Effect of temperature on fluidity of irrigation fluids

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Key points
- The rate of intravasation of irrigating fluids during endoscopic prostatic or gynaecological depends partly on the physical properties of the irrigating fluids: these vary with temperature.
- In this laboratory study, the effect of temperature on intravasation rates of commonly used irrigation fluids was estimated.
- Estimated intravasation rate varied inversely with the temperature of the irrigating solutions.
- If confirmed in clinical practice, the use of warmed irrigating solutions (to prevent patient hypothermia) may potentiate intravasation and so reduce the safe duration of surgery.

Background. Fluid overload is a major complication during surgical hysteroscopy and transurethral resection of the prostate. We evaluated the role of temperature on absorption of the irrigation solution (IRRSOL) in endoscopic surgery when warm fluids are used to minimize hypothermia.

Methods. We measured the density and dynamic fluidity of five IRRSOLs (0.9% saline, Ringer’s lactate, 1.5% glycine, 5% dextrose, and 2.5/0.54% sorbitol/mannitol) at three different temperatures (17°C, 27°C, and 37°C). Next, a hypothetical typical endoscopic resection surgery was defined as the reference: total IRRSOL absorption (750 ml), resection time (30 min), and IRRSOL temperature (17°C). On the basis of Poiseuille’s law, we calculated new values for intravasation using the predetermined dynamic fluidity values at 27°C and 37°C to assess the influence of the IRRSOL temperature on intravascular absorption (under identical conditions) and then estimated the time to reach fluid overload at each temperature with both electrolyte and non-electrolyte IRRSOLs.

Results. Density and fluidity varied with temperature. In these specific conditions, when the temperature of the IRRSOL was increased from 17°C to 37°C, the mean absorption rate was predicted to increase about 54% and the theoretical ‘safe’ duration of surgery decreased by ~65%, for both electrolyte and non-electrolyte IRRSOLs. The reduction in the ‘safe’ duration of surgery averaged 21.1 min for non-electrolyte IRRSOL (reduced from 60.0 to 38.9 min) and 35.2 min when electrolyte IRRSOLs were used (reduced from 100.0 to 64.8 min).

Conclusions. Compared with cold fluids, isothermic IRRSOL may increase the risk of fluid overload because dynamic viscosity decreases at higher temperatures.

Keywords: fluids, irrigating; hysteroscopy; surgery, endoscopic; temperature; transurethral prostate resection; viscosity

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The systemic absorption of irrigation solutions (IRRSOLs) is a major risk factor for complications during hysteroscopy1 and transurethral resection of the prostate2 (TURP).3–5 During surgical resection, hydrostatic pressure is usually higher than intravascular pressures, mainly in the venous bed,6 allowing intravasation of IRRSOL from the surgical field to the intravascular space. The greater the difference between these hydrostatic pressures, the higher the flow rate into the blood and the higher the risk of fluid overload.7 Moreover, although it is important to control surgical time and to keep distension pressure as low as possible, fluid overload may occur before the predicted period.5–8

Currently, either bipolar or monopolar diathermy surgical technique is used to minimize bleeding during hysteroscopy and TURP. Although surgery can be performed with electrolyte IRRSOL when using bipolar cautery, a monopolar probe requires non-electrolyte fluids.9–10 Severe complications may occur with electrolyte IRRSOL,9–11 but fluid overload becomes particularly dangerous when non-electrolyte solutions are used because there is the additional risk of dilutional hyponatraemia and cerebral oedema.12–13

Hypothermia has been shown to increase surgical complications.14–16 Initially, attention was paid towards the theoretical haemostatic effects of locally applied cold IRRSOL used to avoid blood loss during TURP; the results of this were equivocal.17–18 More recently, the benefits of warm IRRSOL for maintaining the core body temperature and homeostasis without increasing blood loss or resection time (especially in older men undergoing TURP) have been realized.19–22

Although it has been shown that less IRRSOL may be used...
in patients receiving cold solutions,\textsuperscript{17} there have been no reports describing the influence of fluid temperature on the intravasation rate itself or on the risk of fluid overload. Therefore, we investigated the potential use of warm IRRSOL during endoscopic surgery, as a means to prevent hypothermia. If warmed IRRSOLs are used, one would expect an increase in the intravasation rate (flow) from physical principles. Our objective was to assess the influence of changes in IRRSOL temperature on dynamic fluidity and, consequently, on the potential absorption rate and risk of fluid overload.

**Methods**

We estimated intravasation rates during hypothetical endoscopic resection surgeries by measuring the physical properties of five common IRRSOLs at three temperatures. Theoretical intravasation rates were calculated according to Hagen–Poiseuille’s law (‘Poiseuille’s law’),\textsuperscript{23} which describes the laminar flow of an incompressible uniform viscous liquid (Newtonian fluid) through a cylindrical tube with a constant cross-section.

