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Case Report

Early Tibial Component Fractures in a Cementless, 3D-Printed, Titanium Implant

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A R T I C L E I N F O

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A B S T R A C T

Fracture of the tibial baseplate in total knee arthroplasty is a rare occurrence, particularly in short- and mid-term follow-up. This case series documents the first known report in the literature of fatigue fracture of a cementless, 3D-printed, highly porous titanium tibial component. We recommend regular follow-up visits with radiographs to confirm adequate total knee arthroplasty component positioning and alignment.

Introduction

Tibial component fractures in total knee arthroplasty (TKA) are a rare complication. Previous studies described metal tibial baseplate fractures in earlier TKA designs, with the first reported case in 1984 [1–4]. As implant design has continued to improve, reports of tibial component fractures have become increasingly rare.

Recently, there has been renewed interest in cementless fixation for TKA. Advancements in the bioengineering of cementless implants have been shown to provide a viable alternative to cemented fixation. The development of highly porous metals is purported to have the biological advantage of mimicking bone structure to facilitate faster osseointegration of the metal components compared to previous ingrowth surfaces [5–7]. Long-term survivorship and outcome studies specific to a cementless highly porous titanium tibial baseplate are limited with the largest follow-up study currently reporting 5-year follow-up data on 228 patients [5,7]. No implant fractures of this design have been reported in these short-term to mid-term follow-up studies [5,7,8].

Case histories

We report the first documented case series of 3 patients with fatigue fracture of a cementless, 3-dimensional (3D)–printed, highly porous titanium tibial baseplate. All patients underwent primary cementless TKA using a highly porous, 3D-printed, titanium-coated baseplate (Triathlon Tritanium Tibial Baseplate; Stryker Orthopedics, Mahwah, NJ).

The patients were informed of our intentions to use data from their cases and provided written consent for publication of the case series.

Case 1

A 60-year-old woman underwent a primary cementless left TKA in June 2017 for advanced osteoarthritis using a size 2 Stryker Tritanium tibial component (Fig. 1a-c). She had a body mass index (BMI) of 30.6 kg/m^2 (70.7 kg, 152 cm). She recovered well without postoperative complications. She later presented 3 years after the initial procedure with increasing left knee pain and instability. Upon clinical evaluation, she had an antalgic gait requiring a walker and varus deformity of the left knee. Inspection revealed a well-healed incision with mild swelling. She demonstrated active painful range of motion of 0°-120°, with significant varus instability and positive anterior/posterior drawer testing.

Radiographs were obtained and indicated a fractured medial tibial tray of the tibial component with anterior dislocation of the polyethylene liner (Fig. 2a-e). A subsequent computed tomography scan confirmed these findings (Fig. 2e).

She underwent revision of the tibial component in June 2020. Intraoperative inspection of the patellar and femoral components showed good fixation to bone and did not require revision. There was visualization of a coronally oriented fracture of the posteromedial

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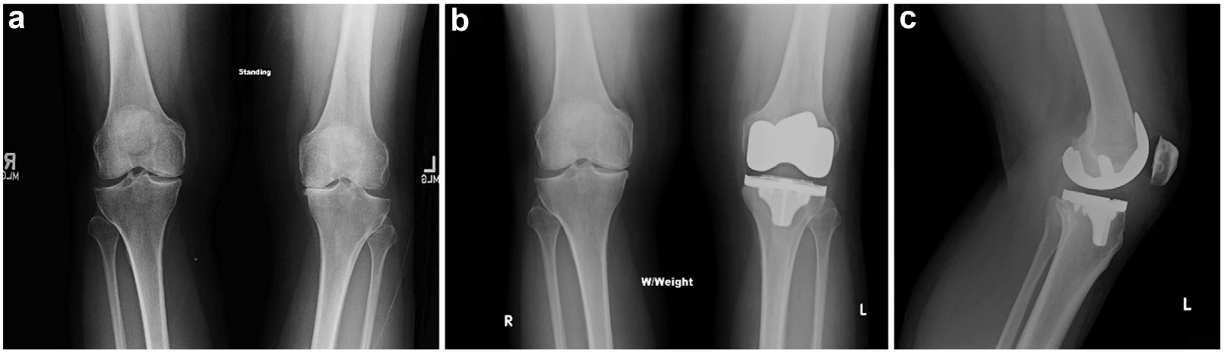

Figure 1. Case 1 preoperative (a) and initial 4-week postoperative (b-c) anteroposterior (AP), lateral bilateral knee radiographs.

tibial baseplate with a lack of bony ingrowth (Fig. 3a-b). There was also damage to the polyethylene liner and disengagement of the locking mechanism. Osseous destruction was contained to the medial tibial condyle and was classified as an Anderson Orthopedic Research Institute type 2A bone defect. The osseous defect was bone grafted using autologous graft from the tibial reaming. A size 2 Stryker Triathlon revision tibial component with a cemented stem was inserted and fixed with cement.

