Chiba Medical J. 98E：47－57，2022
doi:10.20776/S03035476-98E-5-P47

〔Original Article〕

Long-term results of femoral curved varus osteotomy for idiopathic osteonecrosis of the femoral head

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（Received May 14, 2022, Accepted July 26, 2022, Published December 10, 2022.）

Abstract

【Objective】 The purpose of this study was to document the long-term results of femoral curved varus osteotomy（CVO）for osteonecrosis of the femoral head（ONFH）and to identify a predictive factor for the outcome.

【Methods】 From April 1997 through April 2018, 32 patients（39 hips）underwent CVOs for idiopathic ONFH. Mean age at surgery was 33.0 years（standard deviation［SD］8.9）. Potential causative factors of ONFH were corticosteroid in 30 hips, alcohol in five hips, and "idiopathic" causes in four hips.

【Results】 Survival rates after CVO were 96% at 5 and 10 years and 84% at 15 years with total hip arthroplasty（THA）as the endpoint. Survival rates after CVO were 68% at 5 years,

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46% at 10 years, and 28% at 15 years with osteoarthritic change as the endpoint. The Japanese Orthopaedic Association hip score significantly improved from 67.5（SD 19.1）points before surgery to 86.5（13.6）points one year after CVO and 93.0（20.7）points at the final follow-up（p = 0.0002）.

【Conclusion】 The long-term results of CVO for ONFH were favorable with ten-year survival rates of 96% using conversion to THA as the endpoint. The postoperative intact ratio was suggested to be a predictive factor for OA change after CVO.

***Key words*: osteonecrosis of the femoral head, femoral curved varus osteotomy, long-term results, survival rate, predictive factor**

Ⅰ. Introduction

Osteonecrosis of the femoral head（ONFH）causes hip pain, limitation of hip movement, and gait disturbance, impairing activities of daily living and quality of life[1]. Corticosteroid treatment or alcohol intake are regarded as potential causative factors for ONFH. As ONFH is more likely to occur in young people, it is desirable to delay the onset of disability, and several attempts have been made to prevent the collapse of the femoral head using joint preserving surgeries. Femoral intertrochanteric varus osteotomy is designed to move the osteonecrotic lesion medially and bring the lateral intact articular surface into a weight bearing position[2,3]. A finite element analysis indicated that stress reduction was obtained after this procedure [4]. Nishio and Sugioka[5]developed a curved varus osteotomy（CVO）between the greater and the lesser trochanter by cylindrically rotating the femoral head in the coronal plane. As CVO provides a large contact area for the osteotomy surface, it is advantageous for bone fusion[6]and theoretically reduces the likelihood of leg length discrepancy[7,8]. However, there are few reports on the long-term results of CVO[9-11].

The purpose of this study was to document the long-term outcome of CVO for ONFH and to identify a predictive factor for the outcome.

Ⅱ. Methods

From April 1997 through April 2018, 32 patients（11 men and 21 women）in 39 hips underwent CVO for idiopathic ONFH. The patient background is shown in Table 1. There were four type classifications of ONFH size（A, B, C1, and C2）based on the central coronal section of the femoral head on T1-weighted images or the anteroposterior x-ray view. Type A lesions occupy the medial one-third or less of the weightbearing portion. Type B lesions occupy the medial two-thirds or less of the weight-bearing portion. Types C1 and C2 lesions both occupy more than the medial two-thirds of the weight-bearing portion, but whereas type C2 lesions extend laterally to the acetabular edge, type C1 lesions do not[12]. There were five stage classifications of ONFH deformity（1, 2, 3A, 3B and 4）. Stage 1 indicates no specific findings of osteonecrosis on X-ray images, but specific findings are observed on MRI, bone scintigram, or by histology. Stage 2 reveals demarcating sclerosis without collapse of the femoral head. In stage 3, collapse of the femoral head without joint space narrowing is evident. Stage 3A is a collapse less than 3 mm and Stage 3B is a collapse of 3 mm or greater. Stage 4 is obvious osteoarthritis（OA）with articular buckling and collapse creating an incongruent articular surface that eventually results in degenerative arthritis of the joint.

