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***Research Article***

# Effects of Pulsatile Flow on Phosphorylcholine Coated Oxygenator and Arterial Filter

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**Abstract**

Objective: We aimed to compare the effects of pulsatile/nonpulsatile flow on phosphorylcholine coated (PC) oxygenator fibers, arterial filters by using scanning electron microscope (SEM).
Methods: Eleven patients were randomly divided into two groups, as; nonpulsatile and pulsatile flow groups (NP and P groups) by using PC oxygenators. The oxygenator fiber samples were examined under SEM to compare the thickness of absorbed blood proteins and amount of blood cells on the surface of oxygenators. Arterial filters were also analysed by SEM regarding the captured blood elements or particles.
Results: The mean fiber thickness from the axial images were calculated as 46.9 μm and 47.6 μm at group P and NP respectively which is statistically insignificant. Evaluation of the blood samples that were extracted from the arterial filter bring out higher amount of fibrin network and blood cells on fibers at group NP.
Conclusion: We concluded that there is lesser amount of blood components on the fibers of arterial filter at pulsatile flow. Coating of oxygenators is beneficial in case of surface biocompatibility and pulsatile perfusion develops lower amount of blood elements on arterial filter.

**Keywords:** Pulsatile flow, Coated oxygenator, Arterial filter, Cardiopulmonary bypass, Biocompatibility

# Pulsatil Akışın Fosforilkolin Kaplı Oksijenatör ve Arter Filtresi Üzerindeki Etkileri

**Öz**

Amaç: Bu çalışmada Taramalı Elektron Mikroskobu (TEM) kullanarak pulsatil/pulsatil olmayan akışın fosforilkolin kaplı (PC) oksijenatör lifler, arter filtreleri üzerindeki etkilerini karşılaştırılması amaçlandı.
Yöntemler: On bir hasta rastgele iki gruba ayrıldı; PC oksijenatörleri kullanarak pulsatil olmayan ve pulsatil akış grupları (NP ve P grupları), oksijenatör lif örnekleri, emilen kan proteinlerinin kalınlığını ve oksijenatörlerin yüzeyindeki kan hücrelerinin miktarını karşılaştırmak için SEM altında incelendi. Arter filtreleri ayrıca yakalanan kan elementleri veya partikülleri ile ilgili olarak SEM ile analiz edildi.
Bulgular: Aksiyel görüntülerden elde edilen ortalama lif kalınlığı grup P ve NP'de sırasıyla 46.9 μm and 47.6 μm olarak hesaplandı ve istatistiksel olarak anlamlı değildi. Arter filtresinden alınan kan örneklerinin değerlendirilmesi, grup NP'de daha yüksek miktarda fibrin ağı ve lifler üzerindeki kan hücrelerini ortaya çıkardı.
Sonuç: Pulsatil akımda arteriyel filtre liflerinde daha az miktarda kan bileşeni olduğu sonucuna varıldı. Oksijenatörlerin kaplanmasının, yüzey biyo-uyumluluğu durumunda faydalı olduğu ve pulsatil perfüzyon, arteriyel filtrede daha düşük miktarda kan elementi geliştirdiği izlendi.

**Anahtar Kelimeler:** Pulsatil akış, Kaplamalı oksijenatör, Arteriyel filtre, Kardiyopulmoner baypas, Biyo-uyumluluk

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# 1. Introduction

Despite improvements in biomechanical engineering, there is no suitable pump that delivers physiological flow. Pulsatile cardiopulmonary bypass (CPB) considered to be more physiological than nonpulsatile flow, but it is not widely used during cardiac surgery. Improved patency of the vascular bed, enhanced microcirculation and diffusion, low systemic vascular resistance are theoretical advances of pulsatile CPB (Chiu et all, 1984, Laffey et all, 2002, De Leval et all, 1972).

Intermittent high-amplitude pressure and flow pulse are developed to simulate physiological flow during CPB, but pulsatile pumps increase the complexity of the CPB circuit and enhance the destruction of red blood cells and platelets. Decrease in circulating platelet count occurs because of contacting blood and gaseous or synthetic solid surfaces during CPB.

CPB has been demonstrated to induce complex systemic inflammatory response (Dunn et all, 1974) and to affect the haematological system, contributes to several adverse postoperative complications (Iwahashi et all, 2004). Much effort was undertaken to develop more physiological and biocompatible CPB materials. Phosphorylcholine coated (PC) oxygenators and Polyvinyl Chloride tubing systems are developed to reduce inflammatory response (Gorbet and Sefton, 2004).

