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Thromboprophylaxis use in medical and surgical inpatients and the impact of an electronic risk assessment tool as part of a multi-factorial intervention. A report on behalf of the elVis study investigators

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Abstract Venous thromboembolism (VTE) is a major source of morbidity and mortality for both surgical and medical hospitalised patients. Despite the availability of guidelines, thromboprophylaxis continues to be underutilised. This study aims to assess the effectiveness of an electronic VTE risk assessment tool (elVis) on VTE prophylaxis in hospitalised patients. A national, multicentre, prospective clinical audit collected information on VTE prophylaxis and risk factors for VTE in 2,400 hospitalised patients (comprising of equal numbers of medical, surgical and orthopaedic patients). After auditing the standard care use of VTE prophylaxis in 1,200 consecutive patients (audit 1, A1), the elVis system was installed and a second audit (A2) of VTE prophylaxis was performed in a further 1,200 patients. The use of the electronic VTE risk assessment tool was low with 20.5% of patients assessed with elVis. The intervention, elVis plus accompanying education, improved the use VTE prophylaxis to guidelines by 5.0% amongst all patients and by 10.7% amongst high risk patients (adjusted odds ratio (AOR) 1.27 and 1.65 respectively). The use of elVis in A2 varied between hospitals and specialties and this resulted in marked heterogeneity. Despite this heterogeneity, patients assessed with elVis had 1.44 times higher AOR of being treated to guidelines compared to those who were not ($P < 0.05$). The use of elVis accompanied by staff education improved VTE prophylaxis, especially amongst high risk patients. To optimise the effectiveness and support enduring practice change electronic systems, such as elVis, need to be completely integrated within the treatment pathway.

Keywords Deep vein thrombosis · Venous thromboembolism · Pulmonary embolism · Guideline adherence · Prevention · Thromboprophylaxis

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Introduction

Venous thromboembolism (VTE), which comprises of pulmonary embolism (PE) and deep vein thrombosis (DVT), is a major source of morbidity and mortality for both surgical and medical hospitalised patients. It is the most common preventable cause of hospital-related death [1], yet despite the availability of clinical guidelines in Australia [2, 3] and internationally [4, 5], thromboprophylaxis continues to be underutilised [1, 6] and has been identified as "the number one strategy to improve patient safety in hospitals" [5].

In 2008, it is estimated that there were over 14,500 cases of VTE and approximately 5,000 deaths due to VTE in Australia. The estimated financial cost of VTE was in excess of AU$1.7 billion, with 80% of these costs due to

lost productivity as a result of premature death [7]. Western Australian hospital morbidity data determined that in 1999–2001 the rate of VTE was 80 per 100,000 hospitalised patients with equal proportions arising from medical and surgical admissions. Over half of secondary cases of VTE occurred as readmissions within 3 months of the original hospital admission [8]. Most hospitalised patients have one or more risk factors for VTE [3]. Surgery is a well established VTE risk factor and the use of thromboprophylaxis is generally higher amongst surgical patients than medically ill patients [9], however VTE cases in acute hospital settings are equally attributable to medical and surgical admissions [10]. In addition, 50–70% of symptomatic events and 70–80% of fatal PEs occur in non-surgical patients [5, 11–14].

The ENDORSE study has demonstrated that VTE prophylaxis is suboptimal and that the use of thromboprophylaxis in medically ill patients has particular scope for improvement [9]. Amongst medically ill patients, prophylaxis appears to correlate with disease severity rather than medical diagnosis, for example the recommended prophylaxis was more likely to be instituted if the patient was admitted into intensive care or required central venous catheters, markers of severe disease [15].

There have been numerous efforts made to improve VTE prophylaxis. Systematic reviews indicate that passive methods, such as the dissemination of guidelines, is unlikely to translate into improved practice [16–20]. Factors that appear to improve VTE prophylaxis are systems that remind clinicians to assess the VTE risk status of patients, and then assist clinicians prescribe the appropriate prophylaxis for the risk classification. Studies which have used electronic systems to facilitate these processes appear promising in improving VTE prophylaxis [1, 21].

