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Review

The survival and complication profiles of the Compress® Endoprosthesis: A systematic review and *meta*-analysis

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HIGHLIGHTS

- This study conducted a comprehensive analysis of the survival and complication profile of compress® endoprosthesis by combining data from 13 eligible prior studies on compress® endoprosthesis.
- In this study, we utilized a distribution-free method proposed by Comescure et al. to estimate the summary survival curve, subsequently performing a meta-analysis of 13 eligible prior studies on compress® endoprosthesis.
- The results of this study demonstrate that the survival rate, the estimated mean survival time, and complication rates of the compress® endoprosthesis are not inferior to those of the common endoprosthesis.

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ABSTRACT

Background/purpose: This study aimed to summarize the survival and complication profiles of the compress® endoprosthesis (CPS) through a systematic review and *meta*-analysis.
Methods: Online databases (PubMed, EMBASE and Web of Science) were searched from inception to November 2023. Trials were included that involved the use of CPS for endoprosthetic replacement in patients with massive segmental bone defects. Patients' clinical characteristics and demographic data were extracted using a standardized form. The methodological quality of included 13 non-comparative studies was assessed on basis of the Methodological Index for Non-Randomized Studies (MINORS). All the available Kaplan-Meier curves in the included studies were digitized and combined using Engauge-Digitizer software and the R Project for Statistical Computing.
Results: The *meta*-analysis of thirteen included studies indicated: the all-cause failure rates of CPS were 26.3 % after surgery, in which the occurrence rates of aseptic loosening were 5.8 %. And the incidences of other complications were as follows: soft tissue failure (1.8 %), structure failure (8.2 %), infection (9.5 %), tumor progression (1.1 %). The 1-, 4-, and 8-year overall survival rates for all-cause failure with 95 % CI were 89 % (86 %-92 %), 75 % (71 %-79 %) and 65 % (60 %-70 %), respectively. The estimated mean survival time of all-cause failure was 145 months (95 % CI, 127–148 months), and the estimated median survival time of all-cause failure was 187 months (95 % CI, 135–198 months). The 1-, 4-, and 8-year overall survival rates of aseptic loosening with 95 % CI were 96 % (94 %-98 %), 91 % (87 %-95 %) and 88 % (83 %-93 %), respectively. The estimated mean survival time of aseptic loosening was 148 months (95 % CI, 137–153 months).
Conclusion: CPS's innovative spring system promotes bone ingrowth by providing immediate and high-compression fixation, thereby reducing the risk of aseptic loosening caused by stress shielding and particle-induced osteolysis. CPS requires less residual bone mass for reconstructing massive segmental bone defects

Abbreviations: CPS, The compress® endoprosthesis; EPR, Endoprosthetic replacement; MINORS, The Methodological Index for Non-Randomized Studies; 95 % CI, 95 % confidence interval.

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and facilitates easier revision due to its non-cemented fixation. In addition, the survival rate, estimated mean survival time, and complication rates of CPS are not inferior to those of common endoprosthesis.

1. Introduction

With the advancements in radiation, chemotherapy, and surgical procedures over the last half-century, limb salvage has supplanted amputation as the accepted treatment for malignant bone tumors. As a result, endoprosthetic replacement (EPR) has become a frequently used method for limb salvage in cases of primary malignant bone tumors. The endoprostheses have undergone modifications in design to improve the effectiveness as well as efficiency of EPR. The most noteworthy developments are the development of modular endoprostheses, exploration of different fixing methods (cemented or non-cemented), and the replacement of fixed hinges with rotating hinges [1–8]. The ability of EPR to preserve limb function and cosmetic appearance has resulted in its widespread acceptance among patients.

However, EPR is associated with several intermediate- to long-term issues, such as infection, mechanical failure, and especially aseptic loosening, which may ultimately lead to the failure of the endoprosthesis [1]. For this reason, EPR places a strong priority on endoprostheses durability. This is particularly crucial for young, physically active patients who have high expectations for their endoprosthesis. However, aseptic loosening is the most common long-term issue arising from EPR [1,9–12]. In addition, the residual bone mass after the resection of large segments of bone tumors is relatively short, which makes reconstruction challenging. The design of the compress® endoprosthesis (CPS) technology (Biomet, Warsaw, Ind., USA) offers a promising solution to these challenges. With a set of Belleville washers placed on the intramedullary traction bar, the device can be anchored to the bone after tumor resection without the use of bone cement. These circular washers have a curved cross-section, and they work like springs to provide a continuous compressive force proportionate to the degree of deformation when a threaded nut on the traction bar applies compressive force to them. The endoprosthesis is immediately fixed to the bone by the constant compression. Wolff's law states that the compressive force at the endoprosthesis interface may eventually promote bone hypertrophy [13,14]. The effect of this mechanism on bone hypertrophy is to avert stress shielding and safeguard the medullary canal from the impact of particulate debris. And therefore, it is anticipated that this technique will provide better medium- to long-term outcomes compared to common endoprosthesis. However, there remains a paucity of literature that comprehensively analyzes pertinent clinical studies. Therefore, we utilized a distribution-free approach to estimate summary survival curves, aiming to conduct a *meta*-analysis of existing studies on CPS with a focus on the following three questions.

