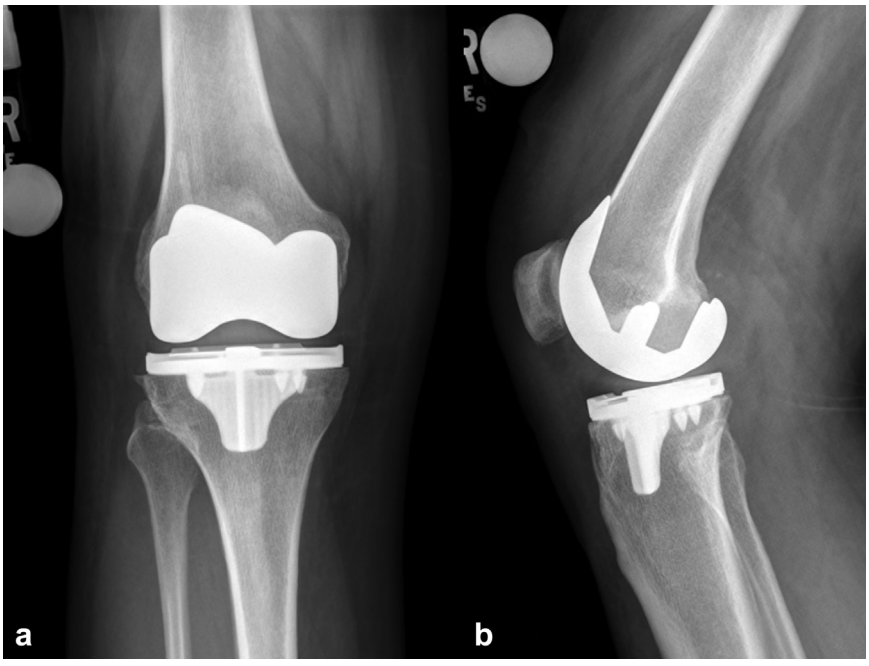

Figure 2. Four-week postoperative (a) AP and (b) lateral radiographs demonstrating press-fit total knee arthroplasty.

