



Hidden blood loss following hip and knee arthroplasty

CORRECT MANAGEMENT OF BLOOD LOSS SHOULD TAKE HIDDEN LOSS INTO ACCOUNT

K. R. Sehat,
R. L. Evans,
J. H. Newman

From Southmead
Hospital, Bristol,
England

Following total hip arthroplasty (THA) and total knee arthroplasty (TKR) only the 'visible' measured blood loss is usually known. This underestimates the 'true' total loss, as some loss is 'hidden'. Correct management of blood loss should take hidden loss into account.

We studied 101 THAs and 101 TKAs (with re-infusion of drained blood). Following THA, the mean total loss was 1510 ml and the hidden loss 471 ml (26%). Following TKA, the mean total loss was 1498 ml. The hidden loss was 765 ml (49%). Obesity made no difference with either operation.

THA involves a small hidden loss, the total loss being 1.3 times that measured. However, following TKA, there may be substantial hidden blood loss due to bleeding into the tissues and residual blood in the joint. The true total loss can be determined by doubling the measured loss.

Despite a negligible, intra-operative blood loss with the use of a tourniquet during total knee arthroplasty (TKA), this operation is associated with a significant post-operative blood loss. A study by Lotke et al¹ concluded that the mean blood loss in TKA, when calculated from the peri-operative drop in haemoglobin, is 1518 ml. Total hip arthroplasty (THA) is also associated with a large blood loss, but a greater proportion of this is intra-operative and readily measured.

Usually the total blood loss recorded during these procedures is the intra-operative bleeding plus the post-operative drainage. This, however, ignores extravasation into the tissues, residual blood in the joint and loss due to haemolysis. Following TKA, patients are frequently found to have a lower post-operative haemoglobin than anticipated, after an apparently satisfactory peri-operative management of blood loss, which may include re-infusion of drained blood.

A preliminary investigation in our unit has shown that TKA carries a substantial hidden blood loss.² In the present study we measured this loss in patients undergoing THA and TKA and then deduced a means of estimating the total true blood loss, given the measured visible loss. The effect of re-infusion used with TKA on hidden loss was also considered.

Patients and Methods

We studied prospectively 101 patients undergoing each procedure (Table I). All arthroplast-

Table I. Patients studied undergoing THA and TKA

	Total number	Men	Women	Mean age (yrs)
THA	101	32	69	67
TKA	101	35	66	70

ies were primary and unilateral and performed at the Avon Orthopaedic Centre, Bristol, UK, between 1999 and 2001. Hip prostheses used included the Exeter (Stryker Howmedica Osteonics, Mahwah, New Jersey), CPT and Harris-Galante (both Zimmer Inc, Warsaw, Indiana), and the knees were cemented Kinemax (Stryker) or PFC Sigma Knee System (DePuy Orthopaedics, Warsaw, Indiana).

The aim of our study was to determine the proportion of blood loss which is hidden, rather than to document actual blood losses. Therefore, to optimise accuracy, six TKR and ten THR patients with very high blood losses requiring large volumes of fluid resuscitation were excluded. The threshold chosen was 2 L and 1.5 L in THA and TKA patients, respectively. These figures were chosen, as beyond these levels, results deviated from the mean due to the effect of haemodilution on the calculations.

Management of blood loss. THAs were performed without using a re-infusion system. Bank blood was transfused during and after operation as indicated. Thirty-one patients (31%) required transfusion.

■ K. R. Sehat, MRCS,
Specialist Registrar in
Orthopaedic Surgery
Department of Orthopaedics,
Derbyshire Royal Infirmary,
London Road, Derby DE1
2QY, UK.

■ R. L. Evans, RGN Dip,
Research Audit Sister
■ J. H. Newman, FRCS,
Consultant Orthopaedic
Surgeon
Avon Orthopaedics Centre,
Southmead Hospital,
Westbury-on-Trym, Bristol
BS10 5NB, UK.

Correspondence should be
sent to Mr K. R. Sehat at 19
Covent Gardens, Radcliffe-
on-Trent, Nottingham NG12
2NF, UK.

