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Effect of pump type on outcomes in neonates with congenital diaphragmatic hernia requiring ECMO

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Abstract

Purpose: With the exception of neonatal respiratory failure, most centers are now using centrifugal over roller-type pumps for the delivery of extracorporeal membrane oxygenation (ECMO). Evidence supporting the use of centrifugal pumps specifically in infants with CDH remains lacking. We hypothesized that the use of centrifugal pumps in infants with CDH would not affect mortality or rates of severe neurologic insult.

Methods: Infants with CDH were identified within the ELSO registry (2000–2016). Patients were then divided into those undergoing ECMO with roller-type pumps or centrifugal pumps. Patients were matched based on propensity score (PS) for the ECMO pump type based on pre-ECMO covariates. This was done for all infants and separately for each ECMO mode, venovenous (VV) and venoarterial (VA) ECMO.

Results: We identified 4,367 infants who were treated with either roller or centrifugal pumps from 2000–2016. There was no difference in mortality or SNI between the two pump types in any of the groups (all infants, VA-ECMO infants, VV-ECMO infants). However, there was at least a six-fold increase in odds of hemolysis for centrifugal pumps in all groups: all infants (odds ratio [OR] 6.99, $p<0.001$), VV-ECMO infants (OR 9.66, $p<0.001$), and VA-ECMO infants (OR 8.11, $p<0.001$).

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Conclusion: For neonates with CDH requiring ECMO, there is no survival advantage or difference in severe neurologic injury between those receiving roller or centrifugal pump ECMO. However, there is a significant increase in red blood cell hemolysis associated with centrifugal ECMO **support.**

Keywords

Congenital diaphragmatic hernia (CDH); extracorporeal membrane oxygenation (EMCO); centrifugal pump; Hemolysis; roller pump

A. Introduction:

Extracorporeal membrane oxygenation (ECMO) is provided with either a roller or a centrifugal pump, each having advantages and disadvantages. Roller pumps use gravity to siphon venous return to the pump mechanism. The roller pump then compresses the tubing and propels the blood forward through a membrane oxygenator. The main advantage of roller pumps is the fine control over flow rates without possibility of retrograde flow. However, because this rolling mechanism can produce essentially unlimited negative pressure, it requires pressure monitoring throughout the circuit and the presence of a venous reservoir with a pressure cut-off switch. This increases the required priming volume and introduces wear on the tubing [1]. Though it is a rare occurrence, roller pumps can also cause the potentially fatal rupture of raceway tubing [2].

Centrifugal pumps use a spinning rotor to generate pressure and forward flow. This mechanism eliminates repeated compression of the tubing [2]. This allows for less blood-prosthetic surface area, protects against cavitation and limits over pressurization of the circuit. Another potential advantage of the centrifugal pump may be ease in transferring patients during extra-corporeal life support (ECLS). However, the primary disadvantage of centrifugal pumps is the increased incidence of red blood cell hemolysis resulting from the shearing forces created by the turbulent flow from the pumphead vortex. Hemolysis and the subsequent increase in plasma free hemoglobin has been linked to acute renal failure, hyperbilirubinemia, and other end-organ injury [3–5].

In an effort to elucidate whether pump type affects mortality in neonates, Barrett et al. compared roller pumps to centrifugal pumps with a propensity matched cohort from the ELSO Registry [3]. In their study, 88 neonates, with various diagnoses, were matched to each pump type and no survival advantage was noted. However, since the publication of their study there has not been a specific effort to evaluate whether in neonates with congenital diaphragmatic hernia (CDH) pump type affects outcomes.

In 1977, German et al. first described the use of ECMO for an infant with CDH [6], and it has since evolved into the most common indication for neonatal ECMO [7]. Given the fact that infants with CDH carry the greatest mortality compared to other indications for neonatal respiratory ECMO [7] and have longer average ECMO runs, we sought to specifically study the effect of pump type on neonates with CDH. One would hypothesize that the largest effect on patient outcome would come from disease-specific characteristics and patient physiology, especially in a complex disease like CDH. However, in order to minimize the

negative effects of a given treatment, the independent effect of that variable must first be defined. We hypothesized that the use of a centrifugal pump would not significantly affect mortality or the incidence of severe neurologic injury (SNI) in CDH infants. Furthermore, we sought to examine if there was a difference in these pump-specific outcomes in venovenous (VV) ECMO vs. venoarterial (VA) ECMO. Lastly, our study was based on a propensity score matched comparison to minimize confounding by indication, i.e. selection bias.

A. Methods

B. Data Source and Cohort

This study was approved by the Children's Hospital of Orange County institutional review board (#150969) and the ELSO Scientific and Oversight Committee. The Extracorporeal Life Support Organization (ELSO) Registry, which collects clinical information for adults and children treated with ECMO, was queried for neonates whose primary diagnosis was CDH from 2000–2016. We excluded patients with missing sex and ECMO mode (51 patients) as well as 168 patients who used "other" pump type, which in total contributed to about 5% of the full cohort. In those neonates that received multiple ECMO runs, the first ECMO run was used. The final study population included 4,367 infants with CDH, all of whom were treated with ECMO.

