

CASE REPORT

Revision Total Hip Arthroplasty with Severe Acetabular Defect: A Preliminary Exploration and Attempt of Robotic-Assisted Technology

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Background: Robotic-assisted technology may be useful in hip revision cases with acetabular defects. However, data on the use of robotic-assisted technology for such complex diseases is lacking.

Case Presentation: This case study described the adoption of MAKO robotic-assisted treatment of revision total hip arthroplasty (THA) combined with severe acetabular defect (Paprosky type IIIB). Robotic-assisted technology accurately achieved preoperative planning; the acetabular component and augment were placed in the original position and angle as planned. Robotic-assisted acetabular reaming was successful in a single pass, preserving the remaining acetabular bone mass very well with no procedure-related complications. The Harris Hip Score (HHS) at 6 months postoperatively was 84 and the Western Ontario and McMaster Universities (WOMAC) Osteoarthritis Index was 24.

Conclusion: Robotic-assisted technology can help in the accurate reconstruction of acetabular defect in complex hip revision surgery.

Key words: acetabular defect; revision; robotic-assisted surgery; total hip arthroplasty

Introduction

Total hip arthroplasty (THA) could provide satisfactory and sustained functional outcomes for end-stage hip diseases. However, the 10-year surgical revision rate remains relatively high, at approximately 10%–15%^{1–3}. Acetabular bone defects are the main concern of hip revision surgery more often than not. The goal of acetabular reconstruction is to restore the normal center of rotation of the hip joint as well as the integrity and continuity of the acetabulum, and to preserve as much of the original bone as possible, ultimately obtaining initial and long-term stability of the prosthesis^{4,5}. With the existing surgical protocols and tools, accurate reconstruction of the acetabular bone defect and the biomechanical structure of the hip joint is difficult. The individual variability of the acetabular bone defect and the diversity of

reconstruction strategies are the main problems of acetabular reconstruction in revision surgery.

Robotic-assisted THA has been in the clinic for nearly 30 years⁶. Robotic-assisted THA was meant to reduce prosthetic mispositioning due to human error, resulting in full kinematic recovery, reduced instability or impingement, and improved patient prognosis⁷. Recent studies have reported that robotic-assisted technology has significantly improved the accuracy and precision of the acetabular positioning in the primary THA, balanced the length of the lower limbs, restored off-set, and demonstrated good results in the short-term outcomes^{8–10}.

However, robotic-assisted hip revision procedures have not been reported in the literature. Acetabular prosthesis loosening is an important reason for hip revision, and acetabular defects are one of the complicated conditions of hip

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revision¹¹. Treating acetabular defects, especially severe acetabular defects, to obtain initial stability of the acetabular cup is the focus of hip revision surgery, although it can be challenging. Previous studies have reported that the use of navigation for revision THA improved cup positioning and reduced the range of outliers. Computed tomography (CT)-based navigation in revision THA is a useful tool that enables the surgeon to implant the acetabular component at the precise angle determined in preoperative planning^{12,13}.

Therefore, we attempted to apply robotic-assisted technology in revision THA, conduct preliminary exploration and summarize the experience. We reported this case of complex hip revision with severe acetabular defect, which adopted the robotic-assisted technology to reconstruct severe acetabular defect and achieve satisfactory clinical and radiological results.

Case Report

Basic Information

The patient was a 67-year-old male patient, who underwent THA in a local hospital in April 2014 for right femoral head necrosis and started to have pain 6 months after surgery, which was ignored. In February 2017, he developed pain and swelling in the right hip, accompanied by abscess formation, which gradually burst and oozed pus persistently.

Before the stage I revision, laboratory tests indicated a C-reactive protein (CRP) of 2.774 mg/dL, interleukin-6 (IL-6) of 27.26 pg/mL, and an erythrocyte sedimentation rate (ESR) of 23 mm/h. The bacterial culture results of the right hip aspiration fluid were *Staphylococcus aureus* and *staphylococcus epidermidis*. Based on the patient's symptoms, laboratory tests, and bacterial culture results, the diagnosis of periprosthetic joint infection was confirmed.

