

Christiansen's artificial hip joints – what went wrong?

SUMMARY Modern arthroplasty is undoubtedly the greatest contribution that orthopaedic surgery has ever made to medical science. The honour for the good results achieved with total hip replacement surgery goes chiefly to the Briton John Charnley (1911–1982). However, the Norwegian Tor Aas Christiansen (1917–1981) has also earned a place in this history. He wanted to improve the operative treatment of dislocated, medial fractures of the femoral neck, and in the 1960s he constructed a hemiprosthesis. Later, he also made a total prosthesis for the hip joint. Over time, the prostheses proved to be less than successful. Nevertheless, approximately 6 500 Christiansen prostheses were fitted in Norway before a prospective Charnley vs. Christiansen study at the Coastal Hospital in Hagevik finally put an end to his prostheses in 1983. Indirectly, the study led to the establishment of a national register of hip prostheses, now the National Arthroplasty Register, at Haukeland University Hospital. Based on our personal cooperation with Christiansen, as well as original drawings and correspondence from the Polaris factory in Sandnes, we will tell the story of Christiansen's hemi- and total prostheses. These are a key element in the history of hip arthroplasty in Norway.

Tor Aas Christiansen (1917–1981) (Figure 1) commenced his hospital career in Porsgrunn in 1949. After a brief period at the Coastal Hospital in Hagevik he went to work at the Department of Pathology at the National Hospital in Oslo, and in the years 1954–1963 he worked at hospitals in Sarpsborg and in Rogaland and Aker Hospital. He had thus acquired a solid training in general surgery and pathology when he was employed as Senior Registrar at Drammen Hospital in 1963. In 1965 he was appointed Senior Consultant at Kongsberg Hospital. He continued working there until he died suddenly in 1981, at the age of only 64 (1).

In the early 1960s, with enthusiastic collegial support from the surgical department at Drammen Hospital headed by Senior Consultant Kaare Liavaag (1908–1981), Christiansen started to design a new type of hip prosthesis. With good support from the medical and technical community there, he succeeded in developing a new type of prosthesis outside the university community. In this article we will show the rocky road leading to Christiansen's hemi- and total prostheses and attempt to provide an answer to the question of why this went wrong.

Material

This article is based on personal contact between Christiansen and Knut Rasmus Ramstad, dating back to when Ramstad was employed as a Junior Registrar at Drammen Hospital in 1963. Einar Sudmann became acquainted with Christiansen through Ramstad in 1967, and later mainly continued this contact by letter, including with comments on and corrections to his draft manuscripts. Lars Birger Engesæter became acquainted with Christiansen when meeting

him professionally. The article is also based on original drawings and correspondence in the file on the Christiansen prosthesis at the Polaris factory in Sandnes.

Medial collum fractures

In Norway, hemiprosthesis were first used as a primary treatment for fractures of the femoral neck in some elderly patients during the mid-1950s, although most femoral neck fractures were nailed in place with the three-flanged Smith-Petersen-Johansson nail. In the early 1960s many departments, including the surgical department at Drammen Hospital, found that postoperative redislocation of the fracture frequently occurred (2). Austin Moore's hemiprosthesis were also fraught with problems, since some stems dislocated and in many patients the metal femoral head caused erosion of the acetabulum and the protrusio acetabuli.

Christiansen, who was Senior Registrar at the hospital at the time, was of the opinion that multiple threaded pins placed peripherally in the collum/caput would prevent rotation of the fracture. He had such pins made by a local mechanical workshop in Drammen. The threaded part, which would be placed in the caput femoris, was welded on to a stainless, smooth steel pin. After some time, due to postoperative strain, these «home-made» threaded pins broke at the welding point. The threaded part remained inside the caput. Multiple peripheral threaded pins of an equivalent type were later made systematically by Deyerle (3).