1. What is the lifespan of the CPS?
2. What are complication profiles of the CPS, especially aseptic loosening?
3. How does the CPS compare to common endoprosthesis?

2. Methods

2.1. Search strategy

We searched several online databases, such as PubMed, EMBASE, and Web of Science. Our search utilized the Boolean logic search phrases including "compress", "compressive", "implant", "prosthesis", "endoprosthesis", and "osseointegration". We included studies published from the databases' inception up to November 2023, without limitations on language, ages, or journal categories. Additionally, we reviewed the references of relevant review articles to identify further studies that might meet our criteria.

2.2. Method of review

Two authors (LHL and ZXX) independently screened the studies to remove duplicates and then assessed the titles and abstracts according to our eligibility criteria. For studies whose title and abstract did not provide sufficient information for a decision, we conducted a full-text review. We also screened the reference lists of these articles to identify additional eligible studies. Any disagreements on study inclusion were resolved through discussion among the authors.

2.3. Eligibility criteria and assessment of quality

Eligible studies were those involving the use of CPS for patients with massive segmental bone defects. These defects can be caused by a range of factors, including the resection of bone tumors, non-union of fractures, infections, and arthroplasty revision. The exclusion criteria were (a) reviews and protocols; (b) animal studies; (c) studies unrelated to endoprosthetic replacement; (d) studies lacking detailed reports on endoprosthesis survival or complications; and (e) the study's full text is not accessible. The methodological quality of the included studies was independently evaluated by two authors (LHL and ZXX) using the Methodological Index for Non-Randomized Studies (MINORS) [15]. Discrepancies in quality assessment were resolved through discussion.

2.4. Data extraction

Based on the failure model categorization for tumor endoprosthesis put forward by Henderson et al. [16], we categorized and analyzed endoprosthesis failure incidences. For each included study, we extracted data on patient demographics, diagnosis, follow-up durations, total failure rates, incidence of aseptic loosening, brand of compress endoprosthesis, research institution, mean bone resection length, and mean remaining bone length. Additionally, we utilized Engauge Digitizer (version 12.1) to extract survival data at specific time periods from survival curves that were based on those provided in the included trials in order to increase the amount of data we had accessed. The estimates for studies lacking data on the number of at-risk patients at various time intervals were computed by applying the methodology previously suggested by Williamson et al. [17] and Tierney et al. [18].

2.5. Statistical analysis

We used Excel (Microsoft 2021) for data summarization. The incidence rate P was calculated as $P=m/n$ [19], where m is the number of failures and n is the total number of cases. To understand the differences in complications between CPS and common endoprosthesis, we used Fisher's exact test to compare the results of our study with those of Haijie et al.'s review on common endoprosthesis [20].

In the survival curve provided by the included studies, since the survival rates of all-cause failure drop frequently during the first 36 months, the probability of survival was determined from the survival curves at closest time points (every three months). After the 36 months, the probability of survival was determined at larger intervals (every 24 months) in order to limit the number of observed conditional survival probabilities equal to 1 [21]. Likewise, the probability of survival of aseptic loosening was determined from the survival curves at closest time points (every 24 months). Using Engauge Digitizer, extract the survival probabilities at different time intervals from the survival curves provided by the included studies, following the above method. The method proposed by Thiery et al. [18] was used to evaluate the number of at-risk patients in each time period, considering both total sample size

and survival probability, as the number of at-risk patients in each time period could not be directly obtained from the included studies. The R package MetaSurv, proposed by Combescure et al. [21], was utilized to obtain a summary survival curve to calculate the average survival time, the median survival, pooled survival probability. This was achieved through analyzing the survival probabilities and numbers of at-risk patients, collected at various time points across the survival curves provided by the included studies. We used the R Project for Statistical Computing (version 4.3.1; R Foundation for Statistical Computing, Vienna, Austria) to conduct the aforementioned statistical analyses. Besides, we also conducted an indirect comparison of the mean survival time and 4- and 8-years survival rates of CPS with that of common endoprosthesis [22].

3. Result

3.1. Selection of studies

The search and inclusion process are depicted in Fig. 1. Initially, 1715 potentially relevant records were identified. After removing 742 duplicates, 973 studies were screened by title and abstract, resulting in the exclusion of 955 studies. A full-text review of the remaining 18 studies led to the exclusion of four due to insufficient relevance. Among the included articles, two studies reported on the same patient cohort with different follow-up durations; we included the study with mid-term results and excluded the one with only short-term outcomes. No additional studies were retrieved from other sources. Ultimately, 13 studies met our inclusion criteria, reporting on 548 CPS implanted in 515 patients [23–35].

