Blood transfusion in elective total hip arthroplasty: can patient-specific parameters predict transfusion?

From Sana Hospitals Sommerfeld, Kremmen, Germany

N. Meißner,[1] A. Strahl,[2] T. Rolvien,[2] A. M. Halder,[1] D. Schrednitzki[1]

[1]Department of Orthopaedic Surgery, Sana Hospital Sommerfeld, Kremmen, Germany
[2]Department of Trauma and Orthopaedic Surgery, Division of Orthopaedics, University Medical Center Hamburg-Eppendorf, Hamburg, Germany

Correspondence should be sent to N. Meißner Nils.Meissner@Sana.de

Cite this article:
Bone Jt Open 2024;5(7): 560–564.

DOI: 10.1302/2633-1462.57.BJO-2023-0157.R1

Aims
Transfusion after primary total hip arthroplasty (THA) has become rare, and identification of causative factors allows preventive measures. The aim of this study was to determine patient-specific factors that increase the risk of needing a blood transfusion.

Methods
All patients who underwent elective THA were analyzed retrospectively in this single-centre study from 2020 to 2021. A total of 2,892 patients were included. Transfusion-related parameters were evaluated. A multiple logistic regression was performed to determine whether age, BMI, American Society of Anesthesiologists (ASA) grade, sex, or preoperative haemoglobin (Hb) could predict the need for transfusion within the examined patient population.

Results
The overall transfusion rate was 1.2%. Compared to the group of patients without blood transfusion, the transfused group was on average older (aged 73.8 years (SD 9.7) vs 68.6 years (SD 10.1); p = 0.020) and was mostly female (p = 0.003), but showed no significant differences in terms of BMI (28.3 kg/m^2 (SD 5.9) vs 28.7 kg/m^2 (SD 5.2); p = 0.720) or ASA grade (2.2 (SD 0.5) vs 2.1 (SD 0.4); p = 0.378). The regression model identified a cutoff Hb level of < 7.6 mmol/l (< 12.2 g/dl), aged > 73 years, and a BMI of 35.4 kg/m^2 or higher as the three most reliable predictors associated with postoperative transfusion in THA.

Conclusion
The possibility of transfusion is predictable based on preoperatively available parameters. The proposed thresholds for preoperative Hb level, age, and BMI can help identify patients and take preventive measures if necessary.

Take home message
- In elective total hip arthroplasty, the need for postoperative blood transfusion can be predicted using preoperative patient-specific parameters.
- Key predictors identified include age (≥ 73 years), preoperative hemoglobin level (< 7.6 mmol/l or 12.2 g/dl), and BMI (≥ 35.4 kg/m^2).

Introduction
Primary total hip arthroplasty (THA) is often associated with substantial blood loss. High blood loss can lead to perioperative and postoperative anaemia. This may result in the need for allogenic blood transfusion.[1,2] Blood transfusion is associated with specific risks, such as the transmission of infectious diseases (human immunodeficiency virus or hepatitis), but also severe systemic side effects, such as transfusion-related acute lung injury and increased risk

Bone & Joint Open

of periprosthetic joint infection.[3-5] Furthermore, blood transfusion is associated with increased morbidity and mortality.[6-8]

Blood loss during THA has been reported in the literature to range from 700 ml to 1,500 ml.[2,9,10] Before the introduction of blood-sparing measures and the implementation of patient blood management protocols, THA was associated with a high risk of transfusion, with transfusion rates ranging from 15% to 69%.[1,11] As a result, patient-specific packed red blood cells were routinely stocked for allogenic blood transfusion. However, in recent years, the implementation of new surgical techniques and patient blood management protocols optimization, as well as the introduction of new transfusion guidelines, have significantly reduced transfusion rates in THA.[12–14] Many studies have also shown the benefit of tranexamic acid (TXA) in THA and its use is now the gold standard, leading to a significant reduction in blood loss and transfusion rates.[15–18]

In recent years, transfusion rates in THA have been reduced to between 2.5% and 15%.[10,12,19,20] Due to the reduced transfusion rate, it can be assumed that the stocking of packed red blood cells is no longer necessary for all patients. This could contribute to significant relief for blood banks, thus reducing discarded blood products. However, optimal cutoff values for preoperatively available, patient-specific parameters are lacking. With more outpatient THAs, there is a need to know which patients might require transfusion.[21] To determine which patients require a stock of patient-specific packed red blood cells, this study aims to analyze whether transfusion can be predicted by preoperative patient-specific parameters. As a secondary aim, we sought to determine the time points of transfusion after surgery.