B. Outcomes, Treatment Variables and Analysis Cohorts

The main exposure was ECMO pump type, centrifugal or roller-pump. We utilized the ELSO Registry pump list to dichotomize pump types to either centrifugal or roller [8]. The primary outcome was mortality at discharge. The secondary outcomes were severe neurologic injury (SNI) and hemolysis. SNI was defined as acute neurologic events during ECMO represented by the ELSO registry—CNS hemorrhage, infarct and/or intraventricular hemorrhage (IVH) grade 3 and 4. Cerebral infarction or intracerebral hemorrhage (ICH) reported to the ELSO Registry are diagnosed using head ultrasonography or computerized tomography [9]. We excluded seizure and grades 1&2 IVH from the definition of SNI. Hemolysis was defined as plasma hemoglobin > 50 mg/dL, using the cut-off recorded in the ELSO Registry. There were 155 infants in the cohort with more than one run, but only one infant changed pump type, therefore there was no need to perform an intent-to-treat analysis in the study design.

We further examined whether ECMO mode (VA vs. VV) affected the primary or secondary outcomes. Neonates who were treated with VA or VA bypass with retrograde venous drainage and those that were converted from VA to VV (VA-VV) were all considered to VA. Neonates treated with venovenous with a double lumen cannula (VVDL), VVDL with retrograde venous drainage (VVDL+V), and VV to VA conversion (VV-VA) were all considered VV[10].

B. Statistical Analysis

Propensity score (PS) matching [11] was performed to select the matched study cohorts. Controls (neonates on roller pumps) were matched to cases (neonates on centrifugal pumps)

based on the estimated PS given his/her baseline pre-ECMO covariates. PS were estimated using logistic regression model of the probability of receiving centrifugal pump or roller pump based on neonates' pre-ECMO covariates: demographics variables including gender, pre-ECMO weight, race, gestational age (GA), post-gestational age, 5min APGAR, side of CDH, prenatal diagnosis, repair prior to ECMO, hand-bagging and pre-ECMO arrest; blood gas/ventilator variables included pH, pCO2 and pO2, mean airway pressure (MAP), oxygenation index (OI); pre-ECMO rescue therapies included inotropes, bicarbonate/ THAM, iNO, surfactant, neuromuscular blockers, Milrinone, Sildenafil and steroids; comorbidity variables included critical congenital heart disease (CCHD), multiple congenital anomalies (MCA), chromosomal anomalies and perinatal infection. Missing values of birth weight, gestational age, pCO2, pO2 and OI were obtained using mean imputation (missing rate: 3.7–10.3%). PS matching criteria was 1:1 greedy match. The success of PS matching to obtain comparable analysis cohorts was checked by comparing the pre-ECMO covariates before and after matching based on their standardized differences. Also, descriptive summary of continuous pre-ECMO variables were reported as mean with standard deviation (SD) and compared using two-sample t-test. Categorical variables were compared using chi-square test before and after PS matching. PS matching and analysis of outcome were conducted on the overall cohort (all infants) and separately for VV and VA in subset analysis.

A priori specified main analyses of the outcomes were univariate logistic regression models based on the matched sets for each cohort. Results were reported as odds ratio (OR) with 95% confidence interval (CI). Logistic regression with adjustment for the estimated propensity score among the matched sets was conducted as a sensitivity analysis to assess the robustness of the results from the main analyses. Analyses were performed using SAS version 9.3 and R version 3.2.2.

A. Results

B. Cohorts and Unmatched Baseline Characteristics

We identified 4,367 infants who were treated with ECMO (roller or centrifugal pump) from 2000–2016. Roller and centrifugal pumps were used in 79% and 21%, respectively (3460 roller and 907 centrifugal). The use of centrifugal pump increased in recent years; between 2000–2010, centrifugal pumps were only used in 6% of neonates, while between 2010–2016 its use grew to approximately 42% of neonates. If only the most recent three years are considered, the proportion of centrifugal pump was greater than fifty percent. Observed mortality in roller and centrifugal were 51% and 56%, respectively. The proportion of SNI was 14% and 18% in each group, respectively. Percentage of hemolysis was about 5 times higher in centrifugal group relative to roller group (Table 1, roller 6% vs. centrifugal 31%). There were 3,560 neonates who were initially treated with venoarterial (VA) and 807 treated with venovenous (VV). The overall proportion of VA was 82% in the full cohort. Roller was utilized more in the VV group (85%) than in the VA group (78%).

Multiple baseline characteristics including demographics, blood gas/ventilator, pre-ECMO rescue therapies and comorbidity variables were found to be significantly different between all infants treated with centrifugal and roller-type pumps. Neonates supported with

centrifugal pump were associated with a lower birth weight, more right-sided hernias, were more likely to be prenatally diagnosed, less hand bagging, lower pH, higher oxygenation index, less frequent use of bicarbonate/THAM, surfactant and neuromuscular blockers, more use of Milrinone, Sildenafil and steroids, and lower prevalence of perinatal infection relative to roller pump. However, there were no statistically significant differences after PS matching (Table 2). This was also true when examined for VA-infants separately. The matching was less effective in the VV cohort, and there were persistent differences in the use of neuromuscular blockers, proportion of pre-ECMO repair, and side of diaphragmatic hernia, due to the small sample size in the VV cohort (Figure 1c).

