Transfusion strategy for primary knee and hip arthroplasty: impact of an algorithm to lower transfusion rates and hospital costs

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Background. Blood transfusion strategies should reduce both blood transfusion and costs. Possible solutions include autologous donation for selected patients and the prescription of erythropoietin (EPO).

Methods. We conducted a quality improvement program to examine the effect of a transfusion strategy algorithm in primary knee (TKA) and hip arthroplasty (THA). Our algorithm is presented as a diagram and is based on tolerated and expected blood losses. Patient characteristics, blood loss, transfusions given, autologous blood wastage, and costs were examined during an initial evaluation and after implementation of the algorithm.

Results. Analysis of 302 (initial evaluation) and 173 (post-implementation) arthroplasties demonstrated a 55% reduction in the prescription of autologous blood donation. The proportion of EPO prescriptions increased from 6.6% to 17.3% (p < 0.05). There was a 56% overall reduction in transfusions to fewer autologous (32% vs 12%, p < 0.0001) and allogeneic transfusions (21% vs 13%, NS). There were 50% fewer wasted autologous blood units (p = 0.002) and a 50% reduction in hospital costs (£345 vs 169) with no significant change in overall costs (£439 vs 407). Anaesthetists applied the algorithm in 97% of patients, and it is still in use 1 yr after evaluation.

Conclusions. In this study, the implementation of an algorithm for transfusion strategy changed practice and improved quality of care. The costs for EPO, its administration, and monitoring outside hospital were offset by the reduction in hospital transfusion costs.

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The widespread use of autologous transfusion because of concerns about contaminated donated blood raises several issues. First, is autologous blood donation (ABD) beneficial for the patient? This practice reduces allogeneic transfusion and risk from viral transfusion. However, it may increase the overall exposure of the patient to allogeneic and autologous transfusion. The risks of clerical errors and bacterial infection which exist for both autologous and allogeneic transfusions outweigh the very low risks of virus transmission by allogeneic transfusion. Secondly, is ABD cost-effective? Previous studies have demonstrated high cost-efficiency ratios related to ABD. This high cost/benefit ratio associated with ABD over prescription and wide variation in hospital practice has led some authors to question the value of ABD. ABD should be restricted to patients who may benefit from its advantages. The use of an individualized strategy adapted to each patient and centre could make it possible to identify patients who would benefit from transfusion-sparing techniques and also those for whom such techniques are not indicated.
Transfusion strategy for arthroplasty

ABD prescription for patients with a high red blood cell (RBC) mass is inappropriate and increases the risks of postoperative anaemia and of perioperative transfusion.9 In such patients, abstention from ABD should be regarded as a transfusion-sparing technique. ABD is also harmful for anaemic patients.13 RBC regeneration induced by ABD is often insufficient to replenish red cell mass in these patients and they account for the majority of patients who receive mixed autologous and allogeneic transfusion.13 Erythropoietin (EPO) rather than ABD should be used in anaemic patients. Marketing authorization in France for the preoperative use of EPO in anaemic patients undergoing orthopaedic surgery was granted in 1998. Its use reduced exposure to all types of transfusions.14 However, recent data suggest that EPO is still not exploited to its full potential. Only 3% of patients received EPO in a large European survey of transfusion strategies in orthopaedic surgery.15 Finally, postoperative blood salvage is a valuable technique and is used in some centres for total knee arthroplasty (TKA).16 Improvements in transfusion-sparing practice depend on facilitating rational, individualized choices among the different techniques described earlier. Strategies based on comparison of expected and tolerated blood losses represent such an approach.9,10 They can be adapted to the blood loss expected in a given type of surgery, in a given centre and to the patient’s RBC mass. However, this type of strategy is based on a calculation, and introducing new guidelines of this type is difficult.

The purpose of this study was to test an algorithm to guide transfusion strategy for patients undergoing THA or TKA in our centre. We constructed an algorithm to use during the preoperative consultation with the anaesthesiologist. For ease of use, it was presented as a diagram. We also evaluated the clinical and economic impacts of this algorithm.

Methods

Clinical study

This study lies within the scope of a joint anaesthesiologist–orthopaedic quality improvement program conducted in the department of orthopaedic surgery in our institution. The study was discussed with the local research ethics committee who stated that ethics committee approval was not required for this use of routine data. No sample size calculation was made, but the number of patients included was similar to that in the previous study.12 The study was conducted in three phases. (1) An initial evaluation was conducted from November 2003 to November 2004. (2) The algorithm was developed and introduced into clinical practice. (3) A post-implementation evaluation was conducted from May 2005 to November 2005.