Operative procedure of the femoral curved varus osteotomy

A longitudinal skin incision was made over the greater trochanter in the lateral decubitus position under general anesthesia. After dissection of the deep fascia of the iliotibial tract, the greater and lesser trochanters were exposed posteriorly by rotating the hip joint internally.

The short external rotators and quadratus muscles were retained with the preservation of the medial femoral circumflex artery. To expose the top of the greater trochanter, the posterior insertion of the gluteus medius and minimus muscles were detached. The method of drawing curved osteotomy lines has changed over time. From 1997 to 2009, a curved Kirschner wire was used by adjusting it under fluoroscopic guidance according to the preoperative two-dimensional radiograph in the line from the greater to lesser trochanter[6]. In 2010, a three-dimensional preoperative plan and a patient-specific guide were introduced (Fig. 1a-d). Multiple Kirschner wires were inserted from the posterior to anterior cortex of the femur. A cylindrical osteotomy was then carried out with 5 mm wide chisels. In 2016, a new bone cutting method was introduced with a crescentic guide (MEIRA Corporation Nagoya, Japan) invented by Prof. Yukiharu Hasegawa (Patent No. 44173303), based on the reports of Okura and Hasegawa et al.[13]. Then, the femoral head was rotated in the varus direction. If the femoral head was difficult to rotate, a chisel with a width of 5 mm was inserted between the bone pieces and rotated like a sleeper to make it easier to move (Ikenoue's method). The varus angle was confirmed by fluoroscopy and the femoral head was fixed with a compression hip screw (HOP system, Teijin Nakashima, Okayama, Japan). Flexion or extension was not added. The internal fixation was removed after bone fusion (Fig. 2).

Assessment

Anteroposterior radiographs of the hip joint in neutral position were taken before surgery and every six months after surgery. The center-edge angle is the angle formed by the line connecting the center of the femoral head and the acetabular edge in the direction of gravity (25° or more is normal). The Sharp angle is the angle between the horizon and the line connecting the tear drop and the acetabular edge (40° or less is normal). The varus angle was calculated by comparing the postoperative neck-shaft angle to the preoperative angle[7]. The intact ratio of the femoral head on the weight-bearing area was calculated[7,14,15]. The weight-bearing area was defined as the area lateral to