**Determination of density and dynamic fluidity**

The density, dynamic viscosity, and fluidity of five IRRSOLs at three temperatures were measured, according to Faria and colleagues,\textsuperscript{24} we chose typical solutions that are used during hysteroscopy and TURP.

Previous measurements of the temperature of saline in our operating theatres were 17–19°C (IFF-FIOCRUZ, Rio de Janeiro, Brazil), so we chose 17°C (290 K) as the minimum temperature, 37°C (310 K) to represent the typical temperature when at equilibrium with the body, and 27°C (300 K) being midway between these two. In fact, 27°C may approximate the actual environmental conditions in tropical countries such as Brazil, without air conditioning (e.g. if the solution bags are stored outside the operating theatre). The three non-electrolyte IRRSOLs were 1.5% glycine (200 mOsm kg\textsuperscript{-1}), a solution of 2.7/0.54% sorbitol/mannitol (178 mOsm kg\textsuperscript{-1}), and 5% dextrose in water (277 mOsm kg\textsuperscript{-1}). The two electrolyte solutions were Ringer’s lactate (273 mOsm kg\textsuperscript{-1}) and 0.9% normal saline (308 mOsm kg\textsuperscript{-1}).

We determined the dynamic viscosity of each fluid by measuring its respective efflux time\textsuperscript{24} with measurements repeated five times at each temperature (17°C, 27°C, and 37°C) and the mean values used to calculate the respective dynamic fluid viscosity. The efflux times were measured with Cannon–Fenske viscosimeters (Schott-Geräte) (internal diameter 0.54 mm, calibrated and certified by the manufacturer). The viscosimeters were coupled to an automatic module (Schott-Geräte, model AVS 350) and then immersed in a thermostatic bath (Schott-Geräte, model CT 1450/2), controlled to within ± 0.01 K. The uncertainty in the efflux time was 0.01 s. For the conversion of efflux time to viscosity, the following equation was used:

\[ \eta = \frac{k(t - \omega)}{\rho} \]

where \( k \) is the viscosimeter constant, \( t \) the efflux time, \( \omega \) the Hagenbach correction (taken from the viscosimeter manual, Schott-Geräte), and \( \rho \) the density. Solution densities were previously measured with a digital viscosimeter (Anton Paar, model DMA 4500) with an uncertainty of \( 5 \times 10^{-5} \) g cm\textsuperscript{-3}. For all samples, and for each temperature, density was measured at least twice; a third measurement was made only if the difference between the two measurements was \( > 3 \times 10^{-5} \) g cm\textsuperscript{-3} (according to routine laboratory procedures). The cell temperature of the density meter was controlled to within ± 0.01 K. Tridistilled water and dry air were used to calibrate the instrument. The uncertainty in the dynamic viscosity was \(< 2 \times 10^{-3}\) mPa s; respective dynamic fluidities were calculated as the reciprocal of viscosity.

**Intravasation rate: estimations based on fluidity values**

Theoretically, dynamic fluid viscosity (and fluidity) remains nearly constant if the vessels are not very small and the temperature remains constant. We also assumed that IRRSOLs show Newtonian behaviour, because the Fahraeus–Lindqvist effect does not occur (viscosity does not change with the diameter of the tube). Hence, theoretical intravasation rates (flow) could be expressed as a linear function of dynamic fluidity according to Hagen–Poiseuille’s law:

\[ \text{Intravasation rate (flow)} = \frac{dV}{dt} = \frac{\pi R^4 |\Delta P|}{8 \eta L}, \]

where \( R \) is the internal radius of the tube, |\( \Delta P \)| the pressure decrease between the two ends (surgical field and intravascular compartment), \( \eta \) the dynamic fluid viscosity (fluidity\textsuperscript{-1}), and \( L \) the total length of the tube system (i.e. opened cut vessels).

Because, in theory, the hypothetical controlled system parameters (\( R \), |\( \Delta P \)|, and \( L \)) were kept constant, estimations of the new intravasation rate should reflect only changes in the fluid composition and temperature (i.e. fluidity). Using hypothetical values at 17°C for mean absorption (Table 1) and actual values of fluidity (Fig. 1), we found the constant \( \pi R^4 |\Delta P|/BL \) for each case. Then, we estimated intravasation rates for each fluid at each temperature as follows:

\[ \text{Intravasation rate (flow)} = F \cdot C, \]

where \( F \) is the dynamic fluidity and \( C \) the constant \( \pi R^4 |\Delta P|/BL \). Assuming that the duration of each endoscopic resection surgery is the same, no matter the magnitude of fluid temperature,\textsuperscript{20} we calculated (for each case) new values for the total absorbed fluid volume at 27°C and 37°C by multiplying the surgical time of each surgery by the respective new mean absorption rate value (Table 1).

