



Original Research

A Comparison of the Caprini Score With an Institutional Risk Assessment Tool for Prediction of Venous Thromboembolism After Total Joint Arthroplasty at an Urban Tertiary Care Health Safety Net Hospital

Brian Gibbs, MD ^a, Samuel Paek, BS ^b, Noelle Wojciechowski, BA ^c, Sean Wrenn, BS ^c, David M. Freccero, MD ^a, Ayesha Abdeen, MD ^{a,*}

^a Department of Orthopaedic Surgery, Boston Medical Center, Boston, MA, USA

^b Geisinger Commonwealth School of Medicine, Scranton, PA, USA

^c Boston University School of Medicine, Boston, MA, USA

ARTICLE INFO

Article history:

Received 2 June 2023

Accepted 17 July 2023

Available online xxx

Keywords:

Venous thromboembolism
Deep vein thrombosis
Pulmonary embolism
Total knee arthroplasty
Total hip arthroplasty
Risk prediction tool

ABSTRACT

Background: Patients undergoing total joint arthroplasty (TJA) are at increased risk for venous thromboembolism (VTE). Prediction tools such as the Caprini Risk Assessment Model (RAM) have been developed to identify patients at higher risk. However, studies have reported heterogeneous results when assessing its efficacy for TJA. Patients treated in an urban health safety net hospital have increased medical complexity, advanced degenerative joint disease, and severe disability prior to TJA increasing the risk of VTE. We hypothesize that use of a tool designed to account for these conditions—the Boston Medical Center (BMC) VTE score—will more accurately predict VTE in this patient population.

Methods: A retrospective case-control study was performed including subjects 18 years of age and older who underwent primary or revision TJA in an urban academic health safety net hospital. Patients with hemiarthroplasties, simultaneous bilateral TJA, and TJA after acute trauma were excluded. A total of 80 subjects were included: 40 who developed VTE after TJA (VTE+) and 40 who did not develop VTE (controls). Subjects were matched by age, gender, and surgical procedure.

Results: There was a statistically significant difference between the mean BMC VTE score for VTE+ and controls (4.40 and 3.13, respectively, $P = .036$). Conversely, there was no statistical difference between the mean Caprini scores for VTE+ and controls (9.50 and 9.35, respectively, $P = .797$).

Conclusions: In a health safety-net patient population, an institutional RAM—the BMC VTE score—was found to be more predictive of VTE than the modified Caprini RAM following TJA. The BMC-VTE score should be externally validated to confirm its reliability in VTE prediction in similar patient populations.

Published by Elsevier Inc. on behalf of The American Association of Hip and Knee Surgeons. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

More than 1 million total hip arthroplasty (THA) and total knee arthroplasty (TKA) are performed in the United States annually. By 2030, these numbers are expected to increase by 174% to 572,000 annually for THA and by 673% to 3.48 million for TKA [1,2]. Potentially life-threatening venous thromboembolism (VTE) is an inherent risk of total joint arthroplasty (TJA) of the hip and knee and occurs with an incidence of 1.4% after primary TKR and 0.6%

after primary THA [3]. VTE mortality rates have been reported to be 0.2% and 0.1% for primary THA and primary TKA, respectively, and are the most frequent cause for emergency readmissions despite appropriate anticoagulation [3–11]. Fatal pulmonary embolism after TKA has been reported to occur in 0.04% of patients and in 0.08% of THA patients [9,12]. Without appropriate chemoprophylaxis, the incidence of VTE has been reported at approximately 40% to 60% following major orthopaedic surgeries TKA and THA. It has therefore become standard of care to use prophylactic anticoagulation for all patients undergoing TJA of the hip or knee according to national guidelines published by the American Academy of Orthopedic Surgeons and the American College of Chest Physicians [7,13]. However, these guidelines include a variety of recommended anticoagulants ranging in potency from low-dose aspirin

* Corresponding author. Department of Orthopaedic Surgery, Boston Medical Center, 85 E. Concord St, 4th Floor, Boston, MA 02118, USA. Tel.: +1 617 638 5633.
E-mail address: Ayesha.Abdeen@bmc.org

to more-potent anticoagulants including direct oral anticoagulants, warfarin, and low-molecular-weight heparin. The risk of VTE must be balanced with the risk of bleeding, the latter of which may also increase morbidity and mortality as well as threaten the function of the joint arthroplasty such as in the case of joint hematoma/infected hematoma. There are clear risk factors for VTE including hypercoagulable states (Factor V Leiden and proteins C and S deficiency), active malignancy, family and personal history of VTE, obesity, and so on. However, it remains unclear whether risk stratification prior to TJA is necessary in order to select patients that may require more-potent or higher doses of anticoagulation; furthermore, if risk stratification is indeed indicated, what is the optimal method of risk stratification remains controversial as well.