3.2. Information of included trials

Based on the available information (Table 1), a total of 13 articles were included in our analysis, which detailed 548 CPS implanted in 515 patients. The cohort consisted of 276 males and 249 females, with the median of mean age was 25.5 years (range, 18–52 years) and the median of mean follow-up durations was 67.2 months (range, 27–144 months). Osteosarcoma was the most common diagnosis (278 patients, 53.0 %), followed by giant cell tumor of bone (24 patients, 4.6 %), chondrosarcoma (19 patients, 3.6 %), Ewing's sarcoma (17 patients, 3.2 %), and other primary bone tumors (77 patients, 14.7 %). Additionally, 110 cases (21.0 %) involved no tumor. Of the 13 included articles, 7 articles [24–26,29,31,34,35] with a total of 293 patients reported exclusively distal femur reconstruction; one research [33] focused on 16 patients with proximal tibia; and the other five studies [23,27,28,30,32] summarized results from multiple sites. Distal femur reconstruction was the most common procedure (425 patients, 81.0 %), with other sites including the proximal femur (52 patients, 9.9 %), proximal tibia (31 patients, 5.9 %), distal humerus (6 patients, 1.1 %), proximal humerus (5 patients, 1.0 %), intercalary femoral (2 patients, 0.4 %), humeral diaphysis (2 patients, 0.4 %), and proximal ulna (2 patients, 0.4 %). 6 studies [23,24,26,31–33] provided the averaged bone resection length, the median of them is 17.4 cm (range, 14.0–19.0 cm); while the remaining bone length is reported by 1 study, that is 20.0 cm (range, 11.0–25.0 cm) [33] (Table 2). In total, there were 548 CPS implanted in 515 patients included in the current review, who all had compress® endoprosthesis (Biomet, Warsaw, Ind, USA) implanted with mean follow-up durations exceeding 24 months.

3.3. Methodological quality

The methodological quality of included 13 non-comparative studies was assessed using the Methodological Index for Non-Randomized Studies (MINORS) [15], and the score outcomes were presented in Table 3. The score range of non-comparative studies evaluated by MINORS were 0–16. Among the included trials, one study [23] scored 12, indicating high quality. While eight studies [24,27–30,32,33,35] scored 10, two studies [26,31] scored 8, the remaining two scored 11 [25] and 9 [34], respectively, indicating moderate quality.

3.4. Overall implant complication profiles

13 Studies were included in the pooled analysis of the complication profiles of CPS, with the median of mean follow-up durations was 67.2 months (range, from 27 to 144 months). To explore the disparities in complications between CPS and common endoprosthesis, we conducted a comparative analysis of our research findings with those presented in Haijie et al.'s literature review on common endoprosthesis [20]. The

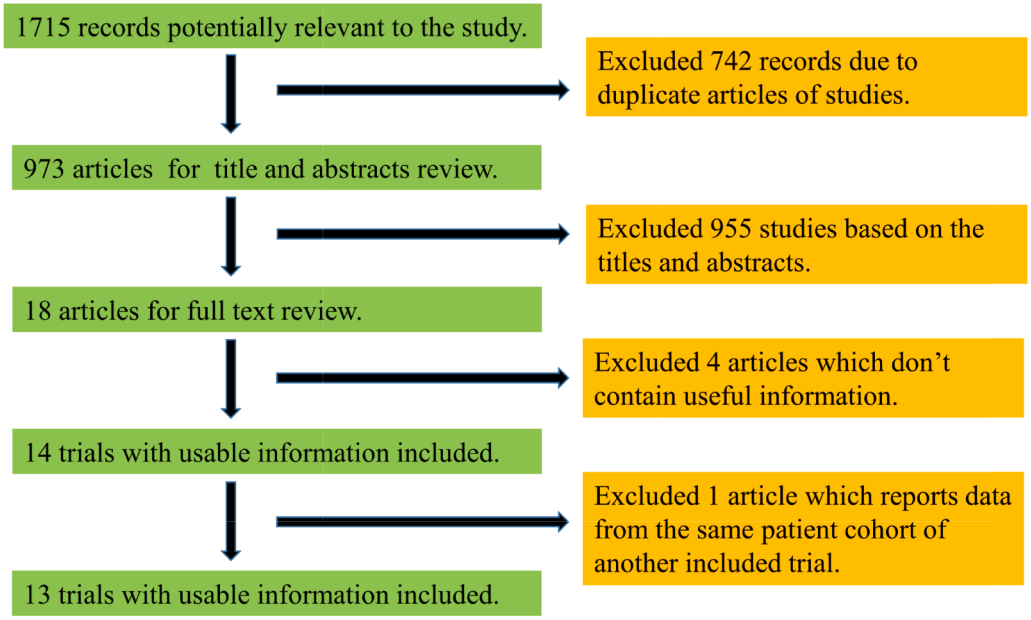

Fig. 1. A flow diagram demonstrates the method of article selection.

Table 1
The characteristics of included trials. (n = 13).