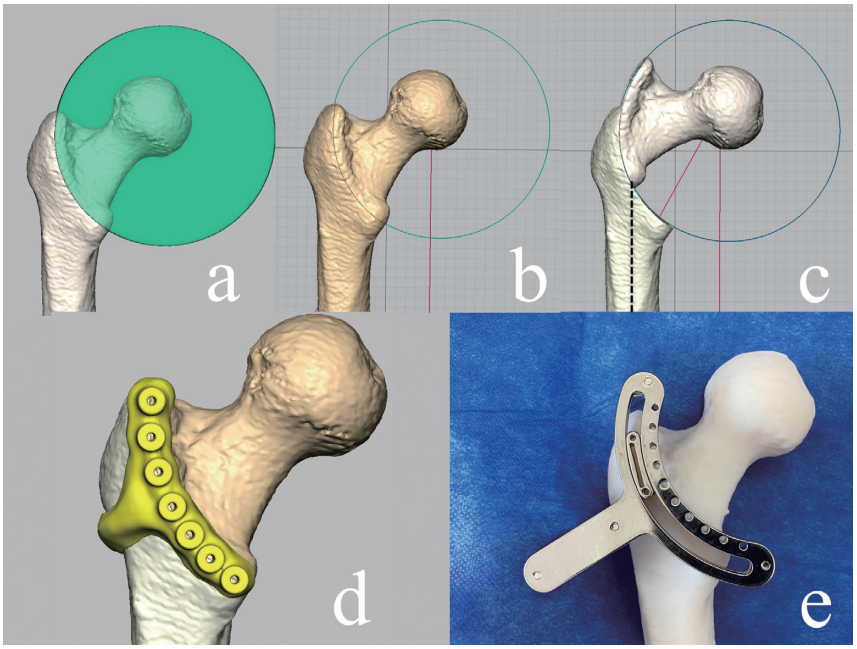

Fig. 1 Three-dimensional preoperative simulation. A circle with a radius of 45 mm was drawn on the intertrochanteric crest from the lesser trochanter to tip of the greater trochanter (**a** and **b**). After a cylindrical osteotomy, the proximal bony fragment including the femoral head was rotated to the varus angle of about 25° until the lesser trochanter was aligned with the axis of the femoral shaft (black dashed line) (**c**). A patient-specific osteotomy guide with multiple holes for K-wires formed an arc of the osteotomy line (**d**). Another osteotomy guide invented by Prof. Hasegawa (MEIRA Corporation Nagoya, Japan) utilizes a reciprocating bone saw (**e**).

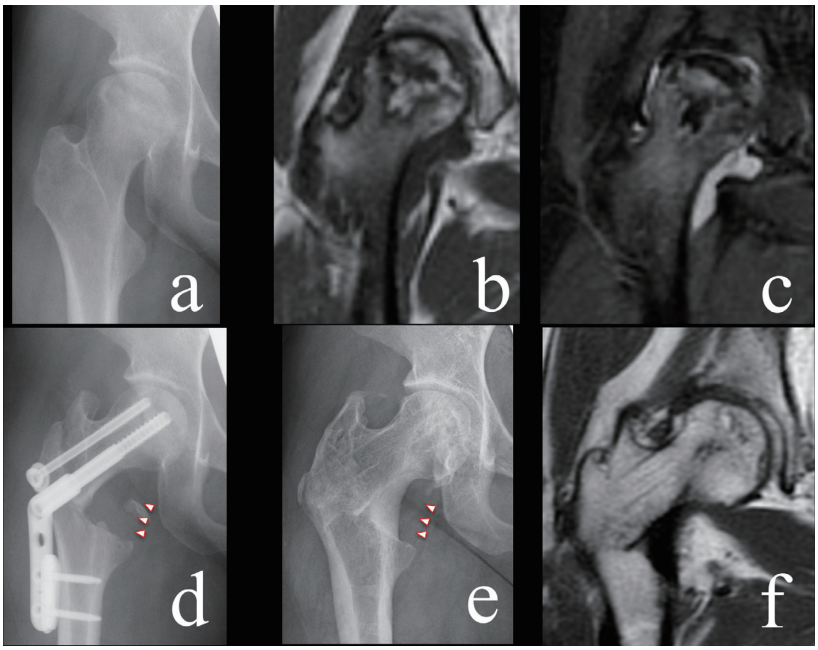

Fig. 2 Representative case of a 24-year-old woman with systemic lupus erythematosus who had osteonecrosis of the femoral head in her right hip. Preoperative X-ray (**a**) showed articular collapse within 2 mm (Stage 3A). MRI revealed a large necrotic area beyond the acetabular edge (Type C2) and bone marrow edema with joint effusion (**b**: T1 image, **c**: STIR image). A femoral curved varus osteotomy gained 32.4% of the intact ratio (the ratio of the non-osteonecrotic area to the weight-bearing area) with 33° of varus correction (**d**). Fifteen years postoperatively, the femoral head had been preserved (**e**) with almost complete remodeling of the os calcar femorale (arrowhead). An MRI T1 image shows reduction of the area surrounding a low intensity band, indicating repair of the osteonecrosis (**f**).

a mid-vertical line through the acetabular edge and the teardrop bottom from anteroposterior radiographs of the hip joint in neutral position. The intact ratio is the ratio of the non-osteonecrotic area to the weight-bearing area.

Remodeling of the osteotomy site by newly formed bone was assessed in a series of radiographs (Fig. 2d-e). Regeneration of the osteonecrotic lesion or articular collapse and additional surgical treatment were recorded. The X-ray findings were judged by two orthopedic specialists with 20 or 10 years of experience, and if the judgments were different, it was decided after consultation. Survival analysis using Kaplan-Meier survival curves was performed with total hip arthroplasty (THA) or OA change as the endpoints. Patient characteristics before CVO and the outcome after CVO were compared with THA and OA, respectively. The clinical score was evaluated using the Japanese Orthopaedic Association (JOA) Hip Score[15].

