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FULL LENGTH PAPER

How to predict structural allograft survival in tibial reconstructions

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Abstract Tibial reconstruction for major bone loss is a challenging surgical situation. For more than 30 years, massive bone allografts entered our therapeutic arsenal as a major tool to reconstruct large bone defect. Despite allograft is valued for its convenience, it is still burdened by a high complication rate. This retrospective monocentric study focuses on the clinical outcomes of massive tibial allografts and their outcome's prediction. Between 1987 and 2022, the files of 148 massive tibial allografts were retrospectively reviewed (registration number B403201523492). Survival curves were calculated based on the allograft success or failure. Survival curves without revision surgery were calculated following the same design. Finally, multiple logistic regression models were set up to point out variables that influence the allograft survival. After 30 years, 87.2% of the patient retained limb function. However, 55% of the allograft failed and had to be removed (mean survival time is 20.06 ± 2.07 years (CI 16.0–24.1)). The estimate mean survival time is 10.26 ± 1.60 years (CI 7.1–13.4) with less than 20% survival for the allografts without revision surgery after 30 years. Tumor and septic indications worsen the prognosis as well as the number of revision surgeries and the osteochondral allograft type. In contrast, PSI use or traumatological indications improve the allograft survival. Despite remaining an excellent surgical reconstructive option, massive tibial allografts show a high revision surgery rate. Thanks to our multiple logistic regression models, we can start to predict and improve the final outcomes of these complex allograft reconstruction.

Keywords Massive bone allograft · Tibia · Survival · Statistical analysis

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Introduction

Large bone losses in the tibia have always been a major concern in the discipline of limb salvage surgery. Indeed, the tibia is an anatomical region exposed to a high rate of different pathologies and traumas (e.g. primary bone tumors and open fractures) (Thompson et al. 2023). In addition, the management of post-operative complications around the tibia has proven to be more difficult to control with high morbidity (Anandasivam et al. 2017; Thompson et al. 2023). Soft tissue management, tissue coverage issues, increased occurrence of non-union and the fact that open fractures are associated with larger bacterial contaminations make reconstructive surgeries of the tibia highly challenging (Tarkin et al. 2010; Anandasivam et al. 2017).

Currently, there are multiple surgical reconstruction techniques but no gold standard has been proven clinically superior. In cases of significant bone loss (Nauth et al. 2018), massive bone allografts, Masquelet technique, vascularized fibula, distraction osteogenesis or modular endoprosthetic implants are currently used depending on the indication, the anatomical location of the bone defect and the surgeon's preferences or habits (Masquelet and Begue 2010; McCall et al. 2010; Zhao et al. 2019).

Massive bone allografts are an effective biological reconstruction technique but with some limitations: as any devitalized material, allografts are susceptible to perioperative bacterial contamination and secondary infection, risk of stress fracture and bone nonunion and finally allograft bone resorption (Delloye et al. 2007; Aponte-Tinao et al. 2016; Zhao et al. 2018; Belluati et al. 2018). These undesirable effects are still difficult to anticipate and occur relatively randomly depending on the patient, the surgical indication or the postoperative events.

The purpose of this study is to investigate the survival curves of massive tibial allografts. As revision surgery is a major factor in these reconstructive surgeries, the occurrence of complications and revision surgery were also investigated. Our research hypothesis is that improved patient and surgical technique screening, focusing on specific clinical variables, may optimize the clinical outcomes of massive allografts.

Material and methods

We studied 125 patients who underwent 148 fresh-frozen non-irradiated massive tibial allografts for limb salvage surgery at our institution from 1987 to 2022. Our inclusion criteria encompassed fresh-frozen tibial allografts with essential mechanical stress support characteristics for limb salvage. No specific size or dimension criteria were applied. Filling bone material allografts were excluded. Allografts were categorized as inlays, intercalary diaphyseal, intercalary metaphyseal, allograft-prosthesis composite (APC), and osteoarticular. The study received approval from the local ethics committee (2015/26JAN/025, Belgian registration number B403201523492), and retrospective evaluation of medical files was conducted using the local tissue bank's internal register.

The 125 patients involved *69% (n = 86)* of men and *31% (n = 39)* of women. The mean age at surgery was 40.95 ± 19.18 years old, ranging from 9 to 81 years old. The mean postoperative follow-up was 8.73 ± 7.29 years, ranging from 0.3 to 35 years. 148 allografts were used in our cohort of 125 patients.