Author/Year	Number of patients #	Number of CPS implanted	Age (mean, range)	Gender (M/F)	Site	Follow-up (mean months, range)	Primary diagnosis (N)	Number of failures $ (N, %)	Number of aseptic loosening (N, %)	Brand	Institution	Mean bone resection length (range, cm)	Mean remaining bone length (range, cm)
Calvert/2014	50	52	20.5 (NA)	25/25	37 dF 6 pF 3 pH 2 pT2 iF	68 (31–113)	Osteosarcoma: 39 Chondrosarcoma: 3 Ewing's sarcoma: 3 Giant cell tumor of bone: 2 Malignant fibrous histiocytoma of bone: 1 Malignant pleomorphic mesenchymal tumor: 1 Desmoplastic fibroma of bone: 1	16, 30.8 %	7, 13.5 %	Biomet, USA	U of U	17.8 (NA)	NA
Corona/2021 ##	10	11	52 (35–73)	8/3	11 dF	27 (12–50)	Open fracture: 8Closed fracture: 3	2, 18.2 %	2, 18.2 %	Biomet, USA	VHUH	14 (8–21)	NA
Farfalli/2009	41	41	27 (7–62)	21/20	41 dF	45 (3–97)	Osteosarcoma: 20 Giant cell tumor of bone: 3 Chondrosarcoma: 2 Low-grade osteogenic sarcoma: 2 Malignant fibrohistiocytoma: 2Prosthetic revision: 12	5, 12.2 %	1, 2.4 %	Biomet, USA	WMCCU	NA	NA
Goldman/ 2016 ##	74	79	26 (7–69)	49/30	79 dF	84 (24–198)	Osteosarcoma: 49 Chondrosarcoma: 2 Ewing's sarcoma/Primitive neuroectodermal tumor: 5 Other malignant neoplasm: 9 Giant cell tumor of bone: 13Chondroblastoma: 1	36, 45.6 %	2, 2.5 %	Biomet, USA	UCSF	18 (13–36)	NA
Goulding/ 2017 ##	8	12	45 (21–62)	7/5	6 dH 2 pH 2 HD2 pU	68 (24–141)	Osteosarcoma: 3 Fibroblastic osteosarcoma: 1 Ewing's sarcoma: 2 Spindle cell sarcoma: 1 Other malignant bone tumor: 1 Infection: 3Open fracture: 1	6, 50.0 %	1, 8.3 %	Biomet, USA	The Mayo Clinic	NA	NA
Groundland/ 2022	20	20	18 (7–50) **	10/10	16 dF4 pF	144 (121–230) ***	Osteosarcoma: 14 Malignant fibrous histiocytoma of bone: 3 Ewing sarcoma: 2Chondrosarcoma: 1	3, 15.0 %	1, 5.0 %	Biomet, USA	U of U	NA	NA
Healey/2013	82	82	20.4 (14–63) **	40/42	82 dF	43 (6–131)	High-grade osteogenic sarcoma: 64 Chondrosarcoma: 5 Malignant fibrohistiocytoma: 5 Giant cell tumor of bone: 3 Low-grade osteogenic sarcoma: 2 Other tumor: 1No tumor (arthroplasty revision): 2	21, 25.6 %	3 *, 3.7 %	Biomet, USA	WMCCU	NA	NA
Kagan/2017	116	137	NA	59/57	64 dF 39 pF13 pT	48 (24–108)	Primary oncologic: 41 Revision arthroplasty: 70Fracture non–/malunion: 5	27, 23.7 %	6, 5.3 %	Biomet, USA	OHSU	NA	NA
Lazarov/ 2015	27	27	27 (9–68)	12/15	27 dF	36 (15–66)	Osteosarcoma: 16 Chondrosarcoma: 2 Leiomyosarcoma: 2 Giant cell tumor of bone: 2 Ewing's sarcoma: 1Tumor-free: 4	4, 14.8 %	2, 7.4 %	Biomet, USA	UHG	15 (8–26)	NA

(*continued on next page*)

Table 1 (*continued*)

Author/Year	Number of patients #	Number of CPS implanted	Age (mean, range)	Gender (M/F)	Site	Follow-up (mean months, range)	Primary diagnosis (N)	Number of failures $ (N, %)	Number of aseptic loosening (N, %)	Brand	Institution	Mean bone resection length (range, cm)	Mean remaining bone length (range, cm)
Monument/ 2015	18	18	21 (7–47)	10/8	15 dF3 pF	96 (60–144)	Osteosarcoma: 12 Ewing's sarcoma: 2 Chondrosarcoma: 1 Parosteal osteosarcoma: 1 Undifferential pleomorphic sarcoma of bone: 1Malignant fibrohistiosarcoma: 1	6, 33.3 %	2, 11.1 %	Biomet, USA	U of U	19 (10–31)	NA
O'Donnell/ 2009	16	16	18 (12–42)	7/9	16pT	54 (24.0–123.6)	Osteosarcoma: 12 Chondrosarcoma: 1 Undifferentiated sarcoma: 1Ewing's sarcoma: 2	6, 37.5 %	1, 6.3 %	Biomet, USA	UCSF	17 (13–24)	20 (11–25)
Pedtke/2012	26	26	24.9 (7–59)	14/12	26 dF	67.2 (13.2–110.4)	Osteosarcoma: 21 Chondrosarcoma: 1 Leiomyosarcoma: 1 Giant cell tumor of bone: 1 Burkitt's lymphoma: 1Tumor-free: 1	5, 19.2 %	1, 3.8 %	Biomet, USA	UCSF	NA	NA
Zimel/2016	27	27	30 (13–62)	14/13	27 dF	90 (24–181) ***	High-grade osteogenic sarcoma: 20 Parosteal osteogenic sarcoma: 2 Chondrosarcoma: 1 Malignant fibrous histiocytoma of bone: 1 Other tumor (pigmented villonodular synovitis, hemangiomatosis, synovial chondromatosis): 2No tumor (infected periprosthetic fracture): 1	7, 25.9 %	3, 11.1 %	Biomet, USA	MSKCC	NA	NA

