

Analysis of the hydrodynamic profile in different roller pumps models used in cardiopulmonary bypass

Análise do perfil hidrodinâmico em diferentes modelos de bombas de rolete utilizadas em circulação extracorpórea

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Abstract

Objective: Among the equipments used in cardiopulmonary bypass the roller pumps have great importance with various models available from several manufacturers. The calibration is an important factor in hemolysis rates and its potential is different in each. Researchers do not always approach details on the pump bed profiles assuming that the standardized calibration settings ensure equal and comparable values for all models of roller pumps. We have mainly two methods for calibration of pumps which also interferes on the hemolytic potential. In both of them, the characteristics of fluid impulsion defined by the pump bed design are not considered. The aim of this study is to compare the hydrodynamic profile of three models of roller pumps available in the Brazilian market.

Method: The rollers occlusion was performed by measures of drop and dynamic calibration. Two different silicone diameter tubes were used (3/8 x 1/16 and 1/2 x 3/32 inches).

Results: The profiles showed differences in their variances, $P < 0.01$ for drop rate measures and $P < 0.0001$ for dynamic calibration. Different changes in pressure were found between the pumps analyzed ($P < 0.002$).

Conclusion: The measures of occlusion are dependent on the design of the pump bed and comparisons involving roller pumps should be performed with caution. Blood tests should be performed to verify the influence of changes in hemolysis pressure.

Descriptors: Extracorporeal circulation. Perfusion. Pulsatile flow. Pumps.

Resumo

Objetivo: Dentre os equipamentos utilizados em circulação extracorpórea, as bombas de rolete têm grande importância, com diversos modelos disponíveis de vários fabricantes. A calibração é um fator importante nas taxas de hemólise e o seu potencial difere em cada uma delas. Pesquisadores nem sempre abordam detalhes sobre os perfis do leito rígido, supondo que as formas padronizadas de calibração garantem valores iguais e comparáveis para todos os modelos de bombas de rolete. Dispomos principalmente de dois métodos para a calibração das bombas, o que também interfere com o potencial hemolítico. Nenhum dos métodos considera as características de impulsão do fluido, definido

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This study was carried out at the Nucleus of Medicine and Experimental Surgery of the School of Medical Sciences, State University of Campinas (UNICAMP) – São Paulo, Brazil.

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pela forma construtiva do leito rígido. O objetivo é avaliar o perfil hidrodinâmico de três modelos de bombas de roletes disponíveis no mercado brasileiro.

Métodos: A oclusão dos roletes foi feita por medidas de velocidade de queda e calibração dinâmica. Foram utilizados dois diferentes diâmetros de tubos de silicone (3/8 x 1/16 e 1/2 x 3/32 polegadas).

Resultados: Os perfis apresentaram diferenças em suas variâncias. $P < 0,01$ para medidas de velocidade de queda e $P < 0,0001$ para medidas de calibração dinâmica. Foram

encontradas diferenças nas variações de pressão entre as bombas analisadas ($P < 0,002$).

Conclusão: As medidas de oclusão são dependentes da forma do leito rígido e comparações envolvendo bombas de rolete devem ser feitas com cautela. Testes com sangue deveriam ser realizados para verificar a influência das variações de pressão na hemólise.

Descritores: Circulação extracorpórea. Perfusão. Fluxo pulsátil. Bombas.

INTRODUCTION

Of all the equipments and devices used in cardiopulmonary bypass (CPB), roller pumps play a particularly important role because they serve to propel the blood through the various devices to the patient.

During CPB, the trauma suffered by the red blood cells releases intracellular content, causing hemolysis. This occurs mechanically, either when the blood passes through the rollers, cannulae and aspirators or from exposure of the blood to different surfaces at different speeds.

The roller pumps currently available on the market in Brazil have several characteristics such as the range of rotation, stability, finishing and handling that permit comparison between models. Calibration of these pumps plays an important role in hemolysis rates [1,2], and new procedures and devices have been evaluated in an attempt to minimize the effects of aspirating blood from the surgical field [3,4].

Various studies have shown the considerable effect of occlusion on hemolysis rates using both occlusive and nonocclusive settings [1,5]; however, comparisons between roller pumps and centrifugal pumps have shown conflicting results with respect to hemolysis [2,6]. The use of roller pumps to aspirate blood from the surgical field plays a role in hemolysis, a finding that has been observed clinically [6-8] and confirmed in experimental studies in which roller pumps were compared with vacuum systems for this purpose [4,9].