Methods

Study cohort

All patients who underwent elective THA for primary hip osteoarthritis were reviewed retrospectively in a single surgery centre in Germany from 2020 to 2021. The study protocol was approved by the local ethics committee (registration number: 2023-5-BO-ff). Patients receiving THA for femoral neck fracture were not included. A total of 2,892 patients (1,191 males (41.2%) and 1,701 females (58.8%)) were available for analysis. The mean age at the time of surgery was 68.7 years (standard deviation (SD) 10.1; 20 to 93), the mean BMI was 28.6 kg/m^2 (SD 5.2; 17.7 to 50.6), and the mean American Society of Anesthesiologists (ASA) grade[22] was 2.14 (SD 0.42; 1 to 4; ASA I 2.9%, ASA II 80.4%, ASA III 16.7%, and ASA IV 0.1%).

Outcome parameters

The preoperative and postoperative haemoglobin (Hb) values were evaluated. In case of transfusion, the time of transfusion, the number of packed red blood cells transfused, and the Hb values at the time of indication were recorded. Preoperative Hb values were recorded on the day before surgery. Postoperatively, the measurement was performed on the first and third postoperative days.

Surgical concepts and patient blood management

Implantation of THA was performed with an anterolateral approach for all patients. Cementless THAs were implanted in press-fit technique. The indication for the use of bone cement was established for patients aged older than 80 years and/or with Dorr type C femora. All patients received preoperative anaemia screening, and were substituted (intravenous 1 g Ferinject; Vifor Pharma, Germany) if there was iron deficiency anaemia. All patients were warmed with an active heating system and received warmed infusion solutions according to hospital standards. Blood-sparing measures included the use of TXA if there were no contraindications (preoperatively 1 g orally or 1.5 g > 100 kg body weight, 500 mg 1-1-1 orally for two days postoperatively). Patients with a contraindication to TXA were excluded from this study. No drains were used. As thrombosis prophylaxis, 40 mg of low molecular weight heparin per day was administered according to German guidelines.[23] If patients received antiplatelet therapy preoperatively, it was continued postoperatively. If patients received direct oral anticoagulants, therapy was paused for two days prior to surgery.

Indication for transfusion

The indication guideline was based on a transfusion trigger checklist. The transfusion triggers were an Hb < 4.8 mmol/l (7.7 g/dl), with cardiovascular symptoms such as hypotension, tachycardia, or electrocardiography ischaemia. Furthermore, in individual cases, transfusion could be considered to be in deviation from fixed transfusion triggers. All data for the study were obtained from the institution's database.

Statistical analysis

Continuous variables are expressed as mean (SD) and range, while categorical variables are expressed as number and percentage. To compare patients with and without blood transfusion in relation to continuous variables, the independent-samples *t*-test was used for normally distributed data. For non-normally distributed data the Mann-Whitney U test was applied, and for categorical variables the chi-squared or Fisher's exact test was applied. Normal distribution was examined using the Shapiro-Wilk test. All data were available for all patients except BMI, which was available for 1,784 patients. While group comparisons were applied to the entire patient cohort, the patient cohort with complete data set (including BMI) was subjected to regression analysis to identify potential predictors of blood transfusion. For continuous predictors of preoperative Hb in mmol/l, age, and BMI, a threshold was defined by Youden's J statistic. The Youden Index is a measure that uses receiver operating characteristic (ROC) curves to determine the best threshold value to distinguish two groups (blood transfusion vs no blood transfusion). Where possible, odds ratios (ORs) with 95% confidence interval (CI) were calculated for all variables. Finally, a multiple logistic regression was performed to determine whether age, BMI, ASA grade, sex, or preoperative Hb predict the appearance of a blood transfusion within the examined patient population. The regressions use the 'Enter' method to examine the significant impact of all variables simultaneously. Lastly, we conducted a subgroup analysis for all THA patients. All analyses were performed using SPSS version 29.0 (IBM, USA) for Windows. Statistical significance was set at a two-tailed p-value of 0.05.