Ⅲ. Results

Survival rates after CVO were 96% at 5 and 10 years and 84% at 15 years with THA as the endpoint (Fig. 3). Survival rates after CVO were 68% at 5 years, 46% at 10 years and 28% at 15 years with OA as the endpoint (Fig. 4). The mean JOA hip score significantly improved from 67.5 (standard deviation[SD]19.1) points before surgery to 86.5 (SD 13.6) points one year after surgery and 93.0 (SD 20.7) points at the final follow-up of 11.1 years (2.3 to 24.3 years) after surgery ($p = 0.0002$, Fig. 5). Remodeling of the osteotomy site was observed in all cases, and the curve of the os calcar femorale was reshaped (Fig. 2d-e).

Comparing the THA group and the Non-THA group, there was no significant factors in the patient characteristics before CVO, but the preoperative JOA hip score tended to be lower in the THA group (Table 1). Subsequently, for the patient outcome after CVO, the postoperative neck-shaft angle was significantly larger in the THA group than in the Non-THA group (121.5

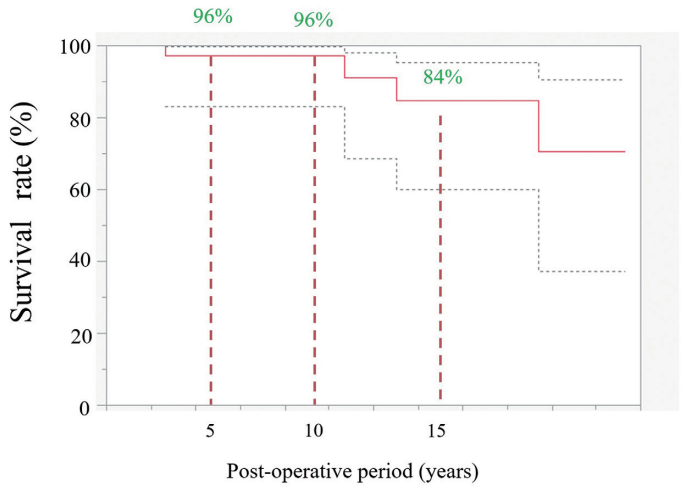

Fig. 3 Kaplan-Meier survival curve with 95% confidence interval using the endpoint of total hip arthroplasty

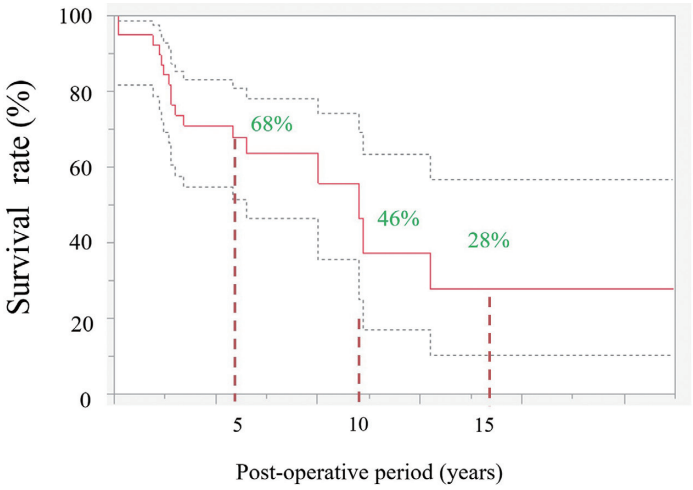

Fig. 4 Kaplan-Meier survival curve with 95% confidence interval using the endpoint of osteoarthritic change