She had no postoperative complications. At her 1.5-year follow-up, she was satisfied with the function of her knee and demonstrated excellent clinical results with pain free range of motion of 0°-120°. (Fig. 4a-b).

Case 2

A 65-year-old man underwent a primary cementless right TKA for advanced osteoarthritis in June 2016 using a size 5 Stryker Tritanium tibial component (Fig. 5). His BMI was 29.6 kg/m^2 (97.5 kg, 183 cm). He recovered well without postoperative complications. However, 4 years after the initial procedure, he presented with 5 months of increasing right knee pain and instability. He denied any trauma or specific cause that contributed to his progressive loss of function and mechanical symptoms of locking and popping. On clinical evaluation, he had mild right knee swelling and a 12° varus angulation. His range of motion was 0°-118° with medial laxity during varus/valgus instability testing.

Radiographs were obtained, which demonstrated posterior subsidence with varus malalignment of the tibial component. There was a radiolucent line around the tibial keel on the lateral radiograph and visible fracture of the medial tibial tray (Fig. 6a-d).

He underwent revision of the tibial component in June 2020. Intraoperative inspection of the patellar and femoral components showed good fixation to bone and did not require revision. There was a sagittally oriented fracture of the anteromedial portion of the component that ran laterally around the locking mechanism (Fig. 7a). The lateral side and keel of the tibial implant were rigidly fixated to the bone. The destruction of the medial tibial plateau was consistent with an Anderson Orthopedic Research Institute type 2A bone defect (Fig. 7b). Revision required a size B tibial medial

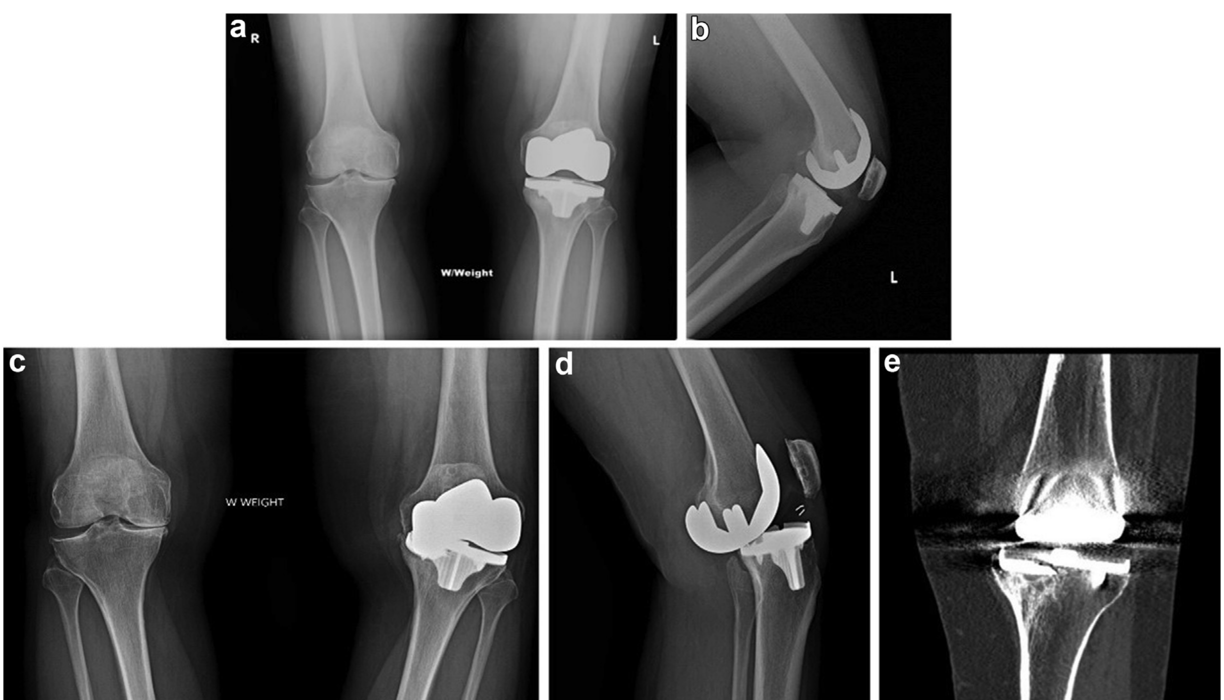

Figure 2. Follow-up radiographs obtained 1 year (a-b) and 3 years (c-d) after index procedure showing medial tibial implant fracture. Note the disengagement of the polyethylene liner along with anterior tibial subluxation. (e) CT scan depicting hardware fracture of tibial component. CT, computed tomography.