©2004 British Editorial
Society of Bone and
Joint Surgery
doi:10.1302/0301-620X.86B4.
14508 \$2.00

J Bone Joint Surg [Br]
2004;86-B:561-5.
Received 23 April 2003;
Accepted after revision
8 September 2003

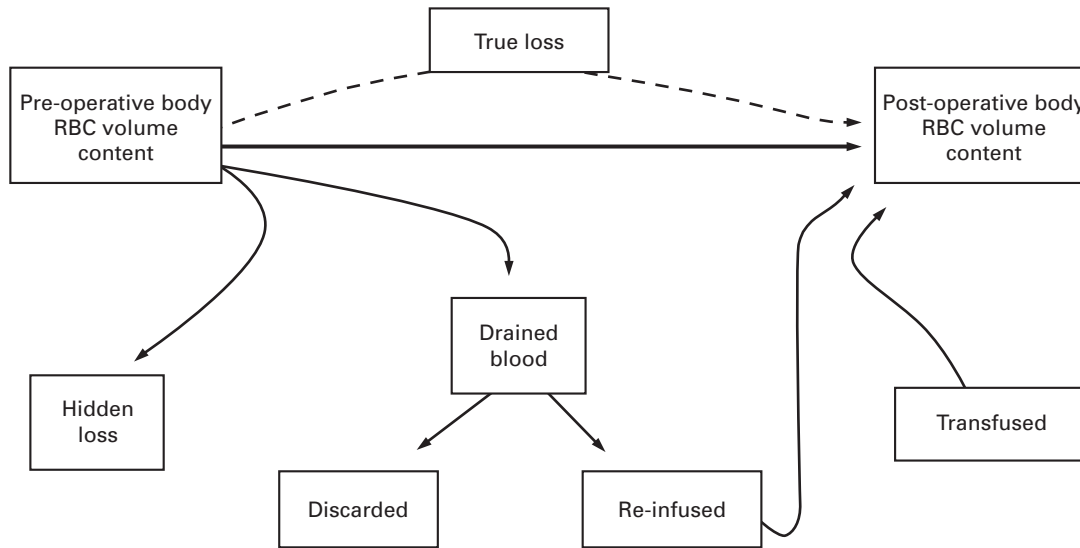


Fig. 1

Flowchart showing the movement of blood between the compartments involved in the peri-operative period.

All but two TKAs were performed under tourniquet, which was released at the end of the procedure after application of pressure bandaging. Thus, intra-operative loss was negligible in most cases. A tourniquet was not used in patients with circulatory disorders of the limb. Epidural anaesthesia was generally employed. TKA patients had drains connected to a post-operative blood salvage system, although not all were re-infused. No TKA patient received bank blood during the period of assessment. Re-infusion of drained blood was performed in the post-operative period. Blood was salvaged using the Dideco 797 Reinfusion apparatus (Sorin Biomedical Ltd, Midhurst, UK). This system maintains a constant suction pressure of -25 mmHg and adds citrate solution anticoagulant to the salvaged blood in a ratio of 1:12. Blood is passed through a 40 μ m filter without washing. When 500 ml has been collected or at least 200 ml has accumulated within six hours, the collected blood is re-infused. Otherwise, it is discarded, but the volume is still recorded.

Other measures in both TKA and THA patients. Prophylaxis against deep vein thrombosis was by means of foot pumps and compression stockings rather than anticoagulant agents.

All patients had a full blood count (FBC) including haematocrit (Hct) before operation and two to three days after. By this time, the patients were haemodynamically stable and thus fluid shifts would have been largely completed. The height and weight were recorded pre-operatively and the body mass index calculated. Visible blood loss in theatre was recorded by the anaesthetist and included the blood in suction bottles and in the weighed swabs. The post-operative drainage was recorded, as well as the volume of blood re-infused.

Calculation of the hidden blood loss. The patient's blood volume (PBV) can be calculated using the formula of Nadler, Hidalgo and Bloch:³

$$PBV = kl \times height (m)^3 + k2 \times weight (kg) + k3$$

where $kl = 0.3669$, $k2 = 0.03219$, $k3 = 0.6041$ for men;

$kl = 0.3561$, $k2 = 0.03308$, $k3 = 0.1833$ for women

Multiplying the PBV by the haematocrit will give the total red cell volume. Any change in red cell volume can therefore be calculated from the change in haematocrit⁴

Total red blood cell (RBC) volume loss = $PBV \times (Hct_{pre-op} - Hct_{post-op})$ ⁴

If a transfusion was performed, a unit of red cell concentrate containing the standard 200 ml of RBCs was used. The volume of whole blood drained or re-infused was measured and converted to the RBC volume using the patient's average haematocrit in the peri-operative period, having deducted the volume of citrate added in the re-infusion process.