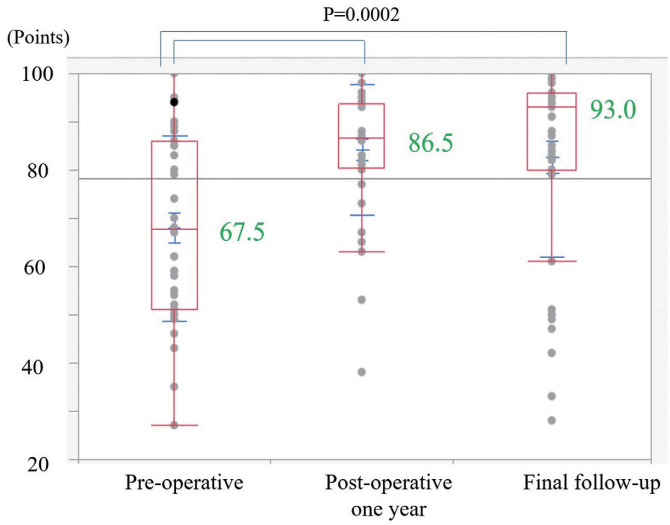

Fig. 5 Clinical outcome after femoral curved varus osteotomy using the Japanese Orthopaedic Association hip score. A p value is 0.0002 in analysis of variance, followed by Wilcoxon test as a post hoc test: pre-operative versus post-operative one year, p = 0.0003 and pre-operative versus final follow-up, p = 0.0006.

Table 1 Patient characteristics before CVO with THA as the endpoint

Groups	Overall	Non-THA	THA	P-value
Number of cases	39	35	4	
Gender, Men: Women	14 : 25	14 : 21	0 : 4	0.1141 *
Age at CVO, median, (SD) years	33.0 (8.9)	33.0 (9.2)	33.5 (7.3)	0.8528 ¶
Potential causative factors of ONFH, Corticosteroid: Alcohol: "Idiopathic"	30 : 5 : 4	27 : 4 : 4	3 : 1 : 0	0.6142 *
Type classification, A : B : C1 : C2	0 : 5 : 23 : 11	0 : 4 : 22 : 9	0 : 1 : 1 : 2	0.3432 *
Stage classification, 1 : 2 : 3A : 3B : 4	1 : 1 : 31 : 5 : 1	1 : 1 : 28 : 4 : 1	0 : 0 : 3 : 1 : 0	0.9288 *
Height, median, (SD) cm	160.0 (8.9)	160.0 (9.0)	158.5 (6.8)	0.3065 ¶
Weight, median, (SD) kg	61.0 (15.0)	61.0 (15.3)	56.0 (10.8)	0.4718 ¶
BMI, median, (SD) kg/m^2	22.9 (4.6)	22.9 (4.6)	21.3 (4.6)	0.5167 ¶
Preoperative CEA, median, (SD) degrees	32.0 (5.4)	32.0 (5.4)	33.5 (5.9)	0.5896 ¶
Preoperative Sharp angle, median, (SD) degrees	41.0 (3.6)	41.0 (3.6)	41.5 (4.1)	0.9412 ¶
Preoperative neck-shaft angle, median, (SD) degrees	130.0 (6.8)	130.0 (6.7)	136.0 (7.4)	0.1802 ¶
Preoperative intact ratio, median, (SD) %	-11.8 (24.2)	-14.1 (25.3)	-6.9 (11.0)	0.5427 ¶
Preoperative JOA hip score, median, (SD) points	67.5 (19.1)	72.0 (18.9)	53.0 (10.2)	0.0823 ¶

CVO: femoral curved varus osteotomy, THA: total hip arthroplasty, SD: standard deviation, ONFH: osteonecrosis of the femoral head, BMI: body mass index, CEA: center-edge angle, JOA: Japanese Orthopaedic Association
*Pearson's chi-square test (Non-THA group versus THA group), ¶ Wilcoxon rank sum test (Non-THA group versus THA group)