A number of validated risk calculators exist to stratify individual patient risk and are critical in assisting clinicians when selecting a prophylactic regimen [14–18]. The 9th edition of the American College of Chest Physicians guidelines for VTE risk stratification recommends using the 2005 Caprini risk assessment model (RAM); however, risk quantification and prophylaxis recommendations for this scoring system were intended for a general surgical population and not orthopaedic patients [13]. The 2005 Caprini RAM assigned all patients undergoing TJA a score of 5, categorizing them as “high risk” by default. This risk calculator was updated in 2013 with new guidelines that account for relevant risk factors associated with VTE events in the current literature such as morbid obesity (defined as body mass index >40), smoking, active malignancy, chemotherapy, diabetes requiring insulin, blood transfusions, surgery length of >2

hours, and bilateral staged joint arthroplasty (Fig. 1) [19]. The 2013 Caprini RAM score has been validated for preoperative patients with hip fractures and postoperatively for foot and ankle procedures [20,21]; however, studies by Bateman et al [14] and Krauss et al [22,23] have reported heterogeneous results when assessing its efficacy for patients undergoing TJA.

Patients treated in an urban health safety net hospital have increased risk of complication following TJA related to increased medical complexity, severe disability, and advanced stages of degenerative joint disease at the time of presentation for TJA, all of which may increase risk of VTE in this patient population [24,25].

In the current study, we introduce a risk stratification tool – the Boston Medical Center (BMC) VTE score – designed to account for the potential increased risk in a health safety population of patients undergoing TJA (Fig. 2). This study seeks to compare the efficacy and accuracy of the BMC VTE score in predicting VTE compared to the 2013 Caprini RAM score. We aim to understand whether the Caprini RAM score, a risk calculator for a general surgery population, is appropriate for a vulnerable patient population with many adverse social determinants of health being treated at a health safety net hospital. The significance of this study would be to more accurately screen and identify patients from this unique group with a high risk of VTE and increase patient safety outcomes by decreasing the incidence of postoperative bleeding and VTE following TJA. Our hypothesis was that the BMC score would more accurately predict the risk of VTE in patients undergoing TJA at a health safety net hospital.

| 1 Point | 2 Points |
|--|---|
| Age 41-60 | Age 61-74 years |
| Minor surgery (less than 45 minutes) is planned | Current or past malignancies (excluding skin cancer, but not melanoma) |
| Past major surgery (more than 45 minutes) within the last month | Planned major surgery lasting longer than 45min |
| Visible varicose veins | Non-removable plaster cast or mold that has kept you from moving your leg within the last month |
| History of inflammatory bowel disease | Tube in blood vessel in neck or chest that delivers blood or medicine directly to heart within the last month (Central line, PICC line) |
| Swollen legs (current) | Confined to a bed for 72 hours or more |
| Overweight or obese (BMI > 25) | 3 Points |
| Heart attack | Age 75 or over |
| Congestive heart failure | History of blood clots (DVT or PE0) |
| Serious infection (for example, pneumonia) | Family history of blood clots |
| Lung disease (for example, emphysema or COPD) | Personal or family history of positive blood test indicating an increased risk of blood clotting |
| On bed rest or restricted mobility, including a removable leg brace for <72 hrs | 5 Points |
| Other risk factors (1 point each)* | Elective hip or knee joint replacement surgery |
| *Additional risk factors not tested in the validation studies but shown in the literature to be associated with thrombosis: BMI > 40, smoking, diabetes requiring insulin, chemotherapy, blood transfusion, operative time >2hrs | |
| For Women ONLY – 1 point | Broken hip, pelvis, or leg |
| Current use of birth control or hormone replacement therapy | Serious trauma |
| Pregnant or had a baby within the last month | Spinal cord injury resulting in paralysis |
| History of unexplained stillborn infant, recurrent spontaneous abortion (more than 3), premature birth with toxemia or growth restricted infant | Experienced a stroke |
| Total Risk Factor Score = | |
| Caprini Score < 10 – Low Risk | |
| Caprini Score ≥ 10 – High Risk | |

Figure 1. Caprini risk assessment model (version 2013) [19].