In September 2020, the patient underwent right hip prosthesis removal and spacer implantation at our hospital. The prosthesis was then exposed along the original incision. After dislocation, the femoral stem and acetabular cup were

removed sequentially, and the inflammatory tissue around the joint, pseudomembrane tissue, and sinus tract were completely removed. Pulsed lavage was then employed to thoroughly rinse the site with a large amount of normal saline, immersed in hydrogen peroxide, and 0.1% iodophor. Antibiotic bone cement (vancomycin 8.0 g + meropenem 4 g + cement 80 g) was used to make a spacer, which was then implanted. The postoperative antibiotic regimen consisted of intravenous infusion of meropenem 1 g (bid), oral rifampicin 300 mg (bid), and linezolid 600 mg (bid) for 6 weeks. This was followed by 8 weeks of oral levofloxacin 500 mg (qd) and rifampicin 600 mg (qd). After 2 weeks of antibiotic discontinuation, the laboratory tests results indicated that the inflammatory indexes returned to normal, with CRP of 0.5 mg/dL, IL-6 of 3.17 pg/mL and ESR of 8 mm/h.

Physical examination showed that the patient had a limping gait, the right lower extremity was shortened by 4 cm, the sinus of the right hip joint had healed, and there was no local redness, swelling, heat, and pain in the right hip joint. The right Hip Harris score (HHS) was 45 points. The X-rays of the patient before the spacer implantation and the second-stage revision surgery were shown in Figure 1(A),(B).

Treatment Plan

Preoperative Plan

The degree of the patient's acetabular bone defect was classified as type IIIB (up and in) according to preoperative X-ray, CT, and the Paprosky classification¹⁴. Therefore, we planned to perform robotic-assisted revision THA with large-sized acetabular cup and patient-specific three-dimensional (3D) printed augment. The robot model was the MAKO robotic hip system (MAKO Rio Robot; Stryker, USA) and the system is programmed with THA3.1. In this case, the express workflow was used.

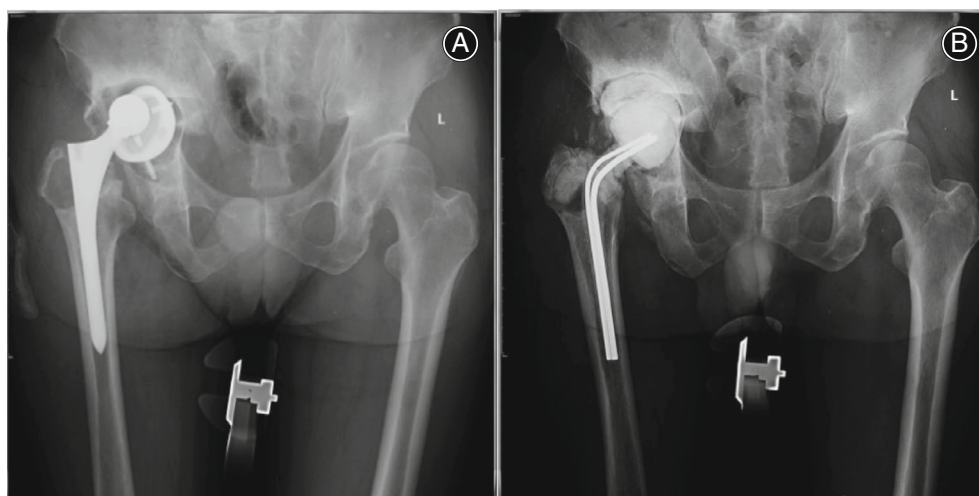


Fig. 1 (A) Preoperative X-ray showed displaced acetabular component and severe acetabular bone defects. (B) X-rays after spacer implantation. X-rays showed that the spacer was appropriately sized and positioned

First, CT scans of the involved hip and knee were obtained, and the CT data was then transferred to the MAKO planning module. Preoperative planning was then performed using the MAKO robotic hip system's 3D template software. We determined the target cup angle at a cup inclination of 40° and the cup anteversion of 20° , according to Widmer's combined anteversion theory¹⁵. The final plan was to use a 62-mm diameter Tritanium acetabular cup (Stryker, USA) (Figure 2(A),(B)).