As blood loss is occurring, the patient's circulating volume will tend to fall. However, simultaneous shift of fluid into the circulating compartment and fluid administered peri-operatively maintains the circulating volume, although with increasingly more diluted blood (i.e. isovolaemic haemodilution), and the haematocrit gradually falls. The RBC loss, as haemorrhage, continues logarithmically. In 1980 Ward et al⁵ published the mathematical solution to this, and the concept was taken forward by Gross in 1983.⁶ A new linear formula using the patient's average haematocrit during the peri-operative course was proposed. Gross tested this in patients undergoing surgery. It was found that the 'Gross' formula closely followed the logarithmic one unless there was substantial or brisk haemorrhage when the formulae drifted apart, thus the

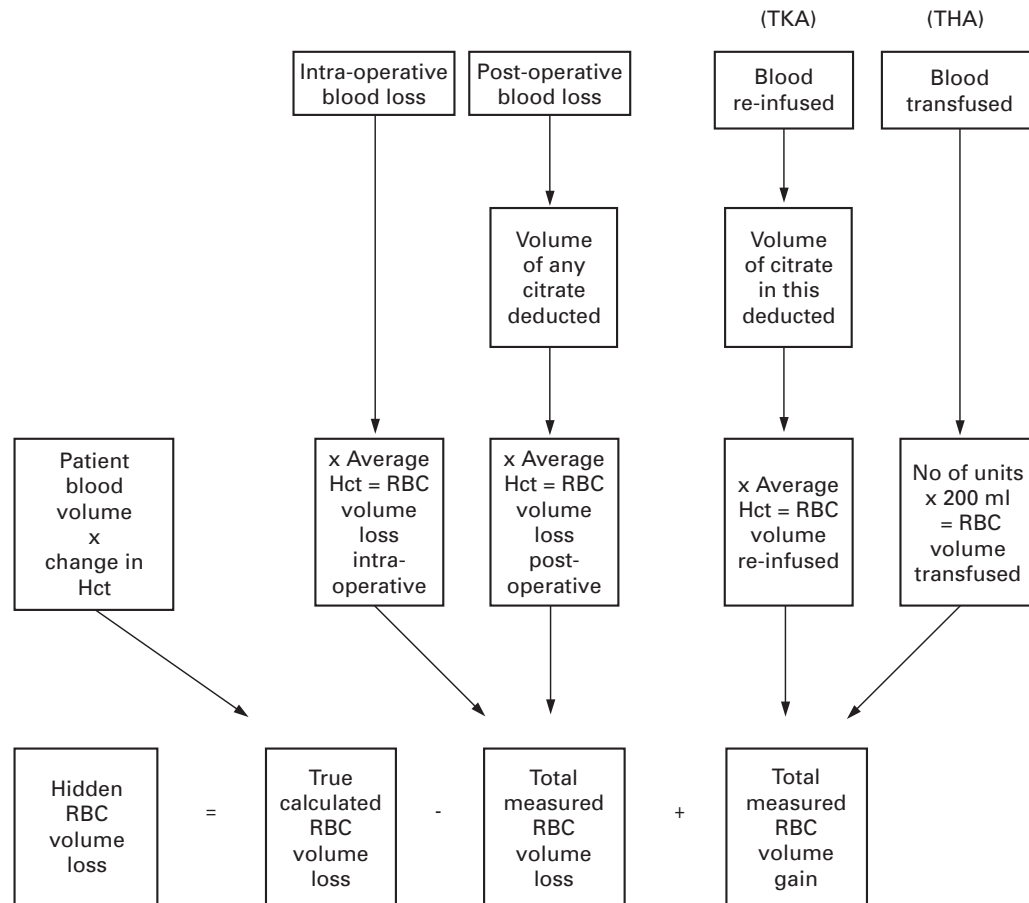


Fig. 2

Flowchart showing the data, as entered into the equation.

exclusion of cases with large losses from this study. The calculations in our study also used the average haematocrit as validated by Gross.⁶

If re-infusion of drained blood (TKAs) or transfusion of bank blood (THAs) takes place, the true loss calculated from the change in haematocrit is smaller than it should be, as re-infusion or transfusion will give the patient a higher haematocrit than would have been achieved without this input of blood. Thus the total loss is equal to the loss calculated from the change in haematocrit plus the volume re-infused or transfused. The hidden loss can then be determined by subtracting the visible loss from the calculated true total loss, then adding the volume re-infused or transfused. The results were converted to whole blood volume for each patient, again using their average haematocrit. If a transfusion had taken place, this would mean a different volume of whole blood in each patient once it had entered the circulating compartment. The equivalent whole blood volume transfused was therefore calculated for each patient individually using the average haematocrit in the peri-operative period during which transfusion took place.

Consideration was also given to the potential effect on calculations of peri-operative retention of body fluid. Studies in cardiac surgery, renowned for fluid retention, have demonstrated retention of approx 2 L.⁷ Fluid retention in orthopaedic surgery has not been accurately studied but could perhaps be significant. Since only one-eighth of body water is in the circulating compartment, which is, on average, 5 L,⁸ even 2 L of retained fluid would amount to a maximum of 5% inaccuracy in our calculations with no bearing on our conclusions. The methods of calculation are shown in Figures 1 and 2.