B. Propensity Score Matched Cohort

C. Primary Outcome: Mortality—The propensity score matching identified 1,808 infants (roller 904, centrifugal 904). Table 2 and Figure 1a show that there were no significant differences in baseline characteristics, blood gas/ventilator, pre-ECMO therapies or comorbidity variables after PS matching. The odds of mortality was not significantly different between centrifugal and roller-type pumps (OR = 1.14, 95% CI: 0.95–1.37, P = 0.17, Table 3; Figure 2a). Sensitivity analysis using logistic regression with the inclusion of the estimated propensity score in matched set as an additional covariate yielded the same conclusion with respect to all outcomes and cohorts

We next examined whether the finding of no treatment difference extends to infants treated with VA or VV ECMO. After matching, a total of 1,564 infants were identified who were treated with VA ECMO, of which 782 centrifugal infants were matched to 782 roller infants. A plot of standardized differences showed no substantive difference in all covariates between pump types in the subpopulation (Figure 1b). Among VA-ECMO infants, there was no significant difference in mortality (OR = 1.14, 95% CI: 0.93–1.39, P = 0.20, Table 3; Figure 2a). A total of 240 infants (roller 120, centrifugal 120) were identified who were treated with VV ECMO. There was no significant difference in mortality for VV-ECMO infants placed on either roller or centrifugal pumps (OR = 0.97, 95% CI: 0.58–1.62, P = 0.90, Table 3; Figure 2a).

C. Secondary Outcomes: SNI and Hemolysis—We then evaluated for potential differences in the secondary outcome of SNI within the PS-matched cohorts. There was no difference in SNI between centrifugal or roller pumps in any of the groups that were examined: all infants, VA-ECMO infants, VV-ECMO infants (Table 3, Figure 2b).

Differences in hemolysis were then examined for centrifugal and roller-type pumps in each of the PS-matched groups. For all infants, there was nearly 7-fold increase in odds of hemolysis for the centrifugal pump group (OR = 6.99, 95% CI: 5.13–9.52, P < 0.0001, Table 3; Figure 2c). This difference remained statistically significant when examining the VA-ECMO (OR = 8.11, 95% CI: 5.65–11.63, P < 0.0001, Table 3; Figure 2c) and VV-ECMO groups (OR = 9.66, 95% CI: 4.32–21.60, P < 0.0001, Table 3; Figure 2c). However, the largest increase in odds of hemolysis was observed in the VV-ECMO group with a nearly 10-fold increase in odds of hemolysis. In a sensitivity analysis, the cohort was divided into two groups by year 2000–2009 and 2010–2016. The results of each time period were similar

to all years combined (2000–2009: OR 12.31, CI: 7.593–19.970, P<0.0001 and 2010–2016: OR 10.64, CI: 5.980–18.916, P<0.0001).

A. Discussion

The results of our study indicate that there is no significant effect of pump type on mortality and SNI for infants with CDH treated with ECMO. In addition to the full cohort, results remained consistent among the sub-cohorts of VA and VV modes of treatment, supporting our hypothesis that pump selection would not significantly affect major outcomes. However, neonates undergoing support with centrifugal pumps were associated with nearly 7 times higher risk (odds) of hemolysis. The effect of pump type on hemolysis was also strongest in the VV ECMO sub-cohort.

Despite the practical advantages of centrifugal pumps [12], roller-head pumps accounted for 80–90% of pediatric cardiopulmonary bypass and ECMO in the early 2000s [13, 14]. Roller-head pumps remained the predominant pump type until 2011 [15], and it still remains the predominant pump type in neonatal respiratory failure [7]. Hemolysis caused by the centrifugal pump has remained a source of ongoing debate when compared to the roller-head pump. Some authors have found an increased incidence of hemolysis [4, 16], while others have found no difference between the two pump types [17, 18]. In contrast, Byrnes et al. actually demonstrated in 2011 an increased degree of hemolysis with the roller-head pump type compared with the centrifugal pump type [19]. The increased hemolysis with the use of a centrifugal pump seen in our study is consistent with work from other authors, though our study is the only one looking specifically at the CDH population. Interestingly, this effect seemed to be most prominent in the VV-ECMO cohort. Because the pump mechanism should be the same, this difference is potentially related to the relatively smaller size of the inflow/outflow lumens in the double lumen cannulas.

Although, the ELSO registry has been utilized by several authors to compare the outcomes between centrifugal and roller-head pumps, no group has specifically studied the CDH-cohort. To that end, we can only compare our study to previous studies evaluating effect of pump type in all neonates. Barrett et al. looked at all neonates undergoing venoarterial-ECMO (VA-ECMO) between 2007–2009 and found that there was a higher rate of hyperbilirubinemia, acute renal failure and hypertension, but no difference in mortality [3]. A similar analysis was also done on pediatric patients (< 18 years of age) undergoing VA-ECMO. They found that while there was no difference in mortality between the two groups, hemolysis, hyperbilirubinemia, need for inotropic support and acute renal failure were more prevalent in the centrifugal pump group [4]. O'Brien et al. showed similar results for pediatric patients in the ELSO registry from 2010–2015 [5]. Similar to previous studies, we found a higher incidence of hyperbilirubinemia (13.2% vs. 4%) and renal complications (40.4% vs. 30.7%) in the centrifugal group when compared to the roller-pump group. However, we also observed a higher incidence of certain mechanical complications with roller pumps, specifically raceway rupture (0.46% vs. 0%), other tubing rupture (0.38% vs. 0.22%) and oxygenator failure (9.9% vs. 6.2%).