| 5 Points Each | 2 Points Each |
|---|---|
| Bilateral Total Hip/Total Knee Arthroplasty | Total hip/knee arthroplasty |
| Staged Bilateral Hip/Knee Arthroplasty (Within 14 Days) | Total hip/knee revision |
| Periacetabular Osteotomy | High tibial osteotomy |
| Hip Fracture | Femoral osteotomy |
| Girdlestone/Hip Resection | Oral contraceptive/hormone replacement therapy |
| Knee Resection | BMI > 35 |
| History of Pulmonary Embolism | To Be Completed by Attending Physician Postoperatively |
| History of DVT (phlebitis requiring Coumadin) | Non-weight bearing (5pts) |
| Cancer within the past year/currently being treated | Touch down weight bearing (2pts) |
| BMI > 40 | Complex multi-ligament reconstruction (2 pts) |
| Aspirin allergy | Complex hip/knee revision (5pts) |
| Total Risk Factor Score = [] | |
| BMC VTE Score < 5 – Low Risk | |
| BMC VTE Score ≥ 5 – High Risk | |

Figure 2. BMC VTE score calculation. BMC, Boston Medical Center; VTE, venous thromboembolism.

Material and methods

After obtaining approval from an institutional review board, a single center, retrospective case-control study was performed in an urban, academic tertiary care health safety net hospital. Inclusion criteria were subjects 18 years of age and older undergoing primary THA, primary TKA, revision THA, or revision TKA. Subjects with hemiarthroplasties, simultaneous bilateral TJA, and TJA after acute trauma were excluded. The study period was from November 1, 2014, to April 30, 2022. The patients were identified by creating a report from the electronic medical record of all arthroplasty patients during this time period. A retrospective chart review was performed to record additional patient demographics and perioperative information. Caprini RAM scores were calculated preoperatively in the preprocedure clinic by an MD (Doctor of Medicine) or NP (Nurse Practitioner). The Caprini RAM scores were calculated prospectively as was an institutional requirement in the electronic medical record for all inpatients in this hospital. The BMC VTE scores were calculated in the preoperative holding area by an MD, NP, or PA (Physician Assistant). Neither score was used to determine postoperative VTE regimen as this was done in accordance with the standardized institutional prophylactic protocol at the time of surgery (see below). Using 70% effect size, 95% confidence interval, and a power calculation of 80%, 80 subjects were included: 40 who developed VTE within 3 months after TJA (VTE+) and 40 who did not develop VTE (controls). Control cases were matched by age, gender, and operation (Table 1). Cases were matched with controls that underwent surgery in the same time frame to ensure the standardized VTE prophylaxis was consistent.

VTE prophylaxis

During the course of the study time frame, the patients received what was considered to be the standardized institutional VTE prophylaxis protocol for TJA patients at the time. From 2014 to 2018, this was enoxaparin 40 mg daily for 2 weeks followed by aspirin 325 mg PO BID for 4 weeks. From 2018 to 2021, this was aspirin 325 mg BID for 4 weeks. From 2021 to 2022 this was aspirin

Table 1

Demographic and surgical characteristics for VTE+ and no VTE cohorts. VTE + cases were matched to controls by age, gender, and operation performed.

| Characteristic | Number |
|-----------------------------------|--------------------|
| Total arthroplasties ^a | 40 |
| Total knee arthroplasty (TKA) | 19 (47.5%) |
| Total hip arthroplasty (THA) | 16 (40%) |
| Revision TKA | 1 (2.5%) |
| Revision THA) | 4 (10%) |
| Age ^b | 62.8 ± 9.2 (44-83) |
| Sex ^a | |
| Male | 14 (35%) |
| Female | 26 (65%) |

^a These values are presented as the number of patients, with the percentage in parentheses.

^b These values are presented as the mean ± standard deviation (range).

81 BID for 4 weeks. The patients on baseline anticoagulation for other diagnoses resumed their usual anticoagulant postoperatively. From 2019 to 2022, 3 patients were enrolled in the PEPPER trial (NCT 02810704) and were randomized to 1 of 3 agents including aspirin 81 mg, warfarin, or rivaroxaban 10 mg for 30 days as per protocol. Neither the Caprini RAM or BMC VTE scores were used for determination of anticoagulant regimen.

Statistical analysis

The primary objective was to compare the effectiveness of the BMC score to predict VTE after TJA compared to the Caprini RAM. A matched paired t-test and Wilcoxon rank sum test were used to compare the differences in mean Caprini RAMs and mean BMC VTE scores for VTE+ and controls, respectively. Differences in patient demographics, comorbidities, and VTE risk scores were summarized based on presence of VTE using univariate analysis. Crude conditional logistic regression models were performed to determine whether the demographic, comorbidity and VTE predictor score variables were associated with developing VTE (Table 1). Confounding and interaction for BMC score was assessed by adjusted logistic regression. Odds ratios (ORs) for developing VTE were calculated for patients that were classified as Caprini RAM high-risk (score ≥10) and BMC VTE score high-risk (score ≥5) compared to those with low-risk scores. Receiver operating characteristic (ROC) curves were generated for the BMC VTE score and Caprini score (Appendix). All statistical analysis was performed using SAS Studio.

