Research Summary

Relevant research regarding the use of pneumatic tube systems for blood product transport in healthcare facilities

This research summary is for healthcare professionals charged with the safe and timely transport of blood products via a pneumatic tube system (PTS.) Whether you work in a hospital, clinic or blood bank, the research findings presented herein offer scientific background relevant to your selection, validation and use of a tube system in your environment. That's important given how extensively PTS solutions are used for the transport of blood products in healthcare settings (see Table 1.)

In order to be included in this report, studies were evaluated against the following criteria:

- Studies directly relevant to the transportation of blood products via PTSs, with preference for recently published content
- Peer-reviewed studies
- Published research presented in respected industry journals
- None of the studies referenced were commissioned, paid for, nor sponsored by Swisslog

For your convenience, we provide links to the Pub Med research website abstracts or, in some cases, to the full-text studies. Full-text articles are typically available for a fee or by signing up at their respective journal/publisher pages.

We urge you to review the content with your specific healthcare facility and transport needs in mind. Take notes. Write down questions. Then, contact a Swisslog PTS specialist at 303-371-7770 or healthcare.us@swisslog.com to discuss your particular issues or needs. Or visit our Blood and Specimen Transport page to learn more.

How this research summary is organized

This report is designed to offer an easy-to-follow format, providing the study title, followed by the primary conclusion, along with key findings. This allows you to review each item at a glance. Hyperlinks to the study abstract or full-length report are included to make it easy for you to access research that piques your interest.

This research summary is subdivided into three sections as follows:

Section 1 summarizes recent blood product PTS transport studies.

Section 2 provides an in-depth roundup of pertinent blood PTS studies. While some of the references are dated, many represent the most recent research available on specific topics.

Section 3 compiles a list of additional resources to aid you in your blood product PTS research. Most are hyperlinked to give you prompt access to the listed materials.

Table 1: Pneumatic tube systems are used to transport:

Blood Products	% who use PTS
Blood Specimens:	67.7%
Blood Cultures:	50.0%
Blood Bags:	38.6%
Blood Gases:	24.0%

Other Uses	% who use PTS
Pharmacy orders and medications:	81.7%
IV Bags:	74.7%
STAT Meds:	63.9%

[Source: 2013 Swisslog Material Transport Survey of PTS owners/operators]

Section 1 — A Summary of Recent Blood Product Transport Studies

The pneumatic tube system does not affect complete blood count results; a validation study at a tertiary care hospital.[1]

Conclusion
"Modern PTS can be safely used for transporting CBC [complete blood count] samples."

Key Findings
One-hundred and fifteen blood samples were tested in a lab to compare the integrity of samples transported via a pneumatic tube system (PTS) versus a courier.

- "Most of the differences in measurement of all CBC parameters were within the 95% confidence interval of the mean difference on Bland-Altman plots."
- "There was excellent correlation between both methods for red blood cell parameters (r range=0.9213-0.9958) and platelet count."
- "White blood cell (WBC) count and differential count showed similar results (r range=0.8605-0.9821) for all, with exception of basophils which showed modest correlation (r = 0.4827 for patients and 0.5758 for normal donors)."

The effects of transport by pneumatic tube system on blood cell count, erythrocyte sedimentation and coagulation tests.[2]

Conclusion
"...the PTS can be used to transport blood samples and yield reliable results for blood cell counts, erythrocyte sedimentation, and several coagulation tests."

Key Findings
'Paired blood samples were separated into groups 1 and 2 and transported to the lab via a PTS or by courier respectively. The samples were tested for blood cell counts, erythrocyte sedimentation, PT and aPTT.'

- "The blood sample test results from groups 1 and 2 were evaluated and compared. No statistically significant differences were observed (P = 0.069-0.977)."

Pneumatic tube transport affects platelet function measured by multiplate electrode aggregometry.[3]

Conclusion
"We advise against clinical decisions regarding platelet function on the basis of samples sent by PTS in our hospital settings."

Key Findings
"We evaluated the effects of PTS transport on platelet function as measured by MEA. Duplicate samples were collected from 58 individuals. One sample was sent using PTS and the other was carried by personnel to the lab."

- "Bias±95% limits of agreement for the ADP test were 26±56% of the average."
- "Bias±95% limits of agreement for the ASPI test were 16±58% of the average."
- "Bias±95% limits of agreement for the COL test were 20±54% of the average."
- "Bias±95% limits of agreement for the RISTO were 14±79% of the average."
- "Bias±95% limits of agreement for the TRAP test were 19±45% of the average."

Sample transport by pneumatic tube system alters results of multiple electrode aggregometry but not rotational thromboelastometry.[4]

Conclusion
"The authors recommend sample transport by hand or the device to be placed patient-side when MEA is performed."