Our data indicate that these findings in the general ECMO population are also true for infants who require ECMO for CDH. Though there may be increased incidence of hemolysis with the pumps, there does not seem to be a significant increase in mortality or severe neurologic injury. To our knowledge, this is the first study to compare the rate of acute neurologic events between roller and centrifugal pumps. It is also the first study to perform a subgroup analysis looking at the interplay between ECMO mode (i.e. VA vs. VV) and pump selection.

Despite the advantages of study design through PS matching, there remain some limitations to the study. The broad period over which this study was conducted means that we cannot infer whether or not hemolysis rates are improving over time, though a sensitivity analysis did reveal that the odds of hemolysis was similar when the group was divided into two time periods. As experience with centrifugal pumps improves, there are likely to emerge modifiable factors to reduce the amount of hemolysis seen with these pumps. The advent of the magnetic levitation centrifugal pumps seems to reduce the shear stress generated by the previous model of centrifugal pump as well as with by the roller pumps [18]. Similarly, there may be other unobserved confounders that may affect the outcomes between groups. This study also suffers from the typical limitations of retrospective database studies, including miscoding errors or treatment selection bias. A detailed look at cannula sizes and manufacturers, as well as pump manufacturers was not the focus of this study. In a future study we plan to look at the potential contributions of cannula size, flow rates and pump manufacturers and their contributions to hemolysis. Furthermore, there may be center specific effects that we can’t include in study design as ELSO does not release center identification codes for research. Center effects may include variations in hemolysis, bleeding and flow rates during the ECMO run. Other center specific effects we can’t capture include possibility of favoring a pump type/manufacturer or abandoning the use of a pump type during the study period due to potential complications. In fact, some centers have chosen to transition back to roller pumps specifically in the NICU population, despite institutional changes towards centrifugal pumps[20].

In summary, the use of centrifugal pumps in neonates with CDH does not appear to negatively affect mortality or SNI. Similar to previously published articles, there is significantly more hemolysis and this effect seems to be especially true during VV-ECMO. However, the significance of this finding is currently unknown. This work provides evidence that the selection of centrifugal pumps is likely safe for CDH-neonates. However, this needs to be tempered by provider experience and the pumps available at each institution as this study cannot address those factors that were “unobserved” (not available) in the ELSO registry. In circumstances where renal protective concerns are significant and patient/cannula sizes are small, roller pumps may be theoretically beneficial because of their ability to reduce hemolysis and end-organ damage.