To reduce the wear to the acetabulum, and on the basis of Pauwels' classical biomechanical work on medial collum fractures (4), Christiansen then constructed a

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Figure 1 Tor Aas Christiansen in 1966. Photo: Knut Rasmus Ramstad

hemiprosthesis in which a plastic femoral head articulated with a trunnion bearing (5).

Christiansen's hemiprosthesis

The trunnion bearing (Figure 2, Figure 3a) was a well-known mechanical device that could be designed for the large forces that act on the hip joint. In Christiansen's hemiprosthesis, the angle between the cylindrical trunnion and the stem of the prosthesis was empirically set to 115°, which permitted a sufficient bearing for movements in the sagittal plane – flexion and extension. Thereby, most of the movements in the hip joint between the artificial femoral head and the acetabulum were transferred to the trunnion bearing.

With the aid of radiological function imaging using a small metal marker in the plastic femoral head, it could be shown that the latter stayed immobile during flexion/extension of the hip joint (6). These findings were later verified by cineradiography (7). During abduction, adduction and rotation, however, the prosthesis functioned as a regular hemiprosthesis with a fixed femoral head.

Christiansen obtained a Norwegian and US patent for his hemiprosthesis, with 26 May 1965 and 24 May 1966 as priority dates, respectively. The first prototypes were made by the Fadum mechanical factory in Drammen by the engineers Robert Johansen and Knut Nilsen. According to a front-page article in the *Fædrelandsvennen* daily, the prosthesis came into production in the autumn of 1968 at the AS Nymo factory, which mostly manufactured maritime equipment (8). To ensure production and distribution, the company AS Joni was registered on 13 September 1966.

In 1965, Christiansen's hemiprotheses were first used in Drammen for dislocated medial collum fractures in patients over 70 years. The artificial femoral head was made of polytetrafluorethylene (Teflon), a material that later proved to be unsuitable. Christiansen, one of the authors (Ramstad) and engineer Nilsen therefore visited John Charnley (1911–1982) at Wrightington Hospital near Wigan in England on 19 September 1966. Charnley had used Teflon for an artificial hip joint socket in his first

total prostheses (9). These patients had to undergo revision surgery, however, since the acetabular sockets wore out quickly (Figure 4) and the Teflon particles caused a massive tissue reaction. Charnley therefore stopped using Teflon in November 1962 (10, 11). After that, he used a cemented stem with a small, fixed femoral head against a thick, cemented hip socket made of high molecular-weight polyethylene (HMWP) (Figure 4). In his book *Low friction arthroplasty of the hip* (12) he showed that this produced very positive long-term results, and this prosthesis later became the gold standard against which all total prostheses were later measured.

When the Norwegian delegation visited Charnley, Christiansen was only interested in hemiprotheses, not total prostheses. In addition, at the time they were sceptical of fixing the femoral stem in the femoral shaft with cement, although not of the choice of steel on polyethylene.

In 1967 Christiansen accordingly exchanged the Teflon femoral head for a corresponding one made of high molecular-weight polyethylene (Figure 2, Figure 3a) (5). However, recalling the tissue reaction caused by the Teflon femoral heads, one of us (Ramstad) suggested applying a two-millimetre stainless steel coating on the polyethylene ball. This was done by the Polaris factory in Sandnes (Figure 3b). For financial reasons, no patent for the steel coating was applied for. The first 150 of a total order of 500 artificial femoral heads with a stainless steel coating and an outer diameter of 44–54 mm were dispatched by Polaris to Joni on 21 September 1968. These femoral heads produced much better results than those made of polyethylene with no steel coating (13).

Ramstad used Christiansen's hemiprosthesis over a ten-year period from 1968 in 200 patients at Bodø Central Hospital. In a follow-up examination of this material with a median observation time of 14 years, altogether 42 patients with a total of 44 hip operations were still alive and able to come to the examination. 25% of the prosthesis stems had become loose (14). All had an artificial femoral head made of polyethylene with a steel coating, with the exception of seven, which had a femoral head made of polyoxymethylene (Delrin) manufactured by Benoist Girard & Co. This was a French company in the Howmedica Inc. group that had taken over the production of Christiansen's hemiprosthesis in 1971.