Key Findings
"Whole blood samples from patients undergoing general or trauma surgery were analysed by MEA after collection (baseline, '0 × PTS') and sent on a predefined PTS track (n = 12). MEA was repeated after samples travelled the track 4 ('4 × PTS'), 8 ('8 × PTS') and 12 times ('12 × PTS') and compared with stationary controls analysed at the same time. An acceleration detector recorded g-forces on the PTS track."

- "At '0 × PTS' no significant differences in MEA results were detected."
- "Values were significantly lower for transported samples compared with controls ('4 × PTS' to '12 × PTS', < 0.001)."
- "MEA results of PTS samples were significantly decreased for '4 × PTS' to '12 × PTS' compared to baseline ($p < 0.001$)."
- "Except for the clotting time in EXTEM PTS transport did not significantly alter results for investigated ROTEM® parameters, compared with baseline and stationary controls."
- "Acceleration detector readout revealed alternating g-forces between -6.3 and +5.9 during transport."
    - "PTS transport caused invalid results in MEA while only one ROTEM® parameter was found to be affected in this study."
    - "Variable acceleration during transport provides a potential reason for platelet activation."

Identifying the potential of changes to blood sample [delivery] logistics using simulation.[5]

Conclusion
"As a consequence of the results obtained in the study, the hospital decided to implement a pneumatic tube system."

Key Findings
'A simulation model was used to evaluate the efficiency of the transportation of blood samples between a Danish hospital's wards and the laboratory. The average wait time (AWT) and maximum wait time (MWT) for a sample to be delivered to the lab were analyzed across four different transport solutions: 1. AGVs, 2. PTS, 3. Couriers when summoned, and 4. Couriers on a 45-minute round schedule.'

- "The pneumatic tube system showed the biggest potential [for] lowering the AWT and MWT [of blood sample deliveries] with approx. 36% and 18%, respectively."

The effect of pneumatic tube system on complete blood count parameters and thrombocyte donation in healthy donors.[6]

Conclusion
"...all healthy volunteers decided as a donor according to the laboratory results independent from transport method."

Key Findings
"Paired blood samples of 26 healthy volunteers were transported by either hand or a pneumatic tube system to the laboratory."

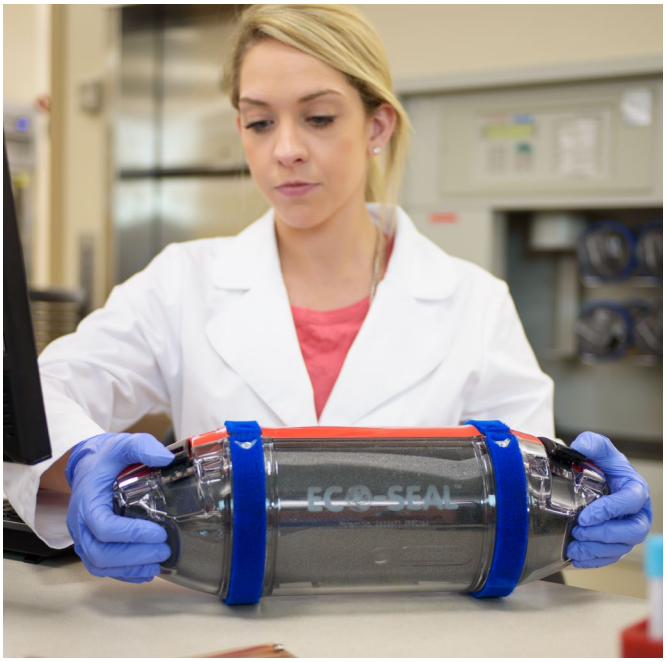
- "No statistically significant differences were observed in order to mean values of routine complete blood cell count and white cell differential parameters that were send for selection of apheresis donor before the procedure."

Random variation and systematic error caused by various preanalytical variables, estimated by linear mixed-effects models.[7]

Conclusion
"The specific sample handling had significant but small random and systematic effects on results for some analytes."

Key Findings
"Blood was collected into 4 serum-separation tubes from each arm of 60 outpatients. In 30 of the patients, half of the tubes were transported in the pneumatic tube system, while the other half were manually delivered."

- "Transporting samples in the pneumatic tube system caused a significant bias to the results for LD (4.5 U/L, p<0.001) and magnesium (0.0021 mmol/L, p=0.003)."
- "For CK and glucose, the preanalytical variation was significantly higher for samples transported in the pneumatic tube system vs manual delivery."
- "Using butterfly needles resulted in lower values (p<0.05) for calcium (-0.0072 mmol/L), CK (-0.75 U/L) and LD (-1.6 U/L) compared with 21-gauge needles."
  - "The preanalytical variation for ALP was significantly higher with butterfly needles."