dF: Distal femur. pH: Proximal femur. iF: Intercalary femoral. dH: Distal humerus. pH: Proximal humerus. pT: Proximal tibia. pU: Proximal ulna. HD: Humeral diaphysis. U of U: The University of Utah. VHUH: Vall d'Hebron University Hospital. WMCCU: Weill Medical College of Cornell University. UCSF: University of California, San Francisco. OHSU: Oregon Health & Science University. UHG: University Hospital Ghent. MSKCC: Memorial Sloan Kettering Cancer Center. NA: Not available. # Number of patient death was included. $ Number of amputations were included. ## In three of the included studies, the statistics of gender, site, and diagnosis were based on the number of implanted CPS rather than the number of patients. * 5 of the 8 patients required prosthetic revision due to aseptic loosening with periprosthetic fracture. ** Median age. *** Median follow-up durations.

Table 2
Patient demographics and clinical characteristics.

Patient factor	Value
Number of patients	515
Number of CPS implanted	548
The median of mean age (years) **	25.5 (18–52) *
Sex ##	
Male	276 (52.6 %)
Female	249 (47.4 %)
Site ##	
dF	425 (81.0 %)
pF	52 (9.9 %)
pT	31 (5.9 %)
iF	2 (0.4 %)
dH	6 (1.1 %)
pH	5 (1.0 %)
HD	2 (0.4 %)
pU	2 (0.4 %)
The median of mean follow-up durations (months)	67.2 (27–144) *
Diagnosis ##	
Osteosarcoma	278 (53.0 %)
Giant cell tumor of bone	24 (4.6 %)
Chondrosarcoma	19 (3.6 %)
Ewing's sarcoma	17 # (3.2 %)
Other primary tumor	77 (14.7 %)
No tumor	110 $ (21 %)
Total rates of aseptic loosening of CPS	5.8 % (32/548)
Total failure rates of CPS	26.3 % (144/548)
The median of mean bone resection length (cm)	17.4 (14.0–19.0) *
The mean remaining bone length (cm) $$	20.0 (11.0–25.0) *

Percent in parentheses. dF: Distal femur. pF: Proximal femur. iF: Intercalary femoral. dH: Distal humerus. pH: Proximal humerus. pT: Proximal tibia. pU: Proximal ulna. HD: Humeral diaphysis. * Range in parentheses. ** Include two studies reported the median age. # Include primitive neuroectodermal tumor. ## In three of the included studies, the statistics of gender, site, and diagnosis were based on the number of implanted CPS rather than the number of patients. $ Include revision, infection and fracture non–/malunion. $$ Only one study was reported.

incidence of soft tissue failure was significantly lower in CPS (1.8 %) compared to common endoprosthesis (11.6 %) ($p < 0.05$). Similarly, the rates of aseptic loosening for CPS and common endoprosthesis were 5.8 % and 7.7 % respectively ($p = 0.138$). For structural failure, CPS had a rate of 8.2 %, while common endoprosthesis had a rate of 6.0 % ($p < 0.05$). In terms of infection rates, CPS had a rate of 9.5 % and common endoprosthesis had a rate of 10.5 % ($p = 0.133$). Furthermore, the rates of tumor progression for CPS and common endoprosthesis were 1.1 % and 6.3 % respectively ($p < 0.05$). Overall, the all-cause failure rates were 26.3 % for CPS and 40.2 % for common endoprosthesis ($p < 0.05$) (Refer to Table 4 and 5). When compared to common endoprosthesis, CPS demonstrated superior outcomes in terms of soft tissue failure, tumor progression, and all-cause failure. However, the performance in aseptic loosening and infection rates was similar between the two, with CPS showing a slightly higher rate of structural failure than common endoprosthesis