Data from patients who underwent primary THA or TKA during periods (1) and (3) were analysed. We excluded revision arthroplasty and partial knee arthroplasty. THA was performed through an anterior incision. TKA was performed with a tourniquet, which was released before closure to achieve haemostasis. General anaesthesia was used in all cases. Anaesthesia was induced with propofol, sufentanil, and atracurium. Patients were intubated and ventilation controlled. Anaesthesia was maintained with sevoflurane administered in 50% oxygen/50% nitrous oxide. Supplemental sufentanil was given as needed. For TKA, a femoral catheter for local anaesthetic was inserted before induction of general anaesthesia. After an initial bolus of 20 ml of ropivacaine 0.2%, a continuous infusion (0.1 ml kg\(^{-1}\) h\(^{-1}\)) was instituted. Anti-thrombotic prophylaxis with Enoxaparin 4000 IU once a day was started the evening after surgery.

Evaluation of cost

We evaluated the overall or global cost of the transfusion strategy using the price of each item at the time of the study expressed in euros (€1=1.2 US$): EPO 40 000 IU €456.13; one autologous RBC unit collection and storage €207.85; one allogeneic RBC unit €171.49; perioperative RBC salvage €145.86; travel expenses and fee for visiting registered nurse to inject EPO €10; blood cell count €10.80; and collection of blood sample €1.08. The costs covered by the hospital were calculated from the expenditure for allogeneic RBC units transfused, the autologous RBC units collected, and the postoperative drainage system. To obtain the global cost, we added to the hospital costs the price of a protocol of three EPO injections given at home by a visiting nurse and the cost of obtaining blood samples and two blood cell counts.

Development and implementation of the algorithm

We simplified the transfusion strategy proposed by Mercuriali and Inghilleri,10 which is based on the
A comparison of tolerated blood loss and expected blood loss by plotting these variables in a diagram. The strategy ‘if the expected losses are greater than the tolerated losses, then a transfusion-sparing technique is necessary’ expressed in mathematical terms by the following inequality:

$$\text{expected losses} - \text{EBV} \times (\text{baseline Hct} - \text{threshold Hct}) > 0,$$

where EBV is the estimated blood volume.

The expected losses were determined from the mean RBC loss during the initial evaluation. We chose to fix the transfusion threshold Hct at 30% and EBV at 65 ml kg\(^{-1}\), which is the value for women of normal weight.\(^{17}\) These choices are examined in the discussion. We obtained an inequality with two variables, weight and baseline Hct:

$$\text{baseline Hct(\%)} < \frac{\text{expected losses}}{(\text{weight} \times 65)} + 0.3.$$

Plotting this inequality as a graph with patient’s initial Hct on the y-axis and weight on the x-axis gives a zone in which tolerated losses are less than the expected losses, so transfusion-sparing methods are required. This zone is limited at the top by the curve corresponding to the following equation:

$$\text{baseline Hct(\%)} = \frac{\text{expected losses}}{(\text{weight} \times 65)} + 0.3.$$

Above this curve, tolerated losses exceed the expected losses and thus transfusion-sparing methods are unnecessary; we refer to it as the abstention zone. We also included the limits for the prescription indication of EPO, haemoglobin between 10 and 13 g dl\(^{-1}\), corresponding to straight lines intersecting the y-axis at Hct of 30% and 39%. Two diagrams were drawn (Fig. 1), one for THA (Fig. 1A) and the other for TKA (Fig. 1B). The diagram for THA gives three possible strategies: abstention, ABD, and EPO. On the TKA diagram, a zone was added corresponding to losses than can be compensated by RBC salvage alone. Therefore, for TKA patients, the four transfusion-sparing options were: abstention, RBC salvage, ABD+RBC salvage, and EPO+RBC salvage.

The results obtained during the initial evaluation and the algorithm were presented during a meeting of the team of nine anaesthesiologists. We explained how the algorithm was constructed and how it should be used. We also reminded the team about the recommendations for transfusion, i.e. transfusion, either autologous or allogeneic, was recommended if the Hct was <24%. For patients with risk factors for myocardial ischaemia, transfusion was recommended for a Hct between 24% and 30%.\(^{18}\) Serial measurements of Hct were made during each operation to guide decisions about intraoperative transfusion. It is our normal practice for patients to have a preoperative consultation with an anaesthesiologist 1 month before surgery. This did not incur an extra cost. Patients arrived at the preoperative consultation with a blood count cell, which had been arranged by the surgeon. This enabled the anaesthetist to use the algorithm to implement the most appropriate transfusion-sparing strategy. In the EPO zone, our protocol comprised three s.c. injections of 40 000 units of EPREX\(^{18}\) at 1 week intervals, starting 3 weeks before surgery. Blood cell counts were obtained before the second and third injections. If the Hct exceeded 45%, the injection protocol was interrupted.