We assumed that the distension pressure remained constant. We also assumed that oscillations in both distension and intravascular pressures were identical in all cases. Other theoretically controlled variables included: depth of
cuts (with resectoscope), internal radius (cross-section) of the cut vessels, duration of surgery, uterine cavity size (i.e. hysterometry), endometrial status and permeability of the Fallopian tubes (if hysteroscopy), prostate weight (if TURP), equipment, body area or BMI, external fluid circuits, and the ability and strategy of the physicians (surgeons and anaesthetists).

For the primary endoscopic surgery, which was theoretically performed with IRRSOL at an ambient fluid temperature of 17°C (comparable with the actual fluid temperature that we use in our operating theatre), we chose hypothetical baseline values as follows: total intravasation 750 ml after 30 min of resection (mean absorption rate 25 ml min\(^{-1}\)). Then, new values for intravasation rate and total intravasation were calculated according to Poiseuille’s law for each solution at 27°C and 37°C (see text for details).

### Results

#### Density and dynamic fluidity variation from 17°C to 37°C

As expected, the dynamic fluidity increases and the fluid density (although more slowly) decreases with temperature. Actually, variations in density were almost imperceptible in this temperature range (Fig. 1).

#### Intravasation rate: estimations based on fluidity values

With respect to specific baseline values (Table 1; in grey), when the temperature of the IRRSOL increased from 17°C to 37°C, the mean absorption rate was predicted to increase by ~54% (changing from 25.0 to 38.6 ml min\(^{-1}\)). Because mainly the dynamic fluidities changed, the predicted time limits for fluid overload were inversely proportional to the

<table>
<thead>
<tr>
<th>Irrigation solutions</th>
<th>Intravasation (ml)</th>
<th>Mean absorption (ml min(^{-1}))</th>
<th>Limit to stop (min)</th>
<th>Electrolytic solution (yes/no)</th>
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<tbody>
<tr>
<td>Glycine 1.5%</td>
<td>750</td>
<td>25.00</td>
<td>60.0</td>
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<td>750</td>
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<tr>
<td>Dextrose 5%</td>
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<td>25.00</td>
<td>60.0</td>
<td>No</td>
</tr>
<tr>
<td>Ringer’s lactate</td>
<td>750</td>
<td>25.00</td>
<td>100.0</td>
<td>Yes</td>
</tr>
<tr>
<td>Saline 0.9%</td>
<td>750</td>
<td>25.00</td>
<td>100.0</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Table 1

<table>
<thead>
<tr>
<th>Intravasation (ml)</th>
<th>Mean absorption (ml min(^{-1}))</th>
<th>Limit to stop (min)</th>
<th>Decrease in safe time (%)</th>
</tr>
</thead>
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<tr>
<td>Glycine 1.5%</td>
<td>945</td>
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<td>Sorb/manit 2.7/0.54%</td>
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<td>Ringer’s lactate</td>
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<tr>
<td>Saline 0.9%</td>
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<td>31.80</td>
<td>78.6</td>
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### Table 2

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<th>Intravasation (ml)</th>
<th>Mean absorption (ml min(^{-1}))</th>
<th>Limit to stop (min)</th>
<th>Decrease in safe time (%)</th>
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<td>Glycine 1.5%</td>
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<td>Sorb/manit 2.7/0.54%</td>
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<td>Dextrose 5%</td>
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<td>38.9</td>
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<tr>
<td>Ringer’s lactate</td>
<td>1160</td>
<td>38.67</td>
<td>64.7</td>
</tr>
<tr>
<td>Saline 0.9%</td>
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<td>38.53</td>
<td>64.9</td>
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</table>
temperature for all solutions. As a consequence, the theoretical safe duration of surgery decreased by \(\approx 65\%\) for both non-electrolyte and electrolyte solutions from 17°C to 37°C. Absolute values averaged 21.1 min (decreasing from 60.0 to 38.9 min) for surgeries using non-electrolyte solutions and 35.2 min (decreasing from 100.0 to 64.8 min) when electrolyte solutions were chosen (Table 1).

**Discussion**

In this study, the physical properties of five different IRRSOLs were determined at three different temperatures (17°C, 27°C, and 37°C). We used actual values of density and dynamic fluidity (determined in the laboratory) and a simplified theoretical model (Hagen–Poiseuille's law). The density of the fluids changed as a function of temperature; however, the observed differences between 17°C, 27°C, and 37°C were irrelevant for practical purposes (<1%). In contrast, the changes in dynamic fluidity were greater, which should be of concern to surgeons and anaesthetists. Furthermore, under otherwise identical conditions, the fluid absorption rate during endoscopic resection surgery was predicted to be directly proportional to fluid temperature. It appears that the main consequence of fluidity changes is to affect the time to overload, which decreases when warmer solutions are being used, because temperature can change dynamic fluidity and, consequently, the flow through a hypothetical tube system (here compared with cut vessels).