We report the results of a multicentre clinical audit before and after an intervention, examining the effectiveness of an electronic risk assessment system on VTE prophylaxis in hospitalised patients. The primary objective was to determine the effect on the rate of VTE prophylaxis in hospitalised patients of an electronic risk assessment tool that guides appropriate management according to guidelines or local protocols. Secondary objectives were to assess the appropriateness of VTE prophylaxis in hospitalised medical, surgical and orthopaedic patients and to describe the types of VTE prophylaxis prescribed.

Methods

A multicentre prospective audit was performed in 6 hospitals across Australia. The audit collected information on VTE prophylaxis and risk factors for VTE in 2,400 hospitalised patients. The selection and use of VTE prophylaxis was based on standard care and was not determined by the audit protocol.

Participants in the audit were adult patients (aged $\geq$18 years) hospitalised for at least 24 h in a medical or surgical ward. Patients were excluded from the study if they had participated in a VTE study in the last 90 days, or if they were admitted to the following hospital wards; intensive care, coronary care, paediatrics, maternity, gynaecology, or psychiatry. Individual patients could only be audited once, if they were re-admitted to hospital, VTE prophylaxis was not audited on subsequent admissions.

Each study site performed a baseline audit of 120 or 240 consecutive patients (comprising of equal numbers of medical, surgical and orthopaedic patients) regarding VTE risks, prophylaxis and bleeding risks. This data was recorded on a data collection form, to reflect the conditions present on admission or developed whilst in hospital, regardless of the length of hospital stay. After completing the first audit (A1), the electronic VTE risk assessment system was installed by Core Medical Solutions into each participating hospital. The electronic VTE risk assessment system allowed VTE risk to be classified as high or not high for each patient, based on local hospital guidelines, and the system flagged any patient that had not had their VTE risk assessed. Implementation of the electronic system was accompanied by medical officer education on its use and a general increase in awareness of VTE prophylaxis. After the electronic risk assessment tool was embedded within the hospital, a second audit (A2) of VTE risks and prophylaxis was conducted on an additional 120 or 240 consecutive patients. The second audit was completed as early as 5 months and no later than 10 months after the first audit. The number of patients to be audited at each hospital was based on the hospital's capacity to complete the audit within the study timeframe. Four hospitals recruited 240 patients in each audit cycle and two hospitals recruited 120 patients per cycle.

This audit was conducted in accordance with the Declaration of Helsinki [22] and written approval was obtained from the relevant Human Research Ethics Committee at each study site. Patient consent was not obtained as the process of obtaining consent posed significant risk of influencing physician behaviour. This was deemed acceptable, as selection of VTE prophylaxis was based on standard care and not by the audit protocol.

We estimated that a total of 2,400 evaluable patients would be required in the audit (1200, 400 medical, 400 surgical and 400 orthopaedic, in each audit cycle) to detect a difference between an A1 (baseline) proportion of patients treated to guidelines of 0.60 and an A2 proportion of patients treated to guidelines of 0.70 (odds ratio = 1.556) and to have a power of at least 80% (5%, two-sided significance level). Data were summarised using descriptive

statistics. The normal approximation method was used to calculate 95% confidence intervals for all sites combined. Logistic regression was used to evaluate the primary end point as to whether the use of the electronic risk assessment system improved the appropriate use of thromboprophylaxis at A2 versus A1 (standard care). Odds ratios for the effect of the electronic risk assessment tool were adjusted for the study design (site and patient specialty type) and for risk status (high risk, not high risk), as appropriate. All statistical analyses were performed using SAS® Version 9.2.

Results

A total of 2,406 patients were audited in this study, 1,206 in Audit 1 (A1), 402 medical, 404 surgical and 400 orthopaedic and 1,200 patients in Audit 2 (A2), 401 medical, 398 surgical and 401 orthopaedic. Demographic data for the patients audited are summarised in Table 1. Patients were well matched for all demographic measures between the two audits, as well as within each patient specialty type. In A1, 947 (78.5%) patients were high risk at admission and a similar percentage 78.7% (944) were high risk in A2. As expected, high risk patients were older (mean age 67.8 years, A1 and 66.0 years, A2) compared to not high risk patients (mean ages 49.1 years, A1 and 54.5 years, A2).