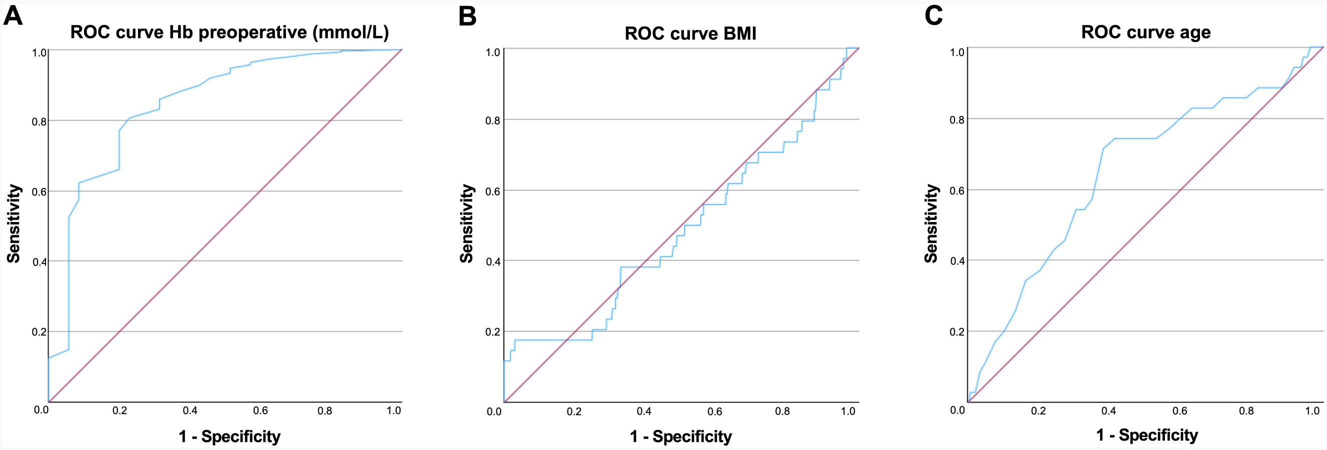

Fig. 1

For all charts, A) receiver operating characteristic (ROC) curve for haemoglobin (mmol/l), B) ROC curve for BMI, and C) ROC curve for age. a) To identify independent predictors for blood transfusion in total hip arthroplasty (THA) patients, the optimal threshold for interval scaled variables were calculated based on ROC curves. b) To identify independent predictors for blood transfusion in THA patients the optimal threshold for interval scaled variables were calculated based on ROC curves. c) To identify independent predictors for blood transfusion in THA patients the optimal threshold for interval scaled variables were calculated based on ROC curves.

Table I. Demographic data and preoperative haemoglobin levels for transfused and non-transfused patients.

Variable	Transfused	Non- transfused	p-value
Mean age, yrs (SD)	73.8 (9.7)	68.6 (10.1)	0.020*
Mean BMI, kg/m^2, (SD)	28.3 (5.9)	28.7 (5.2)	0.720*
Mean ASA grade (SD)	2.2 (0.5)	2.1 (0.4)	0.378†
Mean preoperative Hb preOP, mmol/L (SD)	7.0 (0.9)	11.2 (1.5)	< 0.001
Sex (female:male), n	♀ 29 : ♂ 6	♀ 1,672 : ♂ 1,185	0.003‡

*Independent-samples *t*-test
†Mann-Whitney-U-test.
‡Fisher's exact test.
ASA, American Society of Anesthesiologists; Hb, haemoglobin; SD, standard deviation.

Table II. Risk ratio of single predictors of blood transfusions.