Effect of acceleration forces during transport through a pneumatic tube system on ROTEM® analysis.[8]

Conclusion
"Acceleration forces during transport through a pneumatic tube system have an influence on ROTEM® parameters. Prior to transfer blood samples via pneumatic tube system these influences should be tested to exclude clinically relevant blood coagulation activation in vitro."

Key Findings
"Five whole blood samples were transferred to the central haematology laboratory by either normal transport or pneumatic delivery with different speed and acceleration forces. EXTEM, INTEM, FIBTEM and APTEM were analysed in parallel with two ROTEM® devices and compared. Acceleration forces were measured during transport with two different instruments."

- "Increment of transport time, speed and distance resulted in an augmentation of acceleration forces and peaks."
- "All results of the ROTEM® analysis after manual transport or pneumatic delivery were within normal range."
- "[An] increase in acceleration forces resulted in minimally but statistically significant changes in multiple ROTEM® parameters."
  - "The higher the acceleration forces, the more ROTEM® parameters are influenced."

Effect of pneumatic tube delivery system rate and distance on hemolysis of blood specimens.[9]

Conclusion
"The rate of hemolysis in PTS transported samples, dependent on PTS length and rate, may seriously affect routine tests of non-centrifuged samples."

Key Findings
"We evaluated the effects of pneumatic tube system (PTS) transport rates and distances on routine hematology and coagulation analysis. PTS effects on centrifuged blood samples were also examined. Blood samples were collected at three different locations within the hospital and an emergency department, and delivered to the central laboratory by the PTS or a human carrier."

- "A positive correlation was observed between distance and hemolysis in serum samples transported at 4.2 m/sec, and at 3.1 m/sec for more than 2200 m ($r = 0.774$ and $r = 0.766$, respectively)."
- "Distance and hemolysis were also correlated in non-centrifuged samples ($r = 0.871$)."
- "The alterations in plasma LDH and K levels at different rates and PTS lengths were not statistically significant."

Laboratory-based ROTEM(®) analysis: implementing pneumatic tube transport and real-time graphic transmission.[10]

Conclusion
"At our institution, transport of blood samples by pneumatic delivery does not influence ROTEM(®) parameters."

Key Findings
"Two whole blood samples were transferred to the central haematology laboratory by either normal transport or pneumatic delivery. EXTEM, INTEM, FIBTEM and APTEM were analyzed in parallel with two ROTEM(®) devices and compared."

- "No statistically significant differences between normal transport and pneumatic delivery were observed."
- "All collected ROTEM(®) parameters were within normal limits."

Agreement between paired blood gas values in samples transported either by a pneumatic system or by human courier.[11]

Conclusion
"...samples transported through the PTS resulted in clinically unacceptable PaO_2 values. Delay in transport and analysis of ABG samples should be avoided and samples transported manually if they cannot be assessed on-site."

Key Findings
"We evaluated if arterial blood gas (ABG) samples transported through a pneumatic tube system (PTS) agreed with values transported by a human courier."

- "The mean (±SD) time from sampling to analysis was 35.7±23.2 (courier) and 38.6±22.1 (PTS) minutes."
- "Agreement was good between courier and PTS for pH, $PaCO_2$, bicarbonate, oxygen saturation and PaO_2 values (pc>0.97)."
- "Although the mean difference in PaO_2 values between PTS and courier was small (-0.9 mm Hg) and the agreement was good, individual differences were clinically significant (95% LOA -40.8 to 39.0)."
- "For PaO_2 <160 mm Hg, analysis of PTS samples yielded erroneously high PaO_2 values and vice versa for PaO_2 >160 mm Hg compared to manual courier. This suggested exaggerated oxygen movement between the blood sample and air in the PTS."

Determination of hemolysis thresholds by the use of data loggers in pneumatic tube systems.[12]

Conclusion

"Assessment of 3-axis acceleration by use of data loggers can be used to identify preanalytical deviations that result from the transportation of blood samples in PTSs. Our approach could be used for the evaluation and regular control of PTSs without the need for repeated blood drawing and laboratory analyses."

Key Findings

"We drew duplicate blood samples from 30 volunteers. One sample was hand transported, and the other sample was transported through a PTS together with a mini-data logger that provided continuous measurements of temperature, humidity, pressure, and acceleration."

- "There were no significant differences in temperature, humidity, and pressure between the methods of transport…"
- "…we observed significant differences in 3-axis accelerations."
  - The combined effect of these forces could be described by the right-tailed area under the vector sum acceleration distribution.
- "Our data show that this area correlated with PTS speed and that PTS speed and the area under the curve exhibited a direct relation to the degree of hemolysis."