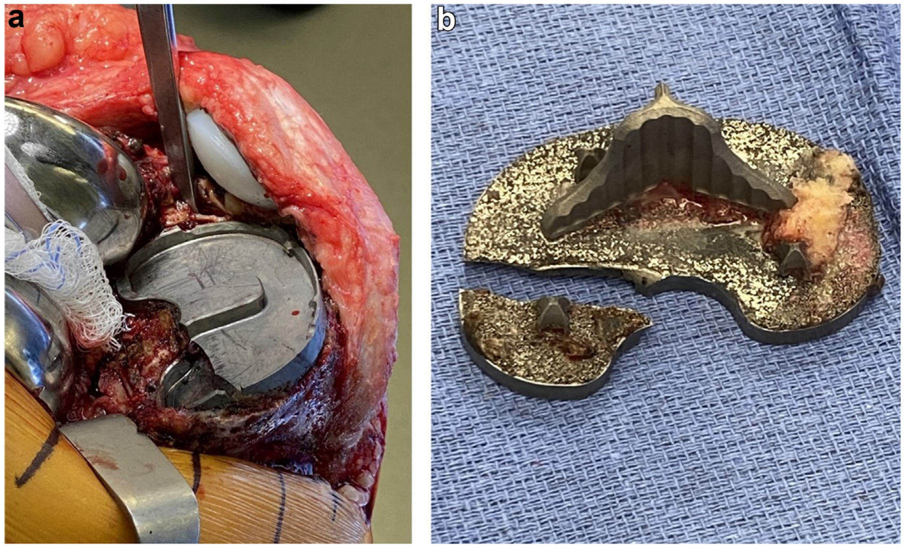

Figure 3. Clinical observation during revision surgery showing (a) coronal fracture of medial tibial component. Orientation of fractured baseplate suggests focal proximal tibial bone loss. (b) Removal of tibial component depicts no bony ingrowth on medial side, contrary to the lateral side.

augment with a size 6 Stryker revision tibial baseplate with a cemented stem.

He had no postoperative complications. At the 1.5-year follow-up, he states he was doing well with no reported discomfort, a pain free range of motion of 0°-130°, and a normal gait without need of assistance (Fig. 8a-b).

Case 3

A 65-year-old man underwent a primary cementless right TKA for advanced osteoarthritis in June 2017 using a size 5 Stryker Tritanium tibial component (Fig. 9a-b). His BMI was 32.9 kg/m^2 (128.8 kg, 198 cm). He recovered well without postoperative complications. He later presented 16 months after his primary TKA with worsening pain and swelling. He denied any known trauma or cause to the development of the pain. On clinical examination, he ambulated with a compensated gait using a walker. There was a well-healed incision seen about the right knee with mild swelling and effusion. He was diffusely tender around the knee and demonstrated active painful range of motion of 0°-120°.

The radiographs obtained depicted a fracture of the tibial baseplate at the keel-baseplate junction (Fig. 10c). There was subsidence of the tibial component and anterior lifting of the tibial baseplate (Fig. 10d).

He underwent revision surgery of the tibial component in November 2018. Intraoperative inspection of the patellar and femoral components showed good fixation to bone and did not require revision. The tibial component was found to be fractured transversely at the keel-baseplate junction. There was lack of bony ingrowth seen on the complete undersurface of the tibial component. However, the keel was rigidly fixed to bone (Fig. 11a-b). One of the posterior pegs of the tibial baseplate was also fixed to bone and had fractured. There was significant but contained medial tibial