The primary outcome was allograft retrieval, analyzed through a survival curve. Multiple logistic regressions were conducted to identify variables influencing allograft retrieval, categorized into demographics, pre-operative conditions, per-/peri-operative conditions, and revision variables. Qualitative variables were presented as percentages and frequencies, while quantitative variables were described with mean, standard deviation, and min/max values. Revision indications and types were treated as quantitative variables due to their enumeration encoding, taking values of 0 and 1.

As the re-operation surgery rate was significant (55.4% underwent at least one revision surgery), we also performed a survival curve of the allografts that didn't undergo second surgeries.

Artificial intelligence tools have been used solely for the purposes of correcting and revising English scientific writing. No data, information or thoughts in this manuscript have been derived from artificial intelligence tools.

Statistical evaluation

A thorough analysis of this large dataset was performed following a sequential approach of descriptive, univariate, and multivariate analyses. First of all, after classical descriptive analyses, survival curves were studied through a *Kaplan–Meier* evaluation for the overall allograft survival. Further survival curves were performed in order to understand the issue more in details: the survival curve of allograft without any surgical revision and a breakdown of the overall allograft's survival curve depending on the grafting indication and the type of allograft. To achieve this, a *Log-Rank (Mantel-Cox)* test was conducted to compare the different survival curves. The loss to follow-up was noted as a censored value in the survival function. *Pearson's r* coefficient was used to test the correlation between quantitative variables. *Cramer's V* coefficient was used to test the correlation between qualitative variables. Statistical inferences were performed thanks to *T-tests* for normally distributed continuous variables and *Chi-squared* tests for qualitative variables. Levene's test was always used to confirm the equality of variances for independent *T-tests*. Multivariate analyses involved successive logistic regression models to identify risk factors for allograft retrieval, as a first step into each sub-section. In order to avoid multicollinearity, some variables were excluded from the regression because of a *Pearson's r* coefficient >0.95 in the correlation matrix or a *VIF (Variance Inflation Factor)* >5. Some criteria were also sorted in ascending order based on medical relevance. A final multiple logistic regression was computed based on selected variables from previous analyses (significant p-values and odd ratio). In order to choose the best model, two stepwise methods were associated (forward and backward stepwise). At each step, the goodness-of-fit of the model was evaluated by the *Hosmer–Lemeshow test*, and the most accurate model was chosen based on its deviance and the *Likelihood Ratio Test (LRT)*.

All tests were two-sided and the statistical significance threshold was set for p-values less than 0.05. 95% confidence interval is noted CI. Standard deviation is noted after a mean value following the symbol $\pm$. All analyses were performed using *Sigmaplot 13 and SPSS softwares (v.20 and V.27, SPSS, Inc., Chicago, IL, USA)*.

Results

Among the 125 patients, only 16 needed to be amputated after 30 years of follow-up. 87.2% of the patients still benefit from their tibial reconstruction. However, this result doesn't tell if the allograft survived. Indeed, among the 148 allografts, 29.7% (n = 44) needed to be surgically removed. Table 1 shows all the variables collected for every allograft and their descriptive data.

"Extended antibiotherapy" was a variable in the two-stage strategy for managing infected non-unions. The first stage involved surgery addressing infected bone and non-union resection, antibiotic-loaded spacer placement, soft tissue reconstruction, and 6 to 8 weeks of antibiotics. The second stage included bone defect reconstruction with a massive bone allograft, followed by 6 weeks of antibiotics, totaling 12 weeks. In non-infected cases, standard antibioprophylaxis was applied (cefazolin 2 g 30 min before incision and two doses at 8 h and 16 h postoperatively).

Table 2 shows the survival data's and the follow-ups of the allografts.

Survival curve of the graft survival is shown in Fig. 1 showing a moderate survival result in a long-term follow-up: $<50\%$ at >30 years and 60% at 15 years follow-up. Estimate mean survival time is *20.06* $\pm$ *2.07* years (*CI 16.0–24.1*).

The overall survival curve for tibial allografts was also broken down by type of allograft and primary surgical indication. We can therefore observe that intercalary allografts (diaphysis) have the lowest survival rate after 15 years of follow-up and that, unsurprisingly, inlay allografts have the best survival rate (Fig. 2). Estimate mean survival time of inlays allografts is *11.87* $\pm$ *1.29 years (CI 9.34–14.40)*. Estimate mean survival time of diaphyseal intercalary allografts is *16.62* $\pm$ *3.78 years (CI 9.20–24.03)*. Estimate mean survival time of metaphyseal intercalary allografts is *23.17* $\pm$ *3.95 years (CI 15.43–30.90)*. Estimate mean survival time of APC is *16.08* $\pm$ *2.62 years (CI 10.94–21.22)*. Estimate mean survival time of osteochondral allografts is *9.67* $\pm$ *3.69 years (CI 2.45–16.90)*. When we compare all the allograft types survival curves between one another (*Log Rank (Mantel-Cox) model*), only the osteochondral allograft survival curve shows a significant statistical difference with inlays ($p = 0.005$), diaphyseal intercalary allografts ($p = 0.017$), metaphyseal intercalary