In the ABD zone, the number of autologous RBC units (two or three) collected was at the discretion of the anaesthesiologist. Blood was collected before operation, one unit per week with 2 weeks between the last collection and the day of surgery. The patients included in an EPO or ABD protocol had oral iron supplements prescribed (240 mg per day). When postoperative salvaged blood was indicated in TKA, the transfusion was systematically performed more than 6 h after surgery regardless of the patient’s Hct.

Patients within a zone corresponding to EPO or ABD and having a contraindication were classified as ‘off
Statistical analysis

Patient characteristics and biological data are expressed as percentage or mean (SD). Data were compared between before and after implementation of algorithm. Data were tested for normality with the Kolmogorov–Smirnov test. Quantitative variables were compared using Student’s t-test (age, weight, height, operative time, RBC reserve, and RBC loss). Quantitative variables found not to be normally distributed were compared using the Mann–Whitney U-test (numbers of collected, transfused, and wasted RBC units and thresholds for allogeneic and autologous transfusion).

Comparisons of the qualitative variables, including autologous and allogeneic transfusions, sex, age > 75 yr, and ASA status, were performed with the χ² test. The statistical analyses were performed using StatView software. Differences were considered significant at P<0.05.

Results

Three hundred and two consecutive patients (223 THA and 79 TKA) were included during the initial evaluation and 173 consecutive patients (120 THA and 53 TKA) were included during the post-implementation evaluation. Ten operations were cancelled during this second period (four for personal reasons and six because the patient displayed evidence of infection) and these patients were not included in the analysis. Patient characteristic are summarized in Table 1. The initial and post-implementation evaluation populations were comparable. Thresholds for autologous and allogeneic transfusions were the same during the two periods.

During the post-implementation evaluation, patients were assigned as follows: 51 (29.5%) to the abstention group, 43 (25%) to the ‘off diagram’ group, 40 (23%) underwent ABD, 30 (17.3%) received EPO, and 33 (19%) underwent RBC salvage, only.

The diagram was not applicable for four patients. The proportion of patients undergoing ABD declined by half after the algorithm was introduced, 148 of 302 (49%) patients compared with 40 of 173 (23%) patients (P<0.05).

The number of RBC units collected per operation fell over half [313 units collected for 302 operations (1.04 per operation) compared with 74 units collected for 173 operations (0.43 per operation) (P<0.001)]. This reduction was observed for both types of arthroplasties (245 and 55 units collected for 223 and 120 total hip replacements, respectively (P<0.05), and 68 and 19 units collected for 79 and 53 total knee replacements, respectively (P<0.05). The proportion of EPO prescriptions increased from 6.6% to 17.3% (P<0.05). Similar use of RBC salvage after TKA was observed for the two periods.

The main difference after implementation of the algorithm was a reduction in the total number of transfused patients from 55% to 24%. There were fewer autologous, allogeneic, and mixed transfusions (Table 2).

Analysis of data from patients undergoing total hip replacement showed significantly lower overall and autologous transfusion rates (Table 2). Fewer allogeneic transfusions and mixed transfusions were observed, but the difference was not significant. For total knee replacement, reductions were also observed with trends towards fewer overall, autologous, allogeneic, and mixed transfusions, although significance was not reached. In the ‘off diagram’ group, allogeneic transfusion rate was 44%. No transfusion errors occurred.

The number of autologous RBC units wasted per arthroplasty was halved during the post-implementation period from 36 units wasted for 173 arthroplasties (21%) compared with 121 units wasted for 302 arthroplasties (40%) (P=0.002). This reduction was observed for both types of surgeries (95 and 36 units wasted for 223 and 120 total hip replacements, respectively (P<0.05), and 26 and 6 units

Table 1 Patients characteristics. THA, total hip arthroplasty; TKA, total knee arthroplasty; RBC loss, red blood cell loss; Baseline RBC mass, red blood cell mass on the day of the anaesthetic consultation; EBV, estimated blood volume. Values are mean (range) or mean (SD) unless stated otherwise. Initial evaluation: evaluation period before the algorithm implementation; after implementation: evaluation period after the algorithm was implemented.