Table 2 Patient outcome after CVO with THA as the endpoint

Groups	Overall	Non-THA	THA	P-value*
Postoperative CEA, median, (SD) degrees	33.0 (5.7)	33.0 (5.7)	33.0 (5.9)	0.8893
Postoperative Sharp angle, median, (SD) degree	41.0 (3.6)	41.0 (3.7)	41.0 (2.7)	0.7619
Postoperative neck-shaft angle, median, (SD) degrees	116.0 (5.7)	115.0 (5.8)	121.5 (2.2)	0.0306
Postoperative intact ratio, median, (SD) %	28.2 (16.8)	27.7 (17.7)	28.2 (4.8)	0.7202
Varus correction angle, median, (SD) degrees	17.0 (6.9)	17.0 (7.0)	15.0 (7.1)	0.750
Postoperative JOA hip score at one year, median, (SD) points	86.5 (13.6)	87.5 (14.4)	80.5 (4.7)	0.1981
Postoperative JOA hip score at final follow-up, median, (SD) points	93.0 (20.7)	93.0 (16.5)	44.5 (7.8)	0.0032
Follow-up period to end point, median, (SD) years	10.7 (7.1)	10.5 (7.1)	11.9 (7.3)	0.7634

CVO: femoral curved varus osteotomy, THA: total hip arthroplasty, CEA: center-edge angle, SD: standard deviation, JOA: Japanese Orthopaedic Association
*Wilcoxon rank sum test (Non-THA group versus THA group)

Table 3 Patient characteristics before CVO with OA as the endpoint

	Non-OA	OA	P-value
Number of cases	22	17	
Gender, Men: Women	11 : 11	3 : 14	0.0367 *
Age at CVO, median, (SD) years	34.5 (9.4)	31.0 (8.2)	0.4185 ¶
Potential causative factors of ONFH, Corticosteroid: Alcohol: "Idiopathic"	15 : 4 : 3	15 : 1 : 1	0.3337 *
Type classification, A : B : C1 : C2	0 : 2 : 15 : 5	0 : 3 : 8 : 6	0.4045 *
Stage classification, 1 : 2 : 3A : 3B : 4	1 : 1 : 18 : 2 : 0	0 : 0 : 13 : 3 : 1	0.4899 *
Height, median, (SD) cm	165.5 (9.8)	160.0 (6.4)	0.0755 ¶
Weight, median, (SD) kg	66.0 (16.0)	53.0 (7.4)	0.0006 ¶
BMI, median, (SD) kg/m^2	24.0 (4.8)	19.5 (2.9)	0.0035 ¶
Preoperative CEA, median, (SD) degrees	33.0 (4.7)	31.5 (6.3)	0.4892 ¶
Preoperative Sharp angle, median, (SD) degrees	40.0 (3.1)	42.5 (4.2)	0.1902 ¶
Preoperative neck-shaft angle, median, (SD) degrees	131.0 (6.5)	130.0 (7.3)	0.6296 ¶
Preoperative intact ratio, median, (SD) %	-7.0 (27.6)	-16.1 (13.4)	0.3239 ¶
Preoperative JOA hip score, median, (SD) points	80.0 (20.0)	58.0 (17.6)	0.3179 ¶

CVO: femoral curved varus osteotomy, OA: osteoarthritis, SD: standard deviation, ONFH: osteonecrosis of the femoral head, BMI: body mass index, CEA: center-edge angle, JOA: Japanese Orthopaedic Association
*Pearson's chi-square test, ¶ Wilcoxon rank sum test

Table 4 Patient outcome after CVO with OA as the endpoint

	Non-OA	OA	P-value
Postoperative CEA, median, (SD) degrees	33.5 (4.5)	32.0 (7.1)	0.8203
Postoperative Sharp angle, median, (SD) degree	40.5 (3.0)	41.0 (4.3)	0.4846
Postoperative neck-shaft angle, median, (SD) degrees	115.5 (5.6)	117.0 (6.0)	0.7436
Postoperative intact ratio, median, (SD) %	31.4 (16.3)	23.5 (13.6)	0.0411
Varus correction angle, median, (SD) degrees	15.0 (7.6)	18.5 (6.1)	0.5389
Postoperative JOA hip score at one year, median, (SD) points	93.0 (13.7)	83.0 (13.9)	0.3569
Postoperative JOA hip score at final follow-up, median, (SD) points	94.5 (14.5)	85.0 (24.7)	0.0223
Follow-up period to end point, median, (SD) years	6.9 (4.8)	4.2 (3.8)	0.0201

CVO: femoral curved varus osteotomy, OA: osteoarthritis, CEA: center-edge angle, SD: standard deviation, JOA: Japanese Orthopaedic Association
Wilcoxon rank sum test