Despite six decades of research, there is still vigorous debate about the benefits of pulsatile perfusion and biocompatible CPB materials. The purpose of this study is to compare the effects of pulsatile-nonpulsatile flow while using phosphorylcholine coated oxygenators and polyvinylchloride tubing systems on oxygenator fibers, arterial filters by using scanning electron microscope (SEM) and coagulation profiles, inflammatory markers, and biochemical blood tests.

# 2. Material and Methods

Eleven patients between 40 and 74 years of age with normal left ventricle ventricular ejection fraction (LVEF) scheduled for elective isolated coronary artery bypass grafting (CABG) were randomly divided into two groups. Non-pulsatile flow was used in group NP (5 patients) and pulsatile flow in group P (6 patients). In all patients phosphorylcholine coated oxygenators and polyvinylchloride tubing systems are used during surgery. The study was approved by the Institutional authorization (11060-24072009).

Emergency procedures, patients with low LVEF (≤%40), patients whom receiving anticoagulants and antiplatelet medications during the one week preceding their admission for surgery and reoperations are excluded from the study.

Anesthetic regimens, CPB and surgical procedures were standard in all cases. Anesthesia induction was consisting of fentanyl, midazolam, thiopentone sodium and tracheal intubation was facilitated by pancuronium bromide. Heparin sulphate was used at an initial dose of 4 mg/kg followed by additional doses to maintain the activated clotting time (ACT) greater than 400 seconds. The CPB system consisted of polyvinyl chloride tubing, Dideco Compactflo Evo oxygenator (Sorin, Sorin Group Italia, Mirandola, Italy), Jostra HL-20 roller pump (Jostra USA, Austin, TX, USA) and Dideco D 734 Micro 40 Adult (Sorin, Sorin Group Italia, Mirandola, Italy) arterial filter line. Prime solution was 1500 mL of Ringers solution and 200 mL of 20% mannitol. A perfusion flow of 2.2-2.42 L/min/m2 BSA was maintained during CPB.

Pulse flow width 60%, base 25% with rate of 60 beats per minute was used in the pulsatile group. The heart was arrested using Plegisol solution (Hospira Inc, North Chicago, USA), arrest was maintained by using intermittent cold blood cardioplegia. The temperature monitored by rectal and blood probes throughout the surgery. All patients were operated under mild and moderate hypothermic CPB. Rewarming was up to 36,6°C rectal temperature before discontinuation of CPB. After weaning from CPB, the residual blood in the circuit was transfused through the aortic cannula. Protamine sulphate was used in the same dose as the initial heparin dose. Reversal was confirmed by ACT has returned to the preoperative value.

## 2.1. Blood analyses

Four blood samples are collected from the patients. All blood samples were collected through the central venous line. Preoperative, immediately after entering CPB, after ending of CPB and at postoperative 24th hour, blood samples are collected. Haematocrit levels, platelet counts, coagulation profiles, serum creatinine, blood urea nitrogen, bilirubin, albumin, ALT, AST, protein, CRP, IL-6, IL-12, S100B, apelin and TNF levels are compared in both groups. IL-6, IL-12 and TNFα were measured in duplicate using commercially available enzyme amplified sensitivity immunoassay (ELISA) kits (Diasource®, Nivelles, Belgium). Apelin was measured in duplicate using commercially available ELİSA kits (Phoneix Pharmaceuticals Inc®, California, USA). S100B were measured in duplicate using commercially available ELISA kits (Diametra®, Milano, Italy).

## 2.2. SEM image analyses

At the end of the operation, oxygenator was filled with 2.5% glutaraldehyde solution by the help of roller pump. Gluheraldehid solution is needed for the fixation of the blood elements and protein adsorption on the fibers. Oxygenator was cut by Dremel lithium-ion 800, and fibers were placed in 50 ml sterilized containers with 20 ml saline. Each fiber is covered with 5 nm chromium by Precision Etching Coating System (PECS) (Gatan 682, USA) and using sputter technique (Shah et all, 2013). Both superficial view and axial sections of the fiber samples were examined under scanning electron microscope (SEM) (FEI QUANTA 200, Oregon, USA). The SEM images were analyzed by using xT microscope Control Software (Gatan Microscopy Suite, USA).