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<tr>
<th></th>
<th>Initial evaluation (n=302)</th>
<th>After implementation (n=173)</th>
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<tbody>
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<td>223</td>
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<tr>
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<td>Height (cm)</td>
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<tr>
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<td>ASA III (n)</td>
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<tr>
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<td>1951 (451)</td>
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<td>106 (31)</td>
<td>109 (37)</td>
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<td>514 (288)</td>
<td>508 (294)</td>
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<td>Threshold allogeneic transfusion Hct (%)</td>
<td>25.3 (4.3)</td>
<td>25.1 (5.2)</td>
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<td>Threshold autologous transfusion Hct (%)</td>
<td>27.4 (3.3)</td>
<td>26.7 (3.3)</td>
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<td>TKA (n)</td>
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<td>Age &gt; 75 yr (n)</td>
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<td>RBC loss (ml 100% Hct)</td>
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<td>610 (228)</td>
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<td>Cell salvage (ml 100% Hct)</td>
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<td>27.9 (2.9)</td>
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<tr>
<td>Threshold autologous transfusion Hct (%)</td>
<td>24.8 (3.17)</td>
<td>24.4 (2.28)</td>
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wasted for 79 and 53 total knee replacements, respectively \((P<0.05)\).

The mean (sd) RBC mass on the day before surgery was higher for both operations during the post-implementation evaluation; for hip arthroplasty, it was before the use of the algorithm 1717 (349) ml compared with 1926 (466) ml after the algorithm was implemented \((P<0.0001)\). For knee arthroplasty, the values were 1751 (347) and 1896 (457) ml, respectively \((P=0.04)\). In patients undergoing THA, the final mean RBC mass was also significantly higher on day 5 after surgery after the algorithm was introduced; 1371 (273) ml during the initial evaluation compared with 1506 (344) ml when the algorithm was in use \((P=0.0003)\). This difference was not significant for TKA; 1343 (374) ml compared with 1356 (295) ml \((P=0.19)\).

The costs for each type of arthroplasty during the two evaluation periods are shown in Table 3. On the basis of the costs of autologous, allogeneic RBC units, and postoperative RBC salvage, the calculated hospital costs per patient were halved after implementation of the algorithm \((€169.26 \text{ vs } 345.05, P=0.0001)\), thereby saving €175.79 per patient during hospitalization. Adding expenditure for 40 000 units of EPO, home nursing care, and ambulatory blood count analyses, the difference in global cost calculated per patient \((-€31.4)\) was not significant \((P=0.10)\).

Discussion

We evaluated the efficacy of a decision-making tool to change medical practice with regard to transfusion-sparing strategies for elective orthopaedic surgery.

Our main finding was the 56% decrease in global transfusion owing to fewer autologous (62%) transfusions. These reductions were similar in both types of arthroplasties but reached significance only for THA. The thresholds for autologous and allogeneic transfusions during the initial and post-implementation phases were similar. Patients had significantly higher RBC reserves the day before and 5 days after surgery during the post-implementation evaluation. Our results are mainly attributable to better use of ABD and EPO. The improved use of ABD led to 58% fewer collections of autologous units, no mixed transfusions and a 47% reduction of wasted autologous RBC units per arthroplasty.

Improved transfusion-sparing strategies reduced hospital costs. The orthopaedic department of the hospital performing the surgery finances the collection of autologous concentrates, postoperative blood salvage systems, and allogeneic RBC units transfused. The anaesthesiologist prescribes EPO treatment, monitoring, and visits by the nurse, and the patient is not required to visit the general practitioner. These out-of-hospital costs are covered by national health insurance in France. The similar global costs before and after the introduction of the algorithm suggest that the (out of hospital) cost of EPO was offset by the reduction in hospital costs. We may be able to further improve cost-effectiveness if the number of EPO injections is prescribed on the basis of baseline Hct.\(^{19}\)

Our algorithm does not discriminate between patients on the basis of medical criteria.\(^{20}\) In our study, apart from patients in whom EPO or ABD is contraindicated, the risks of allogeneic transfusion are comparable for all patients. In contrast, strategies which do not consider RBC mass\(^{21}\) may overexpose women to allogeneic transfusions.

EPO prescription was much higher in our study than the 3% of cases found in a European survey.\(^{15}\) It has been estimated that 30% of patients in this setting could benefit from EPO.\(^{15}\) In our study, EPO prescription was considered to be contraindicated in 65% of patients aged \(>75\) yr. This contraindication is found in neither the market authorization nor the medical literature on EPO prescription. Some anaesthesiologists may take the view that EPO and ABD share the same contraindications, including age more than \(75\) yr. For patients with a life expectancy of \(<10\) yr, ABD is regarded as contraindicated because the benefit (diminution of risk of viral transmission) is low and the inconvenience of ABD can be considerable. However, this does not take into account the problems of allogeneic blood supply. Elderly patients may find receiving EPO less onerous than ABD and it may be more suitable for them. Any wider adoption of EPO should respect
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Table 3 Calculation of costs before and after algorithm implementation. THA, total hip arthroplasty; TKA, total knee arthroplasty. Costs expressed in euros. EPO 40 000 IU=€ 456.13; 1 autologous RBC unit=€ 207.85; 1 allogeneic RBC unit=€ 171.49; 2 drains for postoperative drainage=€ 145.86; visiting nurse injection=€ 10; blood sampling and count analysis=€ 11.88. Initial evaluation: evaluation period before the algorithm implementation; after implementation: evaluation period after the algorithm was implemented. *P<0.01, initial evaluation vs after implementation.