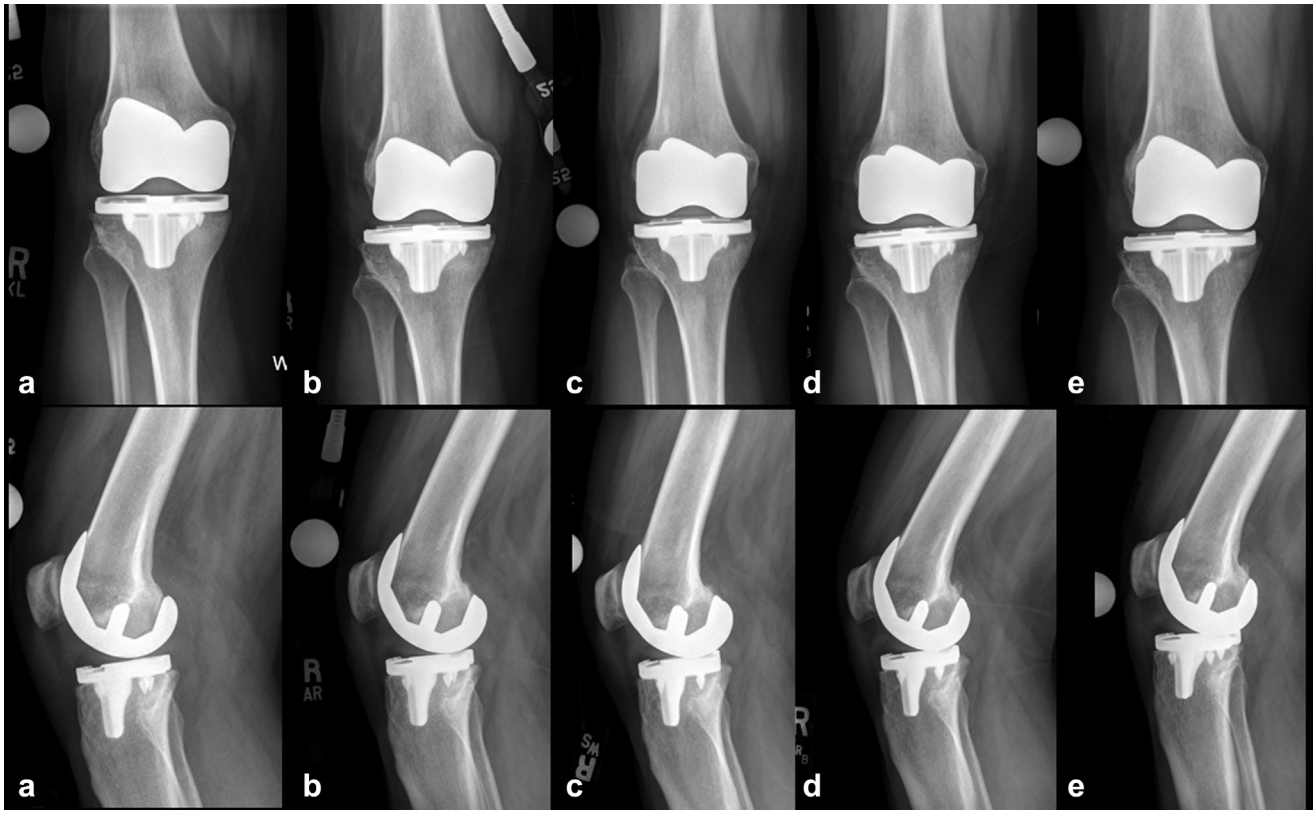

Figure 3. Progression of postoperative standing radiographs at (a) 6 mo, (b) 14 mo, (c) 2 y, (d) 5 y, (e) and 5.5 y demonstrating progressive posteromedial polyethylene wear.

properties. Sequentially annealed polyethylene was used in this case, and interestingly, we found not only catastrophic failure at 5 years but also yellow discoloration consistent with oxidation. There are concerns that annealed polyethylene demonstrates a greater propensity for oxidation because of residual free-radicals [6-8]. This case highlights the fact that because mechanisms of wear and failure of polyethylene in THA and TKA are different, the immense improvement with newer preparations in THA may not be mirrored in TKA. Conventional polyethylene had been associated with good long-term outcomes in TKA, but transition to modern HXLPE demonstrated further improvement in failure because of wear and osteolysis in some studies. Thiele et al. [4] reported a reduction in the proportion of TKA failures because of polyethylene wear with modern polyethylene (7% vs 25% historically). Similarly, Sharkey et al. [5] found only 3.5% of revisions being performed for polyethylene wear. However, when comparing directly rather than using historical controls, other studies have demonstrated no difference in wear rates comparing conventional and modern polyethylene in TKA [9-11].

When it comes specifically to sequentially irradiated and annealed polyethylene in TKA, retrieval studies have demonstrated various wear patterns and oxidation but rarely early catastrophic failure [7,12,13]. MacDonald et al. [12] published the largest retrieval study of sequentially annealed polyethylene in TKA and most commonly found burnishing, pitting, and scratching. Although they reported no cases of revision for polyethylene wear at less than 9.5 years implantation time, they did note 7 cases of delamination and 6 cases of posterior polyethylene fracture of their retrieved liners [12]. Although it has been theorized that sequentially annealing polyethylene improves on once-annealed polyethylene by further removing free radicals and does not have the same negative mechanical effects as remelting, a close look at the data indicates this may not be the case. The polyethylene fractures reported by MacDonald et al. [12] are similar to those reported by Teeter et al. [14] in remelted HXLPE. Our case of early catastrophic wear of sequentially annealed polyethylene further supports the notion that the purported benefits of sequentially annealed polyethylene may not represent an improvement in TKA.

It is well known that numerous factors outside of polyethylene preparation can contribute to wear in TKA. These include surgical factors such as alignment and knee balance, and patient factors such as age, weight, and activity level. Our patient did not report excessive strenuous activity, her BMI at surgery was 31.5 kg/m^2, and her postoperative weightbearing radiographs demonstrated appropriate coronal alignment with a lateral distal femoral angle of 85° and a medial proximal tibial angle of 90°. Interestingly, despite her preoperative alignment of valgus, the patient demonstrated excessive tibial bearing wear posteromedially. An additional consideration is this TKA was a newer TKA design with cementless fixation, which used a 3D-printed titanium tray. However, on inspection, there did not appear to be substantial backside wear on the tibial tray side of the polyethylene insert. Rather, the wear of the polyethylene was on the proximal side which articulates with the femoral component.