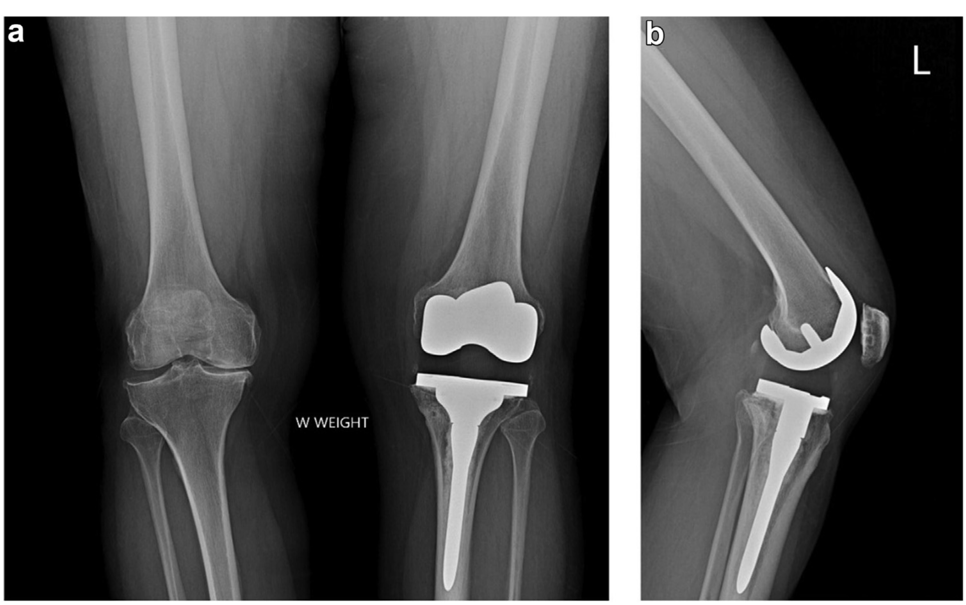

Figure 4. AP bilateral (a) and lateral left (b) knee radiographs obtained at 1.5-year postoperative visit from revision total knee arthroplasty.

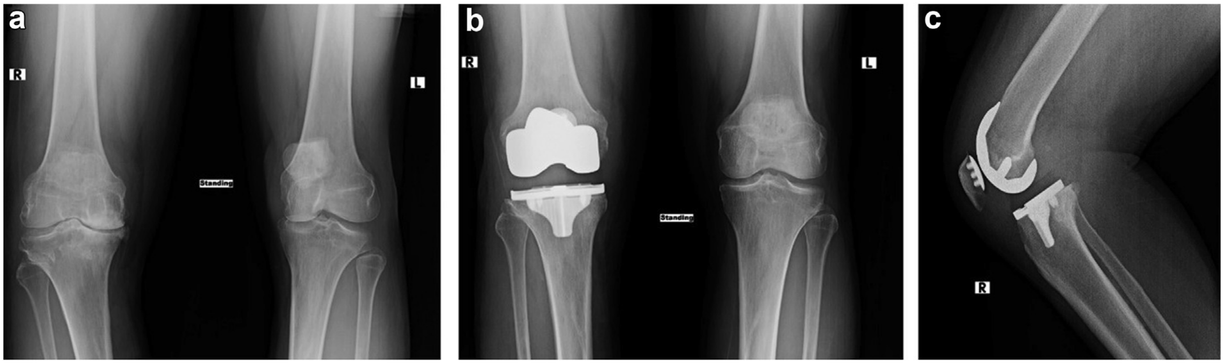

Figure 5. Preoperative (a) and initial 4-week postoperative (b-c) AP bilateral knee radiographs for Case 2.

bone loss, thus classified as an Anderson Orthopedic Research Institute Type 2A bone defect. The medial-sided bone loss was bone grafted using autologous graft. A size 6 Stryker Triathlon revision tibial component with cemented stem was inserted and fixed with cement.

He had no postoperative complications. For his most recent follow-up at 3 years after revision surgery, he states he was doing well with no reported discomfort from his right knee and with pain free range of motion of 0°-130° (Fig. 12a-b).

Discussion

Implant fractures following TKA are extremely rare occurrences, with a reported incidence of 0.13%-0.3% [3]. Tibial component fractures have occurred in both cemented and cementless designs, with osteolysis and long-term polyethylene wear being cited as the primary mechanisms for implant failure [2,9–11]. However, there is recent concern for modern implant fracture based on occurrence of early tibial baseplate failures reported by Scully et al [12] and

Figure 6. Follow-up radiographs approximately 6 months (a-b) and 4 years (c-d) after index procedure depicting tibial baseplate fracture and posterior subsidence.