Table 1 Qualitative and quantitative variables listed for the allograft-centered study and divided into four main categories

Variables (units)	Qualitative variables		Quantitative variables			
	Percentage (%)	Frequency (n)	Mean	Standard deviation	Min	Max
Demographics						
Sex						
Male	67.6	100				
Female	32.4	48				
Age (years)			40.46	19.35	9	81
BMI (kg/m^2)			25.78	5.89	13	48
Medical history						
Tobacco use	28.4	42				
Diabetes	9.5	14				
Vascular pathology	23	34				
Local surgery	77	114				
Infection	55.4	82				
Tumor background	37.8	56				
Surgical indications						
Non-union/trauma	31.1	46				
Infection	50.7	75				
Tumor	26.4	39				
OS failure	6.1	9				
Arthrosis	0.7	1				
Malformation	0.7	1				
Pre-operative treatment						
Radiotherapy	1.4	2				
Chemotherapy	13.5	20				
Spacer	49.3	73				
Per-/peri-operative conditions						
Type of AG						
Inlay	12.8	19				
Metaphyseal intercalary	14.9	20				
Diaphyseal intercalary	39.2	58				

Table 1 (continued)

Variables (units)	Qualitative variables		Quantitative variables			
	Percentage (%)	Frequency (n)	Mean	Standard deviation	Min	Max
APC	25	39				
Osteoarticular	8.1	12				
Type of location						
Proximal metaphysis	47.3	70				
Distal metaphysis	20.3	30				
Diaphysis	32.4	48				
AG size (cm)			8.84	4.85	1	28
First intention arthrodesis	16.2	24				
PSI use	9.5	14				
DBM/autograft use	35.8	53				
Operative time (min)			229.65	98.64	82	616
Type of OS						
Screws only	3.4	5				
Cerclage	0.7	1				
Nail & plate	2.0	3				
Prosthesis	26.4	39				
Nail	34.5	52				
Plate	32.4	48				
Screws in the AG (n)			1.25	2	0	11
Cement use	25.7	38				
Cover						
Rotation flap	8.8	13				
Pedicle flap	2.0	3				
Free flap	0.7	1				
Immediate post-op treatment						
Radiotherapy	0	0				
Chemotherapy	13.5	20				
VAC Prevena	1.4	2				

Table 1 (continued)

Variables (units)	Qualitative variables		Quantitative variables			
	Percentage (%)	Frequency (n)	Mean	Standard deviation	Min	Max
Extended antibiotherapy	45.3	67				
Weightbearing time (weeks)			4.61	3.91	0	16
Revision conditions						
Revision indication						
Non-union			0.26	0.61	0	4
Infection			0.30	0.61	0	3
Fracture			0.05	0.21	0	1
Implant failure			0.14	0.387	0	2
Soft tissue coverage			0.18	0.50	0	3
Tumoral recurrence			0.03	0.18	0	1
AG resorption			0	0	0	0
Type of revision						
Amputation			0.09	0.28	0	1
Arthrodesis			0.01	0.12	0	1
OS change			0.18	0.44	0	2
OS + AG change			0.11	0.31	0	1
TKA revision			0.06	0.34	0	3
Non-union cure			0.20	0.53	0	3
Lavage			0.09	0.33	0	2
Spacer			0.13	0.34	0	1
Soft tissue coverage			0.16	0.45	0	2
Cause of AG retrieval (n)						
Soft tissue coverage failure	0.7	1				
AG fracture	0.7	1				
Implant failure	3.4	5				
Tumoral recurrence	3.4	5				
Persistent non-union	4.1	6				

Table 1 (continued)

Variables (units)	Qualitative variables		Quantitative variables			
	Percentage (%)	Frequency (n)	Mean	Standard deviation	Min	Max
Infection	17.6	26				
Number of revisions			0.98	1.16	0	5

AG allograft; *OS* osteosynthesis; *VAC* vacuum assisted closure; *APC* allograft-prosthesis composite; *TKA* total knee arthroplasty

allografts ($p=0.022$) and APC ($p=0.042$). Survival curves for allografts according to surgical indication show that trauma curves have excellent survival over 20 years compared to infection, tumor or osteosynthesis failure curves. As indications for arthrosis (as post-traumatic arthrosis) or malformation are very infrequent (n = 1), it is not advisable to interpret these two curves (Fig. 3). Nevertheless, a *log rank (Mantel-Cox) model* allows us to evaluate the statistical differences between the curves. Excluding the arthrosis indication, only one significant statistical difference is found between the trauma indication and the tumor indication ($p=0.043$).