Results

Descriptive data

Table 2 provides baseline demographic information based on VTE status. There were no significant differences in patient demographics between the VTE+ and control cohorts. Table 1 shows the breakdown of age, gender, and operation for each matched cohort. There was a statistically significant difference between mean BMC VTE score for VTE+ and controls (4.40 and 3.13, respectively, $P = .036$). Conversely, there was no statistical difference between the mean Caprini scores for VTE+ and controls (9.50 and 9.35, respectively, $P = .797$) (Table 2). Comparing VTE to control patients, there was a significant difference between patients classified as high and low risk for the BMC VTE score ($P = .039$) that was not present with high- and low-risk Caprini scores ($P = .307$) (Table 3). The positive predictive value for the BMC VTE score was 72.2% and the negative predictive value was 56.5%. The positive predictive value for the Caprini score was 51.2% and the negative

Table 2
Comparison of patient demographics between VTE+ and control cohorts.

| | +VTE (n = 40) | No VTE (n = 40) | P-value |
|--|---------------|-----------------|-------------|
| Race ^a | | | .613 |
| White | 15 | 20 | |
| African American | 18 | 14 | |
| Other | 7 | 6 | |
| Ethnicity ^b | | | .754 |
| Hispanic | 36 | 34 | |
| Not Hispanic | 4 | 6 | |
| ASA class ^b | | | .523 |
| ASA 1 or ASA 2 | 16 | 20 | |
| ASA 3 | 24 | 20 | |
| Tobacco use ^a | | | .236 |
| Never | 26 | 19 | |
| Quit | 9 | 12 | |
| Active | 5 | 9 | |
| Active cancer ^b | | | - |
| Yes | 4 | 0 | |
| No | 36 | 40 | |
| Family history of VTE ^b | | | - |
| Yes | 0 | 5 | |
| No | 40 | 35 | |
| Personal VTE history ^b | | | .219 |
| Yes | 5 | 1 | |
| No | 35 | 39 | |
| Average time to VTE (d) | 26 | n/a | n/a |
| Average length of stay (d) ^c | 5.9 | 3.0 | <.001 |
| Average TXA doses given ^c | 1.8 | 1.7 | .444 |
| Patients on prior anticoagulation ^{b,d} | 8 | 2 | .109 |
| BMI ^e | 32.76 | 31.92 | .489 |
| Caprini Score ^b | | | .307 |
| Low risk (<10) | 20 | 21 | |
| High risk (≥10) | 20 | 19 | |
| BMC score ^b | | | .039 |
| Low risk (<5) | 27 | 35 | |
| High risk (≥5) | 13 | 5 | |

Comparison done via crude conditional logistic regression.

Bold indicates significant P-values with values <.05.

ASA, American Society of Anesthesiologists; BMC, Boston Medical Center; BMI, body mass index; VTE, venous thromboembolism.

^a Comparison done via chi-squared test.

^b Comparison done via McNemar's test.

^c Comparison done via Wilcoxon Rank Sum test.

^d Reasons for preoperative anticoagulation included prior VTE, atrial fibrillation, and aortic stenosis.

^e Comparison done via paired t-test.

predictive value was 51.2%. ORs for increased risk of VTE given BMC VTE score ≥ 5 or Caprini RAM ≥ 10 were found to be insignificant (Table 4). Generated ROC curves demonstrate that the BMC score had a poor predictability, with an area under the ROC curve of 0.61 compared to 0.52 for the Caprini RAM, which was not statistically significant (Appendix).

Discussion

VTE remains a potentially severe complication following total joint arthroplasty, with an estimated incidence between 0.6% and 1.5% [26]. Mortality rates for patients who develop VTE after

Table 3
Comparison of mean Caprini and BMC scores.

| | + VTE | No VTE | P value |
|----------------------------|-----------------|-----------------|-------------|
| Caprini Score ^a | 9.50 \pm 2.18 | 9.35 \pm 2.24 | .797 |
| BMC Score ^b | 4.40 \pm 3.24 | 3.13 \pm 1.86 | .036 |

Bold indicates significant P-values with values <.05.

BMC, Boston Medical Center.

^a Matched t-test.