3.5. Summary survival curve

Nine studies offered Kaplan-Meier survival curves for all-cause failure of CPS, [23–26,28–30,32,34] and six provided the same for aseptic loosening of CPS [23,24,30,32,34,35]. The Kaplan-Meier survival curves for all-cause failure and aseptic loosening of CPS, extracted from the studies, as well as the summary survival curve with fixed effects for both all-cause failure and aseptic loosening of CPS, are shown in Fig. 2. The 1-, 4-, and 8-year overall survival rates of all-cause failure of CPS with 95 % CI were 89 % (86 %-92 %), 75 % (71 %-79 %) and 65 % (60 %-70 %), respectively. The estimated mean survival time of all-cause failure of CPS was 145 months (95 % CI, 127–148 months), and the estimated median survival time of all-cause failure of CPS was 187 months (95 % CI, 135–198 months). The 1-, 4-, and 8-year overall survival rates of aseptic loosening of CPS with 95 % CI were 96 % (94 %-98 %), 91 % (87 %-95 %) and 88 % (83 %-93 %), respectively. The estimated mean survival time of aseptic loosening of CPS was 148 months (95 % CI, 137–153 months) (Table 6). The 4-, and 8-years overall survival rates of all-cause failure of common endoprosthesis were 70 % and 58 %, respectively. The estimated mean survival time of all-cause failure of common endoprosthesis was 36 months (95 % CI, 1–84 months). The 4-, and 8-years overall survival rates of aseptic loosening of common endoprosthesis were 92 % and 85 %, respectively. The estimated mean survival time of aseptic loosening of common endoprosthesis was 54 months (95 % CI, 1–96 months) [22] (Table 7).

Table 3
The quality assessment of MINORS.

Author/Year	MINORS A clearly stated aim	Inclusion of consecutive patients	Prospective collection of data	Endpoints appropriate to the aim of the study	Unbiased assessment of the study endpoint	Follow-up period appropriate to the aim of the study	Loss to follow up less than 5 %	Prospective calculation of the study size	Total scores
Calvert/2014	2	2	0	2	0	2	2	2	12
Corona/2021	2	2	0	2	0	2	2	0	10
Farfalli/2009	2	2	0	2	1	2	2	0	11
Goldman/2016	2	2	0	2	0	2	0	0	8
Goulding/2017	2	2	0	2	0	2	2	0	10
Groundland/2022	2	2	0	2	0	2	2	0	10
Healey/2013	2	2	0	2	0	2	2	0	10
Kagan/2017	2	2	0	2	0	2	2	0	10
Lazarov/2015	1	2	0	1	0	2	2	0	8
Monument/2015	2	2	0	2	0	2	2	0	10
O'Donnell/2009	2	2	0	2	0	2	2	0	10
Pedtke/2012	2	2	0	2	0	2	0	0	9
Zimel/2016	2	2	0	2	0	2	2	0	10

Score determination: 0 not reported. 1 reported but inadequate. 2 reported and adequate. The global ideal score being 16 for non-comparative studies. Reference: Slim, K., et al., Methodological index for non-randomized studies (minors): development and validation of a new instrument. ANZ J Surg, 2003. 73(9): p. 712–6.

Table 4
Overall implant complication profiles.

Study	Type I Soft-tissue failure Event	Type II Aseptic loosening Event	Type III Structure failure Event	Type IV Infection Event	Type V Tumor progression Event	Total Event	Total
Calvert/2014	2	7	1	6	0	16	52
Corona/2021	0	2	0	0	0	2	11
Farfalli/2009	0	1	4	0	0	5	41
Goldman/2016	5	2	19	10	0	36	79
Goulding/2017	1	1	3	1	0	6	12
Groundland/2022	0	1	2	0	0	3	20
Healey/2013	0	3	10	5	3	21	82
Kagan/2017	1	6	2	17	1	27	137
Lazarov/2015	0	2	1	1	0	4	27
Monument/2015	1	2	0	2	1	6	18
O'Donnell/2009	0	1	2	3	0	6	16
Pedtke/2012	0	1	1	3	0	5	26
Zimel/2016	0	3	0	4	0	7	27
Total (percentage)	10, (1.8 %)	32, (5.8 %)	45, (8.2 %)	52, (9.5 %)	5, (1.1 %) *	144, (26.3 %)	548

Percent in parentheses. * The denominator in the calculation of this data has excluded 110 non-tumor cases.

Table 5
Comparison between CPS and common endoprostheses in regard to complication profiles.

Types	CPS	Common	*p*-value *
I Soft-tissue	1.8 %	11.6 %	< 0.05
II Aseptic loosening	5.8 %	7.7 %	0.138
III Structure failure	8.2 %	6.0 %	< 0.05
IV Infection	9.5 %	10.5 %	0.133
V Tumor progression	1.1 % **	6.3 %	< 0.05
All-cause failure	26.3 %	40.2 %	< 0.05

* Fisher's precision probability test. ** The denominator in the calculation of this data has excluded 110 non-tumor cases.

4. Discussion

As patient longevity increases, extending the survival of our implants has become increasingly crucial. Despite continuous improvements in implant design leading to reported higher implant survival rates [36,37], complications and long-term failure rates of endoprostheses cannot be ignored. Notably, aseptic loosening has emerged as the primary failure mode, replacing infection, especially over longer follow-up periods [10,38–41]. Compressive osseointegration fixation holds the potential advantage of mitigating the negative effects of stress shielding and particle-induced osteolysis. Ultimately, this approach is a possibility that the incidence of aseptic loosening in the CPS may decrease [36,38]. Moreover, the CPS offers the distinct benefit of reduced reliance on the existing bone stock. This characteristic is particularly advantageous for the effective limb-salvage reconstruction of extensive segmental bone defects subsequent to the radical resection of malignant bone tumors. The non-cemented nature of the CPS fixation also facilitates easier revision [27,35]. CPS has become a widely used implant for EPR in patients of massive segmental bone defects. Since then, several studies have investigated the survival and complication profiles of compression bone integration techniques, but these studies have been limited by small sample size and limited follow-up durations. Our study will provide a comprehensive overview of the survival and complications associated with CPS.