Assessment of platelet function in whole blood by multiple electrode aggregometry: transport of samples using a pneumatic tube system.[13]

Conclusion

"The present study demonstrates that transport of correctly prepared samples by a state-of-the art PTS for platelet aggregation tests using the Multiplate device does not alter the results of platelet function testing."

Key Findings

"A pair of blood samples from 20 consecutive patients scheduled for coronary angiography was collected into tubes containing the anticoagulant hirudin. Immediately after collecting the blood sample, one tube was packed into a plastic bag, placed in a pneumatic tube container, and sent to the central laboratory with a transport time of less than 1 minute. The other tube was transported on foot by a human courier."

- "Transport of correctly prepared samples for platelet aggregation tests using the Multiplate device can be done with a state-of-the art PTS."
- "Concerning the PTS, it is important that acceleration and deceleration phases, particularly at bends, transfer units, and at the terminal stop in the laboratory, are minimized. Different hospitals may use different transport systems and different blood collecting tubes. Therefore, it is recommended that each institute evaluate its own systems."

Pneumatic tube delivery system for blood samples reduces turnaround times without affecting sample quality.[14]

Conclusion
"The use of a pneumatic tube delivery system for transporting blood samples from the emergency department to the laboratory can significantly reduce the turnaround times of results without a reduction in sample quality."

Key Findings
"In this study, blood samples from ED patients that were delivered to the laboratory by a pneumatic tube delivery system and by a human courier were compared for timeliness and quality of results."

- "There was no significant difference in hemolysis rate between the 2 methods of delivery (7/121 [5.79%] with a pneumatic tube system and 20/200 [10%] with a human courier)."
- "When delivered with a pneumatic tube system, the mean turnaround times (with ranges) for both hemoglobin (33 minutes [4-230]) and potassium (64 [34-208]) were shorter than those delivered by a human courier (43 minutes [3-150] and 72 [28-213], respectively)."

Speed of sample transportation by a pneumatic tube system can influence the degree of hemolysis.[15]

Conclusion
"Hospitals should validate their PTS before use and, by altering speed of sample transportation, hemolysis may be obliterated."

Key Findings
'Fifty-two, 215 and 45 serum tube pairs, respectively, were evaluated according to three PTS speed/distance phase tests: "short distance and high speed (115 m at 3 m/s)", "long distance and high speed (225 m at 3 m/s)" and "short distance and slow speed (115 at 2 m/s)".'

- "Mean transit time of samples through the PTS was much shorter as compared to human courier in all three phases."
- "LD was elevated in PTS arm in the "short distance and high speed" phase and in the "long distance and high speed" phase, all three indices of hemolysis - Hb, K+ and LD - showed elevation in the PTS arm. However, at "short distance and slow speed" phase, there was no hemolysis in the PTS arm."

The effect of a pneumatic tube transport system on platelet aggregation using optical aggregometry and the PFA-100.[16]

Conclusion
"...pneumatic tube sample transport impairs the platelet aggregation. Therefore, we recommend the manual transport of whole blood samples which are collected for optical aggregometry or PFA-100 analysis."

Key Findings
"Blood samples from 15 healthy subjects were collected before and after treatment with acetylsalicylic acid. Sample tubes were transported by pneumatic tube transport while the corresponding sample tubes were hand-delivered."

- "Using the collagen-induced optical aggregometry a significant decrease of the aggregation amplitude (n = 30) was observed in tubed samples in comparison to the corresponding hand-delivered samples (low collagen concentration: 52.5% vs 56.1%, p = 0.006; and high collagen concentration respectively: 63.9% vs 67.1%, p = 0.011)."
- "...a slight prolongation of the PFA-100TM closure time for the epinephrine/collagen and the ADP/collagen stimulation was found in the tubed samples compared to the hand-delivered samples."

Pre-analytical effects of pneumatic tube transport on impedance platelet aggregometry.[17]

Conclusion
"...clinical decisions regarding platelet function and aspirin responsiveness should not be based on blood specimens transported by a PTS system."

Key Findings
"The aim of this study was to evaluate the influence of a pneumatic tube system (PTS) for specimen transport on impedance platelet aggregometry."

- "PTS transport had a significant influence on platelet function testing by the Multiplate® analyzer. Significantly fewer test results indicated normal platelet function in TRAP test and reduced aspirin responsiveness in ASPI test after PTS transport."
- "In the reference measurements, 48/50 (96%) of TRAP values were within the normal range. After PTS transport, 35/50 (70%) of TRAP measurements in the central laboratory were within the normal range ($p < 0.001$). Mean +/- SD for ASPI test was 175 +/- 137. Bias +/- 95% limit of agreement for ASPI test were 12 +/- 109 ($n = 25$) for untransported and 68 +/- 250 ($n = 25$) for PTS transported samples. In the reference measurements, 7/50 (14%) ASPI values were above the cut-off level and defined as reduced aspirin responsiveness."