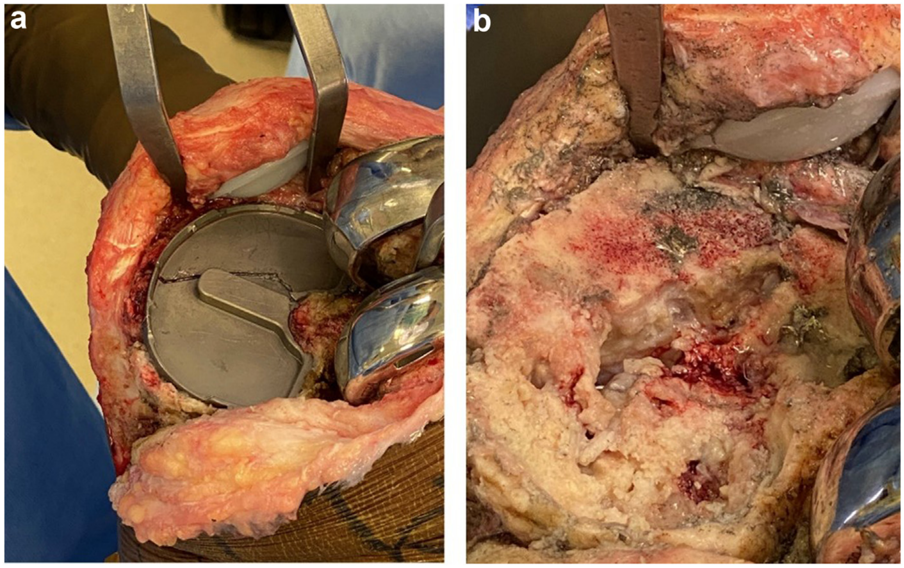

Figure 7. (a) Intraoperative photographs depicting sagittal fracture of tibial component. (b) Removal of tibial component reveals underlying bone defect of medial tibial plateau.

Sepehri and Masri [13], who utilized cementless and cemented fixation strategies, respectively. This case series details the first documented occurrences of component failure of a cementless, 3D-printed, highly porous titanium tibial baseplate.

We concluded that the mechanism for tibial component failure was due to fatigue fracture after focal loss of structural bony support underneath the implant. Lack of bony ingrowth below a portion of the implant led to micromotion of the unsupported implant, which over time with repetitive forces resulted in implant fatigue failure. Chatterji et al [9] found a 100% correlation between the site of the fractured tibial baseplate and the underlying proximal tibial bone loss in 25 cases. Absence of bony support can consequently lead to cantilever forces interacting between the osseointegrated and unsupported portions of the tibial components [2,9–11,13–15]. Weight-bearing led to the asymmetrical stress transmission of forces onto the inadequately fixed implant that precipitated tibial component failure. In our cases, failure of bony ingrowth was observed on the medial baseplate of 2 tibial implants (Figs. 3a and 7a) and the complete undersurface in one (Fig. 11b), which matched with the site of the fracture. The tibial pegs served as an extension of the limited bone fixation, which became an additional stressor from the lack of even bone ongrowth. Another possible mechanism leading to component fatigue failure can be instability/subluxation, which has been documented in several studies during short- to mid-term follow-up [5,6,8].

The time to fracture was short in our case series, with the mean occurrence being 30.6 (range 16-42) months after the primary TKA procedure. This contrasts with previous cases that reported tibial component fractures after long-term follow-up, including polyethylene wear and osteolysis [9–11,16,17]. During intraoperative inspection, the polyethylene insert showed minimal wear given the relatively short time since the index procedure and was not considered to be a contributing factor to component failure.

One noteworthy finding was how the 2 medial-sided tibial baseplate fractures correlated with the presence of highly sclerotic bone seen on preoperative radiographs before primary TKA (Figs. 1a and 5a). Scully et al [12] recently reported a similar case in failure of a modular, trabecular metal tibial baseplate. There is suspicion that

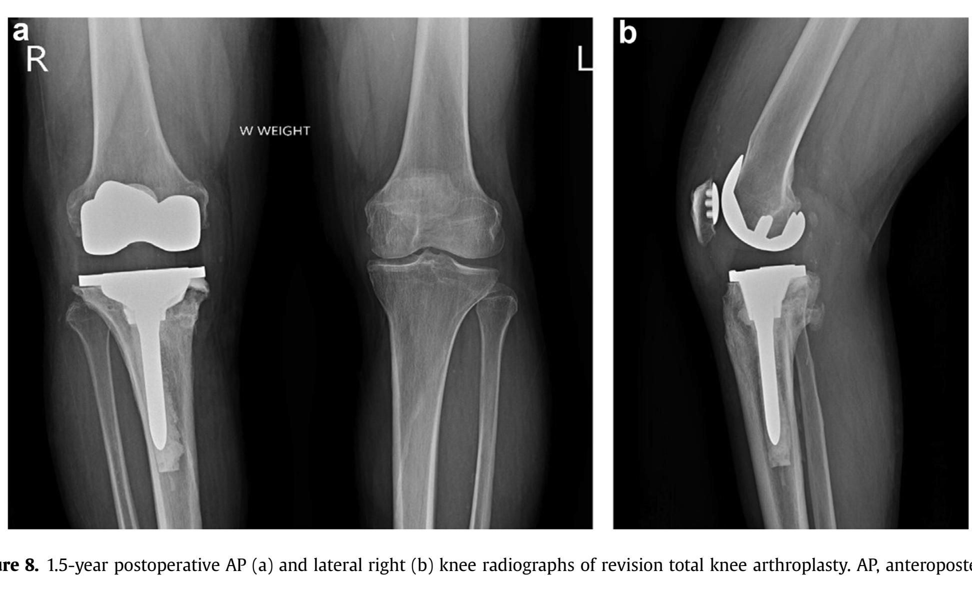

Figure 8. 1.5-year postoperative AP (a) and lateral right (b) knee radiographs of revision total knee arthroplasty. AP, anteroposterior.