Allograft complications focus

Among the 148 tibial allografts, 44.6% (n = 66) have not undergone any revision surgery. 29.7% (n = 44), 14.2% (n = 21), 7.4% (n = 11), 2.7% (n = 4) and 1.4% (n = 2) underwent respectively 1, 2, 3, 4 and 5 revision surgeries.

The overall survival curve of the allografts (Fig. 4) shows that after 20 years of follow-up, 20% of the allografts were never surgically revised. After 30 years, this percentage drops around 15%. Estimate mean survival time is *10.26 ± 1.60 years (CI 7.1–13.4)*. High rate of censorship has to be declared from here.

Prediction of the allograft retrieval

Statistical inferences comparing groups with and without allograft retrieval are summarized in the Table 3. Only the significant different variables are shown. This table highlights that the allograft retrieval is much more influenced by medical criteria than by demographics, and especially by revision conditions, such as the revision indication, the type or the number of revisions. Interestingly, the tumoral background is significantly different in the group with or without allograft retrieval ($\chi^2=5.547$, *p-value* $=0.026$).

Multiple logistic regression models were created for each sub-section in order to assess separately all the variables, and to highlight the most statistical relevant ones in each sub-section. The final prediction

Table 2 Quantitative data: survival and follow-ups of the allografts

Variables	Mean	Standard deviation	Range	Minimum	Maximum
Allograft survival (years)	6.26	6.35	34.64	0.12	34.76
Follow-up without revision surgery (years)	4.03	4.91	32.68	0.10	32.78
Follow-up from last surgery (years)	6.70	6.17	32.74	0.04	32.78