The VTE risk factors found in patients are shown in Table 2. Orthopaedic patients generally had fewer risk factors however there was a considerable difference in A1 compared to A2 (no risk factors in 76.5% vs. 52.4%, $P < 0.05$). Differences were also observed in the prevalence of specific co-morbidities that increased VTE risk between the two audits, for example active cancer was more prevalent in A1 than A2, especially amongst medical patients, while acute inflammation was more prevalent in A2 than A1 amongst surgical and orthopaedic patients. The number of VTE risk factors per patient is illustrated in Fig. 1. The most common VTE risk factors reported in A1 were acute infection or acute inflammatory disorder (31.7%, 382/1206) and active cancer (10.8%, 130/1206). These risk factors were also the most common in A2 (Table 2). In both audits, only a minority of patients had a risk factor for bleeding at admission (A1, 9.5% 114/1206 and A2, 5.8% 69/1200). The most common bleeding risk was hepatic impairment (Table 2). Almost 20% of patients had a contraindication to adding thromboprophylaxis in the audit (A1, 19.0% 229/1206, and A2, 16.0% 192/1200). The most common contraindications for initiating thromboprophylaxis included high risk of bleeding, active bleeding and range of other contraindications such as, renal impairment, chronic kidney disease, palliative care and falls risk. Seventy-two patients in A1 and 60 patients in A2 were already taking thromboprophylaxis at admission (Table 2).

In A1, 66.8% (806/1206) of all patients and 63.5% (601/947) of high risk patients were treated to guidelines. This increased by 5.0% to 71.8% (862/1200) of all patients ($P < 0.05$) and by 10.7% to 74.2% (700/944) for high risk patients ($P < 0.05$) (Fig. 2a, b). The adjusted odds ratio (AOR) of being treated to guidelines as a result of participating in the audit increased significantly by 1.27 (95% CI 1.07–1.49), indicating that patients in A2 had a 1.27 times higher odds, adjusted for risk status, of receiving appropriate VTE prophylaxis than from standard care, in A1. Similarly the AORs of being treated to guidelines for high risk patients was 1.65 (95% CI 1.37–1.99, $P < 0.05$).

The use of the electronic risk assessment tool in A2 to assess VTE risk varied between the participating centres, ranging from none to half of the patients assessed using this tool. Overall elVis was used in 22.6% (213/944) of high

Table 1 Patient demographics

	Medical		Surgical		Orthopaedic		Total	
	Audit 1 (n = 402)	Audit 2 (n = 401)	Audit 1 (n = 404)	Audit 2 (n = 398)	Audit 1 (n = 400)	Audit 2 (n = 401)	Audit 1 (n = 1206)	Audit 2 (n = 1200)
Male (%)	213 (53.0%)	198 (49.4%)	225 (55.7%)	220 (55.3%)	183 (45.8%)	191 (47.6%)	621 (51.5%)	609 (50.8%)
Female (%)	189 (47.0%)	203 (50.6%)	178 (44.1%)	178 (44.7%)	217 (54.3%)	210 (52.4%)	584 (48.4%)	591 (49.3%)
Mean age years (SD)	71.1 (17.7)	73.7 (16.2)	58.2 (20.2)	56.6 (20.3)	62.1 (19.4)	60.2 (19.7)	63.8 (19.9)	63.5 (20.2)
Mean weight kg (SD)	71.5 (21.4)	71.4 (21.8)	78.9 (19.8)	78.2 (19.5)	82.7 (19.7)	82.0 (19.8)	79.1 (20.4)	78.3 (20.5)
	(n = 97)	(n = 121)	(n = 250)	(n = 219)	(n = 219)	(n = 238)	(n = 566)	(n = 578)
Mean height cm (SD)	169.0 (10.0)	165.3 (9.0)	167.6 (11.2)	167.5 (10.7)	167.0 (11.3)	166.7 (11.6)	167.3 (11.2)	166.9 (11.1)
	(n = 13)	(n = 15)	(n = 144)	(n = 130)	(n = 149)	(n = 193)	(n = 306)	(n = 338)
Mean BMI kg/m^2 (SD)	20.7 (6.8)	22.1 (5.6)	27.9 (7.4)	27.7 (5.7)	30.4 (6.6)	30.2 (7.9)	28.9 (7.3)	28.9 (7.3)
	(n = 10)	(n = 14)	(n = 142)	(n = 130)	(n = 145)	(n = 190)	(n = 297)	(n = 334)

Table 2 VTE risk factors, bleeding risk factors and contraindications to thromboprophylaxis