Hemiprosthesis with a ball bearing

Christiansen's patents not only included a trunnion and a trunnion bearing, but also a fully cast prosthesis stem with a small caput, similar to Charnley's ball-and-socket



Figure 2 Christiansen's hemiprosthesis in 1967. Femoral heads made of polyethylene, diameter 44 mm and 52 mm, without a steel coating. Stems of varying sizes, a file and a punch to drive them into the femoral shaft. During the surgery, a sterile slide caliper was needed to find the diameter of the caput femoris that had been removed by the surgeon. Photo: Einar Sudmann

joint; in other words: a bipolar hemiprostheses (15). The same principle was later used by Professor M. Devas at the Royal East Sussex Hospital in Hastings to avoid acetabular erosion (16).

In a later ten-year prospective study from this hospital, including 561 dislocated fractures of the femoral neck in 546 patients, they could find few clinical results that were any better than those for conventional hemiarthroplasties with a fixed femoral head, but the acetabular erosion had been halved (17). This Charnley-Hastings prosthesis has later been slightly modified, but in principle it has remained unaltered until today (Figure 3d). It is now widely used as primary treatment of fractura colli femoris in elderly patients (18).

Norway's first total prosthesis

In spring 1969, as a recently appointed Junior Registrar at the Sophies Minde Orthopaedic Hospital, one of the authors (Sudmann) unsuccessfully attempted to persuade Professor Ivar Alvik (1905–1971) to use the Charnley prosthesis rather than arthrodesis for treatment of coxarthrosis.

Then one afternoon, Alvik came in and said: «Mr Sudmann, tomorrow you will assist me in total prosthesis surgery,» showing Weber's total prosthesis (19). Like Christiansen's hemiprostheses it had a trunnion bearing. The initial results were positive, but the long-term results were extremely poor (P. Benum, personal communication).

Christiansen's total prosthesis

Towards the end of the 1960s, Christiansen started constructing a total prosthesis. A construction drawing of a trunnion sleeve and hip socket made of Delrin and a femoral head in stainless steel has been dated 7 February 1970. Christiansen's total prosthesis (Figure 3c) was widely used in Scandinavia and – not least – Italy. According to Dumbleton, by the end of 1977 approximately 7 000 such prostheses had been inserted – with very good results (20).

At the Coastal Hospital in Hagevik, no agreement could be reached as to what kind of total prosthesis to use. Deputy Senior Consultant Milan Rait (1924–2011) had faith in the Charnley prosthesis, while the head surgeon, Otto Brinchmann-Hansen, favoured Christiansen's prosthesis. From 1974 onwards they therefore implanted Charnley and Christiansen prostheses in every other patient, 200 patients in all, but after one year they stopped using the Christiansen prosthesis because it produced poor outcomes.

At a meeting of the Norwegian Orthopaedic Association on 18 November 1978, Brinchmann-Hansen and his collaborators