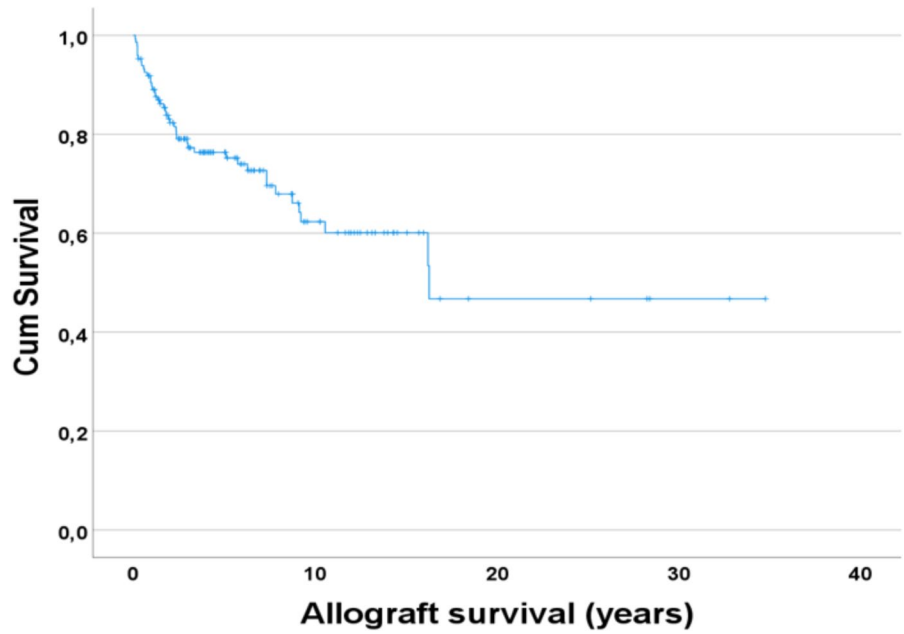

Fig. 1 Kaplan–Meier survival curve of the allograft survival

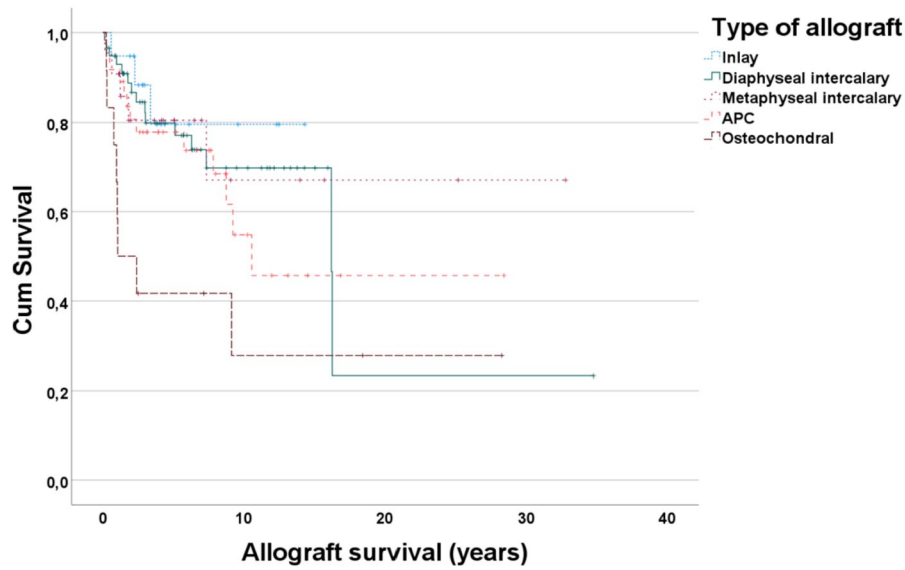

Fig. 2 Kaplan–Meier survival curve of the allograft survival according to the type of allograft

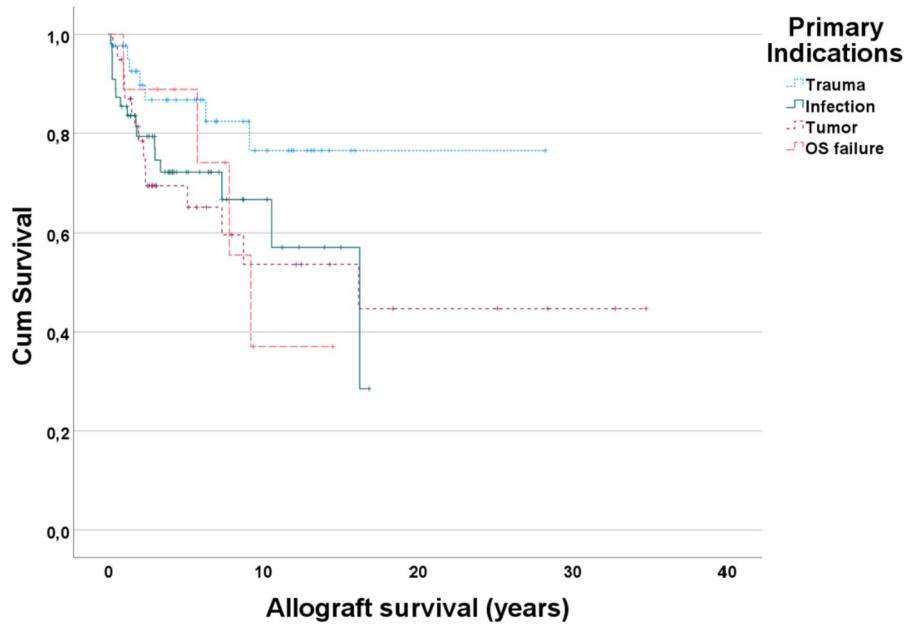

Fig. 3 Kaplan–Meier survival curve of the allograft survival according to the primary surgical indication. *OS* Osteosynthesis