Thereafter, a patient-specific 3D printed model of the pelvis was then generated based on preoperative CT images and simulated the acetabular component implantation procedure based on the preoperative planning by the MAKO robotic hip system's 3D template software. Manual acetabular reaming was performed to place the best sized acetabular component in the best possible position (Figure 2(C)–(E)). When the acetabular component was implanted and fixed, the bone defect was filled and shaped, and the augment was customized according to the shaping results (Zheng tian Medical Devices Co., Ltd. Tianjin. China) (Figure 2(F)).

Surgical Procedure

Spacer Removal

During the procedure, three pins were implanted at the anterior superior iliac spine to fix the pelvic reference frame. The posterolateral approach was taken and exposed. The spacer was successfully removed, and the cement and biofilm around the acetabulum and in the femoral medullary cavity were thoroughly cleaned. The acetabulum was fully exposed using four acetabular retractors and the soft tissues in the acetabulum were cleaned. During the cleaning of the soft tissue and bone cement on the lateral side of the acetabulum, we proceeded with caution and care in order to preserve as much of the remaining acetabular bone as possible.

MAKO Robot-Assisted Procedure

Registration

A patient-specific 3D printed model of the pelvis and proximal femur-based preoperative CT was created by the robotic system that was used to guide the performance of hip revision. Acetabular registration was completed by touching 32 required points on the acetabulum and surrounding bone with a probe. Owing to the presence of a severe defect in the acetabulum, the checkpoint selected for registration was located in an area of good bone quality, avoiding the area of bone defect, to ensure the accuracy of acetabular registration. Finally, the registration accuracy was 0.3 mm (Figure 3(A),(B)).

Acetabular Reaming and Component Implantation

After the acetabular registration was completed, the procedure plan was reconfirmed, and the acetabular reamer was registered. The acetabulum was then reamed at the "40/20" position using a 62-mm reamer under 3D real-time navigation (Figure 3(C)). After the acetabular bone preparation was completed, the augment and acetabular cup trial molds were installed. Acetabular stability was also tested, and the results showed that the acetabular stability was excellent (Figure 3(D)).

The augment was implanted according to the preoperative 3D printed template and the augment was fixed with three screws. The augment stability was confirmed by checking if it was well-fixed and in the proper position. Cement was applied to the contact area between the augment and the acetabular cup, which was implanted with the assistance of the MAKO robotic arm at the "40/20" position and fixed with three screws (Figure 3(E)). Intraoperative robotic measurements showed 38° of inclination and 19° of anteversion (Figure 3(F)).

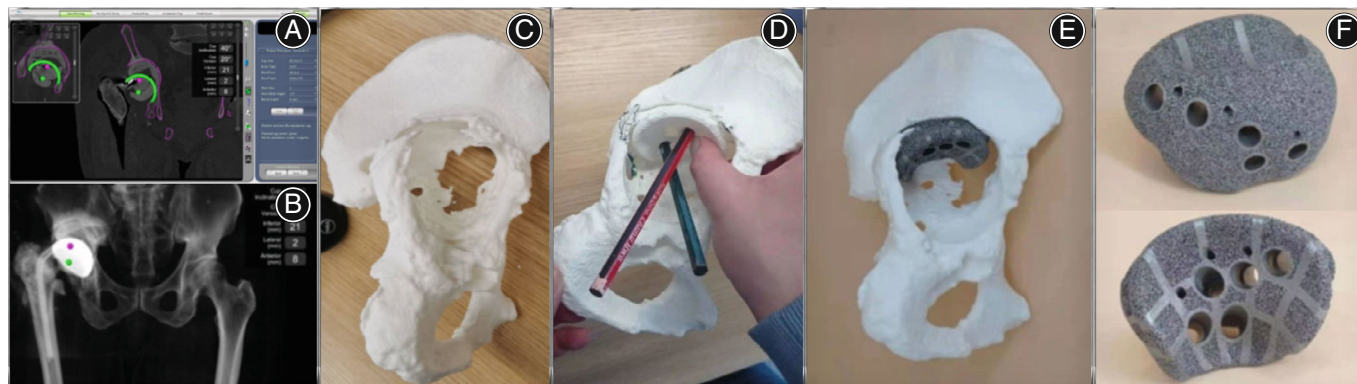


Fig. 2 (A) and (B) Preoperative planning was performed via the MAKO robotic workstation. The angle of the acetabular cup was set at 20° of anteversion and 40° of inclination. (C) CT-based 3D-printed pelvis model showing acetabular bone defect type as Paprosky IIB (up and in). (D) and (E) Simulation of acetabular implant surgery according to preoperative plan, shaping of the defect and custom augment. (F) Customized augment by 3D printing technology based on the results of simulated acetabular component implantation procedure. Description: customized bone defect augment; Size: 69-36-47 mm