Variable	Risk ratio	95% CI	p-value*
Age ≥ 73 years	4.2	2.0 to 8.8	< 0.001
Female sex	3.4	1.4 to 8.3	0.006
BMI ≥ 35.4 kg/m^2	1.8	0.7 to 4.4	0.197
Preoperative Hb < 7.6 mmol/l	14.5	7.1 to 30.1	< 0.001

*Fisher's exact test.
CI, confidence interval; Hb, haemoglobin.

Results

The overall transfusion rate was 1.2% (35/2,892 patients) in this population. On average, 1.8 packed red blood cells (SD 0.5; 1 to 3) were transfused. The first transfusion was performed after 2.8 days (SD 1.5; 1 to 6). During surgery or on the day of surgery, no transfusions were performed. If transfusion was necessary, the mean indication Hb was 4.7 mmol/l (SD 0.2; 3.9 to 4.9) or 7.5 g/dl (SD 0.3; 6.3 to 7.9). Compared to the group of patients without blood transfusion, the transfused group was on average older (73.8 years (SD 9.7) vs 68.6 years (SD 10.1); p = 0.020) and was mostly female (p = 0.003, Fisher's exact test), but showed no significant differences in terms of BMI (28.3 kg/m^2 (SD 5.9) vs 28.7 kg/m^2 (SD 5.2); p = 0.720, independent-samples *t*-test) or ASA grade (2.2 (SD 0.5) vs 2.1 (SD 0.4); p = 0.378, Mann-Whitney-U-test). The preoperative Hb values were 7.0 mmol/l (SD 0.9) (11.2 g/dl (SD 1.5)) for transfused patients and 8.3 mmol/l (SD 0.9) (13.3 g/dl (SD 1.4)) for non-transfused patients (t-test, p < 0.001). In summary, the groups of transfused and non-transfused patients significantly differed in age, sex, and preoperative Hb. There were no significant differences in BMI or ASA grade (Table I).

To identify independent predictors for blood transfusion in THA patients, a multiple logistic regression analysis was performed. For this purpose, the optimal threshold for interval scaled variables was calculated based on ROC curves and Youden's J statistic. The best thresholds for age and preoperative Hb were 73 years and 7.6 mmol/l (12.2 g/dl), respectively (Figure 1). In a first step, single logistic regression analyses were performed to evaluate the influence of single predictors on the probability of transfusion. The results indicate that age ≥ 73 years and a preoperative Hb < 7.6 mmol/l (12.2 g/dl), as well as female sex, significantly increase the odds of blood transfusion (Table II). In a second step, all potential predictors were investigated simultaneously in a multiple regression model. The regression analysis was statistically significant (χ^2 (5) = 60.6; p < 0.001, chi-squared test), and finally identified three independent predictors associated with postoperative blood transfusion. In the overall regression model, sex was not a significant independent risk factor. However, BMI could be identified as an additional independent predicting variable. The model explained 19.4% (Nagelkerkes R^2) of the variance. The results indicate that an age of 73 years or older, a BMI of 35.4 kg/m^2 or higher, and a preoperative Hb less than

Table III. Logistic regression for independent predictors of blood transfusion for patients with total hip arthroplasty.

Variable	β	SE β	Wald's χ^2	df	p-value*	OR	95% CI
Constant predictor	-5.19	1.12	21.50	1	< 0.001	0.006	N/A
Age, yrs†	1.31	0.42	9.88	1	0.002	3.69	1.64 to 8.33
BMI, kg/m²†	1.40	0.52	7.16	1	0.007	4.06	1.46 to 11.33
ASA grade	-0.18	0.42	0.19	1	0.663	0.83	0.36 to 1.90
Sex	-0.40	0.47	0.73	1	0.393	0.67	0.24 to 1.69
Preoperative Hb†	2.36	0.45	27.99	1	< 0.001	10.60	4.42 to 25.43
Test							
Overall model evaluation: Omnibus test			60.63	5	< 0.001		
Goodness-of-fit test: Hosmer-Lemeshow test			3.33	8	0.912		

*Wald test.
†Dichotomous variable based on Youden's J threshold value; Regression with "Enter"-method. Nagelkerkes $R^2 = 0.194$.
ASA, American Society of Anesthesiologists; CI, confidence interval; df, degrees of freedom; Hb, hemoglobin; OR, odds ratio; SE, standard error.