The cross-sectional images of the fibers were obtained by cutting with ultra-microtome (LEICA EM FC6, Germany). The fibers were frozen by pulverized 50% propanol alcohol and 50% water at -120 $C^0$. Nitrogen gas was sprayed on fibers to vaporize the water and alcohol on them following the cutting procedure. All samples were placed on silicon wafer and analysed with SEM.

## 2.3. Arterial Filter

Arterial filter was filled with phosphate buffer solution and then samples were obtained at 60th minute by sonic waves. It is possible to obtain blood elements and proteins that were absorbed by fibers. The samples were dried by critical point dry method and ethanol in a clean room (Pivush et all, 2012). The

dried samples were placed on silicon wafer and analyzed by SEM.

The Statistical Package for Social Sciences program version 16.0 (SPSS Inc, Chicago, IL, USA) was used. Descriptive data were expressed as mean and standard deviation. Parametric tests were used for data with a normal distribution, and non-parametric tests were applied to data without a normal distribution. Distribution of normality was tested with the Kolmogorov–Smirnov test. The Mann–Whitney U- and Wilcoxon tests were used for comparing variables between groups. Chi-squared, Fisher's and Mantel Haenszel tests were performed for comparison of categorical variables. Level of significance was set at $p < 0.05$.

# 3. Results and Discussion

Mean age, body weight, body surface area, cardiopulmonary bypass time, pump flow, min temperatures, aortic cross clamp time and number of target vessels were compared in both groups. There was no significant difference between groups (Table 1).

***Table 1:*** *Clinical data and cardiopulmonary perfusion findings according to the groups.*

| | **Group P** (n=6) | **Group NP** (n=5) | **P value** |
|---|---|---|---|
| Age | 66.8±7.7 | 55.6±11.1 | 0.08 |
| Weight (kg) | 71.3±6.4 | 77.8±8.7 | 0.22 |
| BSA (m2) | 1.7±0.1 | 1.8±0.1 | 0.23 |
| CPB time (min) | 98±23.2 | 101.5±20.8 | 0.82 |
| X clamp time (min) | 54.4±16.7 | 69.2±26.5 | 0.32 |
| Pump flow (L/min/) | 4.2±2.8 | 4.5±4.8 | 0.29 |
| Number of target vessels | 3.8±1.1 | 3.8±0.8 | 0.96 |
| Minimum CPB temperature (°C) | 30.6±1.5 | 31.7±2.0 | 0.62 |

Haematocrit value, platelet counts, fibrinogen and prothrombin levels were slightly decreased and then increased but d-dimer level was first increased and then decreased insignificantly (Table 2).

***Table 2:*** *Hematologic and coagulation profile of the patients' blood samples according to the groups.*

| | **Group P** (n=6) | **Group NP** (n=5) | | **P value** |
|---|---|---|---|---|
| **Hematocrit values** | | | | |
| Preoperative | 36.2±3.5 | 36.3±7.6 | | 0.98 |
| During CPB | 26.5±3.1 | 30.9±7.7 | | 0.28 |
| After CPB | 26.8±2.6 | 28.1±2.9 | | 0.45 |
| Postoperative 24th hr | 28.7±4.5 | 27.9±2.7 | | 0.76 |
| **Platelet values (n/μL)** | | | | |
| Preoperative | 199±48.7 | 196±88.1 | | 0.94 |
| During CPB | 139.2±27.8 | 209.6±66.6 | | 0.06 |
| After CPB | 126.6±22.4 | 170.2±70.1 | | 0.22 |
| Postoperative 24th hr | 148.2±35 | 189.7±51 | | 0.22 |
| **Fibrinojen (g/L)** | | | | |
| Preop | 3.77±1.75 | 3.82±0.33 | | 0.95 |
| During CPB | | | | |
| After CPB | 2.26±1.60 | 2.45±0.59 | | 0.83 |
| Postop 24th hr | 4.15±1.38 | 4.42±1.52 | | 0.79 |
| **D-Dimer (<0.4 mcg/mL)** | | | | |
| Preop | 0.32±0.09 | 0.36±0.11 | | 0.53 |
| During CPB | 5.31±4.24 | 4.28±3.75 | | 0.69 |
| After CPB | 9.45±8.61 | 5.54±2.50 | | 0.35 |
| Postop 24th hr | 1.21±0.30 | 2.22±1.66 | | 0.27 |
| **Prothrombin (U/ml)** | | | | |
| Preop | 512±112 | 407±205 | | 0.4 |
| During CPB | 432±82 | 457±74 | | 0.67 |
| After CPB | 414±94 | 468±120 | | 0.50 |
| Postop 24th hr | 454±117 | 378±34 | | 0.26 |

Blood urea nitrogen, serum creatinine, bilirubin, AST, ALT, protein, and albumin levels were all decreased and return back to initial values without any significant changes between the groups at any time points (Table 3).