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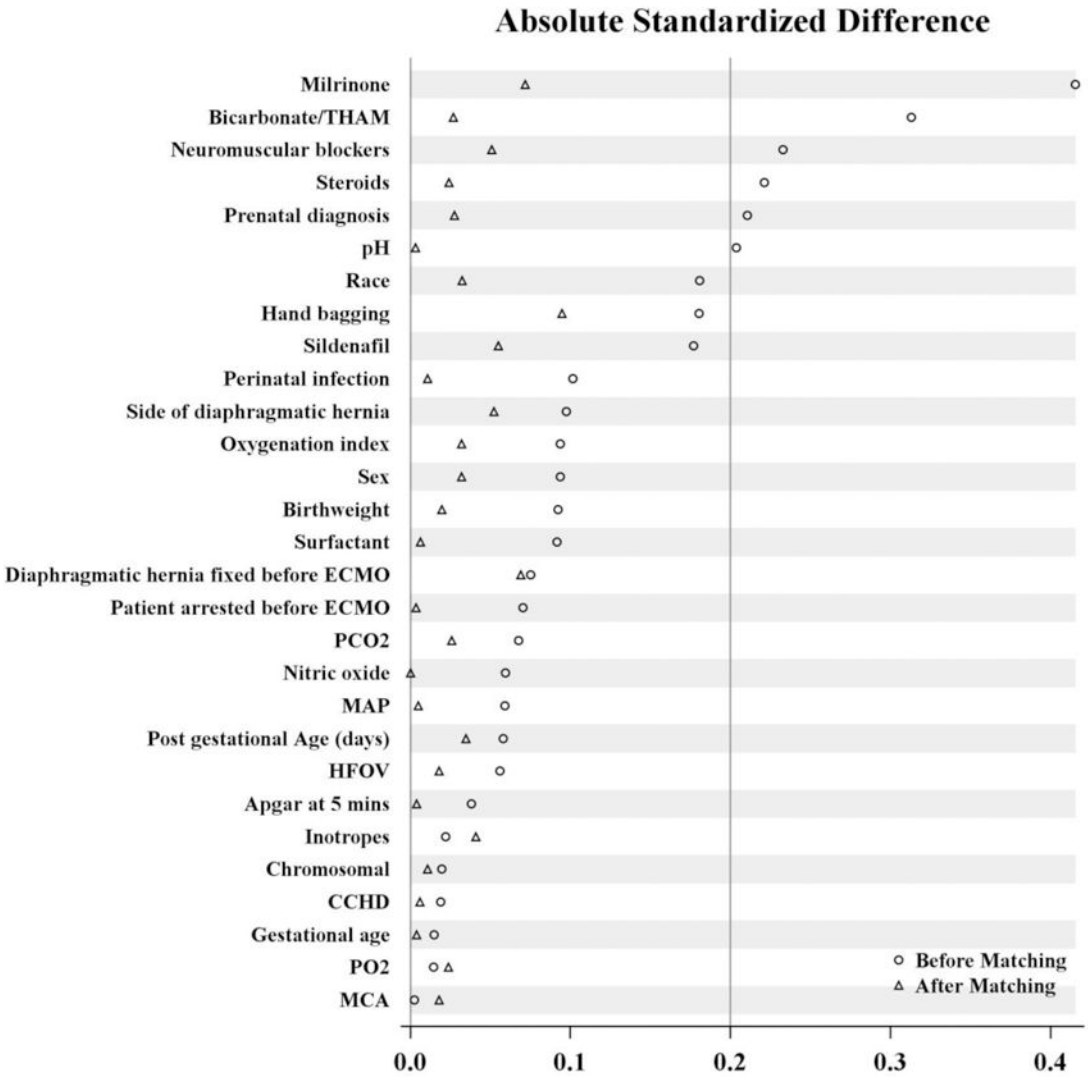
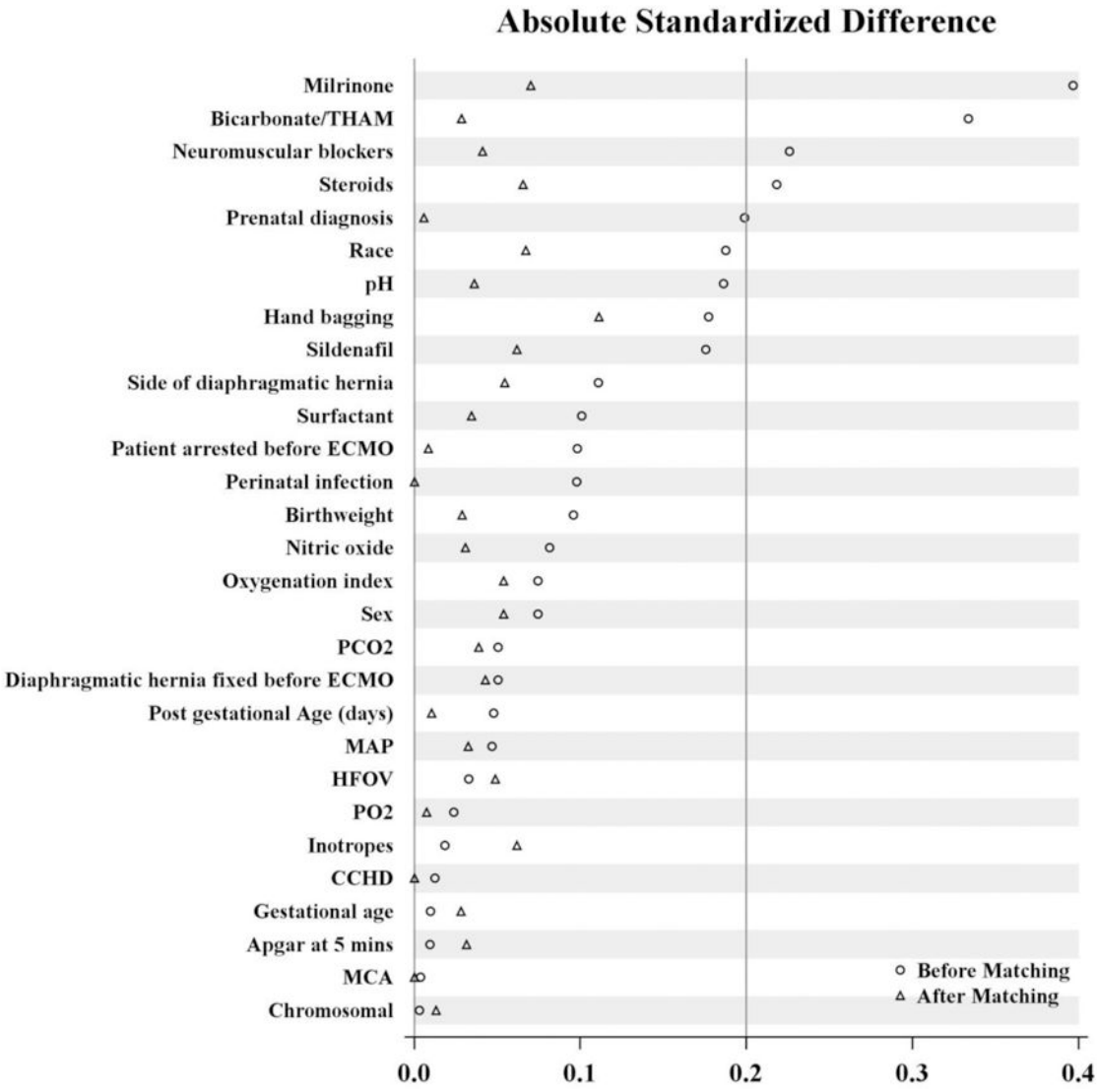
a) All infants