7.6 mmol/l (12.2 g/dl) significantly increases the odds of blood transfusion after THA (Table III).

Discussion

This study aimed to investigate the timing of postoperative transfusion in primary THA and whether it is predictable based on simple, preoperative, patient-specific parameters. The body of literature has consistently shown that THAs are associated with considerable blood loss.[10,24,25] Due to demographic changes and the predicted increase in THA procedures, it can be assumed that demand for blood transfusion will also increase.[26] In this regard, it is important to note that the relative frequency of transfusions in primary THA has decreased in recent years.[20] In addition to blood-sparing measures, the introduction of new drugs (TXA) and stricter indication triggers have also contributed to a decrease in the relative risk of transfusion. Jeschke et al[20] showed a decrease in transfusion frequency between 2011 and 2017 by 52.8% in primary THA. In this study cohort, the transfusion rate was even lower, with an overall transfusion rate of 1.2%. Therefore, the question should be raised if we can predict who receives transfusions after THA and, moreover, if need-based ordering of packed red blood cells is possible and safe for patients.

There is little evidence in the literature for cutoff parameters and predictors of a blood transfusion,[27–29] and to our knowledge no evidence for the timing of transfusion. As a result, more packed red blood cells were stored in blood banks than necessary. This study identified two independent predictors associated with blood transfusion after THA, which were Hb < 7.6, age ≥ 73 years, and a BMI ≥ 35.4 kg/m². Furthermore, female sex was associated with a relevant increase in the risk of transfusion (OR 3.4; 95% CI 1.4 to 8.3), although it was not an independent predictor in the multiple logistic regression model. Examining multiple variables can affect the significance of individual predictors, rendering non-significant variables significant when analyzed in an overall statistical model. In order to obtain a more comprehensive understanding of interactions, it is essential that individual variables are not only examined in independence but also analyzed in a comprehensive multiple regression model. Interestingly, transfusions were shown to not be required on the day of surgery and within 24 hours after surgery. This results in a safe time window, where physicians can react to possible postoperative anaemia.

Overall, this cohort describes one of the largest consecutive monocentric retrospective data analyses with respect to blood transfusions, its predictability, and timing for transfusion. Limitations for this study are the retrospective study design and the absence of a multicentric study cohort. While other influencing factors such as terminal kidney disease or time of surgery were not assessed, the calculated regression model was statistically significant and provided clinically useful information. In conclusion, we demonstrated that the possibility of transfusion after THA is predictable based on preoperatively available parameters, especially preoperative Hb and patient age. While the overall probability of transfusion was low (1.2%), the cutoffs identified in this study can help clinicians to assess the risk of blood transfusion in individual patients. Thus, from the authors' point of view, a need-based ordering of packed red blood cells is possible while maintaining patient safety. This adds useful information to determine which patients are suitable for outpatient THA.

References

1. **Rosencher N**, **Kerkkamp HEM**, **Macheras G**, **et al**. Orthopedic Surgery Transfusion Hemoglobin European Overview (OSTHEO) study: blood management in elective knee and hip arthroplasty in Europe. *Transfusion*. 2003;43(4):459–469.
2. **Carling MS**, **Jeppsson A**, **Eriksson BI**, **Brisby H**. Transfusions and blood loss in total hip and knee arthroplasty: a prospective observational study. *J Orthop Surg Res*. 2015;10:48.
3. **Spiess BD**. Transfusion of blood products affects outcome in cardiac surgery. *Semin Cardiothorac Vasc Anesth*. 2004;8(4):267–281.
4. **Rawn J**. The silent risks of blood transfusion. *Curr Opin Anaesthesiol*. 2008;21(5):664–668.
5. **Frisch NB**, **Wessell NM**, **Charters MA**, **Yu S**, **Jeffries JJ**, **Silverton CD**. Predictors and complications of blood transfusion in total hip and knee arthroplasty. *J Arthroplasty*. 2014;29(9 Suppl):189–192.
6. **Koch CG**, **Li L**, **Sun Z**, **et al**. Hospital-acquired anemia: prevalence, outcomes, and healthcare implications. *J Hosp Med*. 2013;8(9):506–512.