***Table 3:*** *Blood liver and kidney functions of the patients according to the groups.*

| | **Group P** (n=6) | **Group NP** (n=5) | **P value** |
|---|---|---|---|
| **Creatinin (mg/dl)** | | | |
| Preop | 1.07±0.63 | 0.94±0.31 | 0.71 |
| During CPB | 0.92±0.54 | 0.68±0.09 | 0.41 |
| After CPB | 0.95±0.58 | 0.8±0.23 | 0.5 |
| Postop 24th hr | 1.34±1.03 | 0.97±0.16 | 0.76 |
| **Blood urea nitrogen (mg/dl)** | | | |
| Preop | 39.4±18.3 | 35.7±9.3 | 0.73 |
| During CPB | 36.8±16.9 | 32.2±6.0 | 0.62 |
| After CPB | 36.4±16.0 | 33±5.5 | 0.66 |
| Postop 24th hr | 49.5±40.0 | 32.5±2.6 | 0.43 |
| **Bilirubin (total) (mg/dl)** | | | |
| Preop | 0.5±0.4 | 0.5±1.8 | 0.79 |
| During CPB | 0.6±0.3 | 0.6±0.2 | 0.74 |
| After CPB | 0.5±0.3 | 0.5±0.2 | 0.8 |
| Postop 24th hr | 1.4±1.2 | 0.7±0.6 | 0.35 |
| **AST (IU/L)** | | | |
| Preop | 15±3.7 | 16.7±5.1 | 0.57 |
| During CPB | 19±5.8 | 24.7±2 | 0.1 |
| After CPB | 29±6 | 30±4.1 | 0.76 |
| Postop 24th hr | 42.5±15.9 | 40.5±17.3 | 0.44 |
| **ALT (IU/L)** | | | |
| Preop | 14.2±3.7 | 19±8 | 0.27 |
| During CPB | 10.6±3.3 | 13.7±1.8 | 0.14 |
| After CPB | 12.8±1.9 | 14.8±2.6 | 0.21 |
| Postop 24th hr | 14.5±6.3 | 18±5.7 | 0.44 |
| **Protein (total) (mg/dl)** | | | |
| Preop | 5.5±0.4 | 5.4±1.8 | 0.96 |
| During CPB | 3.4±0.7 | 3.7±0.6 | 0.56 |
| After CPB | 3.5±0.3 | 3.9±0.8 | 0.34 |
| Postop 24th hr | 5±0.2 | 5.1±1.1 | 0.85 |
| **Albumin (mg/dl)** | | | |
| Preop | 3.5±0.4 | 3.3±1.2 | 0.72 |
| During CPB | 2.1±0.3 | 2.1±0.4 | 0.96 |
| After CPB | 2.2±0.2 | 2.3±0.4 | 0.76 |
| Postop 24th hr | 3.3±0.3 | 3.3±0.6 | 0.96 |

Inflammatory biomarkers such as CRP, IL-6, TNFα were first increased and then decreased, Apelin, IL-12 and s100B first increased and decreased during the further measurements without having any significant differences in between the groups (Table 4).