Table 5 Comparison of previous literature

Author names	Zhao et al.[9]	Hamanishi et al.[10]	Osawa et al.[11]	
CVO with bone impaction grafting	No	No	No	Yes
Number of cases	73	53	47	40
Gender, Men:Women (%)	45 : 55	25 : 28	30 : 14	24 : 13
Age at CVO, median, years	33.3	38	40.1	37.2
Potential causative factors of ONFH, Corticosteroid: Alcohol: "Idiopathic"	52 : 11 : 8	28 : 21 : 3	NA	NA
Type classification, A : B : C1 : C2	0 : 2 : 56 : 15	0 : 1 : 46 : 6	0 : 8 : 32 : 7	0 : 6 : 25 : 9
Stage classification, 1 : 2 : 3A : 3B : 4	0 : 0 : 48 : 23 : 2	1 : 29 : 21 : 2 : 0	0 : 13 : 24 : 10 : 0	0 : 8 : 22 : 10 : 0
Survival rates after CVO with THA as the endpoint (%)	91.8	98.1	83.5	87.3
Survival rates after CVO with OA as the endpoint (%)	83	86.8	71.7	68.8
postoperative intact ratio	57.2	51.7	NA	NA
Varus correction angle	24.9	22	NA	NA
Follow-up period (years)	12.4	6.3	14.5	12.2

degrees in THA group versus 115.0 degrees in Non-THA group, p = 0.0306, Table 2). The Postoperative JOA hip score at final follow-up was, of course, significantly lower in the THA group than in the Non-THA group (44.5 points in THA group versus 93.0 points in Non-THA group, 0.0032, Table 2). In the THA group, the JOA hip score recovered to 86 points after THA.

Comparing the OA group and the Non-OA group, the OA group had a higher proportion of women, less weight, and lower BMI than the Non-OA group (Table 3). The preoperative JOA hip score tended to be lower in the OA group (Table 3). Subsequently, for the patient outcome after CVO, the postoperative intact ratio was significantly lower in the OA group than in the Non-OA group (23.5% in OA group versus 31.4% Non-OA group, p = 0.0411, Table 4). The Postoperative JOA hip score at final follow-up was significantly lower in the OA group than in the Non-OA group (85.0 points in OA group versus 94.5 points in Non-OA group, 0.0223, Table 4).

Ⅳ. Discussion

CVO is a joint-preserving surgery for ONFH, as is Sugioka's transtrochanteric rotational osteotomy[14]. CVO is less invasive and less technically demanding compared with a transtrochanteric rotational osteotomy [9,16]. In addition, the medial femoral circumflex artery can be safely protected as the procedure does not require the dissection of the quadratus femoris which is located just superior to this artery. Recently, using a crescentic guide has made it very easy, safe, and accurate to perform a columnar osteotomy (Fig. 1e). Zhao et al.[9]reviewed 73 hips in 62 patients with a mean follow-up of 12.4 years (5 to 31.1 years); 67 hips (91.8%) remained intact without conversion to THA at the final follow-up. Hamanishi et al.[10]reported 53 hips in 51 patients with a mean follow-up of 6.3 years (1 to 16.3 years); 46 hips (86.8%) remained intact with one (1.9%) conversion to THA at the final follow-up. Osawa et al.[11]reported CVO with bone impaction grafting (BIG group) in 40 hips of 37 patients with a mean follow-up of 12.2 years (10.0 to 16.5 years) and 47 hips in 44 patients with CVO alone (CVO group) with a mean follow-up of 14.5 years (10.0 to 21.0 years). The ten-year survival rates using conversion to THA as the endpoint were 83.5% for the BIG group and 87.3% for the CVO group (p = 0.758)[11]. The ten-year survival rates using radiological failure as the endpoint were 71.7% for the BIG group and 68.8% for the CVO group (p = 0.644)[11]. We reported CVO outcomes of 96% for ten-year survival rates using conversion to THA as the endpoint on 39 hips of 32 patients with a mean follow-up of 11.1 years, showing

similar clinical results to the past literature[9-11]. On the other hand, the survival rates were lower in OA change than in THA as the endpoint. Namely, imaging findings and clinical symptoms do not always match. For example, there were some cases in which the JOA score was maintained, and THA was not required even if OA was progressing.