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<th>Initial evaluation</th>
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specific contraindications such as severe heart disease, vascular disease, or recent heart attack or stroke.

The wide safety margin in our algorithm merits further discussion. The algorithm was constructed to avoid allogeneic transfusion and we chose in our calculations of tolerated blood loss to use high Hct thresholds (30%) and to calculate EBV using the lower figure given for women (65 ml kg\(^{-1}\)). This safety margin allowed us to obtain a very low allogeneic transfusion rate of 13%, 3–5 times lower than that in large-scale descriptive studies\(^{11,15}\) and a low failure rate. A failure occurred in patients for whom the diagram choice was abstention but who received an allogeneic transfusion. Two failures were observed in patients undergoing THA (1.1%); the blood losses for those two patients were 2400 and 2700 ml. Both were transfused for haemoglobin values below 8 g dl\(^{-1}\). This failure rate was low compared with more restrictive strategies. These two failures represent 9% of the allogeneic transfusions compared with nearly half of the patients given allogeneic transfusions by Couvret and colleagues.\(^{21}\)

The finding of inappropriate ABD prescription is not new. This practice, based on the fear of virus contamination during the 1980s and 1990s, is not supported by current data on the risks of virus transmission by transfusion. A psychosocial approach classifies current practice as part of professional ethos.\(^{22,23}\) Such practice is resistant to change and evolves slowly.\(^{23}\) Knowledge and awareness of a problem are not enough to change behaviour.\(^{17,24}\) We used an algorithm to accelerate change and to ensure its persistence.\(^{17}\) In our centre, the entire anaesthesia team adopted the diagram and it was applicable for 97% of cases during our study. It is still being used 1 yr after the end of the post-implementation study. Analysing the reasons for its success, we found that it covers most of the development, diffusion, and implementation criteria classified as having high rates of efficacy.\(^{25}\) It is simple and quick to use. One diagram shows the different available transfusion-sparing means and the variables guiding their use. It is rich in implicit information and may be used as an educational tool to persuade a patient of the value of the chosen approach. It overcomes psychological barriers, such as the fear of exposing the patient to a transfusion risk.\(^{23}\)

To summarize, in this quality improvement program, our algorithm for transfusion-sparing strategy halved the patient transfusion rate and the wasted autologous RBC units per arthroplasty. There was a 50% reduction in hospital costs and no increase in overall cost. We have demonstrated the value of an algorithm such as ours for changing medical practices.
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Appendix: total blood loss formulas

Total RBC loss was calculated with the following formulae:\textsuperscript{10 11 20}

\[
\text{RBC mass} = \text{EBV} \times \text{Hct}
\]

\[
\text{EBV (ml)} = \text{Body surface area (m}^2\text{)} \times \alpha
\]

where \(\alpha = 2430\) for women and 2530 for men.

Total RBC loss \(=\) uncompensated RBC loss \(+\) compensated RBC loss

Uncompensated RBC loss \(=\)

RBC mass \(-\) RBC mass \(D\) \(+\) 5

\[
= [\text{EBV} \times \text{Hct} \times \text{D} - 1] - [\text{EBV} \times \text{Hct} \times \text{D} + 5]
\]

Compensated RBC blood loss

\[
= [\text{Sum of RBC received from the various sources of transfusion (i.e. autologous, allogeneic, postoperative blood salvage)}] - \text{RBC unit}
\]

\[
= 250 \text{ ml (for a 60\% Hct)}
\]

\[
= 150 \text{ ml (for a 100\% Hct) and mean haematocrit of postoperative blood}
\]

salvaged \(=\) 30\%.

Therefore,

compensated RBC blood loss

\[
= (\text{number of RBC units transfused} \times 150)
\]

\[
+ (\text{volume salvaged} \times 0.3)
\]

For calculation and presentation, all data concerning blood loss and transfusion are expressed with a Hct of 100\%.

EBV, estimated blood volume; D\(-\)1, the day before surgery; D\(+\)5, 5 days after surgery; RBC, red blood cell.

References