An episode of increased hemolysis due to a defective pneumatic air tube delivery system.[18]

Conclusion
"Laboratories should be aware that defects may arise in tube systems that may result in rapid sample deceleration and excessive hemolysis."

Key Findings
"Hemolysis rates in samples delivered with a [pneumatic] tube system installed 3-4 months previously were followed up retrospectively and prospectively. The laboratory database was searched over a 3-year period for serum potassium results and the number of hemolyzed samples rejected that had been delivered by pneumatic tube or by hand."

- "Before the tube system was installed, the weekly mean hemolysis rate was 3.3%. After installation, the rate was 10.9% for 12 weeks but then it increased to 54%."
- "After a fault was corrected, values fell to 9.0% and to 7.1% after samples were bubble-wrapped."

Section 2—A Roundup of Blood Product Transport Studies

Section 2 features the findings collected in a round-up article published by Chris Higgins at acutecaretesting.org. The scope of the Higgins report is broad, and the studies he reviews are directly relevant to your interest in blood product transport via pneumatic tube systems. Consequently, this section includes summaries for many of the 18 references cited in his bibliography.

While Higgins' article focuses on practical considerations for sensitive blood gas handling they address other important issues such as the reliability of PTS solutions, turnaround time (TAT), point of care testing (POCT), satellite laboratory testing and more.

Please keep in mind that the research results are based on discrete PTS solutions by various manufacturers and vintages—all utilizing a wide spectrum of system technologies across varied transport environments. These details matter significantly in the performance of a PTS solution.

Swisslog pneumatic tube systems incorporate design features, such as "soft arrival" and the ability to send carriers at slow speeds, that address the issue of hemolysis in blood samples. Your Swisslog representative can provide details on best practices and how to ensure that your PTS contributes to the safe handling of blood products.

Pneumatic tube transport of samples for blood gas analysis[19]

Conclusion

"The validity of using PTS to transport samples for blood gas analysis has been tested in a number of studies over 30 years.

Although PTS has been widely used for the transport of specimens to the laboratory for more than 25 years, there remains no consensus about the advisability of using PTS to transport samples for blood gas analysis.

There is, however, consensus that where PTS systems are used, every effort must be made to ensure that protocols for the elimination of air from arterial blood specimens, prior to transport, are as effective as possible and rigorously enforced. The use of pressure-sealed containers warrants further investigation."

Key Findings [article references are numbered in brackets and are explored in the following pages.]

- "PTS has no effect on pH or pCO_2. [6, 9,10,11,12,13]"
- "PTS does not affect pO_2 so long as pO_2 is close to that of ambient air (20 kPa / 150 mmHg.) [17]"
- "PTS can cause an increase in pO_2 for samples whose pO_2 is less that 20 kPa (150 mmHg) and a decrease in pO_2 for samples whose pO_2 is greater than 20 kPa (150 mmHg.) [17]"
- "The main cause of the change in pO_2 induced by PTS is contaminating air. [15,17]"
- "Clinically significant aberrant pO_2 results can occur if samples are not purged of air before transport via PTS. [17,12,18]"
- "If air could be reliably excluded from an arterial sample before transport, the changes in pO_2 induced by PTS would be clinically insignificant. [12,17,18]"
- "Protocols aimed at purging air from arterial specimens are neither 100 % effective nor universally applied. [12,13,17]"
- "The effect of PTS on pO_2 values can be ameliorated by reducing the speed at which samples are sent via PTS [17] and by sending samples in pressure-sealed containers [13]."

Full bibliography to Chris Higgins article

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19. Fernandes CM, Worster A, Eva K, Hill S, McCallum C. Pneumatic tube delivery system for blood samples reduces turnaround times without affecting sample quality. J Emerg Nurs. 2006 Apr;32(2):139-43.

Roundup Article References

The following summaries detail select references cited in the Higgins article. The number appearing in the bracket corresponds with its bibliographical number above.

Acute care testing. Blood gases and electrolytes at the point of care [1]. [20]

Conclusion
"POCT testing for blood gases and electrolytes was once considered to lie in the future but is now commonplace and may one day become the standard of care."

Key Findings
"The standard turnaround time for acute care laboratory testing in tertiary care institutions is typically less than 15 minutes for blood gas or electrolyte values. From a clinical perspective, however, the desirable turnaround time is more on the order of 5 minutes, and this is technically achievable."