The mean values for hidden loss were determined for all THAs and TKAs, and separate analyses was made of the TKA subgroup with high drainage volumes who were re-infused and the subgroup with a small amount of drainage who were not. The table of results also states 95% confidence intervals (CIs) for mean values. Results which led to a direct comparison between two populations were analysed using the two-sample Student's *t*-test to determine the *p* value. Significance was attributed to a *p* value of <0.05. Statistical analyses were performed using Microsoft Excel Statistics Tool (Microsoft Corporation, Redmond, Washington).

Table II. The mean values of results obtained (95% CIs in parentheses)

	Number	Drainage (i.e. visible loss)	Volume of blood re-infused or transfused	Volume of drained blood discarded	Calculated blood loss (calculated from the change in haematocrit)	True total blood loss (i.e. hidden and visible loss)	Hidden loss	Hidden loss as a percentage of true total blood loss
THA	101	1039 ml (966 to 1112)	388 ml (266 to 509)	1039 ml (966 to 1112)	1122 ml (1021 to 1224)	1510 ml (1398 to 1623)	471 ml (379 to 563)	Mean 26% (21 to 31)
All TKAs	101	733 ml (670 to 796)	388 ml (322 to 454)	345 ml (296 to 395)	1110 ml (1019 to 1202)	1498 ml (1393 to 1603)	765 ml (669 to 861)	Mean 49% (45 to 53)
TKA with re-infusion	69	846 ml (781 to 911)	567 ml (508 to 627)	279 ml (229 to 328)	1041 ml (947 to 1135)	1608 ml (1493 to 1724)	762 ml (656 to 868)	Mean 45% (41 to 49)
TKA without re-infusion	32	489 ml (388 to 589)	-	489 ml (388 to 589)	1260 ml (1057 to 1464)	1260 ml (1057 to 1464)	772 ml (563 to 980)	Mean 58% (49 to 66)

Results

The mean values of the results obtained are shown in Table II. THA patients had a mean total true loss of 1510 ml. Their calculated hidden loss was 471 ml, which is 26% of the total loss (95% CI 21 to 31). Following TKA, the mean total blood loss was 1498 ml. The mean visible loss was 733 ml, and the mean hidden loss was 765 ml, 49% of the total loss (95% CI 45 to 53).

With TKA patients divided into subgroups which were re-infused or not, the total loss in the re-infused group was 1608 ml, the hidden loss being 762 ml. In the group who were not re-infused, the total loss was smaller at 1260 ml, but the hidden loss was similar at 772 ml. The difference in total loss between the two groups is to be expected as only those with significant loss were selected for re-infusion. However, the magnitude of hidden loss is similar (762 ml and 772 ml) and hence not influenced by re-infusion. It can be seen that there is a difference in the percentage of loss that is hidden, but we must bear in mind that this is dependent on the total loss which is less when re-infusion is used. Therefore this difference is not conceptually relevant. Thus THA results in a much smaller hidden loss than TKA ($p = 3.85 \times 10^{-11}$).

Closer analysis of the TKA group shows that in the re-infused subgroup 279 ml of drained blood was discarded as compared to 489 ml in the non-reinfused group, so one might expect a greater fall in haemoglobin in the latter group, and this was observed. The fall in haemoglobin was 3.3 if no re-infusion took place, as opposed to 2.8 if re-infused ($p = 0.035$).

Table III shows the fall in haemoglobin that occurred following TKA and THA. Although the haemoglobin level has not been used in our calculations, it is the common method of assessing peri-operative blood loss in clinical practice and these values are presented to illustrate the blood loss in terms of the fall in haemoglobin. We investigated the effect of obesity on hidden blood loss and the results are shown in Table IV. In both the THA and TKA, there was no significant difference ($p = 0.32$).

Discussion

This study demonstrates that both THA and TKA involve some hidden blood loss which is not recognised by the

Table III. Peri-operative change in haemoglobin (Hb) level (mean values)

	Pre-op Hb gm/dl	Post-op Hb gm/dl	Fall in Hb gm/dl
THA	13.5	10.5	3.0
All TKAs	13.9	10.9	3.0
TKA with re-infusion	14.0	11.2	2.8 ($p = 0.035$)
TKA without re-infusion	13.7	10.4	3.3 ($p = 0.035$)

Table IV. Percentage hidden blood loss, comparing obese and non-obese patients. There was no statistically significant difference between them

	Obese (BMI > 30) (%)	Non-obese (BMI < 30) (%)	
THA	30	25	NS
TKA	51	48	NS

usual practice of assessing intra-operative loss and post-operative drainage.