Investigators do not always report details on the different characteristics of roller pump raceways. The working hypothesis is that if calibration is standardized, then adjustments to the pumps will be the same for all models.

Two forms of adjustment are most commonly used, drop rate measurement (a static method) and the dynamic calibration system proposed by Tamari et al. [2]. Drop

rate is normally measured by using the lower point of the raceway or the mean between 2 or 3 points close to the lower point.

The characteristics of the design of the raceway vary from one model of pump to another. This may affect the calibration settings that are used as references. These characteristics are intrinsic to each pump model and may affect hemolysis rates.

The aim of this study was to assess the hydrodynamic profile of three models of roller pumps available on the Brazilian market using the drop rate method and dynamic calibration.

METHODS

The present study was performed in the Nucleus of Medicine and Experimental Surgery of the School of Medical Sciences, State University of Campinas (UNICAMP). Three models of roller pumps in perfect working condition were tested. The pumps were manufactured by two different Brazilian companies and the raceway diameter was 6 inches in all cases. The other characteristics of the three pumps are listed in Table 1.

Drop rate

The hydrodynamic profile of the pumps was established by measuring drop rate in $3/8 \times 1/16$ inch silicone tubing. The

Table 1. General characteristics of the roller pumps tested

Characteristic	Pump 1	Pump 2	Pump 3
Time of use	New	6 years	8 years
Modularity	Individual	Adjoining (4)	Individual
Simultaneous adjustment of roller occlusion	Yes	Yes	Yes
Fine setting of the rollers	Yes	No	No
Locking of rollers	Yes	Yes	No
Rotor speed control	Fine	Coarse	Fine

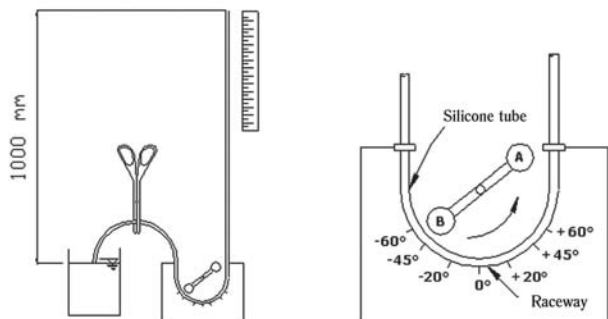


Fig. 1 - Illustration of the system used to measure drop rate and the standardized angles

standard angles of the pump raceways were used, as illustrated in Figure 1.

Drop rate was measured as the time for a fixed variation of 50 mm in a column of 0.9% saline solution standardized at 1000 mm of height in a 1/4 inch PVC tube. A digital chronometer accurate to one-hundredth of a second was used to record times. The measurements used in roller pump models A and B were, sequentially, -60°, -45°, -20°, 0°, +20°, +45° and +60°. With the pump adjusted to the desired occlusion point, the roller was moved manually until the column of saline solution reached a height of 1050 mm. Roller A was initially placed at the first standard angle of -60° and the tubing was clamped at its inlet point. After waiting a few seconds to allow stabilization to occur, the tubing was then released and the times between the 1000 and 950 mm positions were recorded.

With the roller in the same position, the tubing was once again clamped at its inlet point and a syringe was used to fill the column up to the 1050 mm position following which a second measurement was taken at the same position following stabilization. The roller was then moved to the next position (-45°), clamped and once again filled with the aid of a syringe up to the 1050 mm position. This procedure was then repeated for the other standard angles. The same process was performed for roller B, measurements being taken twice for each angle.

For each set of measurements taken using rollers A and B at each of the standard angles, the drop rate that was adopted for use consisted of the mean of the eight values measured in the two rollers. The temperature of the saline solution was maintained at $24 \pm 1.0^\circ\text{C}$ and the environmental temperature at $24 \pm 2.0^\circ\text{C}$ throughout all the experiments.

Mean drop rate was calculated using the values obtained with the -20°, 0° and +20° angles.