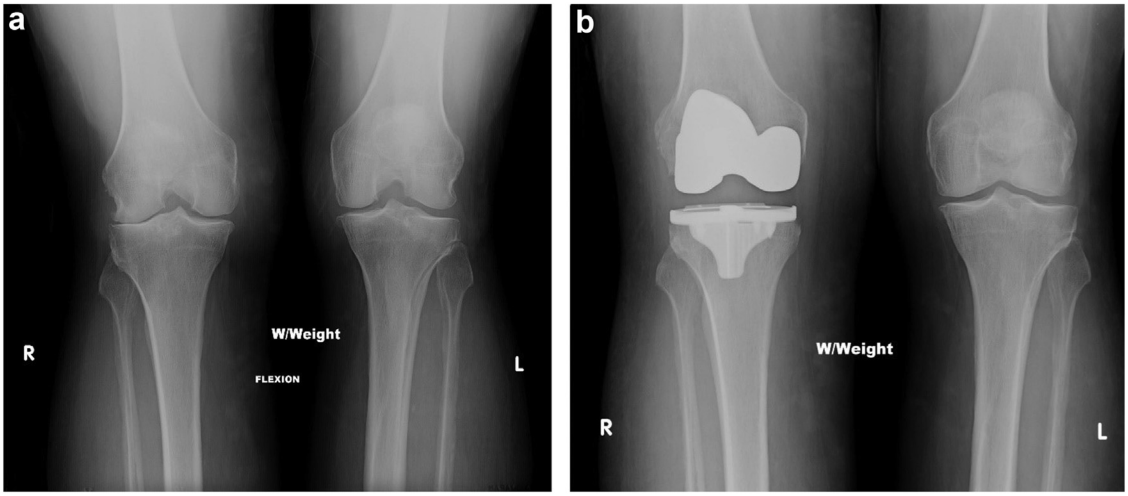

Figure 9. Preoperative (a) and initial 4-week postoperative (b) AP bilateral knee radiographs for Case 3.

the initial varus malalignment before primary TKA and associated sclerotic changes may have compromised the strength of the proximal medial tibial bone stock [18]. Given the sclerotic subchondral bone and associated properties of stiffness and microdamage [19], this may predispose the tibial component to incomplete biological ingrowth.

Incorrectly aligned components, varus malalignment, and ligament imbalance have been associated with possible factors that