In contrast to common endoprosthesis, which typically exhibit gradual failure over time, osseointegration failures in CPS primarily manifest within the initial three years. Studies included in the current research have shown that the three-year all-cause failure rates of CPS ranged from 11.5 % to 29.1 % [23–26,28,30,32,34,35], with incidences of aseptic loosening varying from 2.4 % to 18.1 % [23–25,28,30,32,34,35]. Early reliance on compression rather than friction, along with the relatively limited contact area between the

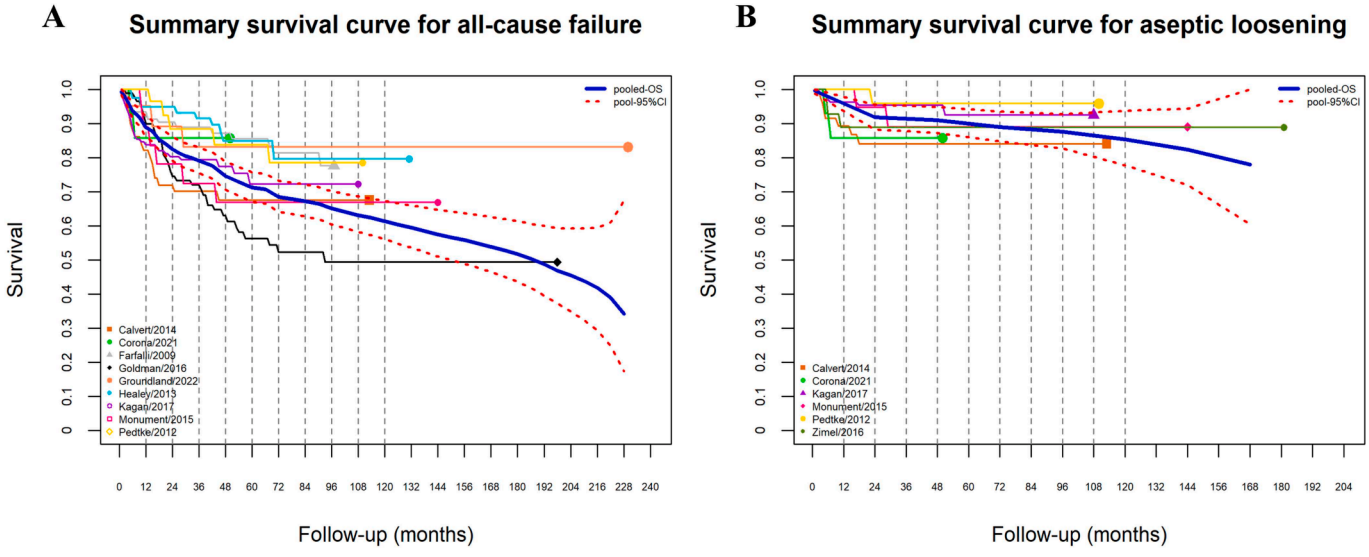

Fig. 2. Summary survival curve for all-cause failure and aseptic loosening. (A) All-cause failure; (B) Aseptic loosening. OS, overall survival; 95 % CI, 95 % confidence interval.

Table 6
Summary survival curve for all-cause failure and aseptic loosening.

	All-cause failure		Aseptic loosening	
	Pooled survival	95 % CI	Pooled survival	95 % CI
1-year	89 %	86 %-92 %	96 %	94 %-98 %
2-years	82 %	79 %-86 %	92 %	88 %-95 %
4-years	75 %	71 %-79 %	91 %	87 %-95 %
5-years	71 %	67 %-76 %	90 %	86 %-94 %
6-years	69 %	64 %-73 %	89 %	85 %-93 %
8-years	65 %	60 %-70 %	88 %	83 %-93 %
10-years	61 %	56 %-67 %	85 %	78 %-94 %
12-years	58 %	51 %-65 %	82 %	72 %-94 %
14-years	54 %	46 %-63 %	77 %	59 %-99 %
16-years	49 %	40 %-60 %	NA	NA
18-years	42 %	29 %-59 %	NA	NA
Median survival time (months)	187	135–198	NA	NA
Mean survival time (months)	145	127–148	148	137–153

NA: Not available.

implant and bone, may contribute to early failures. However, subsequent bone hypertrophy and the inherent avoidance of stress shielding in compressive osseointegration can help prevent late failures due to aseptic loosening. This aligns with the design principle of CPS aimed at reducing the occurrence of aseptic loosening in endoprosthesis [20,23–35,42–44]. Studies included in the current research also suggested various methods to mitigate early CPS failures. Following lower limb endoprosthesis replacement surgery, it is advisable to restrict weight-bearing on the operated limb for six weeks. Subsequently, a gradual 25 % increase in weight-bearing per week is recommended, with the goal of achieving unassisted walking within three months post-operation [23,30,31]. Antirotational pins are utilized during surgery to prevent device loosening from rotational forces post-operation, and activities that induce joint rotational torque should be avoided in the early postoperative phase [31]. Enhanced patient selection and precise surgical techniques also offer potential avenues for reducing early failures [23]. Nevertheless, as risk factors associated with early failures have not been fully elucidated, more targeted preventive strategies remain undiscovered.