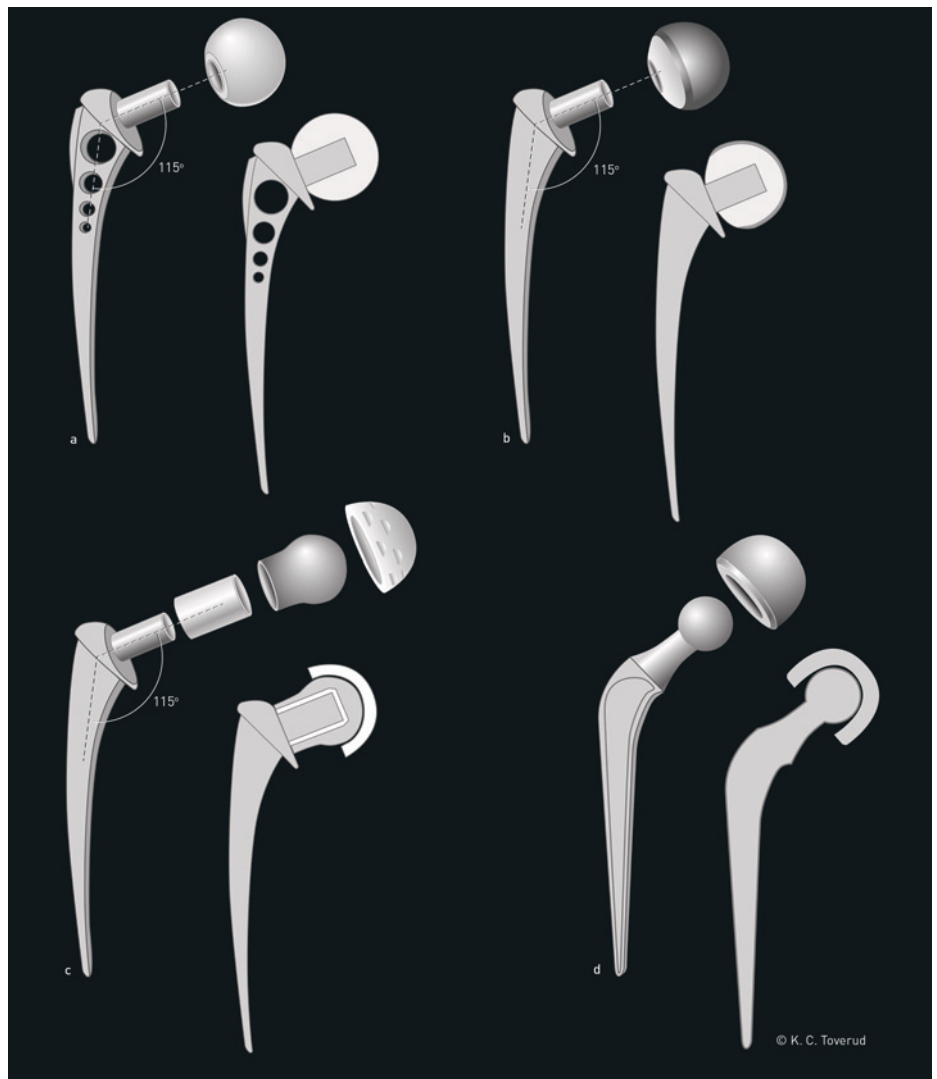


Figure 3 a) Christiansen's hemiprostheses as used in the period 1965–67. A loose femoral head articulates with a cylindrical trunnion on the stem of the prosthesis, the trunnion bearing. To achieve a lasting fixation in the femoral canal, the stem of the prosthesis had several perforations, similar to the stem of an Austin Moore hemiprostheses. The perforations were intended to permit ingrowth of bone tissue to fixate the stem permanently to the bone. The angle between the head and the stem is 115°. The femoral head was initially made of Teflon, from 1967 of polyethylene. b) Christiansen's hemiprostheses as used from 1968. The loose femoral head, with a steel coating added by the Polaris factory in Sandnes, was initially made of polyethylene, later of Delrin. The stem is smooth for fixation with cement. c) Christiansen's total prosthesis as used from 1970. The relatively large metal femoral head articulates on the inside against a sleeve of Delrin and on the outside against a relatively thin-walled artificial acetabular cup made of Delrin. The acetabular cup has small indentations on the outside to enable adherence of the cement. The stem is smooth for fixation with cement. d) A modern Charnley-Hastings hemiprostheses with a loose femoral head of polyethylene with a steel coating. The femoral head articulates against a standard Charnley stem with a small head, and the steel coating – as in all other hemiprostheses – against the joint cartilage in the acetabulum. In 1969, Christiansen was granted a US patent for this kind of «ball-and-socket joint», bipolar hemiprostheses in 1969.