	Medical		Surgical		Orthopaedic		Total	
	Audit 1 (n = 402)	Audit 2 (n = 401)	Audit 1 (n = 404)	Audit 2 (n = 398)	Audit 1 (n = 400)	Audit 2 (n = 401)	Audit 1 (n = 1206)	Audit 2 (n = 1200)
VTE risk factors (incidence ≥5% in any group)								
None	116 (28.9%)	136 (33.9%)	182 (45.0%)	180 (45.2%)	306 (76.5%)	210 (52.4%)	604 (50.1%)	526 (43.8%)
Previous VTE	22 (5.5%)	20 (5.0%)	16 (4.0%)	11 (2.8%)	7 (1.8%)	11 (2.7%)	45 (3.7%)	42 (3.5%)
Decompensated heart failure	46 (11.4%)	58 (14.5%)	1 (0.2%)	2 (0.5%)	1 (0.3%)	1 (0.2%)	48 (4.0%)	61 (5.1%)
Acute respiratory failure	25 (6.2%)	11 (2.7%)	9 (2.2%)	3 (0.8%)	1 (0.3%)	–	35 (2.9%)	14 (1.2%)
Acute infection or acute inflammatory disorder	197 (49.0%)	204 (50.9%)	133 (32.9%)	186 (46.7%)	52 (13.0%)	178 (44.4%)	382 (31.7%)	568 (47.3%)
Recent ischaemic stroke	38 (9.5%)	30 (7.5%)	6 (1.5%)	8 (2.0%)	2 (0.5%)	4 (1.0%)	46 (3.8%)	42 (3.5%)
Active cancer	44 (10.9%)	21 (5.2%)	67 (16.6%)	44 (11.1%)	19 (4.8%)	8 (2.0%)	130 (10.8%)	73 (6.1%)
Thrombophilia	30 (7.5%)	17 (4.2%)	17 (4.2%)	12 (3.0%)	20 (5.0%)	10 (2.5%)	67 (5.6%)	39 (3.3%)
Other	15 (3.7%)	4 (1.0%)	23 (5.7%)	14 (3.5%)	19 (4.8%)	6 (1.5%)	57 (4.7%)	24 (2.0%)
Bleeding risk factors at admission (incidence ≥2% in any group)								
None	337 (83.8%)	362 (90.3%)	367 (90.8%)	376 (94.5%)	388 (97.0%)	393 (98.0%)	1092 (90.5%)	1131 (94.3%)
Known bleeding disorder	19 (4.7%)	9 (2.2%)	11 (2.7%)	2 (0.5%)	5 (1.3%)	2 (0.5%)	35 (2.9%)	13 (1.1%)
Active gastrointestinal bleeding	15 (3.7%)	9 (2.2%)	12 (3.0%)	12 (3.0%)	–	2 (0.5%)	27 (2.2%)	23 (1.9%)
Hepatic impairment	26 (6.5%)	15 (3.7%)	14 (3.5%)	8 (2.0%)	4 (1.0%)	2 (0.5%)	44 (3.6%)	25 (2.1%)
Other	14 (3.4%)	8 (2.0%)	10 (2.5%)	3 (0.8%)	5 (1.3%)	2 (0.5%)	29 (2.4%)	13 (1.1%)
Contraindications to additional thromboprophylaxis								
None	258 (64.2%)	274 (68.3%)	351 (86.9%)	365 (91.7%)	368 (92.0%)	369 (92.0%)	977 (81.0%)	1008 (84.0%)
Acute infectious endocarditis	3 (0.7%)	1 (0.2%)	–	–	–	–	3 (0.2%)	1 (0.1%)
High risk of bleeding	33 (8.2%)	19 (4.7%)	18 (4.5%)	6 (1.5%)	12 (3.0%)	4 (1.0%)	63 (5.2%)	29 (2.4%)
Hypersensitivity to heparin/LMWH	–	–	1 (0.2%)	1 (0.3%)	–	–	1 (0.1%)	1 (0.1%)
Other	62 (15.4%)	75 (18.7%)	15 (3.7%)	9 (2.3%)	23 (5.8%)	21 (5.2%)	100 (8.3%)	105 (8.8%)
Active bleeding	15 (3.7%)	8 (2.0%)	14 (3.5%)	9 (2.3%)	–	2 (0.5%)	29 (2.4%)	19 (1.6%)
Previous HITS[a]	–	1 (0.2%)	1 (0.2%)	–	–	–	1 (0.1%)	1 (0.1%)
Anticoagulant use at admission								
Current LMWH/UFH/warfarin[b]	54 (13.4%)	42 (10.5%)	14 (3.5%)	11 (2.8%)	4 (1.0%)	7 (1.7%)	72 (6.0%)	60 (5.0%)