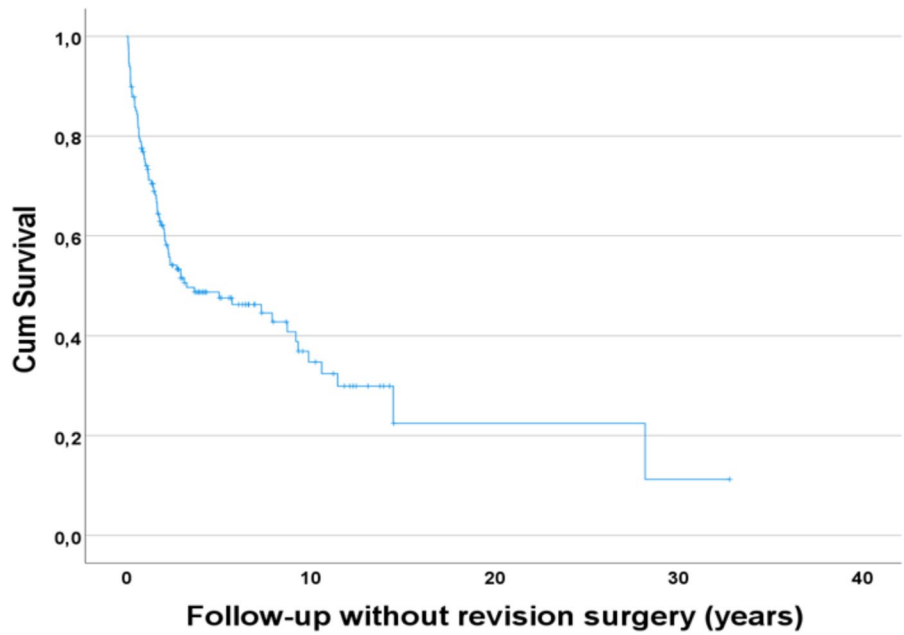

Fig. 4 Kaplan–Meier survival curve of the allografts who didn't suffer from any revision surgery

model was then computed and chosen according to the best accuracy. All the outcomes are pooled in the Table 4 .

A prediction formula was modelized on the final prediction model and allowed us to predict the risk of the allograft retrieval.

$$\begin{aligned}\text{Logit } P = &-4.258 - (1.669 * \text{Trauma indication}) \\ &+ (0.496 * \text{Type of AG}) - (4.332 * \text{PSI use}) \\ &+ (0.331 * \text{Screws in the AG}) + (2.529 * \text{Septic revision}) \\ &+ (1.032 * \text{Number of revisions})\end{aligned}$$

Table 3 Statistical inferences comparing groups with or without allograft retrieval

Variables	Test value		df	*p-value*
	T-test (*t*)	Chi-square (χ^2)		
Demographics				
Medical history				
Tumor background		5.547	1	*0.026*
Pre-operative conditions				
Surgical indication				
Non-union/trauma		6.729	1	*0.011*
Per-/peri-operative conditions				
Type of AG		11.053	4	*0.026*
Operative time	−2.483		52.4	*0.016*
Revision conditions				
Revision indication				
Infection	−5.777		48.5	*< 0.001*
Soft tissue coverage	−3.700		48.1	*0.001*
Tumor recurrence	−2.348		43	*0.024*
Type of revision				
Amputation	−4.246		43	*< 0.001*
OS + AG change	−4.543		44.5	*< 0.001*
Spacer	−5.285		44.4	*< 0.001*
Cover	−2.905		50.3	*0.005*
Cause of AG retrieval		148.000	6	*< 0.001*
Number of revisions	−7.390		62.5	*< 0.001*

Quantitative variables were analyzed by T-test and qualitative variables were analyzed by Chi-squared test. *AG* allograft; *OS* osteosynthesis. Italicized p-values indicate statistical significance. Specifically, $p < 0.05$ is considered significant, $p < 0.01$ highly significant and $p < 0.001$ very highly significant.

Although the tumoral background significantly influences the risk of allograft retrieval based on the demographic model ($p = 0.021$), it doesn't predict the outcome when all the criteria were considered and was removed from the final prediction score ($LRT = 0.958$, $p = 0.328$).

The type of allograft was not a direct significant predictor, the model needed to be adjusted for this variable. A stratified univariate analysis according to the type of allograft showed that the osteochondral one was the only significant type that reduce the allograft survival prognosis (*OR 5.56; CI 1.58 – 19.57*, $p = 0.008$).

The traumatic indication as well as the use of a PSI decrease the risk of allograft retrieval ($p = 0.029$ and 0.027 respectively). However, the number of screws inserted in the allograft seems to increase the risk of allograft retrieval ($p = 0.027$) but its odds ratio is not that far from 1. Septic indication for revision and the number of revisions significantly worsen the allograft outcomes, increasing the retrieval risk in the final prediction model ($p = 0.027, < 0.001$ and < 0.001 respectively) which confirms and reinforces the previous findings. A Pearson's r coefficient revealed a significant positive correlation between the infection complication and the number of re-operation ($r = 0.562$, $p < 0.001$).

Discussion

This retrospective study affirms the continued validity of using massive allografts for substantial tibial bone defects even after a 30-year follow-up. While relatively few patients undergo amputation, it is crucial to acknowledge the high complication rate associated with reconstructing tibial bone defects using massive allografts. Surgeons must be prepared to address the complexities and challenges involved in these reconstructions. The study emphasizes the importance of considering various clinical variables to anticipate the success or failure of such surgeries.