7. **Musallam KM**, **Tamim HM**, **Richards T**, **et al**. Preoperative anaemia and postoperative outcomes in non-cardiac surgery: a retrospective cohort study. *Lancet*. 2011;378(9800):1396–1407.
8. **Farrow L**, **Brasnic L**, **Martin C**, **et al**. A nationwide study of blood transfusion in hip fracture patients : linked analysis from the Scottish Hip Fracture Audit and the Scottish National Blood Transfusion Service. *Bone Joint J*. 2022;104-B(11):1266–1272.
9. **Wei W**, **Wei B**. Comparison of topical and intravenous tranexamic acid on blood loss and transfusion rates in total hip arthroplasty. *J Arthroplasty*. 2014;29(11):2113–2116.
10. **Meißner N**, **Halder AM**, **Schrednitzki D**. Cemented and hybrid total hip arthroplasty lead to lower blood loss in primary total hip arthroplasty: a retrospective study. *Arch Orthop Trauma Surg*. 2023;143(10):6447–6451.
11. **Browne JA**, **Adib F**, **Brown TE**, **Novicoff WM**. Transfusion rates are increasing following total hip arthroplasty: risk factors and outcomes. *J Arthroplasty*. 2013;28(8 Suppl):34–37.
12. **Komnos GA**, **Manrique J**, **Foltz C**, **Klement MR**, **Restrepo C**, **Parvizi J**. Transfusion rates in total hip arthroplasty are lower in patients with direct anterior approach. *Arch Bone Jt Surg*. 2021;9(6):659–664.
13. **Bedard NA**, **Pugely AJ**, **Lux NR**, **Liu SS**, **Gao Y**, **Callaghan JJ**. Recent trends in blood utilization after primary hip and knee arthroplasty. *J Arthroplasty*. 2017;32(3):724–727.
14. **Meybohm P**, **Herrmann E**, **Steinbicker AU**, **et al**. Patient blood management is associated with a substantial reduction of red blood cell utilization and safe for patient's outcome: a prospective, multicenter cohort study with a noninferiority design. *Ann Surg*. 2016;264(2):203–211.
15. **Magill P**, **Hill JC**, **Bryce L**, **et al**. Oral tranexamic acid for an additional 24 hours postoperatively versus a single preoperative intravenous dose for reducing blood loss in total hip arthroplasty: results of a randomized controlled trial (TRAC-24). *Bone Joint J*. 2021;103-B(7):1197–1205.
16. **Lee QJ**, **Chang WYE**, **Wong YC**. Blood-sparing efficacy of oral tranexamic acid in primary total hip arthroplasty. *J Arthroplasty*. 2017;32(1):139–142.
17. **Yue C**, **Kang P**, **Yang P**, **Xie J**, **Pei F**. Topical application of tranexamic acid in primary total hip arthroplasty: a randomized double-blind controlled trial. *J Arthroplasty*. 2014;29(12):2452–2456.
18. **Hsu CH**, **Lin PC**, **Kuo FC**, **Wang JW**. A regime of two intravenous injections of tranexamic acid reduces blood loss in minimally invasive total hip arthroplasty: A prospective randomised double-blind study. *Bone Joint J*. 2015;97-B(7):905–910.
19. **Zhao H**, **Xiang M**, **Xia Y**, **Shi X**, **Pei FX**, **Kang P**. Efficacy of oral tranexamic acid on blood loss in primary total hip arthroplasty using a direct anterior approach: a prospective randomized controlled trial. *Int Orthop*. 2018;42(11):2535–2542.
20. **Jeschke E**, **Citak M**, **Halder AM**, **et al**. Blood transfusion and venous thromboembolism trends and risk factors in primary and aseptic revision total hip and knee arthroplasties: A nationwide investigation of 736,061 cases. *Orthop Traumatol Surg Res*. 2022;108(1):102987.
21. **Naathan H**, **Ilo K**, **Berber R**, **Matar HE**, **Bloch B**. Are postoperative blood tests always required after lower limb arthroplasty? *Bone Jt Open*. 2023;4(5):357–362.
22. **Saklad M**. Grading of patients for surgical procedures. *Anesthesiol*. 1941;2(5):281–284.
23. S3-Leitlinie Prophylaxe der venösen Thromboembolie (VTE). Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachgesellschaften. 2015. https://register.awmf.org/assets/guidelines/003-001l_S3_VTE-Prophylaxe_2015-10-abgelaufen_01.pdf (date last accessed 25 June 2024). Published in German.
24. **Hochreiter J**, **Hejkrlik W**, **Emmanuel K**, **Hitzl W**, **Ortmaier R**. Blood loss and transfusion rate in short stem hip arthroplasty: a comparative study. *Int Orthop*. 2017;41(7):1347–1353.
25. **Carling MS**, **Jeppsson A**, **Eriksson BI**, **Brisby H**. Transfusions and blood loss in total hip and knee arthroplasty: a prospective observational study. *J Orthop Surg Res*. 2015;10(1):48.
26. **Pilz V**, **Hanstein T**, **Skripitz R**. Projections of primary hip arthroplasty in Germany until 2040. *Acta Orthop*. 2018;89(3):308–313.
27. **Yeh JZY**, **Chen JY**, **Bin Abd Razak HR**, **et al**. Preoperative haemoglobin cut-off values for the prediction of post-operative transfusion in total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(10):3293–3298.
28. **Maempel JF**, **Wickramasinghe NR**, **Clement ND**, **Brenkel IJ**, **Walmsley PJ**. The pre-operative levels of haemoglobin in the blood can be used to predict the risk of allogenic blood transfusion after total knee arthroplasty. *Bone Joint J*. 2016;98-B(4):490–497.
29. **Nuñez JH**, **Mora L**, **Carbonell C**, **et al**. Is routine blood typing and screening necessary before primary total hip or knee arthroplasty in the 21st century? *Transfusion*. 2022;62(2):316–323.