[a] Heparin induced thrombocytopenia

[b] *LMWH* low molecular weight heparin, *UFH* unfractionated heparin

risk patients and 20.5% (246/1,200) of all patients. Its use also differed between specialty types, with highest use amongst medical patients 35.2% (141/401), followed by surgical patients, 17.8% (71/398) and orthopaedic patients, 8.5% (34/401). Due to the low use of the electronic risk assessment tool, an additional logistic regression analysis was conducted to determine its impact amongst patients in audit 2 only. Seventy-eight percent (192/246) of patients assessed using the electronic risk assessment tool received appropriate prophylaxis versus 70.2% (670/954) for those whose risk was assessed using another method. Adjusting for risk status, patients assessed with electronic risk assessment had 1.44 times greater odds of receiving appropriate VTE prophylaxis than patients who were not assessed using this system (AOR 1.44, 95% CI 1.04, 1.99). Statistically significant improvements in the percentage of all patients treated to guidelines were observed in A2 for both medical patients and orthopaedic patients (AOR 1.56 and 1.36 respectively) but not for surgical patients (Fig. 3a). Similar findings were observed amongst high risk patients; however the study was not powered to detect significant differences in this subanalysis (Fig. 3b).

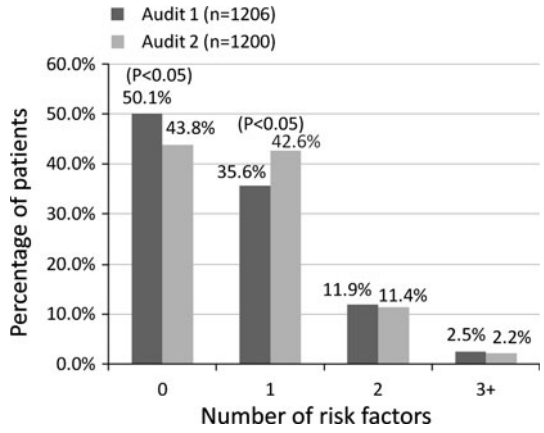

Fig. 1 Number of VTE risk factors per patient (all patients)

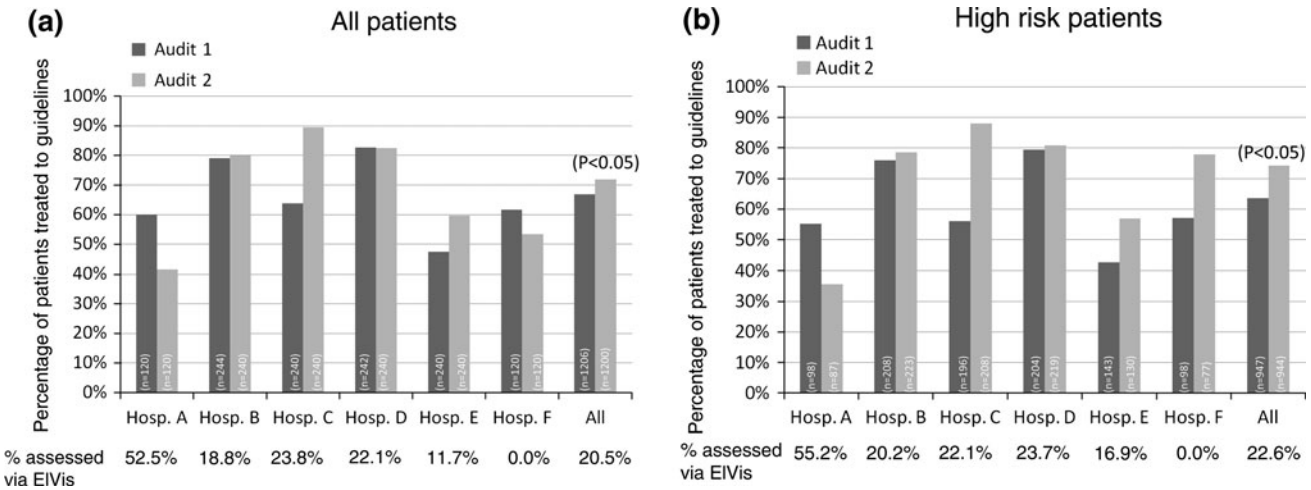

Fig. 2 Percentage of patients treated to guidelines. **a** All patients. **b** High risk patients