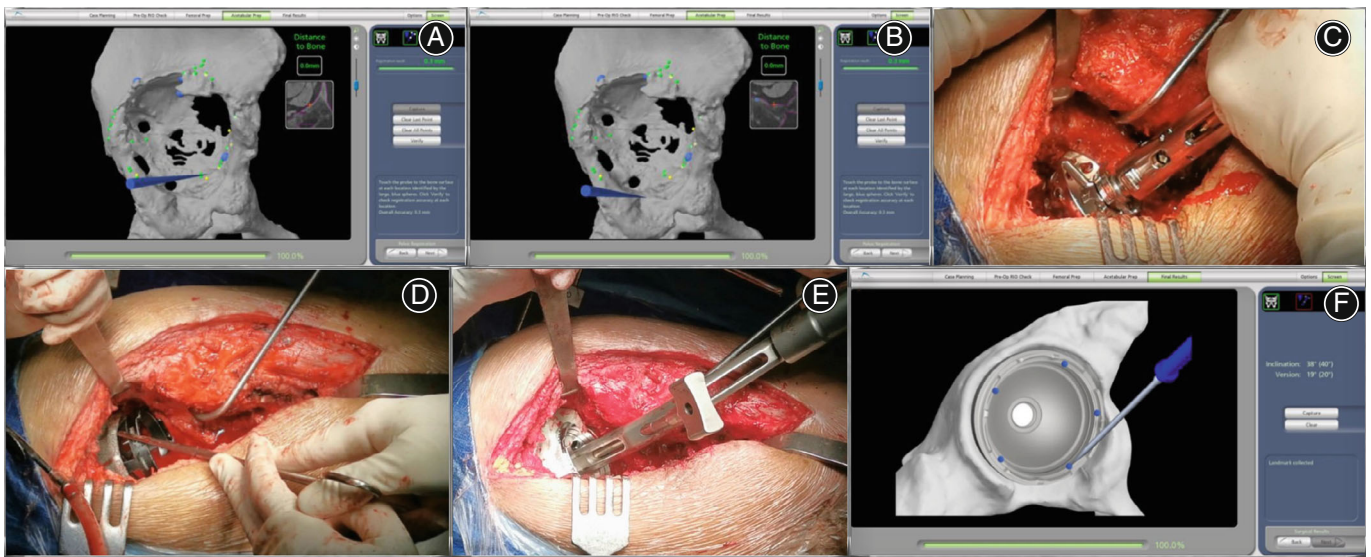


Fig. 3 (A) and (B) Pictures showed the intraoperative acetabular registration process, avoiding the acetabular bone defect site and registering on the remaining acetabular bone. (C) Robot-assisted acetabular reaming under 3D real-time navigation. (D) Intraoperative examination showed good position and stability of the acetabular cup. (E) Robot-assisted acetabular component implant. (F) Intraoperative measurement of acetabular angle results

Femur Procedure

The medullary cavity was cleaned again, the proximal femur was reamed with a medullary file No. 8–10 in sequence, the proximal femur was fixed with a titanium cable. A No. 10 Corail Revision femoral stem (DePuy, USA) was implanted, a 36 + 1.5-mm diameter delta ceramic femur head was implanted, and the hip stability was tested by full range of hip mobility. The external rotation muscle groups were reconstructed, and the incision was closed.

Postoperative Outcome

Postoperative supine anteroposterior pelvic X-rays showed that the acetabular cup positioning was basically consistent

with the preoperative plan (Figure 4(A),(B)). The anteversion angle of the acetabular cup measured by ORTHVIEW software was 21° , the inclination angle was 42° , and the leg length discrepancy was 2 mm. The center of rotation of the acetabulum was slightly shifted upward, the offset was well-recovered. The postoperative function was well-recovered, and the HHS and WOMAC were 84 and 24 at the 6-month postoperative follow-up, respectively. According to the supine anteroposterior pelvic X-rays, the acetabular cup was well-positioned and some bone ingrowth was visible (Figure 4(C),(D)). This patient could walk with a single crutch, and the quality of life has been greatly improved.