Author information

N. Meißner, MD, Orthopedic Surgeon
A. M. Halder, MD, Professor, Orthopedic Surgeon
D. Schrednitzki, MD, Orthopedic Surgeon
Department of Orthopaedic Surgery, Sana Hospital Sommerfeld, Kremmen, Germany.

A. Strahl, MD, Orthopedic Surgeon
T. Rolvien, MD, PhD, Orthopedic Surgeon
Department of Trauma and Orthopaedic Surgery, Division of Orthopaedics, University Medical Center Hamburg-Eppendorf, Hamburg, Germany.

Author contributions

N. Meißner: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing.
A. Strahl: Formal analysis, Investigation, Methodology, Visualization, Writing – review & editing.
T. Rolvien: Investigation, Supervision, Writing – review & editing.
A. M. Halder: Investigation, Supervision, Writing – review & editing.
D. Schrednitzki: Conceptualization, Data curation, Project administration, Writing – review & editing.

Funding statement

The author(s) received no financial or material support for the research, authorship, and/or publication of this article.

ICMJE COI statement

A. Halder and D. Schrednitzki disclose consulting fees and payment for presentations from Zimmer Biomet. A. Halder is vice-president of the European Knee Society, all of which is unrelated to this paper.

Data sharing

The datasets generated and analyzed in the current study are not publicly available due to data protection regulations. Access to data is limited to the researchers who have obtained permission for data processing. Further inquiries can be made to the corresponding author.

Ethical review statement

The study protocol was reviewed and approved by the local ethics committee prior to commencement (IRB ID: 2023-5-BO-ff).

Open access funding

The open access fee for this article was funded by Sana Hospitals Sommerfeld, Kremmen, Germany.