***Table 4:*** *Blood Inflammatory markers of the patients according to the groups*

| | **Group P** (n=6) | **Group NP** (n=5) | **P value** |
|---|---|---|---|
| **CRP (mg/dl)** | | | |
| Preop | 12.3±15.0 | 7.9±2.2 | 0.53 |
| During CPB | 9.5±10.3 | 5.8±1.1 | 0.45 |
| After CPB | 8.2±7.9 | 5.7±0.7 | 0.50 |
| Postop 24th Hour | 123.7±71.3 | 123±99 | 0.99 |
| **Apelin (ng/ml)** | | | |
| Preop | 1370±265 | 989±165 | 0.05 |
| During CPB | 1653±104 | 1397±281 | 0.13 |
| After CPB | 1471±267 | 1450±249 | 0.91 |
| Postop 24th Hour | 1187±368 | 1099±80 | 0.65 |
| **IL-6 (total) (pg/ml)** | | | |
| Preop | 73.5±46.4 | 140.5±175.5 | 0.48 |
| During CPB | 56.5±23.7 | 62.7±34.8 | 0.77 |
| After CPB | 289±293 | 368±315 | 0.72 |
| Postop 24th Hour | 333±202 | 210±87 | 0.30 |
| **IL-12 (pg/ml)** | | | |
| Preop | 347±184 | 224±76 | 0.26 |
| During CPB | 341±186 | 275±55 | 0.51 |
| After CPB | 380±155 | 403±90 | 0.81 |
| Postop 24th Hour | 220±142 | 151±109 | 0.47 |
| **S100B (pg/ml)** | | | |
| Preop | 116±142 | 51±18 | 0.39 |
| During CPB | 298±210 | 198±113 | 0.43 |
| After CPB | 412±134 | 214±118 | 0.07 |
| Postop 24th Hour | 308±514 | 40±3 | 0.33 |
| **TNF α (pg/ml)** | | | |
| Preop | 993±1860 | 50±16 | 0.35 |
| During CPB | 183±271 | 41±11 | 0.33 |
| After CPB | 292±480 | 49±26 | 0.35 |
| Postop 24th Hour | 231±351 | 41±18 | 0.32 |

Axial sections of the fiber samples which were examined under SEM were analyzed. Section of the fibers before and after the CPB were measured to understand the adsorbed protein thickness on fibers. Section of fiber axis before CPB (non-used oxygenator) was measured as 46.06 μm and accepted as reference value (Figure 1).

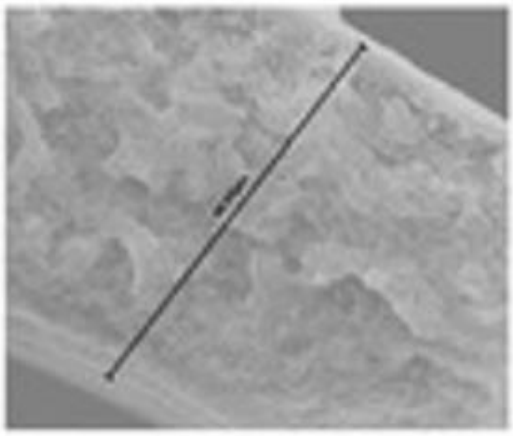

***Figure 1:*** *Section of non-used phosphorylcholine coated oxygenator fiber axis view by scanning electron microscopy (voltage 15.00 kv, sample-objective lens distance 11.5mm and magnification 5000x). Fiber thickness is 46.05 μm before cardiopulmonary bypass perfusion (reference value)*

Samples of fiber thickness measurements are shown at Figure 2a, 2b and 3a, 3b following pulseless and pulsatile cardiopulmonary bypass perfusion.

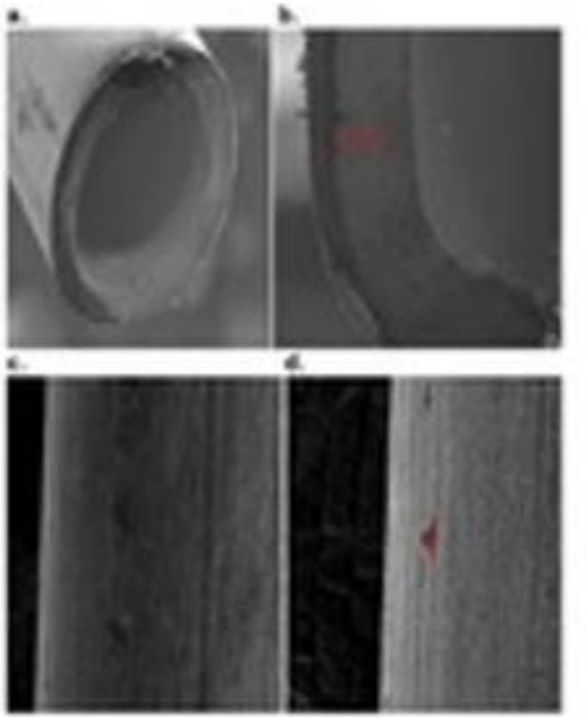

***Figure 2:***

***a.*** *Section of a fiber axis view by scanning electron microscopy (voltage 5.00 kv, sample-objective lens distance 1.8 mm and magnification 400x) with an phosphorylcholine coated oxygenator following pulseless cardiopulmonary bypass flow.*

***b.*** *A sample of fiber thickness is 47.79 μm measured following pulseless cardiopulmonary bypass perfusion (voltage 5.00 kv, sample-objective lens distance 1.8 mm and magnification 2000x).*