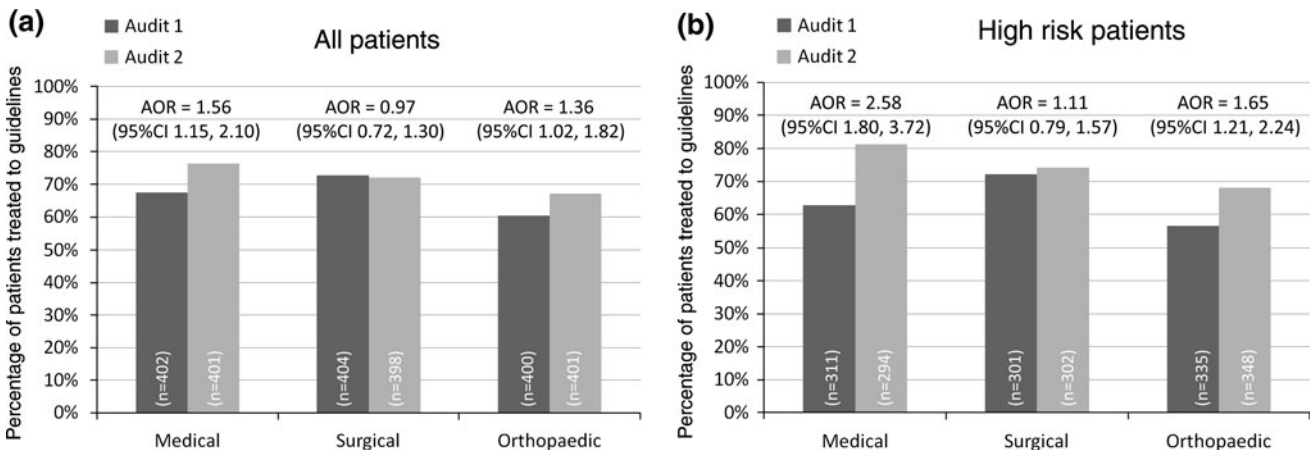

Fig. 3 Percentage of patients treated to guidelines by specialty group. **a** All patients. **b** High risk patients

Table 3 Percentage of patients receiving VTE prophylaxis

	Medical			Surgical			Orthopaedic			Total		
	Audit 1 (n = 402)	Audit 2 (n = 401)	Difference (95% CI)	Audit 1 (n = 404)	Audit 2 (n = 398)	Difference (95% CI)	Audit 1 (n = 400)	Audit 2 (n = 401)	Difference (95% CI)	Audit 1 (n = 1206)	Audit 2 (n = 1200)	Difference (95% CI)
Any prophylaxis	213 (53.0%)	255 (63.6%)	10.6% (3.8%, 17.4%)	310 (76.7%)	308 (77.4%)	0.7% (−5.2%, 6.5%)	311 (77.8%)	300 (74.8%)	−2.9% (−8.8%, 3.0%)	834 (69.2%)	863 (71.9%)	2.8% (−0.9%, 6.4%)
Anti-coagulant only	141 (35.1%)	183 (45.6%)	10.6% (3.8%, 17.3%)	46 (11.4%)	70 (17.6%)	6.2% (1.3%, 11.1%)	133 (33.3%)	65 (16.2%)	−17.0% (−22.9%, −11.2%)	320 (26.5%)	318 (26.5%)	0.0% (−3.6%, 3.5%)
Mechanical only	17 (4.2%)	18 (4.5%)	0.3% (−2.6%, 3.1%)	48 (11.9%)	30 (7.5%)	−4.3% (−8.4%, −0.3%)	36 (9.0%)	30 (7.5%)	−1.5% (−5.3%, 2.3%)	101 (8.4%)	78 (6.5%)	−1.9% (−4.0%, 0.2%)
Both anti-coagulant and mechanical	55 (13.7%)	54 (13.5%)	−0.2% (−5.0%, 4.5%)	216 (53.5%)	208 (52.3%)	−1.2% (−8.1%, 5.7%)	142 (35.5%)	205 (51.1%)	15.6% (8.8%, 22.4%)	413 (34.2%)	467 (38.9%)	4.7% (0.8%, 8.5%)