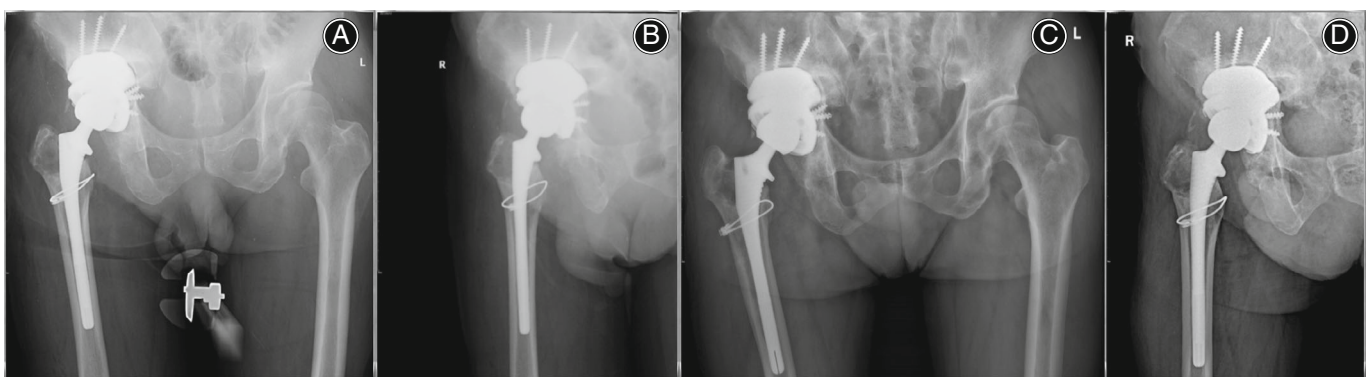


Fig. 4 (A) and (B) Immediate postoperative radiographs showed excellent positioning of the acetabular cup, and the preoperative plan was well-achieved with the robotic-assisted technique. (C) and (D) The postoperative X-ray at 6 months showed excellent position and stability of the acetabular cup with no early loosening, and bone growth around the prosthesis was visible

TABLE 1 Previous reports on revision total hip arthroplasty

Author	System	Methods	Conclusion
Nakamura <i>et al.</i> ¹⁹	Stryker CT-based hipnavigation system; Stryker, Freiburg, Germany	Intraoperative Navigation	This CT-based navigation system appears as useful in revision THA as in primary THA.
Kubota <i>et al.</i> ¹²	VectorVision compact hip CT version 3.5.2; Brainlab, Munich, German	Intraoperative Navigation	The results show that the use of navigation for revision total hip arthroplasty improved cup positioning and reduced the range of outliers.
Kuroda <i>et al.</i> ¹³	CT-based Hip, version 1.0; Stryker Navigation, Freiburg, Germany	Intraoperative Navigation	CT-based navigation in revision THA is a useful tool that enables the surgeon to implant the acetabular component at the precise angle determined in preoperative planning.
Chang <i>et al.</i> ²⁰	Imageless computer-assisted navigation (VectorVision; BrainLab, Munich, Germany)	Intraoperative Navigation	CT-based navigation in revision THA is a useful tool that enables the surgeon to implant the acetabular component at the precise angle determined in preoperative planning.
This study	MAKO robotic hip system (Stryker)	Robotic-assisted acetabular reaming and cup implantation	With the robotic assistance, this severe acetabular defect was precisely reconstructed with a superior cup and augment positioning and satisfactory postoperative function.

Discussion

Acetabular revision can be a highly complex operation depending on the defect. In difficult cases such as Paprosky types IIIA and IIIB, research showed that current processing methods are using reinforcement rings, oblong cups, tantalum cementless porous cup associated with tantalum augments, and the bone impacting grafting technique¹⁶. A study by Zhou *et al.* also confirmed the combination of tantalum augments and conventional titanium-coated cups achieved satisfactory long-term radiographic and clinical outcomes for Paprosky type III acetabular bone defects¹⁷. In this case, we also used a large size Tritanium cup and a patient-specific 3D-printed augment. The augment was reverse-customized to the site of the bone defect by simulating acetabular implantation on the 3D-printed pelvis according to the preoperative plan.