Rait, Lunde and Mølster presented their one-year results – no revisions in the Charnley group as compared to 5% in the Christiansen group. Unfortunately, Rait had performed virtually all of the surgeries in the Charnley group and Brinchmann-Hansen most of those in the Christiansen group. The participants in the meeting were therefore critical of the results, and Christiansen's prosthesis continued to be used as previously in a large

number of Norwegian hospitals, despite the fact that the short-term results for the hemiprostheses as well as the total prosthesis were not entirely positive.

When one of the authors (Sudmann) was appointed Medical Director at the Coastal Hospital in Hagevik one year later, he had to solve an administrative, medical and human problem. As it turned out, many patients had had the Christiansen prosthesis



Figure 4 Two samples from autopsies. On the left, a Teflon acetabular cup worn out after some years of use. Note vertical direction of wear track. On the right, the future-oriented prosthesis with an acetabular cup made of ultra-high molecular-weight polyethylene first used by Charnley in 1962. The picture was taken in 1967 when Sudmann visited Charnley. Photo: Einar Sudmann

implanted once or even twice in the same hip in other hospitals. Later they would come to the Coastal Hospital to have it replaced by a Charnley prosthesis. To produce the evidence that could stop this unfortunate practice, a follow-up study was made of the patients who had been included

in the prospective hip study conducted by Brinchmann-Hansen and collaborators.

The results of this follow-up study were presented at a meeting of the Norwegian Orthopaedic Association at Sophies Minde Orthopaedic Hospital on 24 April 1982. The study showed that in the Charnley

group only 4 % of the patients had needed revision surgery, compared to 31 % in the Christiansen group. There were quite varying assessments of these results among the attendees. Senior Consultant Rolf Hagen (1925–2002) at Martina Hansens Hospital claimed that a ten-degree increase in the angle between the trunnion and the stem could have improved the long-term results of Christiansen's prosthesis. This modified prosthesis was already being manufactured by Benoist Girard & Co., and Hagen had recruited a number of Norwegian departments to a prospective study. Only few months later, however, these departments stopped using Christiansen's prosthesis and started using Charnley's instead. The results from the Coastal Hospital in Hagevik were published in 1983 (21). Before this publication, as a result of which all production and sales of Christiansen's prosthesis were finally discontinued, a total of 6 500 of these prostheses had been implanted in Norway (22).

Christiansen's prostheses did not produce good long-term results, but it should be taken into account that other prostheses were equally bad or even worse. During the period 1977–1984, altogether 145 of Wagner's joint resurfacing prostheses (23) were implanted at the Coastal Hospital in Hagevik. After ten years, 75 % of them had undergone revision (H.K. Meyer, personal communication).

Could things have gone better?

In hindsight, we may wonder what the long-term results of his hip prostheses would have looked like if Christiansen had stuck to polyethylene and not exchanged it for Delrin, or if he had used the bipolar «ball-and-socket joint» hemiprosthesis (Figure 3d) for which he was granted a US patent. The first prototypes of the hemiprosthesis were made in a workshop in Drammen. There, they could easily manufacture a trunnion bearing, but hardly a «ball-and-socket» joint. We therefore assume that this claim was added as regular assurance of a patent application by his American patent attorney. Such assurance is also embedded in the claim for the angle between the head and the stem, of less than 135°, illustrated by 115° (15).

Like Charnley, Christiansen first chose Teflon. In vitro, this man-made material worked well (and moreover, it could be sterilised in an autoclave), but it was useless in vivo. Then, Christiansen tested high molecular-weight polyethylene. Polyethylene could not be treated in an autoclave, and in this country the femoral head was sterilised by leaving it overnight in Cidex, an activated dialdehyde solution.