b) VA mode infants



c) VV mode infants

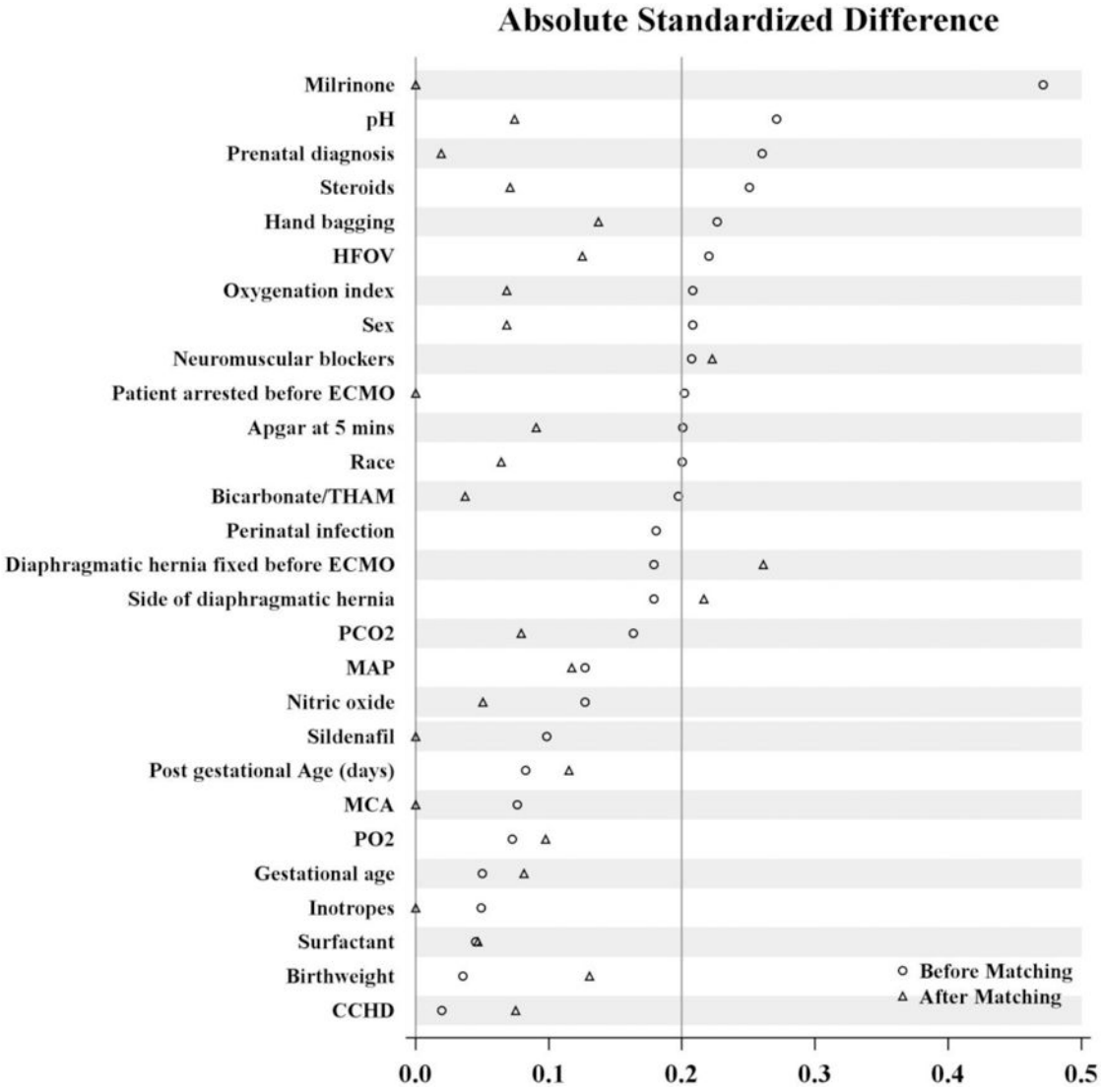


Figure 1.

Plot of standardized difference of all covariates before and after matching: a) all infants, b) VA mode infants, c) VV mode infants.