Dynamic calibration

The method proposed by Tamari et al. [2] was used to measure dynamic calibration:

- The pump circuit is filled with 0.9% saline solution;
- The pressure sensor is placed at the pump outlet;
- The rollers are retracted to a nonocclusive position;
- The pump is set at a constant 10 rotations per minute (rpm)
- The outlet tubing is clamped at a point distant from the pressure sensor;
- Occlusion of the rollers is set to the desired average pressure.

The measurements of dynamic calibration were performed in fifteen $3/8 \times 1/16$ inch tubes and in twenty-four $1/2 \times 3/32$ inch tubes. A data acquisition system, model PCI-9112, manufactured by Adlink, Chungho, Taiwan, was used in this study, together with a pressure sensor (Ashcroft Willy Instrumentos de Medição Ltda, São Paulo, Brazil) calibrated to a pressure range of -1.10^5 to 2.10^5 Pa (i.e. -750 to 1500 mmHg). A data acquisition program was developed to read and store data. Figure 2a illustrates the methodology used for the measurements, while Figure 2b shows the pressure values recorded during dynamic calibration and illustrates the type of measurement used.

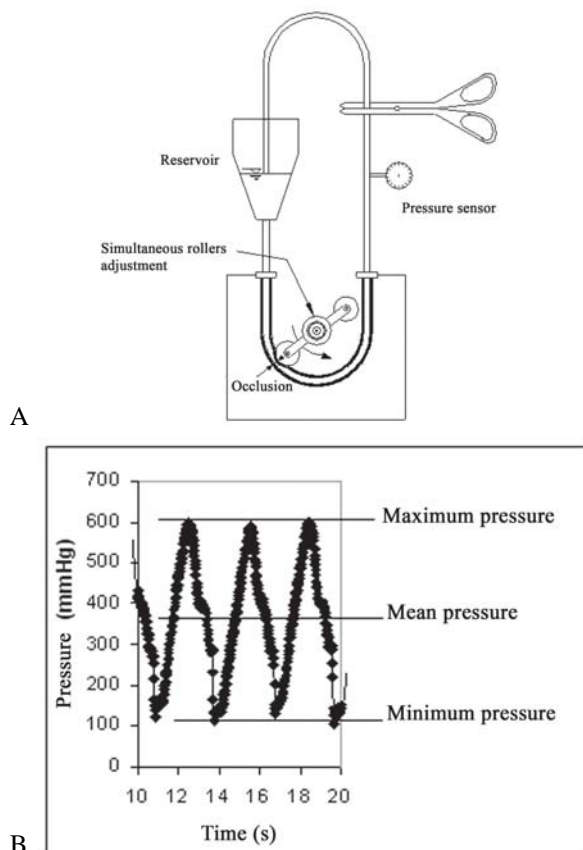


Fig. 2 - A - Illustration of the methodology used for measuring dynamic calibration. B: Maximum, minimum and mean pressure values during the process of dynamic calibration

In view of the pulsatile characteristic of roller pumps, the mean pressure values measured during the process of dynamic calibration were the measurements adopted. The mean pressure readings were obtained from the values recorded in the database with an interval of 20 milliseconds (ms) between measurements for a total duration of 30 seconds (n=1500).

Minimum and maximum pressure ranges were based on the mean maximum values recorded at each peak or trough during the recorded time interval (30 seconds).

Statistical analysis

All the values registered in the database were analyzed using a confidence level of 95%. Analysis of variance (ANOVA) was used in the statistical analysis when data distribution was normal and Levene’s test when distribution was not normal. Linear regression analysis and the t-test were used to compare angular coefficients and intercepts of two regressions.

RESULTS

Drop rate

Figure 3 shows the profiles of drop rate for the three pump models with drop rate values close to point 0°.

The distribution of the data shown in Figure 3 is normal (P>0.11) and comparison of variances are shown in Table 2.

Figure 4 shows the hydrodynamic profiles and the respective pressure readings measured during the dynamic calibration process. The distribution of the pressure values measured in the three pumps was not normal (P<0.01).

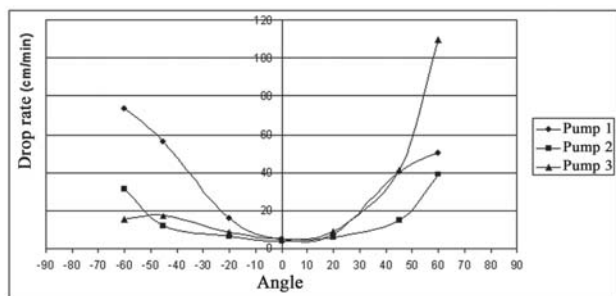


Fig. 3 - Profile of drop rate in the three pump models

Table 2. Comparison of variances in drop rate profiles (n=7) for the three pump models.