Kulatilake and colleagues\(^1\) found no significant differences in blood loss or in mean operating time, when TURP was carried out with cold IRRSOL (8°C) rather than with IRRSOL at room temperature (not specified). Curiously, they did not test the influence of temperature on intravasation itself and they found statistically significant differences in the consumption of IRRSOL. When their surgeries were performed with an IRRSOL at a temperature of 8°C, the IRRSOL consumption was reduced by 39.0%. Walton and Rawstron\(^2\) reported a small reduction in blood loss when TURP surgeries were carried out with very cold distension media (2°C). Unfortunately, data concerning intracavitary pressure, fluid temperature in the ambient group, and, in particular, fluid balance with respective estimates of intravasation were not reported. In addition to the intrinsic temperature-dependent fluidity changes, the flow is directly proportional to the fourth power of the internal radius of tubes (i.e. vessels). This suggests that cold irrigation fluids may decrease absorption, since the vasoconstriction reflex of cut vessels to lower temperature decreases their cross-section significantly. Therefore, this hypothesis should be tested in real patients, in order to evaluate the complex interactions that likely occur among a
mechanically distended cavity, the fluid kinetics driven by hydrostatic and osmotic pressure differences, and the physiological system response during endoscopic resection surgery (not considered in this study).

Despite the current controversies about platelet functions during hypothermia, a nearly constant core body temperature should be maintained in order to retain biological homeostasis, normal oxygen balance, and coagulation status. In practice, hypothermia often occurs during endoscopic resection surgery even if isothermic IRRSOLs are used. This may be explained by a decrease in fluid temperature while bags are being emptied, body exposure to cold air and solutions in the operating theatre, and physiological alterations secondary to anaesthesia.

Alterations in the redistribution of body heat are the major initial cause of hypothermia in patients administered general or regional anaesthesia. Although epidural or spinal anaesthesia may be helpful because redistribution during neuraxial anaesthesia is typically restricted to the legs, the use of general anaesthesia may be advantageous because it may permit earlier hospital discharge. However, when compared with general anaesthesia, regional techniques (per se) improve neither irrigation fluid absorption nor safety, and intraoperative shivering may be a problem during surgery under regional blockade because of movements during endoscopic resection especially with cold IRRSOL.

Fluid absorption through Fallopian tubes may also vary according to temperature as the dynamic fluidities of fluids will increase as their temperature increases. Thus, when warmed, fluids tend to flow more easily from the higher to the lower pressure compartments. Also, our experience performing laparoscopic surgery immediately after complex operative hysteroscopy supports data from Molnar and colleagues, who found no major effect of tubal patency on fluid balance. Especially when we are assuming (distension pressure below 100 mm Hg), we believe that no significant amount of distension medium could flow through tubal ostia.

During hypothermia, shivering increases oxygen consumption and surgical bleeding. Older patients are more susceptible to shivering and to other hypothermia-related complications, including myocardial morbidity and a higher relative risk for transfusion. With respect to intravasation and risk of fluid overload, the resection time limit should be shorter in the elderly. Elderly patients undergoing TURP usually do not tolerate rapid increases in preload, and hyponatraemia occurs with lower fluid absorption volumes because the total body water is decreased. Fortunately, patients undergoing hysteroscopy for complex multiple myomectomy are mostly young and often otherwise healthy. Thus, cold IRRSOL may benefit the younger patient population without major negative consequences, whereas the elderly undergoing TURP are at higher risk for both hypothermia and fluid overload.

The present study suggests that intravasation flow may increase significantly at higher temperature. On the basis of actual fluid measurements combined with the specifics of human physiology, our data predict a lower risk of fluid overload in endoscopic resection procedures when a colder IRRSOL is used. It is uncertain as to whether these benefits will translate into clinical practice in the absence of data from randomized clinical trials. Although some flow is often necessary for irrigating and cleaning the surgical field during resection, the bladder and uterus may warm fluids (at least slightly) by direct contact. Therefore, we suggest that future trials should consider the effects of using IRRSOL temperatures as low as possible.

In conclusion, we believe that isothermic IRRSOL may increase the risk of fluid overload when compared with cold or ambient fluids because dynamic viscosity decreases at higher temperatures (subject to controlled evaluation in clinical trials). Warm IRRSOL may worsen the benefit/risk profile.

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Conflict of interest

None declared.

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