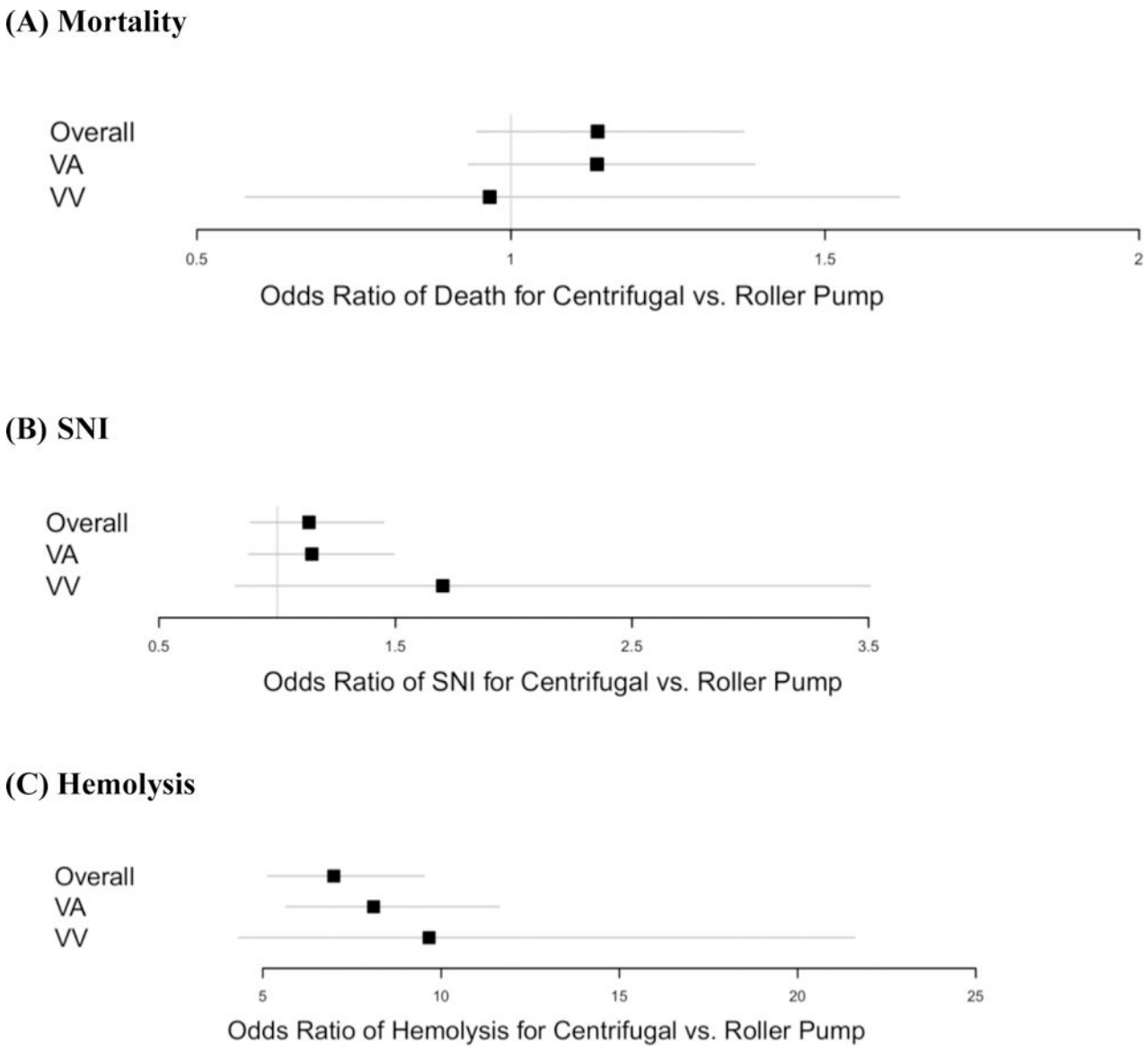


Figure 2.

Comparison of effect on primary (mortality) and secondary (SNI and hemolysis) outcomes for each of the ECMO delivery modes (VA and VV)

Table 1.

Frequency of mortality, SNI and hemolysis by pump type.

	Roller	Centrifugal	Total
N (Percent)	3460 (79.23%)	907 (20.77%)	4367
Death (Percent)	1762 (50.92%)	510 (56.23%)	2272 (52.03%)
SNI (Percent)	487 (14.08%)	162 (17.86%)	649 (14.86%)
Hemolysis (Percent)	204 (5.90%)	279 (30.76%)	483 (11.06%)

Table 2.

Demographics, blood gas/ventilator, pre-ECMO rescue therapies and comorbidity variables in neonates treated with VV or VA ECMO before and after propensity score matching.

		Before Matching (n = 4,364)				After Matching (n = 1,808)			
Parameter	**Category**	**Roller (n = 3,460) n (Percent)/ Mean (SD)**	**Centrifugal (n = 904) n (Percent)/ Mean (SD)**	**Standardized Difference**	**P value**	**Roller (n = 904) n (Percent)/ Mean (SD)**	**Centrifugal (n = 904) n (Percent)/ Mean (SD)**	**Standardized Difference**	**P value**
Sex	Female	1468 (42.43)	378 (41.81)	0.0937	0.7395	375 (41.48)	378 (41.81)	0.0319	0.8862
	Male	1992 (57.57)	526 (58.19)			529 (58.52)	526 (58.19)		
Birth weight		3.06 (0.50)	3.01 (0.51)	−0.0922	0.0131	3.02 (0.49)	3.01 (0.51)	−0.0198	0.6734
Race	Whites	2097 (60.61)	566 (62.61)	0.1806	<0.0001	561 (62.06)	566 (62.61)	0.0322	0.9255
	Hispanics	650 (18.79)	125 (13.83)			135 (14.93)	125 (13.83)		
	Blacks	427 (12.34)	102 (11.28)			99 (10.95)	102 (11.28)		
	Others	286 (8.27)	111 (12.28)			109 (12.06)	111 (12.28)		
Gestational age		38.10 (1.56)	38.00 (1.74)	−0.0566	0.2215	38.09 (1.54)	38.00 (1.74)	−0.0532	0.2753
APGAR at 5 mins		6.19 (1.99)	6.27 (1.93)	0.0381	0.3118	6.26 (2.02)	6.27 (1.93)	0.0040	0.9321
Post gestational Age (days)		2.27 (3.77)	2.50 (3.96)	0.0581	0.1149	2.36 (4.01)	2.50 (3.96)	0.0347	0.4603
Side of diaphragmatic hernia	Left	2533 (73.21)	640 (70.80)	0.0976	0.0468	657 (72.68)	640 (70.80)	0.0521	0.7469
	Right	749 (21.65)	204 (22.57)			190 (21.02)	204 (22.57)		
	Both	67 (1.94)	31 (3.43)			26 (2.88)	31 (3.43)		
	Missing	111 (3.21)	29 (3.21)			31 (3.43)	29 (3.21)		
Prenatal diagnosis		2230 (64.45)	670 (74.12)	0.2106	<0.0001	659 (72.90)	670 (74.12)	0.0276	0.5577
Diaphragmatic hernia fixed before ECMO	No	2876 (83.12)	741 (81.97)	0.0753	0.1206	747 (82.63)	741 (81.97)	0.0691	0.3404
	Yes	307 (8.87)	99 (10.95)			83 (9.18)	99 (10.95)		
	Missing	277 (8.01)	64 (7.08)			74 (8.19)	64 (7.08)		
Hand bagging	No	3193 (92.28)	855 (94.58)	0.1803	0.0003	840 (92.92)	855 (94.58)	0.0948	0.1318
	Yes	175 (5.06)	45 (4.98)			53 (5.86)	45 (4.98)		
	Missing	92 (2.66)	4 (0.44)			11 (1.22)	4 (0.44)		