The types of VTE prophylaxis prescribed in both audits are shown in Table 3. The level of VTE risk and bleeding risk differed between A1 and A2 and this influenced the use of VTE prophylaxis. The percentage of patients overall receiving any VTE prophylaxis in A2 compared to baseline (A1) increased by 2.8% (not statistically significant), with a statistically significant increase observed for the use of the combination of anti-coagulant and mechanical prophylaxis.

The most frequently prescribed anticoagulant prophylaxis in all patients was enoxaparin (42.9% in A1 and 46.4% in A2), followed by unfractionated heparin and dalteparin. The prescribing of enoxaparin increased in A2 amongst both medical and surgical patients, but decreased amongst orthopaedic patients. Unfractionated heparin prescribing decreased amongst surgical patients but increased amongst medical patients. Dalteparin was only used amongst orthopaedic patients. The most frequently prescribed mechanical prophylaxis in patients overall was graduated compression stockings.

Discussion

The routine use of VTE prophylaxis in hospitalised patients is generally suboptimal, with the percentage of at risk patients who receive prophylaxis according to guidelines ranging from 13 to 64%, depending on the patient population being investigated [23–26]. Data from the multinational ENDORSE study demonstrated that less than half of patients at risk received prophylaxis and prophylaxis was generally higher amongst surgical patients than medical patients (58.5% surgical and 39.5% medical) [9]. The hospitals that participated in our study performed VTE prophylaxis at a relatively high rate in A1, prior to the intervention, with approximately two-thirds of both, all patients and high risk patients receiving appropriate prophylaxis in A1. Despite these high baseline levels implementing the electronic risk assessment tool and the accompanying education activities resulted in further improvements in VTE prophylaxis, increasing by 5.0% for all patients and 10.7% for patients at high risk. This finding is consistent with that of other investigators that confirm that implementing active strategies that remind clinicians to assess VTE risk and assist with appropriate prescribing are effective [21, 27, 28]. For example, Durieux et al. investigated the use of a computer-based clinical decision support system on VTE prophylaxis amongst orthopaedic patients. Use of the computerised system further improved the percentage of patients treated to guidelines by 12.1%, from 82.8 to 94.9% [28].

Our study also investigated VTE prophylaxis amongst three discrete patient specialty types, medical, surgical and orthopaedic patients, in equal proportions. Previous studies

have indicated that VTE prophylaxis is generally implemented better amongst surgical patients than medical patients [9]. Although a higher percentage of surgical patients received appropriate prophylaxis (72.8%) in A1, the rate of prophylaxis according to guidelines amongst medical patients was also high at 67.4% and higher than orthopaedic patients at 60.3%. Improvement in VTE prophylaxis was greatest amongst medical patients (8.9% amongst all medical patients and 18.6% amongst high risk medical patients). Significant improvements were also observed amongst orthopaedic patients, whilst no significant change was observed amongst surgical patients. These differences between patient specialty type are partially explained by the differing use of the electronic risk assessment tool, which was most frequently used with medical patients.

There was marked heterogeneity between the audited hospitals and within patient specialty types. Hospitals and specialty subgroups with the highest percentage of appropriate prophylaxis use in A1 (>80%) generally demonstrated little change (marginal improvement) in VTE prophylaxis as a result of participation in the audit. Amongst the remaining hospitals three demonstrated improvements in VTE prophylaxis, whilst in one hospital the intervention appeared to impede appropriate prophylaxis.