Regarding the predictive factors for varus osteotomy, there are many reports that postoperative recovery of the intact ratio is important[6-11]. Zhao et al.[9]proposed that the cut-off point of the postoperative intact ratio to prevent the progression of articular collapse was 33.6%, and the cut-off point to prevent both that and joint-space narrowing was 41.9%. In this study as well, OA progressed in all cases with an intact ratio of 33.6% or less. Kubo et al.[17]proposed that the existence of anterior osteonecrosis is a prognostic factor. We suggested that the postoperative intact ratio is a predictive factor for OA change after CVO.

Repairing the osteonecrotic lesion in the femoral head with necrosis is successful (Fig. 2f). Nakamura et al.[18]reported spontaneous repair of the pre-collapsed ONFH in about half of the patients over 10 years. Hasegawa et al.[19]reported a case of complete disappearance of ONFH after CVO. By removing the osteonecrotic lesion from the weight-bearing portion of the joint by osteotomy, stress concentrations on the lesion might be alleviated. Improving blood flow by surgery may promote regeneration of the necrotic lesion.

In the proximal part of the femur after CVO, the curve of the thick cortical bone at the medial aspect of the femoral neck (Adams' arch) is broken by the varus correction, but bone formation occurs in this part over time and bone mass is regenerated[20](Fig. 2d-e). This is a proof of Wolff's law that "takes the form and construction that most efficiently supports the external force applied to the bone."[6].

Preoperative three-dimensional (3D) simulation of CVO using 3D computed tomographic (CT) images is useful to determine proper indications for these procedures (Fig. 1). Takao et al.[21]performed CVO using CT based navigation and achieved an angle error of the osteotomy and a positional error both within a few degrees. Navigation can only be performed in a limited number of medical institutions, but 3D surgical support is expected as a next-generation treatment.

There are several limitations to this study. First, because the number of cases was small, sub-analysis by background factor, type, and stage has not been enough. Second, there is an influence due to the transition of CVO technique, as mentioned in the Operative procedure section. We did not examine the relationship between the outcome and the difference by surgeons or modification of surgical procedures. Third, change of osteonecrotic lesion after CVO was not observed with MRI because of the artifact of metal screws and plate.

In conclusion, the long-term results of CVO for ONFH was favorable with ten-year survival rates of 96% using conversion to THA as the endpoint. The postoperative intact ratio was suggested to be a prognostic factor for OA change after CVO.

Contributors

The Corresponding author declares that all co-authors meet the authorship contribution of the International Committee of Medical Journal Editors Recommendations for the Conduct, Reporting, Editing, and Publication of Scholarly Work in Medical Journals. All authors contributed to the study conception and design. Material preparation and data collection were performed by SY, JN, SH, YK, SI, SK, TN, TS, SM, KY, and YH. Data analysis was performed by SO1, YE, KI, and YS. The first draft of the manuscript was written by SY and JN. All authors commented on and revised previous versions of the manuscript. TA and SO2 revised and approved the final version of the manuscript as a graduate school advisor. All authors read and approved the final manuscript.

Financial support

The corresponding author JN received a Venture Business Laboratory in Chiba University, Hip Joint Foundation of Japan, and a research and development grant from Chiba Bank.

Conflict of interest

The corresponding author JN is the chief executive officer of Calm Lana Inc. SO2 is an editorial board member of this journal. The other authors have no conflicts of interest.

Ethical approval

The research protocol of this retrospective observational cohort study was approved by the Research Ethics Committees of the Graduate School of Medicine, Chiba University Board (Receipt number 3422) in compliance with the Helsinki Declaration. The participants were informed by bulletin board. This is not animal research.

Data availability

The data that support the findings of this study are available from the corresponding author, JN, upon reasonable request.

Acknowledgements

We thank JAM Post (https://www.jamp.com/index.cfm) for English language editing.

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