^b Wilcoxon rank sum test.

primary TKA and THA are reported to be 0.1% and 0.2%, respectively [3]. Mortality from VTE after revision procedures is slightly higher at 0.5% and 0.7%, respectively [27]. Careful consideration of each individual patients' risk of VTE should be taken in order to prescribe appropriate chemoprophylaxis, while balancing the risk of postoperative bleeding. Given the heterogeneous reports of the Caprini score in predicting VTE after TJA, there remains a need for risk calculators to stratify VTE risk more accurately for those undergoing TJA of the hip and knee. The demographics at an urban, safety net hospital are different than the population as a whole, with patients often having increased medical comorbidities and a higher risk for VTE after surgery [28,29]. We believe our institution-specific risk assessment tool, the BMC VTE score, to be better at delineating between those high- and low-risk patients.

The results of our study reflect findings similar to those by Bateman et al [14] whereby the Caprini score did not provide clinically useful risk stratification for TJA patients. Our findings were from a single institution, as were previous studies, suggesting that patient demographics may play a role in risk calculator efficacy. We matched patients by age, gender, and procedure in an effort to reduce potential confounding variables and found that the 2 cohorts were comparable regarding demographics. In response to the critiques by Bateman et al [14], Krauss et al [14] noted deficiencies in how their preoperative scores were reported and how bilateral cases were calculated. We excluded bilateral surgeries from our study and Caprini scores were routinely calculated by anesthesiologists during the preoperative evaluation. Bateman et al [14] argued that in the older version of the Caprini score, all TJA patients were given a score of 5, automatically classifying them as "high risk." Krauss et al [19] modified their classification system in response, saying that a Caprini RAM score of 10 or higher classified patients as "very high risk." In our study, we grouped Caprini RAM scores into low-risk (<10) and high-risk (≥ 10), consistent with recommendations from Krauss et al [14], and still found no significant difference when predicting VTE event.

Parvizi et al [30] introduced the VTEstimator as another tool, available as an iOS application, to help stratify patients into VTE risk categories. This identified a series of significant VTE risk factors including hypercoagulable disorders, chronic obstructive pulmonary disease, malignancy, stroke, and sepsis. Bateman et al report no significant difference in distribution of VTE estimator scores for patients with and without VTE. The VTEstimator, a proprietary tool, was not used at our institution due to limited resources, and thus could not be assessed in this study [30]. However, malignancy, personal history, and family history of VTE events were incorporated into the BMC VTE score to automatically classify patients with these diagnoses as high risk.

The BMC VTE score was created for implementation at a health safety net hospital. It has been shown that health safety net hospitals have a patient population with a relatively high percentage of comorbidities compared to other hospitals [28,29]. Due to the nature of the patient population, a higher proportion of these patients will meet "very-high-risk" criteria when using more standardized risk assessment models such as the Caprini score. Not all of these patients necessarily require more potent chemoprophylaxis after TJA, and this could potentially increase the risk of postoperative bleeding complications in such patients. The BMC VTE score takes into account the unique demographics of our hospital and in doing so was found to be a more reliable predictor of VTE.

A notable discrepancy between the BMC VTE score and the Caprini score is the increased risk when a patient has a history of past VTE or a family history of VTE. Zoller et al [31] demonstrated the importance of this relationship, and it's accounted for in the BMC VTE score by automatically classifying a patient as high risk (5 points). The Caprini score assigns a value of 3 points to a patient

Table 4
Odds ratios for VTE predictor variables.

| Variable | Categories | +VTE (n = 40) | No VTE (n = 40) | OR (95% CI) | P value |
|--------------------------------|------------------------|--------------------|--------------------|-------------------|---------|
| Caprini | Low risk (<10) | 20 | 21 | 1.11 (0.45, 2.73) | .82 |
| | High risk (\geq 10) | 20 | 19 | | |
| BMC VTE | Low risk (<5) | 27 | 35 | 3.0 (0.97, 9.3) | .057 |
| | High risk (\geq 5) | 13 | 5 | | |
| ASA class | ASA 1 or ASA 2 | 16 | 20 | 1.8 (0.6, 5.4) | .29 |
| | ASA 3 | 24 | 20 | | |
| | | | | | |
| Tobacco use | Never | 26 | 20 | ~ | .32 |
| | Quit | 9 | 11 | | |
| | Active | 5 | 9 | | |
| Active cancer | Yes | 4 | 0 | ~ | ~ |
| | No | 36 | 40 | | |
| Family history of VTE | Yes | 0 | 5 | ~ | ~ |
| | No | 40 | 35 | | |
| BMI | ~ | 32.8 (\pm 5.52) | 31.9 (\pm 5.05) | 1.03 (0.95, 1.12) | .47 |
| Personal VTE History | Yes | 5 | 1 | 5.0 (0.58, 42.8) | .14 |
| | No | 35 | 39 | | |
| Patients prior anticoagulation | Yes | 8 | 2 | 7.0 (0.86, 56.9) | .069 |
| | No | 32 | 38 | | |

Comparison done via crude conditional logistic regression.