Model of Pump	P-value
Pump 1 x Pump 2	0.07
Pump 1 x Pump 3	0.21
Pump 2 x Pump 3	0.01

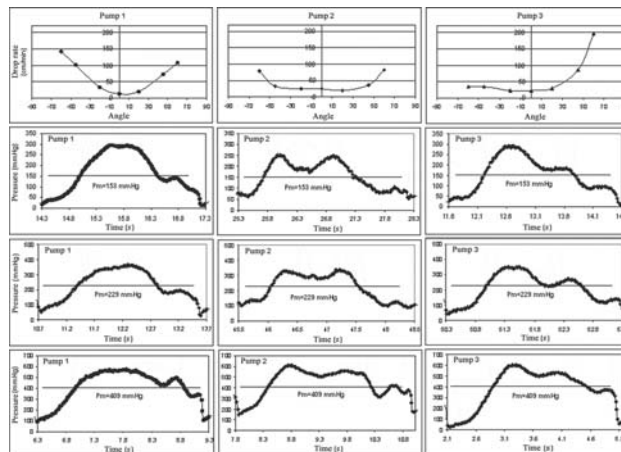


Fig. 4 - Profiles of drop rate with respective diagrams of pressure during dynamic calibration. Pumps 1, 2 and 3

With mean pressures measured during the process of dynamic calibration of 153 ± 3 (mean ± standard deviation), 229 ± 5 and 408 ± 1 mmHg, statistically significant differences in variances were found when comparisons were made between pairs (p<0.0001 in all three cases) (Levene’s test).

Figure 5 shows the results of the measurements of drop rate in pumps 1 and 3 at 0° compared with the mean value calculated between the angles of -20°, 0° and +20°.

In pumps 1 and 3, the coefficient of determination (R²) was 0.92 and 0.97, respectively, regression coefficients (P>0.56) and intercepts (P>0.68) being similar.

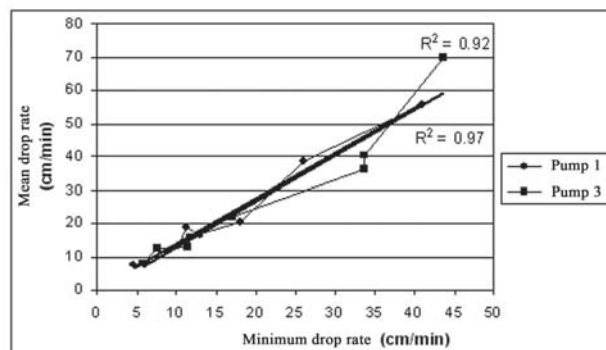


Fig. 5 - Comparison between drop rate at 0° and mean drop rate at three points for various occlusions

Dynamic calibration

Figure 6 shows the results of the mean pressure tests of dynamic calibration in accordance with the differences in the pressure recordings. Thirty ½ x 3/32 inch tubes were used in these calculations.

Distribution of the data shown in Figure 6 was normal ($P < 0.05$). Table 3 shows the probability values of the angular coefficients and respective intercepts obtained by comparing linear regressions.

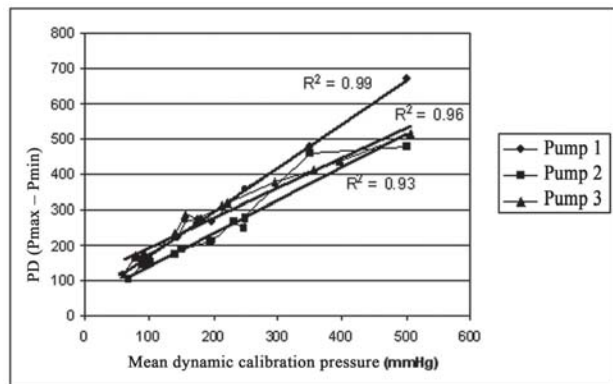


Fig. 6 - Ratio between mean dynamic pressure calibration and the difference in pressure ($P_{max} - P_{min}$). Pumps 1, 2 and 3

Table 3. Comparison between regressions of the mean pressure measurements of dynamic calibration and the respective differences in pressure for the three models of pump (n=13).