- "To achieve a turnaround time of 5 minutes, it is necessary to move the "laboratory" closer to the patient and to have more than one instrument available."

Quantification of medical and operational factors determining central versus satellite laboratory testing of blood gases [2]. [21]

Conclusion
'The use of a PTS system helped to markedly lower the cost per reportable blood test result however with a turn-around time (TAT) that was 33 percent higher.'

Key Findings

- "The total cost per reportable result was substantially higher for the satellite laboratory [no PTS] than for the central laboratory [PTS-enabled]."
- "The satellite lab [no PTS] posted average TATs of 4.5 minutes versus the central lab's [PTS-enabled] TAT of 6 minutes. "The difference is attributable to transit time in the pneumatic tube and accessioning time in the central laboratory."

Evaluation of a soft-handling computerized pneumatic tube specimen delivery system. Effects on analytical results and turnaround time. [8] [22]

Conclusion
"The system evaluated is a rapid, efficient mechanism for sending specimens to the clinical laboratory that produces no significant effects on analytical results and has the ability to decrease turnaround time."

Key Findings
'A computerized pneumatic tube specimen delivery system with system-wide air cushion soft handling features was evaluated against a courier-delivery method for their effect on blood tests.'

- "There were no significant differences in values (largely normal) for components of a standard chemical profile or complete blood count in specimens delivered from the outpatient center or neonatal intensive care unit by pneumatic tube [system] compared to couriers."

- "The pneumatic tube system also did not affect values for pO_2, pCO_2, and pH over a wide range (pO_2, 25 to 438 mmHg) in specimens sent from the operating room during cardiac surgery."

- "The pneumatic tube system decreased the median turnaround time for potassium and hemoglobin results on specimens from the emergency department by 25%."

Blood gas analysis: POCT versus central laboratory on samples sent by a pneumatic tube system. [11] [23]

Conclusion
"Irrespective of air bubbles, the transport by PTS has very little or no effect on pH and pCO2. If air bubbles cannot be excluded with certainty, PTS is not an appropriate transport medium for measurement of pO2 on blood gas samples."

Key Findings
"[Blood] Specimens from two locations [Lung Function Laboratory (LFL) and pneumology ward] were first analysed locally and then sent to the CL [central laboratory] via PTS."

- "The mean time difference between the first [point of care time] and the second [central laboratory time] determinations from LFL was 13.3+/-5.4 min (n=27) and from the wards 20.2+/-11 min."
- "For pO_2 the differences between LFL and CL results, for patients undergoing a 100% O_2 test, were unacceptably large."
  - "For pO_2 range 41-407 mm Hg, the difference was -2.4+/-3.2 (n=25)."
  - "For the samples from the wards, the difference in pO_2 between ward (range 37-183 mm Hg) and CL was -13+/-18 mm Hg."

Changes in blood gas samples produced by a pneumatic tube system. [12] [24]

Conclusion
"Samples for blood gas analysis should be transported via a PTS using a pressure sealed container to avoid artefacts in the pO_2."

Key Findings
"Blood gas samples were analysed immediately or sent via the PTS to the laboratory for analysis. In addition, samples sent via the PTS in a pressure sealed container were compared with those sent non-pressure sealed to the laboratory."

- "Samples sent via the PTS had significant alterations in their pO_2 values, which were not seen when samples were carried by hand to the laboratory."
- "There was no effect on pCO_2 and pH values."
- "The use of a pressure sealed container abolished the alteration in pO_2 values seen."

Air bubbles and temperature effect on blood gas analysis. [13] [25]

Conclusion
'Air bubbles in blood specimens can significantly raise the pO_2 of the sample.'

Key Findings
"The effect of temperature, time of storage, and presence of air bubbles in specimens for blood gas analysis was studied."

- "...air bubbles in a 10% proportion are undesirable because of significant elevation in the pO_2."
- "...the storage of anaerobic blood samples at room temperature (25 degrees C) is acceptable when measurements are done within the first 20 minutes."

Blood gas analysis: effect of air bubbles in syringe and delay in estimation. [14] [26]

Conclusion

"For accurate estimation of pO_2 and pCO_2 it is necessary to avoid frothing, to expel all air bubbles within two minutes, and to inject the sample into the machine within 10 minutes or store the syringe in crushed ice. The requirements for blood pH and base excess measurement are less exacting."

Key Findings

'The effect of air bubbles in a syringe and a delay in estimation on blood sample test results was studied. Syringes were stored at 0 degree C, (crushed ice), 4 degrees C (refrigerator) and 22 degrees C (room temperature).'