ASA, American Society of Anesthesiologists; BMC, Boston Medical Center; BMI, body mass index; CI, confidence interval; OR, odds ratio; VTE, venous thromboembolism.

with personal or family history of VTE, which after combining with elective TJA only yields a score of 8 (low risk) [19].

By using matched cohorts, we were able to produce similar demographics between the VTE and control groups, further isolating the significant effect that the BMC score had on predicting VTE. In addition to mean BMC VTE scores being significantly different for VTE patients and control patients, ROC curves generated for both the BMC VTE and Caprini scores demonstrated that the BMC VTE appears to be a better predictor for our patient population. We acknowledge the area under the curve in this study suggests that the BMC VTE score is a poor predictor of VTE, however, when compared to the ROC curve generated for the Caprini score we found it to be superior. In Table 4, we see the increased OR for patients whose BMC VTE score classify them as high risk (OR = 3.0). Although statistically insignificant, compared to the OR for the Caprini score of 1.11, we see that the BMC VTE score trends toward being a better predictor.

One limitation of this study is the retrospective nature and small sample size. Although VTE events are clinically important events, they fortunately occur infrequently (<1% incidence) after TJA and therefore within the 9-year span of the study only 40 VTE events were identified which were then matched to 40 controls [3–5, 8–11]. Consequently, the results did not reach statistical significance for OR calculations, nor did they generate an ROC curve capable of giving a reliable cutoff score. A second limitation is that the standard deviation for the BMC VTE score is large, therefore a large percentage of VTE patients have similar scores to control patients. This could be improved by further increasing our sample size to narrow the standard deviation. Another significant limitation of this study is the heterogenous anticoagulant protocols used throughout the course of the study that reflected the institutional protocol in use at the time of surgery. Neither Caprini-RAM nor the BMC VTE score were used for anticoagulant selection at the time of surgery, rather this was dictated by hospital protocol and in the instance of the 3 patients in the PEPPER trial, the randomization of anticoagulants included in the trial. Furthermore, there was no difference in prophylactic regimen for controls and VTE events. Therefore, while anticoagulant selection certainly may have influenced incidence of VTE, the choice of anticoagulant was independent of both scoring systems and was not biased by the risk calculator tools that were being evaluated in the study.

The study was performed in an urban, tertiary care health safety net hospital where medical and surgical complexity is high and thus these findings may not be applicable to other patient populations.

Conclusions

In an urban, tertiary care health safety net hospital, the institutional BMC VTE score was found to be more strongly correlated with VTE after primary and revision TJA of the hip and knee when compared to the Caprini RAM. Our patient population represents a highly ethnically diverse population with complex comorbid conditions and social disparities. Our findings suggest that such medically and socially complex patients may require alternate VTE predictive tools than the ones typically used. The BMC VTE score will require further validation in a larger sample size such as that achievable in a multicentered study. We recommend future studies to include other health safety net hospitals in the United States in a prospective, multicenter design to determine whether our findings are applicable to other similar institutions.

Conflicts of interest

Freccero has stocks in Romtech; received research support from Depuy and Conformis; and is a member of AAHKS committee member and AAOS committee member. Abdeen has stocks in Brixton biosciences; is a paid consultant for Depuy, Smith and Nephew, Brixton Biosciences, and Teladoc; is a part of editorial board of the Journal of Arthroplasty; and is a member of AAHKS quality committee and AAOS OITE committee. All other authors declare no potential conflicts of interest

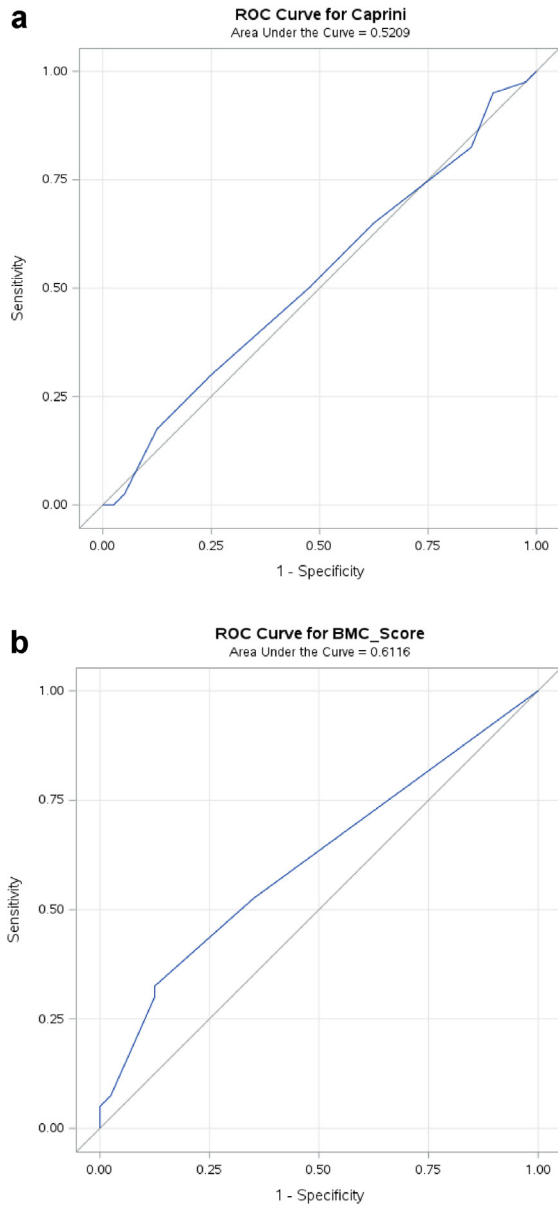
For full disclosure statements refer to <https://doi.org/10.1016/j.artd.2023.101194>.