Model of Pump	Angular Coefficient	Intercept
Pump 1 x Pump 2	$P < 0.002$	$P < 0.0001$
Pump 1 x Pump 3	$P < 0.0001$	$P > 0.23$
Pump 2 x Pump 3	$P > 0.37$	$P < 0.0001$

DISCUSSION

Roller pumps play an important role in cardiac surgery. Their adjustment is an important factor in determining hemolysis rates and has been the focus of attention of various studies. The characteristics of the raceway design vary in the different models of pump available on the market. These differences are not always described in the literature, and may lead to differences in the results obtained with the calibration methods.

The hydrodynamic profile measured by drop rate in pump 1 (Figure 3) showed symmetry between the inlet point and the outlet of the rollers. However, a small portion of the raceway close to the central axis of the pump, where the greatest occlusions occurred, is noteworthy.

Pump 2 is characterized by symmetry in drop rate between the inlet point and the outlet of the rollers. Most of the occlusions occurred in a part of the raceway in which drop rate is constant. This characteristic of pump 2 leads to a longer time of compression of the tubing compared to pump 1.

In pump 3, the area of greatest occlusion was at the inlet point of the rollers and there was an increase in drop rate after the central axis.

The differences between the three models are evident from the pressure measurements taken during dynamic calibration (Figure 4) for the three different adjustment conditions. There were statistically significant differences ($p < 0.0001$) in the pressure measurements, which decreased in conjunction with the drop rate measurements along the raceway in the three models.

The pressure measured at the pump outlet during dynamic calibration is analogous to the static pressure established by the column of saline solution during the measurement of drop rate [2]. However, pressure measurement is representative of the drop rate measurements along the raceway.

The differences between P_{max} and P_{min} measured in the three models of pump (Figure 6) confirm the differences in the characteristics of these pumps. The longer time of occlusion results in lower mean values compared to shorter occlusion times. When the period of occlusion is shorter, the maximum and minimum values need to be higher to result in the same mean pressure.

Experimental studies have shown empirically that hemolysis rates depend more on the shear stress to which the red blood cells are submitted than to the time of exposure to this stress [10].

During perfusion, the red blood cells may be submitted to different pressures and different times of exposure to this pressure, depending on the model of pump used. This may affect hemolysis rates and should be appropriately investigated.

When the drop rate measurements are taken in an operating room, the exact position of the rollers in relation to the raceway is not always taken into consideration. The different profiles of the pumps may affect the measurements and may not represent the point of greatest occlusion.

Some perfusionists [11] use other methods of adjusting pumps, taking the measurements at points to the left and to the right of the 0° angle and adopting the mean. The same procedure may provide different occlusion values depending on the characteristics of the pump used.

In the three models of pump evaluated in the present study, the point at which drop rate was lowest was between the angles of -20° and $+20^\circ$ and, in some of the tests, the point of greatest occlusion was not 0° .

Three different batches of tubing were used for the tests and possible variations in diameter were not taken into consideration in the conclusions and considerations made in this study.

During the process of dynamic calibration, the position of the rollers at the moment of occlusion had an effect on the variation in pressure observed. When occlusion was

performed with one of the rollers at the 0° position, the opposite roller was the one with more occlusion. Therefore, there were differences in the pressure measurements in rollers A and B that in some cases exceeded 50 mmHg. This phenomenon was observed with the three models of pump but was more noticeable in models 1 and 2.

Variations in rotation (± 1 RPM) during dynamic calibration were greater with pump 2. In pump models 1 and 3, stability was greater, varying ± 0.5 RPM.

CONCLUSION

In conclusion, there are differences in the hydrodynamic profiles of the models of pumps analyzed in this study. These differences depend on the design of the raceway and may result in inaccurate measurements of occlusion. When used to compare different models of pump or to compare one pump with another devices, changes to setting values should be made with caution.

Under these test conditions, the drop rate measurements calculated by the mean were not indicative of the lesser occlusion in all pump models.

The different variations in pressure (Pmax-Pmin) obtained during dynamic calibration may contribute towards increasing hemolysis rates. Tests should be performed using blood to assess this effect.

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