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		Before Matching (n = 4,364)				After Matching (n = 1,808)			
Parameter	**Category**	**Roller (n = 3,460) n (Percent)/ Mean (SD)**	**Centrifugal (n = 904) n (Percent)/ Mean (SD)**	**Standardized Difference**	**P value**	**Roller (n = 904) n (Percent)/ Mean (SD)**	**Centrifugal (n = 904) n (Percent)/ Mean (SD)**	**Standardized Difference**	**P value**
Patient arrested before ECMO		268 (7.75)	88 (9.73)	0.0705	0.0517	89 (9.85)	88 (9.73)	−0.0037	0.9369
pH		7.18 (0.17)	7.15 (0.17)	−0.2036	0.0000	7.15 (0.18)	7.15 (0.17)	−0.0031	0.9473
pco2		68.31 (27.57)	70.21 (28.55)	0.0678	0.0666	69.49 (28.04)	70.21 (28.55)	0.0257	0.5853
po2		39.13 (26.82)	39.58 (34.96)	0.0146	0.6715	40.37 (30.91)	39.58 (34.96)	−0.0239	0.6107
HFOV		2510 (72.54)	678 (75.00)	0.0559	0.1383	671 (74.23)	678 (75.00)	0.0178	0.7052
MAP		16.44 (4.11)	16.71 (4.79)	0.0591	0.0974	16.69 (4.35)	16.71 (4.79)	0.0050	0.9146
Oxygenation index		53.13 (31.24)	56.48 (39.67)	0.0937	0.0069	55.28 (35.18)	56.48 (39.67)	0.0319	0.4981
Inotropes		3045 (88.01)	802 (88.72)	0.0222	0.5558	790 (87.39)	802 (88.72)	0.0409	0.3842
Bicarbonate/THAM		1243 (35.92)	198 (21.90)	−0.3131	<0.0001	188 (20.80)	198 (21.90)	0.0270	0.566
Nitric oxide		2844 (82.20)	722 (79.87)	−0.0594	0.1067	722 (79.87)	722 (79.87)	0.0000	1
Surfactant		589 (17.02)	124 (13.72)	−0.0918	0.0167	126 (13.94)	124 (13.72)	−0.0064	0.8916
Neuromuscular blockers		2105 (60.84)	446 (49.34)	−0.2328	<0.0001	423 (46.79)	446 (49.34)	0.0509	0.279
Milrinone		205 (5.92)	176 (19.47)	0.4155	<0.0001	151 (16.70)	176 (19.47)	0.0719	0.1266
Sildenafil		24 (0.69)	28 (3.10)	0.1770	<0.0001	20 (2.21)	28 (3.10)	0.0551	0.2419
Steroids		203 (5.87)	110 (12.17)	0.2213	<0.0001	103 (11.39)	110 (12.17)	0.0240	0.6096
CCHD		107 (3.09)	31 (3.43)	0.0190	0.6065	30 (3.32)	31 (3.43)	0.0061	0.8964
MCA		12 (0.35)	3 (0.33)	−0.0026	0.9454	4 (0.44)	3 (0.33)	−0.0178	0.7049
Chromosomal		28 (0.81)	9 (1.00)	0.0197	0.5864	10 (1.11)	9 (1.00)	−0.0108	0.8176

Table 3.

Odds ratio of (A) mortality, (B) SNI and (C) hemolysis for centrifugal and roller-type pumps for each of the ECMO mode groups: all infants, VA mode infants and VV mode infants in the primary analysis

(A) Mortality				
Parameter	**Category**	**OR**	**95% Confidence Interval**	**P value**
Pump Type	**Overall**			
	Roller		1.00 (Reference)	
	Centrifugal	1.138	(0.946–1.370)	0.1709
	VA			
	Centrifugal	1.137	(0.932–1.388)	0.2047
	VV			
	Centrifugal	0.966	(0.577–1.618)	0.8954
(B) SNI				
Parameter	**Category**	**OR**	**95% Confidence Interval**	**P value**
Pump Type	**Overall**			
	Roller		1.00 (Reference)	
	Centrifugal	1.134	(0.887–1.449)	0.3170
	VA			
	Centrifugal	1.146	(0.880–1.493)	0.3122
	VV			
	Centrifugal	1.700	(0.824–3.507)	0.1511
(C) Hemolysis				
Parameter	**Category**	**OR**	**95% Confidence Interval**	**P value**
Pump Type	**Overall**			
	Roller		1.00 (Reference)	
	Centrifugal	6.990	(5.131–9.523)	<0.0001
	VA			
	Centrifugal	8.108	(5.654–11.627)	<0.0001
	VV			
	Centrifugal	9.662	(4.322–21.597)	<0.0001