Robotic-assisted revision THA had not been reported in the literature. Newer semi-active systems such as Mako allow for greater operating guidance while still maintaining the benefits of robotic precision for both acetabular reaming and cup placement. Further benefits include intraoperative calculations of hip length, offset, and combined version, and the ability to make the relevant component adjustments accordingly¹⁸. In this complex revision case, we used robotic technology to assist in the implantation of the acetabular cup, and the procedure went smoothly and according to the postoperative measurements, we performed the procedure exactly according to the preoperative plan. Previous studies have reported the application of CT-based navigation techniques for revision THA, but intraoperative acetabular reaming and acetabular cup implantation were still required manually¹³. In contrast to CT-based navigation technology, the advantage of robotic-assisted technology is that it could

accurately execute the preoperative plan, and avoid the dislocation caused by human factors and catastrophic postoperative complications (Table 1).

In revision cases, where there has been acetabular bone loss, preserving the remaining bone volume of the acetabulum was a major concern. In conventional procedure, the acetabular reaming was completed through the acetabular ream from small to large. In this process, although the angle of “20/40” was maintained as much as possible, the direction could not be accurately maintained, and it took several attempts. The reaming was completed, which may result in additional loss of acetabular bone mass. The use of MAKO robotic arm to assist acetabular reaming was completed under 3D real-time navigation according to the preoperative plan. Only one reaming was required, and the remaining bone mass of the acetabulum was theoretically preserved. The acetabular cup could be accurately implanted at a “20/40” angle by adopting robot-assisted technology.

In this case, completing the registration of the robotic program accurately was difficult. Due to the presence of the acetabular bone defect, the checkpoint at the time of registration of the robotic system could not be used properly. Therefore, we avoided the acetabular bone defect site during registration and used the remaining acetabular bone for registration without using routine checkpoints in the robotic software. A registration accuracy of 0.3 mm met the requirements of the robot system and ensured the accuracy of the revision surgery. Based on the postoperative radiographs, the depth of the acetabular cup did not appear to be as deep as planned. We assessed the possible effects of metal artifacts, and bone destruction during prosthesis exposure or removal on the accuracy of acetabular registration. Although the above-mentioned factors may affect the acetabular registration results, our registration

accuracy still met the requirements of the robotic system, and we completed the surgery essentially as planned preoperatively, obtaining good hip reconstruction results. This also demonstrated the feasibility of using the remaining acetabular bone for registration when there is an accompanying acetabular bone defect, providing a new method of registration for robotic-assisted revision procedures.

There were some limitations in this case. Firstly, the preoperative plan was developed in MAKO 3D planning software based on the results of the preoperative simulated acetabular component implantation surgery while the augment was generated by another software and prepared for 3D printing based on the results of the simulated surgery, and the two software applications were not combined, potentially leading to errors. Secondly, this study was a case report and has a short follow-up period, which needs to be confirmed by a higher quality study.

Conclusion

With the robotic assistance, this severe acetabular defect was precisely reconstructed with a superior cup and augment positioning and satisfactory postoperative function. However, the robot planning software was unable to design the augment directly, and future robotic studies should add this function.

Authors' contributions

All authors have made substantial contributions to the following: (1) the conception and design of the study, acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important

intellectual content, and (3) final approval of the version to be submitted. Shuai Zhang and Yu-bo Liu: primarily responsible for all computational analyses in the article and the drafting of the manuscript. Shuai Zhang and Yu-bo Liu contributed to this work equally and both were co-first author. Xiangpeng Kong and Wei Chai: primarily responsible for oversight of the research project, including all data acquisition and analysis, manuscript preparation and approval. Xiangpeng Kong and Wei Chai contributed to this work equally and both were co-corresponding author. Mingyang Ma, Zheng Cao: revised the manuscript and helped perform the analysis with constructive discussions. All authors have read and approved the final submitted manuscript.

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Disclosure

The authors declare that they have no competing interests. No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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