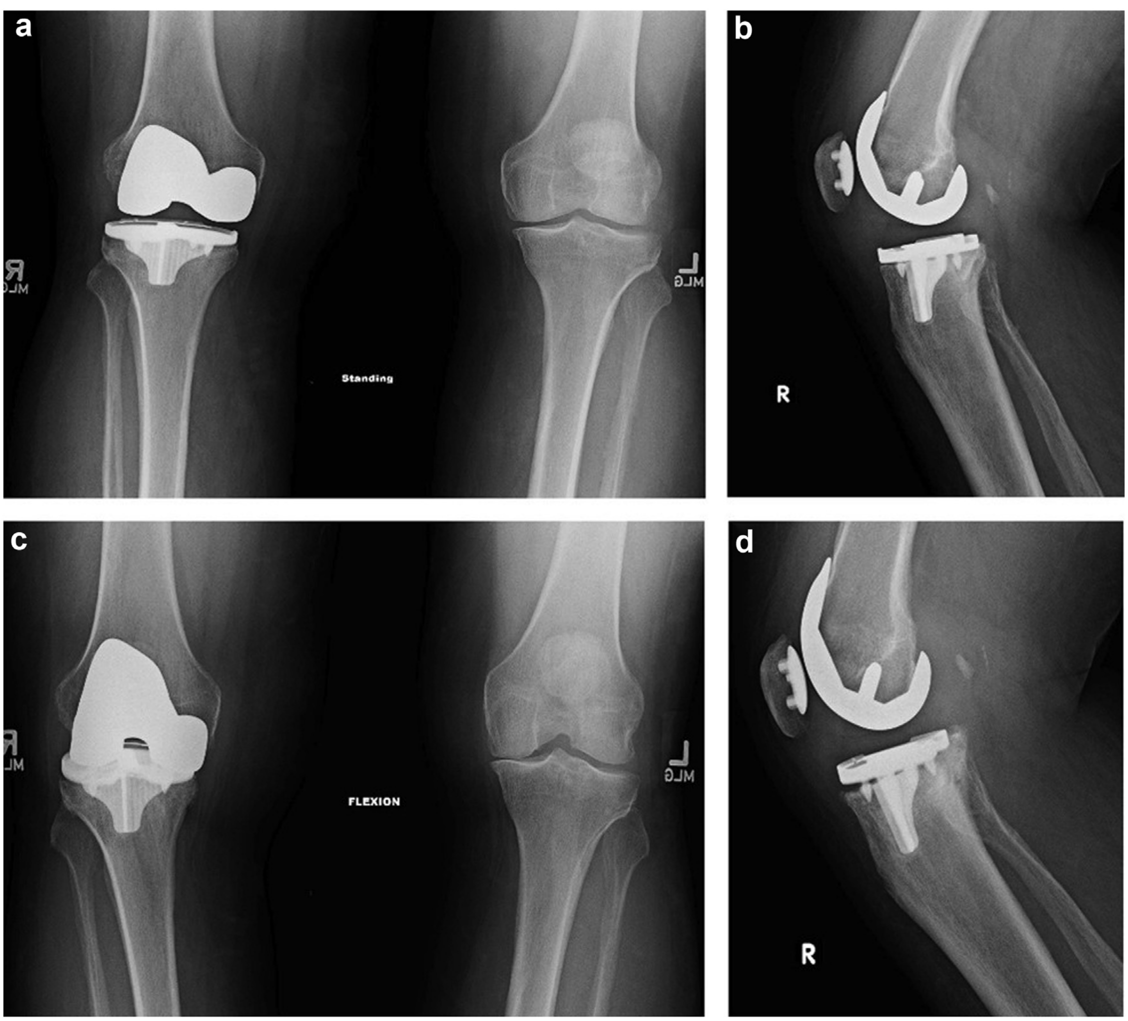

Figure 10. Follow-up radiographs obtained approximately 6 months (a-b) and 1.5 years (c-d) after index procedure depicting tibial component fracture at keel-baseplate junction. Note anterior lifting of tibial baseplate.

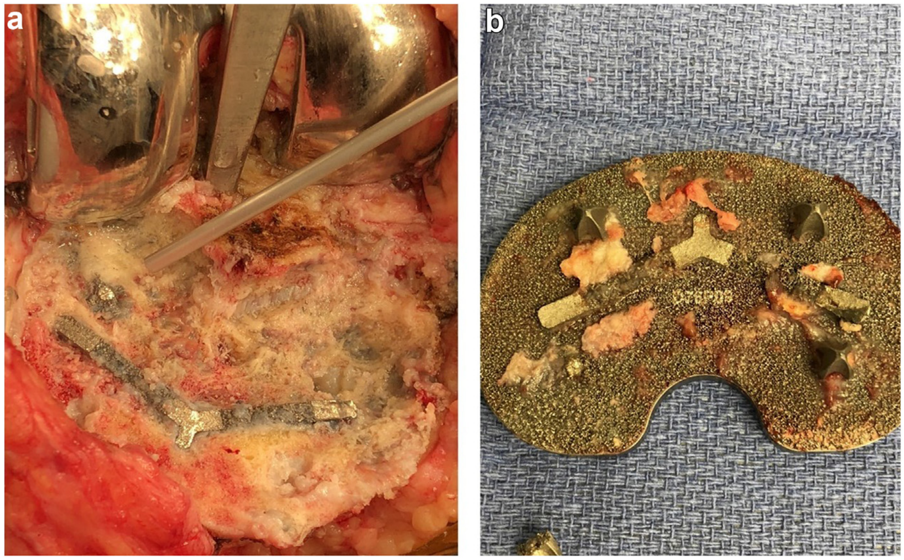

Figure 11. Intraoperative photographs displaying (a) rigidly fixed keel to bone and retained tibial spike. Note the contained medial tibial bone loss. (b) Underside of tibial baseplate after removal shows minimal bony ingrowth.

lead to tibial component failure [4,12,13,16,20]. Gilg et al [3] and Abernethy et al [4] suggested that a failure to correct varus deformity following TKA can lead to displacement of the mechanical axis to the medial side and subsequent fracture. We did not believe this to be a major cause to compromising component integrity due to the patients' 1-month postoperative radiographs indicating neutral alignment in all 3 cases. However, successive radiographs performed at regular intervals did show a progression toward varus deformity leading to eventual component fracture. The mean knee angulation calculated at patients' 1-month postoperative visit from primary TKA and at time of component fracture using anteroposterior knee radiographs was 1.8° (range 0.5°-3.9°) valgus to 14.2° (range 11°-16.5°) varus alignment, respectively. This may have occurred from the natural pattern of load shifting to the medial compartment during one's gait while walking despite normal knee alignment [21].