Figure 5 A Christiansen prosthesis revised at the Coastal Hospital in Hagevik. The Delrin cup has been worn right through. This cup (without the cement) was used by Leif Ivar Havelin and collaborators as an illustration of the wear in Christiansen prostheses (25). Such asymmetric wear on the cup is also a recurring feature of the Christiansen prosthesis depicted in the Norwegian Arthroplasty Register's logo. Photo: Einar Sudmann

In the exchange of letters between Christiansen and Polaris, it appears that the factory in Sandnes had difficulties in machining polyethylene without discrepancies from one production series to the next, since the material easily changed its dimensions at varying temperatures. In addition, they complained that residue from the machining, such as oil, would easily cling to the finished product. Moreover, polyethylene was *extremely* difficult to machine compared to Delrin. In a letter from Polaris on 7 September 1970, they argued that the polyethylene should be replaced by Delrin. It was only when Christiansen started to use femoral heads made of Delrin that these production problems disappeared.

Delrin was not only easier to machine, it was self-lubricating and for this reason often used for industrial bearings. Its resistance to shrinkage was only one tenth of the resistance of ultra-high molecular-weight polyethylene. This man-made material was approximately ten times harder and thus more resistant to fragments of bone or cement in an artificial hip joint (20). Like thermoplastic polymer made by polymerisation of formaldehyde, it could perhaps also prevent local infections. Finally, it could be sterilised in an autoclave, although a metal casing had to be placed in the sleeve of the trunnion bearing in order to prevent shrinkage.

Professor John Scales (1920–2004) (24) in the UK argued in writing and in person in favour of using Delrin, and in a personal conversation with one of the authors (Ramstad) in Drammen, he expressed his low opinion of Charnley's concept. Ramstad took this information to Christiansen in Kongsberg. It should therefore come as no surprise that Christiansen abandoned polyethylene and started using Delrin.

Metal on plastic causes wear on the plastic. Havelin and collaborators showed occasional strong asymmetric wear in revised Christiansen prostheses (Figure 5) (25). E.B. Mathiesen at the Karolinska Institute was given access to revised acetabular sockets and biopsies taken during revision hip replacement surgery at the Coastal Hospital in Hagevik. He showed that first, friction resistance was twice as high in Delrin cups as in Charnley's polyethylene cups, and second, that the Delrin particles produced a much stronger tissue reaction than particles of ultra-high molecular-weight polyethylene (26, 27).

Again, it thus appeared that a man-made material with very good properties *in vitro* could produce poor results *in vivo*. This prompted Sudmann to argue in person and in writing that we needed a national joint

register equivalent to that of our neighbouring countries Sweden and Finland (28).

The Norwegian Arthroplasty Register

During the annual fracture training course at Voss, the Voss Course, in February 1983, Sudmann invited some of the instructors for an evening session where the strategy for establishing a Norwegian arthroplasty register was discussed. It was agreed that Sudmann should be spokesman for a national hip register in addressing the Norwegian Orthopaedic Association, the Norwegian Directorate of Health and the Ministry of Social Affairs.

In his lobbying efforts he received ample support from Tore Grønmark, then chairman of the association, and from the case officer in the Norwegian Directorate of Health, Chief Architect Jacob Nordan. The physical registration activities were to be located at Haukeland Hospital in Bergen, where Junior Registrar Lars B. Engesæter would take care of the practical work.

The annual meeting of the Norwegian Orthopaedic Association in 1983 adopted Sudmann's proposal for establishment of a national register. Following comprehensive work on the registration form, databases and several trial registrations at the Coastal Hospital in Hagevik, Haukeland Hospital, Rogaland Central Hospital and Trondheim Regional Hospital, official registrations started on 17 September 1987.

It was Christiansen's work on dislocated medial collum fractures that – indirectly – gave us an internationally renowned and respected national arthroplasty register at Haukeland University Hospital (29). Christiansen's prosthesis, with asymmetric wear on the acetabular socket, is the registry's logo. From 2005, a nationwide registration of all hip fracture surgeries also began. We had come full circle!

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The author has completed the ICMJE form and declares no conflicts of interest.

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The author has completed the ICMJE form and declares no conflicts of interest.

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