Compared to common endoprosthesis, CPS is a potentially superior option for limb salvage in patients with oncologic diagnoses, due to its requirement for shorter diaphyseal segments and the lower occurrence of aseptic loosening. While CPS may reduce the risk of long-term loosening, it can lead to specific structural failures that necessitate revisions. Theoretically, the larger resection length of CPS leads to a greater lever arm and higher stress on the bone-prosthesis interface, making patients more vulnerable to higher torque, especially when enduring rotational stress, which ultimately leads to rotational failure at the bone-prosthesis interface. However, no research has yet discovered the correlation between resection length and rotational failure [26]. Another specific structural failure is the fracture or crumbling of the underlying bone between the anchor plug and the spindle [28,29]. Other structural failures include spindle failure, bone-implant interface collapse, fracture about the anchor plug, periprosthetic fracture, transverse pin migration, bending or fracture of the traction bar, polyethylene wear, and absence of bone growth into the porous spindle [23,26,28–30,32,34]. Furthermore, we conducted an indirect comparison between CPS and common endoprosthesis, exercising great caution in the interpretation of the results. The results showed that the structural failure rate of CPS was slightly higher than that of common endoprosthesis, but it exhibiting similar performance in aseptic loosening and infection. It demonstrated its advantages in soft tissue failure, tumor progression and all-cause failure. The 4-years overall survival rate of aseptic loosening of CPS is similar to that of common endoprosthesis, while the 4-years and 8-years survival rates of all-cause failure of CPS and the 8-years survival rate of aseptic loosening of CPS are slightly higher than those of common endoprosthesis. The above results indicate that CPS is not inferior to common endoprosthesis in terms of complications and lifespan.

Despite the large amount of data included, this systematic review still has several limitations. For example, our results are based on published studies that exhibiting significant heterogeneity in patient numbers, institutions, and time spans, which may not accurately represent outcomes across the community. In the studies included in the current research, many studies have incorporated CPS applications to different sites and for various causes. We acknowledge the significance of these confounding factors in influencing the failure rate of the prosthesis. However, due to the lack of original data from the included studies (despite efforts to obtain these data through email communication with the corresponding authors), it is not feasible to conduct a focused analysis or subgroup analysis on a specific site or diagnosis (such as tumor or non-tumor patients). Moreover, the primary objective of this study is to provide a preliminary overview of the survival and complication rates associated with CPS, without restricting the analysis solely to tumor-related procedures. And our findings indicate that the survival and complication profiles of CPS exhibit distinct characteristics compared to common endoprosthesis, despite similar patient demographics and clinical features. While we recognize the limitations of this indirect comparison, it is essential to interpret our results cautiously.

5. Conclusion

CPS requires less residual bone mass for reconstructing massive segmental bone defects and facilitates easier revision due to its non-cemented fixation. Our study demonstrates that the survival rate, the estimated mean survival time, and complication rates of CPS are not inferior to those of common endoprosthesis. In conclusion, this is an exhaustive and illustrative summary of the past 20 years of experience with CPS, providing a more reliable theoretical basis for the clinical application of CPS and more options for clinicians in the EPR following

Table 7
Comparison between CPS and common endoprostheses in regard to Implant Survival.

		Mean follow-up (months)	4-years overall survival rate	8-years overall survival rate	Mean survival time (months)
All-cause failure	CPS	67.2 ** (27–144) #	75 %	65 %	145 (127–148) $
	Common *	48 (24–96) #	70 %	58 %	36 (1–84) $
Aseptic loosening	CPS	67.6 ** (27–96) #	91 %	88 %	148 (137–153) $
	Common *	48 (24–96) #	92 %	85 %	54 (1–96) $

* Rotating-hinge GMRS (Stryker Inc, Rutherford, NJ, USA) knee megaprosthesis. ** The median of mean follow-up durations for each study. # Range in parentheses. $ 95 % CI in parentheses.

resection of a malignant bone tumor. However, it is imperative that future research still need to collect long-term survival data of CPS, and further confirmation is still needed regarding the potentially influential factors of CPS's failure.

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CRediT authorship contribution statement

Haolong Li: Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Xinxin Zhang:** Formal analysis, Conceptualization. **Xinyu Li:** Writing – review & editing. **Jingnan Shen:** Conceptualization. **Junqiang Yin:** Conceptualization. **Changye Zou:** Writing – review & editing, Conceptualization. **Xianbiao Xie:** Writing – review & editing, Conceptualization. **Gang Huang:** Writing – review & editing, Conceptualization. **Tiao Lin:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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