Increased BMI and obesity status could also compound the compressive forces on the tibial implant with weight-bearing, leading to greater complications of varus malalignment and ultimately implant failure. In this case series, all patients were either overweight or obese during the surgical procedures. One patient gained significantly more weight in the time leading to his revision, increasing from a BMI of 32.85 to 36.4. Previous studies have mentioned how the asymmetrical forces associated with obesity and soft-tissue imbalance could compromise implant life span and lead to fracture [17,20]. Bagsby et al [22] reported cementless fixation using the Stryker Triathlon Tritanium design performed better than cemented fixation in patients who are morbidly obese with regards to revision rate and long-term survivorship. However, Goh et al [23] found no significant differences in the clinical outcomes and mid-term survivorship between cementless and cemented TKA in patients with obesity with BMI $\geq$ 35 using the same prosthesis.

Two patients required revision tibial components that were one size larger (ie, size 5-size 6) than the ones placed during their index procedure. This may suggest potential undersizing of the tibial component, making the prosthetic less effective at transferring loads to the underlying proximal tibial bone [12,16,24]. Given inadequate coverage of the cortical bone surface, the tibial baseplate sustained greater forces that led to its eventual failure. Although care should always be taken to appropriately size implants to maximize surface contact between cancellous and cortical

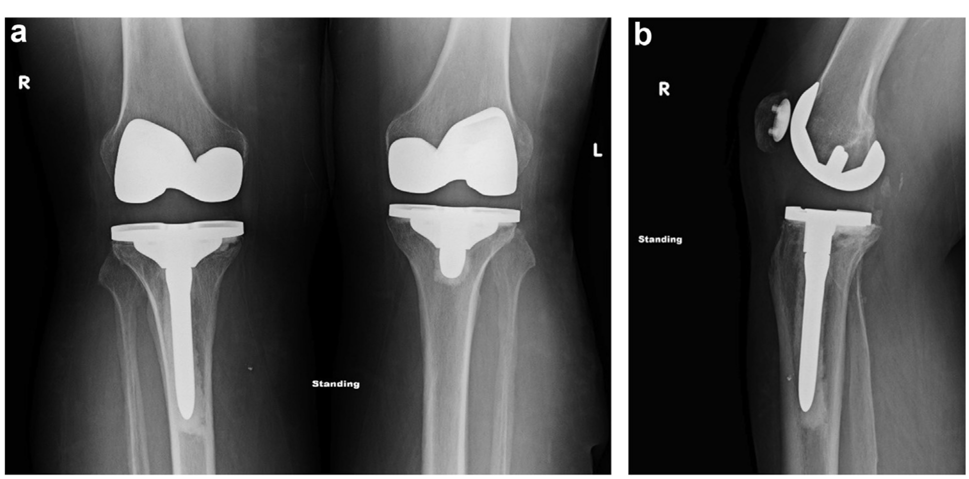

Figure 12. 3-year postoperative AP (a) and lateral right (b) knee radiographs of revision total knee arthroplasty. AP, anteroposterior.

bone and the component [24], oversizing is preferably avoided to reduce risk of postoperative pain.

These are the first reported cases that we are aware of in which fatigue fracture has been reported with a cementless Stryker Triathlon Tritanium tibial implant. Current long-term follow-up data concerning this specific implant is limited. Since there was no previous trauma that preceded implant fracture and the time to failure was relatively short-term, we recommend routine monitoring of TKA components via follow-up radiographs to ensure correct positioning and alignment. The nature of implant production via additive manufacturing and its effect on implant microstructure was not explored in our case series and may warrant further investigation. We suggest further study with long-term follow-up outcomes of this cementless TKA design.

Summary

This is the first reported case series of fatigue fracture of cementless, 3D-printed, highly porous titanium tibial baseplate in a modern TKA design. Cantilever forces generated from the interaction between the non-ingrown and osseointegrated portions of the tibial component led to eventual failure. The cementless, 3D-printed design of the Stryker implant as well as the strength at the keel/tibial baseplate junction is of concern. Further study of this design is recommended.

Informed patient consent

The author(s) should confirm that written informed consent has been obtained from the involved patient(s) or if appropriate from the parent, guardian, power of attorney of the involved patient(s); and, they have given approval for this information to be published in this case report (series).

Please refer to Elsevier's policy regarding written patient consent requirements https://www.elsevier.com/about/policies/patient-consent#:~:text=That%20individual%2C%20legal%20guardian%20or,writing%20of%20all%20such%20conditions

Conflicts of interest

Gavan P. Duffy received royalties from, is a speaker for, and is a paid consultant for Depuy Orthopedics. The other author declares no potential conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2022.08.002.

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