Acknowledgments

We would like to acknowledge Dr. Eric Smith for his assistance in creating the BMC VTE score and Xiebin Gu for his help with the statistical analyses.

References

- [1] Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. *J Bone Joint Surg Am* 2007;89:780.
- [2] Maradit Kremers H, Larson DR, Crowson CS, et al. Prevalence of total hip and knee replacement in the United States. *J Bone Joint Surg Am* 2015;97:1386.
- [3] Warren JA, Sundaram K, Anis HK, Kamath AF, Higuera CA, Piuze NS. Have venous thromboembolism rates decreased in total hip and knee arthroplasty? *J Arthroplasty* 2020;35:259.
- [4] Bawa H, Weick JW, Dirschl DR, Luu HH. Trends in deep vein thrombosis prophylaxis and deep vein thrombosis rates after total hip and knee arthroplasty. *J Am Acad Orthop Surg* 2018;26:698.
- [5] Johanson NA, Lachiewicz PF, Lieberman JR, et al. Prevention of symptomatic pulmonary embolism in patients undergoing total hip or knee arthroplasty. *J Am Acad Orthop Surg* 2009;17:183.
- [6] Lieberman JR, Bell JA. Venous thromboembolic prophylaxis after total hip and knee arthroplasty. *J Bone Joint Surg Am* 2021;103:1556.
- [7] Mont MA, Jacobs JJ. AAOS clinical practice guideline: preventing venous thromboembolic disease in patients undergoing elective hip and knee arthroplasty. *J Am Acad Orthop Surg* 2011;19:777.
- [8] Zhang H, Mao P, Wang C, et al. Incidence and risk factors of deep vein thrombosis (DVT) after total hip or knee arthroplasty: a retrospective study with routinely applied venography. *Blood Coagul Fibrinolysis* 2017;28:126.
- [9] Bayley E, Brown S, Bhamber NS, Howard PW. Fatal pulmonary embolism following elective total hip arthroplasty: a 12-year study. *Bone Joint Lett J* 2016;98-B:585.
- [10] Cote MP, Chen A, Jiang Y, Cheng V, Lieberman JR. Persistent pulmonary embolism rates following total knee arthroplasty even with prophylactic anticoagulants. *J Arthroplasty* 2017;32:3833.
- [11] Lieberman JR, Cheng V, Cote MP. Pulmonary embolism rates following total hip arthroplasty with prophylactic anticoagulation: some pulmonary emboli cannot be avoided. *J Arthroplasty* 2017;32:980.
- [12] Quah C, Bayley E, Bhamber N, Howard P. Fatal pulmonary embolism following elective total knee replacement using aspirin in multi-modal prophylaxis - a 12-year study. *Knee* 2017;24:1187.
- [13] Stevens SM, Woller SC, Kreuziger LB, et al. Antithrombotic therapy for VTE disease: second update of the CHEST guideline and expert panel report. *Chest* 2021;160:e545.
- [14] Bateman DK, Dow RW, Brzezinski A, Bar-Eli HY, Kayiaros ST. Correlation of the Caprini score and venous thromboembolism incidence following primary total joint arthroplasty-results of a single-institution protocol. *J Arthroplasty* 2017;32:3735.
- [15] Krauss ES, Cronin M, Dengler N, Simonson BG, Enker P, Segal A. Lessons learned: using the Caprini risk assessment model to provide safe and efficacious thromboprophylaxis following hip and knee arthroplasty. *Clin Appl Thromb Hemost* 2020;26:1076029620961450.
- [16] Merrill RK, Ibrahim JM, Machi AS, Raphael JS. Analysis and review of automated risk calculators used to predict postoperative complications after orthopedic surgery. *Curr Rev Musculoskelet Med* 2020;13:298.
- [17] Deng W, Huo L, Yuan Q, Huang D, Li Q, Tian W. Risk factors for venous thromboembolism in patients with diabetes undergoing joint arthroplasty. *BMC Musculoskelet Disord* 2021;22:608.