Re-infusion of drained blood following TKA reduces the need for transfusion,⁹ but some patients still remain anaemic despite this. The presence of a hidden loss helps to provide an explanation. The figure of 49% of hidden loss in TKA is higher than we expected but Table III shows a mean fall of haemoglobin following TKA of 3.0 gm/dl. This figure is much greater than can be attributed to the visible loss and therefore supports the presence of a substantial hidden loss.

THA also carries a large total true blood loss of a similar magnitude but the proportion of that loss that is hidden is much less. It would therefore appear that hidden blood loss greatly affects the management of TKA, but is a much smaller problem in THA. This may be due to the anatomy involved and it seems more likely that operating with a tourniquet and achieving haemostasis chiefly with a pressure bandage may predispose to the larger hidden blood loss seen after TKA.

Where can the hidden loss be found? Pattison et al¹⁰ demonstrated that the post-operative loss may be, at least, partly attributable to haemolysis and Faris et al¹¹ have shown increased levels of haemolysis in unwashed, fil-

tered blood that is re-infused. In their study, a mean volume of 1.3 L of blood was re-infused which produced a plasma haemoglobin level of 50 g per L in the patient. This level of haemolysis is not sufficient to produce haemoglobinuria, but it makes the re-infused blood less effective. However, two experiments by Erskine et al¹² and McManus et al¹³ have demonstrated, using labelled red cells, that the unexplained loss was attributable entirely to peri-operative bleeding, presumably into tissue compartments.

This study has shown that there is often a substantial hidden or unmeasured blood loss in TKA. In addition, when post-operative re-infusion with autologous blood is used, there may be a further deficit due to haemolysis in the re-infused blood. However, since the tissue loss is the same in both the group which was re-infused and that which was not the figures from this study question this. Re-infusion makes no difference to hidden loss and hence does not cause appreciable haemolysis. This is possibly attributable to the very low suction pressures used by the Dideco re-infusion system, but it may be greater with other methods.

No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this article.

References

1. Lotke PA, Faralli VJ, Orenstein EM, Ecker ML. Blood loss after total knee replacement: effect of tourniquet release and continuous passive motion. *J Bone Joint Surg [Am]* 1991;73-A:1037-40.
2. Sehat KR, Evans RL, Newman JH. How much blood is really lost in total knee arthroplasty?: correct blood loss management should take hidden loss into account. *The Knee* 2000;7:151-5.
3. Nadler SB, Hidalgo JU, Bloch T. Prediction of blood volume in normal human adults. *Surgery* 1962;51:224-32.
4. Bourke DL, Smith TC. Estimating allowable haemodilution. *Anaesthesiology* 1974;41:609-12.
5. Ward CF, Meathe EA, Benumof JL, Trousdale F. A computer nomogram for blood loss replacement. *Anaesthesiology* 1980;53:S126.
6. Gross JB. Estimating allowable blood loss: corrected for dilution. *Anaesthesiology* 1983;58:277-80.
7. Jarvela K, Kaukinen S. Hypertonic saline (7.5%) decreases perioperative weight gain following cardiac surgery. *J Cardiothorac and Vasc Anesth* 2002;16:43-6.
8. Guyton A. The body fluid compartments: extracellular and intracellular fluids, interstitial fluid and edema. In: *Textbook of medical physiology*. Eighth edition. Philadelphia. WB Saunders, 274-7.
9. Newman JH, Bowers M, Murphy J. The clinical advantages of autologous transfusion: a randomized, controlled study after knee replacement. *J Bone Joint Surg [Br]* 1997;79-B:630-2.
10. Pattison E, Protheroe K, Pringle RM, Kennedy AC, Dick WC. Reduction in haemoglobin after knee joint replacement surgery. *Ann Rheum Dis* 1973;32:582-4.
11. Faris PM, Ritter MA, Keating EM, Valeri CR. Unwashed filtered shed blood collected after knee and hip arthroplasties: a source of autologous red blood cells. *J Bone Joint Surg [Am]* 1991;73-A:1169-78.
12. Erskine JG, Fraser C, Simpson R, Protheroe K, Walker ID. Blood loss with knee joint replacement. *J Royal Coll Surg Edin* 1981;26:295-7.
13. McManus KT, Velchik MG, Alavi A, Lotke PA. Non-invasive assessment of post-operative bleeding in TKA patients with Tc-99m RNCs. *J Nuclear Med* 1987;28:565.