The survival curve of the allograft itself exhibits a moderate outcome, with just under 50% survival at the 30-year follow-up. When considering the breakdown of the overall survival curve based on the allograft type, intercalary allografts show a higher rate of removal in the initial years, although the logistic regression does not identify this allograft type as favoring failure. This elevated revision rate can be attributed to the more frequent use of intercalary grafts in indications associated with higher failure rates, such as infected chronic non-unions. The osteochondral allograft displays one of the poorest survival curves, aligning with the logistic regression model. Conversely, the overall survival curve, when segmented by allografting indication, aligns effectively with the multiple logistic regression, with trauma

Table 4 Multiple logistic regression models depending on each sub-section of criteria, and the final computed model

Variables	Multiple logistic regressions		
	Coefficient	*OR [95% IC]*	*p-value*
Demographics			
Medical history			
Tumor background	1.421	*4.14 [1.23, 13.88]*	*0.021*
Pre-operative conditions			
Surgical indication			
Non-union/trauma	− 1.309	*0.27 [0.08, 0.95]*	*0.040*
Per-/peri-operative conditions			
Type of AG	0.650	*1.92 [1.01, 3.63]*	*0.046*
PSI use	− 2.566	*0.08 [0.01, 0.96]*	*0.046*
Screws in the AG	0.332	*1.39 [1.05, 1.85]*	*0.021*
Cement use	− 2.405	*0.09 [0.01, 0.94]*	*0.044*
Immediate post-op treatment			
Weightbearing time	− 0.200	*0.82 [0.70, 0.96]*	*0.016*
Revision conditions			
Indication revision			
Infection	2.185	*8.89 [2.27, 34.74]*	*0.002*
Number of revisions	1.078	*2.94 [1.23, 7.01]*	*0.015*
Final prediction model			
Surgical indication			
Non-union/trauma	− 1.669	*0.19 [0.04, 0.84]*	*0.029*
Type of AG	0.496	*1.64 [0.99, 2.73]*	*0.055*
PSI use	−4.332	*0.01 [< 0.01, 0.61]*	*0.027*
Screws in the AG	0.331	*1.39 [1.04, 1.87]*	*0.027*
Indication revision			
Infection	2.529	*12.54 [3.45, 45.66]*	*< 0.001*
Number of revisions	1.032	*2.81 [1.57, 5.01]*	*< 0.001*

Only the statistically different data are showed for sub-sections while all the selected variables are described in the final prediction model. *AG* allograft; *PSI* patient specific instrument. Italicized p-values indicate statistical significance. Specifically, $p < 0.05$ is considered significant, $p < 0.01$ highly significant, and $p < 0.001$ very highly significant.

indications demonstrating significantly better survival compared to tumor, chronic infected non-unions, and osteosynthesis failure indications.

Massive allografts of the tibia pose substantial challenges in follow-up, both concerning the treated bone and the allograft implant. The survival curve indicates less than 50% allograft survival at 30 years and 60% at 10 years, which, given the complexities of the treated bone and the involved massive allograft technique, represents satisfactory outcomes(Aponte-Tinao et al. 2020; Giannini et al. 2020; Thompson et al. 2023). However, some nuance is warranted. While the survival curves extend up to 30 years post-surgery, over 50% of the data is censored within the first 10 years of follow-up. Many patients (or allografts) underwent surgery less than 5 or 10 years ago, diminishing the precision of the survival curve beyond the 10-year mark.

Furthermore, as suggested by the literature(Giannini et al. 2020), is there an importance of the complication rate? The literature confirms our results(Giannini et al. 2020) demonstrating a strong impact of the occurrence of complications on the reconstruction survival. Indeed, when comparing the survival curves described above with the survival curves without surgical revision, the differences are flagrant. Censoring is a little less present and the survival curves without revision surgery are poor. Indeed, after 15 years of follow-up, only 20% of patients or allografts will never have undergone a re-operation for complication.

When analyzing the multiple regressions and the different variables influencing allograft failure, several items can be discussed. The retrieval of the allograft is essentially influenced by medical criteria rather than demographics (i.e. there seems to be

no impact of tobacco use or diabetes), which is quite surprising compared to the literature(Mahajan et al. 2021). Furthermore, revision conditions such as the indication revisions or the number of revisions have a particularly significant impact.