- [18] Garfinkel JH, Gladnick BP, Roland N, Romness DW. Increased incidence of bleeding and wound complications with factor-Xa inhibitors after total joint arthroplasty. *J Arthroplasty* 2018;33:533.
- [19] Cronin M, Dengler N, Krauss ES, et al. Completion of the updated Caprini risk assessment model (2013 version). *Clin Appl Thromb Hemost* 2019;25:1076029619838052.
- [20] Luksameearunothai K, Sa-Ngasoongsong P, Kulachote N, et al. Usefulness of clinical predictors for preoperative screening of deep vein thrombosis in hip fractures. *BMC Musculoskelet Disord* 2017;18:208.
- [21] Saragas NP, Ferrao PN, Saragas E, Jacobson BF. The impact of risk assessment on the implementation of venous thromboembolism prophylaxis in foot and ankle surgery. *Foot Ankle Surg* 2014;20:85.
- [22] Krauss ES, Segal A, Dengler N, Cronin M, Pettigrew J, Simonson BG. Utilization of the Caprini score for risk stratification of the arthroplasty patient in the prevention of postoperative venous thrombosis. *Semin Thromb Hemost* 2022;48:407.
- [23] Krauss ES, Segal A, Cronin M, et al. Implementation and validation of the 2013 Caprini score for risk stratification of arthroplasty patients in the prevention of venous thrombosis. *Clin Appl Thromb Hemost* 2019;25:1076029619838066.
- [24] Arlas N, Jergesen H. Hip and knee replacement in safety-net hospitals: recognizing the challenges. *J Health Care Poor Underserved* 2016;27:238.
- [25] Jergesen HE, Yi PH. Early complications in hip and knee arthroplasties in a safety net hospital vs a university center. *J Arthroplasty* 2016;31:754.
- [26] Santana DC, Emara AK, Orr MN, et al. An update on venous thromboembolism rates and prophylaxis in hip and knee arthroplasty in 2020. *Medicina (Kaunas)* 2020;56:416.
- [27] Warren JA, Sundaram K, Kamath AF, et al. Venous thromboembolism rates did not decrease in lower extremity revision total joint arthroplasty from 2008 to 2016. *J Arthroplasty* 2019;34:2774.
- [28] La M, Tangel V, Gupta S, Tedore T, White RS. Hospital safety net burden is associated with increased inpatient mortality and postoperative morbidity after total hip arthroplasty: a retrospective multistate review, 2007-2014. *Reg Anesth Pain Med* 2020;45:e2.
- [29] Browne JA, Novicoff WM, D'Apuzzo MR. Medicaid payer status is associated with in-hospital morbidity and resource utilization following primary total joint arthroplasty. *J Bone Joint Surg Am* 2014;96:e180.
- [30] Parvizi J, Huang R, Rezapoor M, Bagheri B, Maltenfort MG. Individualized risk model for venous thromboembolism after total joint arthroplasty. *J Arthroplasty* 2016;31(9 Suppl):180.
- [31] Zoller B, Ohlsson H, Sundquist J, Sundquist K. Familial risk of venous thromboembolism in first-, second- and third-degree relatives: a nationwide family study in Sweden. *Thromb Haemost* 2013;109:458.



Appendix Figure 1. (a) ROC curve for Caprini-RAM. AUC = 0.52. (b) ROC curve for BMC VTE Score. AUC = 0.61.

Appendix Table 1
 Postoperative chemoprophylaxis regimens for VTE+ and control patients.

| Postoperative prophylactic regimens | VTE+ | Control | Total |
|---|------|---------|-------|
| ASA 81 BID | 2 | 4 | 6 |
| ASA 325 BID | 3 | 20 | 23 |
| Apixaban 2.5 mg BID | 1 | 0 | 1 |
| Enoxaparin 40mg daily | 3 | 3 | 6 |
| Enoxaparin in hospital, transition to ASA 325 BID after d/c | 20 | 10 | 30 |
| Enoxaparin and ASA 325 simultaneously | 1 | 0 | 1 |
| Heparin (patient's home dose) | 1 | 1 | 2 |
| Warfarin (patient's home dose) | 8 | 2 | 10 |
| Rivaroxaban 10 mg daily | 1 | 0 | 1 |