The main limitation of our study resulted from the low and variable use of the electronic risk assessment tool, ranging from one hospital not assessing any patients with the tool to its use to assess two-thirds of all medical patients in another hospital. This variation arose from several factors of which the two most significant were software related issues and clinical leadership. In the pilot study conducted at Geelong Hospital, the electronic risk assessment tool was fully integrated within the hospital admission system [29]. Hence, the risk assessment tool formed a seamless part of the admission system. For all the hospitals in our study, elVis was not fully integrated within the hospital's patient admission system but was a separate, stand alone application. This created a major impediment to its routine use, as clinicians needed to specifically open the electronic risk assessment tool to assess VTE risk. In addition, the routine use of the electronic risk assessment system was further compromised by implementation issues that arose at some hospitals, where synchronisation of patient lists between the hospital admissions system and the VTE risk assessment tool was not always achieved with 100% accuracy. When patients were missing from the VTE database, VTE risk assessment defaulted to standard care. The importance of clinical leadership was clearly demonstrated from within hospital comparisons between patient specialty types. Where clinical leadership was strong and supportive of electronic risk assessment, usually in medical departments, so was the use of the tool. Although patients in each audit were well matched based on demographic variables, differences in risk factors were observed. Whilst adjustments have been made for measured confounders, it is not possible to account for unmeasured confounders and their potential impact on our results. Other limitations of our study are the multiple statistical analyses conducted increasing the chance of false positive results, the lack of clarity as to the effect of elVis over education and whether these improvements in VTE prophylaxis are sustainable.

Despite the varied use of elVis, analysis of patients within the second audit identified a clinical benefit associated with the use of this tool. Patients assessed using the electronic risk assessment had 1.44 times higher odds, adjusted for risk status, to receive appropriate VTE prophylaxis than patients who were not assessed using this system ($P < 0.05$).

The most significant challenge in the area of VTE prophylaxis is the application of existing evidence into everyday clinical practice. Quality improvement and practice change is possible but for it to be sustained it requires that the change be integrated into daily patient care [21, 30, 31]. The use of computerised risk assessment and reminder systems make this possible and has been demonstrated to be effective tools of change in the area of preventative care [27–30]. For example, a randomised clinical trial in 2,506 hospitalised patients demonstrated that the use of computerised alert system increased physician use of VTE prophylaxis versus control (33.5% vs. 14.5%, $P < 0.001$) and reduced the risk of DVT or PE at 90 days by 41% ($P = 0.001$) [27]. In addition, a systematic review by Tooher et al. [21], found that computer based clinical decision support systems were amongst the most effective strategies for improving prescribing practice as they minimise errors made by clinicians with varying degrees of knowledge, interest and motivation for VTE prevention. This review also identified that the studies that achieved at least 90% adherence to VTE guidelines involved either an iterative process of audit and review or an active reminder system.

In our study, the absolute improvement in the percentage of patients that were treated to guidelines was 5.0% amongst all patients and 10.7% amongst high risk patients as a result of the audit intervention. The audit intervention, although focused on the use of the electronic risk assessment tool was effectively a multimodal intervention, involving clinical leadership, professional education, increased awareness of VTE prophylaxis, as well as the use of the elVis electronic risk assessment tool. The absolute improvement in appropriate VTE prophylaxis increased by 7.8% amongst patients who were assessed using the electronic risk assessment compared to not using this tool. This level of absolute improvement in clinical practice is comparable to other change management tools aimed at

improving guideline implementation. Grimshaw et al. [32] identified that reminder systems were the most effective tool for change (median absolute effect of 13.1%), followed by healthcare professional education at 8.1% (noting that the benefits from this tool of change is short-lived), audit and feedback 7.0% and multifaceted interventions involving educational outreach at 6.0%.

Conclusion

The use of elVis, an electronic VTE risk assessment tool, accompanied by staff education overall improved VTE prophylaxis, especially amongst high risk patients. However, the response to this intervention varied between participating hospitals and between medical, surgical and orthopaedic patients. Our study confirmed that the ongoing challenge of applying VTE prophylaxis guidelines into routine clinical practice can be assisted with the use of electronic assessment and decision support tools. To be maximally effective and to deliver enduring practice change, these tools need to be fully integrated within the treatment pathway in a readily accessible, easy to use manner.

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Conflict of interest Professor Edward Janus: In addition to the funding of the research nurse for the 2010 elVis study I have received a further 2 grants over 2007–2009 for $99,500 from sanofi-aventis to employ a research nurse to work on improving VTE prophylaxis. I received sanofi-aventis support to attend one Conference on VTE prophylaxis in Sydney. Dr Jackson, Dr Anmol Bassi, Professor Nandurkar and Associate Professor Mark Yates have no declared conflict.

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