- "The pressure of oxygen pO_2 fell significantly by 20 minutes at 4 degrees C and 22 degrees C but did not change significantly at 0 degree C for up to 30 minutes."
- "Blood pH, pressure of carbon dioxide pCO_2, and base excess did not change significantly for up to 30 minutes at 4 degrees C and 22 degrees C and up to 60 minutes at 0 degrees C."
- "pO_2 rose significantly after two minutes' contact with froth and two minutes' contact with the air bubble, and pCO_2 fell significantly after three minutes' contact with the air bubble. Size of the bubble had little effect on rates of change. Blood pH, bicarbonate, TCO_2, and base excess did not change significantly after up to five minutes' contact."

Pneumatic transport exacerbates interference of room air contamination in blood gas samples. [16] [27]

Conclusion

"Interference can be minimized by carefully purging samples of all air bubbles using the following protocol: invert syringe to check for air bubbles, then retap and reexpel bubbles if necessary. Personnel that collect and send blood gas samples via PTS should be educated about the problem of interference. Modifications both to pneumatic sample transport systems and to blood gas syringes should be investigated to minimize the effect."

Key Findings

'Blood samples were analyzed for $p(O_2)$ to determine possible effects of air contamination from PTS transport.'

- "Interference from air contamination was worse after PTS transport compared with manual transport of the specimen."
- "Over a wide range, the $p(O_2)$ in specimens after PTS transport tended toward 160 mm Hg."
- "Samples from hypoxemic patients were prone to errors in $p(O_2)$ that could have resulted in clinical misinterpretation; 5 of 10 samples with a baseline $p(O_2)$ less than 85 mm Hg had increases of 10 mm Hg or more when contaminated with air."
- "Cooling samples with high $p(O_2)$s minimized changes to $p(O_2)$, probably by increasing the solubility of oxygen."
  - "Mechanical buffering by various liners used in the carriers did little to alleviate the interference."
  - "Decreasing the speed of pneumatic transport by 50% lessened the effect on $p(O_2)$."

Effects of air bubbles and tube transportation on blood oxygen tension in arterial blood gas analysis. [17] [28]

Conclusion

"Trapped air in the syringe should be expelled as thoroughly as possible, since the presence of only 1% air bubbles can result in aberrance in pO_2 measurement. Samples for blood gas analysis should be carried in ambient pressure to the laboratory because pneumatic tube delivery systems significantly aggravate the air bubble-related aberrance in pO_2 measurement."

Key Findings

"Blood gas samples from 15 patients and a pooled wasted blood mixture with 3 different levels of pO_2 were analyzed to determine the effects of air bubbles and manual versus pneumatic tube transportation on pO_2 levels."

- "pO_2 increased significantly in samples containing 10% air bubbles and was exaggerated by pneumatic tube transport (from 115.63 +/- 9.31 mm Hg to 180.51 +/- 11.29 mm Hg, $p < 0.001$)."
- "In samples with low pO_2 (approximately 30 mm Hg), the measurement was not aberrant regardless of the method of transportation or the amount of air bubbles contained in the specimen."
  - "...in samples with medium and high pO_2 (> 70 mm Hg), aberrances in measurements were noted even with only 0.5% air bubbles and regardless of whether the sample was transported by manual methods or pressurized tube."
- "The increments of pO_2 correlated positively with the amount of air introduced into the specimens."
  - "...the measured pO_2 increased 8.13 and 31.77 mm Hg when 0.5% and 10% air bubbles were introduced, respectively, to samples with medium pO_2 ($p < 0.05$)."
  - "The interaction between the amount of air bubbles and the method of transportation was significant ($p < 0.001$)."

Effects of a pneumatic tube system on routine and novel hematology and coagulation parameters in healthy volunteers. [18] [29]

Conclusion

"Although further study regarding the mean platelet component may be required, transport through a pneumatic tube system has no clinically significant effect on hematology and coagulation results obtained with certain modern instruments in blood samples from healthy volunteers."

Key Findings

'To determine the effects of sample transport, paired blood samples from 33 healthy volunteers were either hand delivered to the clinical laboratory or transported through a pneumatic tube system. The samples were analyzed and routine and novel hematology and coagulation parameters obtained on state-of-the-art analyzers.'

- "There were no statistically significant differences for prothrombin time, activated partial thromboplastin time, waveform slopes for prothrombin time or activated partial thromboplastin time, fibrinogen, or fibrin monomers."
- "No statistically significant differences were observed for routine complete blood cell count and white cell differential parameters or markers of platelet activation, such as the mean platelet component, or of red cell fragmentation."
- "When 2 donors who reported aspirin intake were excluded from the analysis, there was a statistically, but not clinically, significant impact of transport through the pneumatic tube system on the mean platelet component."