Summary

Attempts to minimize free radicals while maintaining structural integrity and maximizing wear characteristics led to the introduction of sequentially irradiated and annealed HXLPE. Most reports in the literature comparing sequentially annealed HXLPE with conventional polyethylene have supported equivalent or improved rates of wear and oxidation. However, we present a case of early catastrophic wear, resulting in metallosis requiring revision at 5 years postoperative. Although there are theoretical benefits of sequentially irradiated and annealed polyethylene, our case

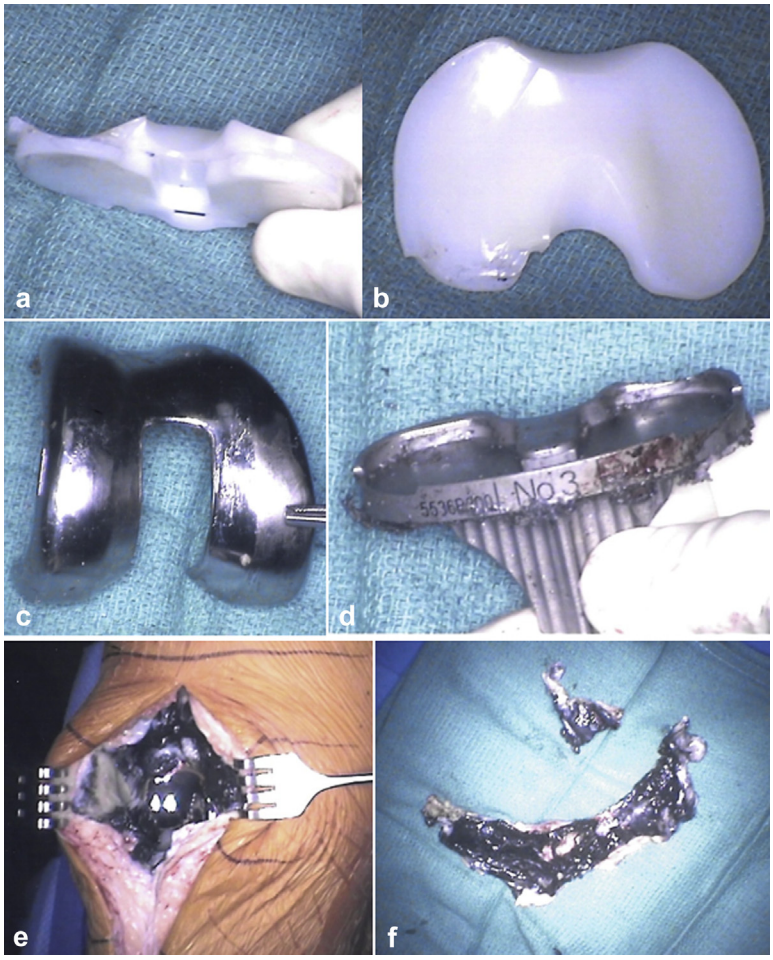

Figure 4. Photographs at the time of surgery demonstrating (a and b) posteromedial polyethylene wear resulting in (c and d) metal-on-metal articulation and (e and f) intra-articular metallosis.

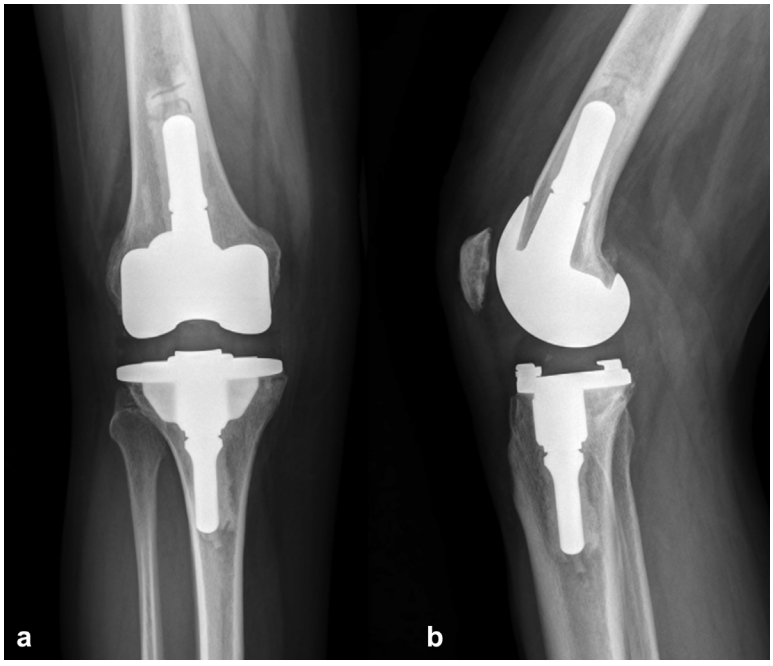

Figure 5. Postoperative (a) AP and (b) lateral radiographs after revision total knee arthroplasty.

suggests that further research is warranted before widespread adoption in TKA. Alternative methods of improving oxidation resistance such as vitamin-E infusion may provide oxidative stability without negatively affecting mechanical properties. However, further research is required to determine these long-term outcomes.

Acknowledgments

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