The primary indication can predict the risk of allograft retrieval. As such, a trauma leads to better survival of the allograft, maybe suggesting a richer biological environment, vascularization and soft tissues status around the fracture, compared to chronic infected non-union, non-union or other prior surgeries(Hotchen et al. 2020). As a matter of fact, 55.4% of our cohort (82/148) had a history of prior local infection as chronic infected non-union was the primary surgical indication in 50.7% (75/148). Of these, 49.3% (73/148) benefited of a staged surgery with a spacer implanted prior the definitive reconstruction with an allograft. In addition to this predominantly septic population, the predictive logistic regression also highlighted a significant decrease of graft survival depending on the number of revisions for septic indications. All this needs to be carefully considered, taken into account the fact that non-union is related to local infection in 40% of the cases(Mills et al. 2016). An allograft, in the same way as osteosynthesis material, is to be considered as a non-vascularized foreign body which can be the breeding ground for septic recurrence, biofilm and sequestration(Lozano-Calderón et al. 2016; Huang et al. 2022). However, current research tends to prove excellent results when allografts are used as antibiotics carriers. In fact, the local use of antibiotics on allografts during one-stage septic reconstruction surgeries show their effectiveness as antibiotic deliverers(Peeters et al. 2019).

The osteochondral type was the most critical allograft type in terms of survival. This observation can be explained by multiple characteristics of the graft. Firstly, the primary aim of these osteochondral allografts is to preserve limb length and bone stock, mainly in pediatric patients, in anticipation of future total knee arthroplasty. The allograft helps to preserve growth of the distal femur and provides a sufficient base for the prosthesis and cement of the future reconstruction. It is therefore almost always anticipated that the osteochondral allograft will either be removed to place a mega prosthesis, or reused to totalize the knee joint(Chui et al. 2015). Secondly, It involves half an articulation and grafting articular cartilage still shows poor results of viability(Torrie et al. 2015).

Utilizing a PSI not only aids in securing safe margins and enhancing surgical accuracy, as demonstrated before (Evrard et al. 2019), but also plays a crucial role in optimizing the fit between the resection and transplanted allograft. This careful alignment promotes improved bone contact, fostering potential bone healing.

Even if bone allograft can be long-lasting when complications are absent or well managed, some emerging researches are ongoing to improve their biological status and their long-term outcomes. Whether this comes from the removal of intrinsic immune components(Evrard et al. 2023) or from the provision of extrinsic biology via an induced neomembrane(Manon et al. 2023), the common goal is to improve the bone integration, the vitality and the durability of these allografts.

The study's monocentric nature represents a clear limitation. More robust and accurate results could be obtained with a multicentric cohort and an extended follow-up. Our study's design did not explicitly list irrelevant revision surgery indications, like material removal for skin discomfort, as complications. In the logistic regression, certain variables associated with the operators were omitted under the assumption that all surgeons involved possessed equivalent expertise in implanting these allografts. Furthermore, certain variables outlined in the study design, such as postoperative radiotherapy and allograft resorption, were not observed in our cohort.

Massive tibial allografts are not the only technique available for reconstructing major bone defects. Not to mention off-the-shelf or custom-made metal implants, biological reconstructive techniques such as bone transfers or the Masquelet technique are also alternatives to massive allografting(Bezstarosti et al. 2021). Recent studies have demonstrated a complication rate for these techniques comparable to that of our series, with the difference that our series has a follow-up of over 20 years, compared with follow-up of less than 3 or 2 years(Giannini et al. 2020).

This study lays the groundwork for a potential success/failure score for massive tibial allografts. Expanding this research on a larger scale could yield a predictive score, guiding the use of allografts based on patient profiles and specific indications. Our predictive model provides more precise guidelines for

optimizing the clinical outcomes of massive allografts. From a surgical perspective, minimizing the number of screws placed in the allograft is crucial, and the integration of patient-specific instrumentation (PSI) should be systematically considered when implanting massive allografts. Regarding surgical indications, massive allografts should be prioritized in trauma cases, whereas their use in septic indications should be approached with caution.

Conclusion

While massive bone allografts yield favorable functional outcomes in tibial reconstructions, their elevated rates of revision surgery and complications warrant careful consideration before undertaking such reconstructions. Variables such as tumor and septic indications, the frequency of revision surgeries, and osteochondral allografts increase the likelihood of allograft retrieval. Conversely, traumatological indications and the utilization of PSI are factors that contribute to the success of the allograft.

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Author contributions Authors contribution Evrard R.: Conceptualization; Data curation; formal analysis; investigation; methodology; project administration; writing—original draft Manon J.: Conceptualization; formal analysis; investigation; methodology Docquier P-L.: Supervision; validation; visualization; writing—review & editing Cornu O.: Supervision; validation; visualization; writing—review & editing Schubert T.: Conceptualization; supervision; validation; visualization; writing—review & editing.

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Declarations

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