Transport of blood gas samples: is the pneumatic tube system safe? [19] [30]

Conclusion
"Transport of samples for blood gas analysis via a modern pneumatic tube system is safe when samples are correctly prepared."

Key Findings
"A total of 4 consecutive blood gas samples were obtained intraoperatively from 54 different patients and sent to the central laboratory. Of these, 3 samples were transferred using the pneumatic tube system but by different methods and 1 sample was transported personally which served as a reference. The results of sample analysis concerning blood gases, electrolytes and haemoglobin were compared and examined for differences."

- "No statistically significant differences could be determined between the different modes of transportation."

Commentary on the Research

A few of the studies referenced above describe issues with the integrity of blood samples transported via a pneumatic tube system. This in turn, led to inconsistent, or unreliable results for some specific blood test types.

At Swisslog, we are steadfastly dedicated to researching, developing, manufacturing and implementing safe and efficient pneumatic tube systems. And one of the reasons that we've been successful doing this, is because we embrace the Japanese concept of "Kaizen", or continuous improvement. In practice, that means hiring talented doctors, technicians and engineers who create viable and effective improvements to our technologies and processes. Highlights of these improvements are summarized here.

Innovations designed to ensure the safe pneumatic tube system transport of blood products

- Variable speed delivery. We designed this feature to mitigate the potential degradation of samples that are sensitive to PTS-transport g-forces. Our patented technology adds a "slow-send" delivery option to achieve this end.

- Gentle arrival and landing features.
  - The Swisslog Whisper Receiving System promotes the integrity of delicate payloads by treating carriers to a soft deceleration and landing at their destination.
  - The Swisslog Laboratory-horizontal-reception feature guarantees the soft arrival of sensitive samples for analysis in the lab.

- Carrier-specific features.
  - Leak-resistant carriers combat the incidence of cross-contamination and decontamination events.
  - Intra-container materials:
    - Carrier liners provide additional cushioning to safeguard the integrity of samples.
    - Zip N' Fold® Pouches deliver optimal protection against spills.

Section 3—Additional Resources

Healthcare Industry Organizations

American Association of Blood Banks (AABB)
The AABB is an international, not-for-profit association representing individuals and institutions involved in the field of transfusion medicine and cellular therapies. The association is committed to improving health by developing and delivering standards, accreditation and educational programs that focus on optimizing patient and donor care and safety. AABB membership consists of nearly 2,000 institutions and 8,000 individuals, including physicians, nurses, scientists, researchers, administrators, medical technologists and other health care providers. Members are located in more than 80 countries.

AABB provides a wide range of printed and on-line resource materials. That includes the informative pamphlet, Guidelines for Pneumatic Tube Delivery Systems: Validation and Use to Transport Blood Components, which is available for a small fee.

Acute Care Testing
acutecaretesting.org bridges the gap between scientific publications and daily practice with user-to-user information about the daily issues surrounding acute care testing. Healthcare professionals from around the world provide the content, including key opinion leaders, lab managers, point-of-care coordinators, physicians and nurses.

College of American Pathologists (CAP)
The College of American Pathologists, the leading organization of board-certified pathologists, serves patients, pathologists, and the public by fostering and advocating excellence in the practice of pathology and laboratory medicine worldwide.

Infection Control Today
Infection Control Today is the leading information source for infection preventionists and their colleagues in operating rooms, sterile processing, and environmental services and materials management. Infection Control Today has been serving hospitals and their critical information needs in the area of infection prevention since 1997. Infection Control Today magazine, website and e-newsletters deliver the timely, relevant practice guidance that medical professionals need to protect their institutions, their patients and their fellow healthcare workers, and to eliminate healthcare-acquired infections.

Footnotes

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Swisslog Healthcare Solutions Web Links

- Blood Specimen and Transport Solution Page
- Pneumatic Tube Systems Solution Page
- RoboCourier Autonomous Mobile Robot Solution Page

Swisslog Resources

Video Resources
Visit the Swisslog YouTube channel at: www.youtube.com/SwisslogHCS to watch videos related to TransLogic Pneumatic Tube Systems.

Resources
Visit the Swisslog Blood and Specimen Transport page at: www.swisslog.com/blood to access resources including information relevant to the transport of blood and specimen products via a PTS.

- Four Critical Procedures for Infection Control with a Pneumatic Tube System
- Swisslog PTS solution overview brochure
- Application of the Swisslog PTS solution for blood banks

Contact Swisslog with questions or for more information on blood transport through a PTS.

Swisslog Healthcare Solutions
Email: healthcare.us@swisslog.com
USA: 800.764.0300
Canada: 877.294.2831 | 905.629.2400

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