***c.*** *Surface of a fiber axis view by scanning electron microscopy (voltage 5.00 kv, sample-objective lens distance 11.1 mm and magnification 800x) with an phosphorylcholine coated oxygenator following pulseless cardiopulmonary bypass flow.*

***d.*** *Surface of a fiber axis view by scanning electron microscopy (voltage 5.00 kv, sample-objective lens distance 11.3 mm and magnification 3000x) with a phosphorylcholine coated oxygenator following pulseless cardiopulmonary bypass flow.*

The mean fiber thickness from the axial images were calculated as 46.9 μm and 47.6 μm at group P and NP respectively (Figure 4). The difference is statistically insignificant (p=0.053). Superficial view of the fiber samples which were examined under SEM were subjectively analyzed from the images. The platelet, leukocyte and erythrocyte amount are not different at pulsatile flow group if compared with the pulseless group (Figure 2c, 2d and Figure 3c and 3d).

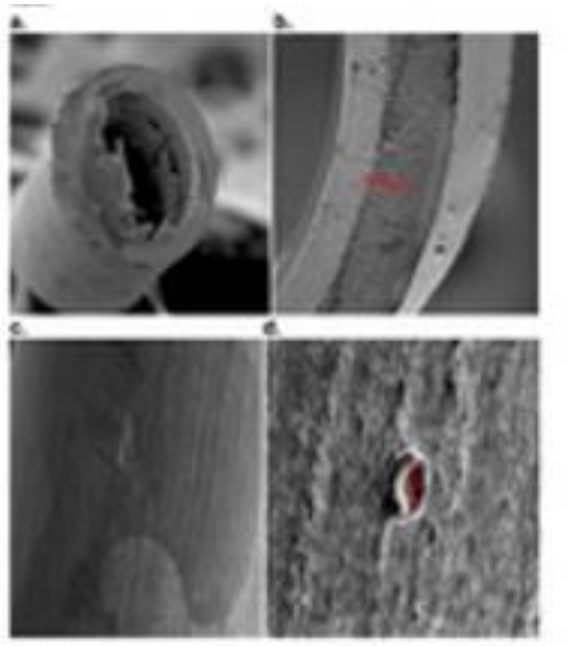

***Figure 3:***
***a.*** *Section of a fiber axis view by scanning electron microscopy (voltage 5.00 kv, sample-objective lens distance 19.9 mm and magnification 400x) with a phosphorylcholine coated oxygenator following pulsatile cardiopulmonary bypass flow.*
***b.*** *A sample of fiber thickness is 46.82 μm measured following pulsatile cardiopulmonary bypass perfusion (voltage 5.00 kv, sample-objective lens distance 2.7 mm and magnification*
***c.*** *Surface of a fiber axis view by scanning electron microscopy (voltage 5.00 kv, sample-objective lens distance 11.2 mm and magnification 800x) with a phosphorylcholine coated oxygenator following pulsatile cardiopulmonary bypass flow.*
***d.*** *Surface of a fiber axis view by scanning electron microscopy (voltage 5.00 kv, sample-objective lens distance 11.3 mm and magnification 8000x) with a phosphorylcholine coated oxygenator following pulsatile cardiopulmonary bypass flow*

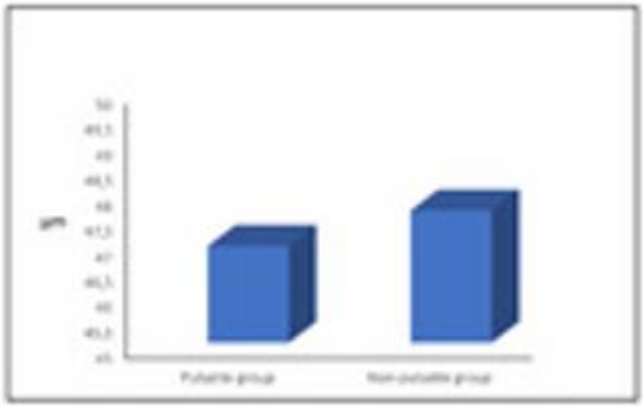

***Figure 4:*** *The amount of protein adsorbed on the oxygenator fiber (p=0.053) (reference=46.06 μm) according to the groups.*

Evaluation of the blood samples that were extracted from the arterial filter bring out higher amount of fibrin network and blood cells on fibers at pulseless group (Figure 5).

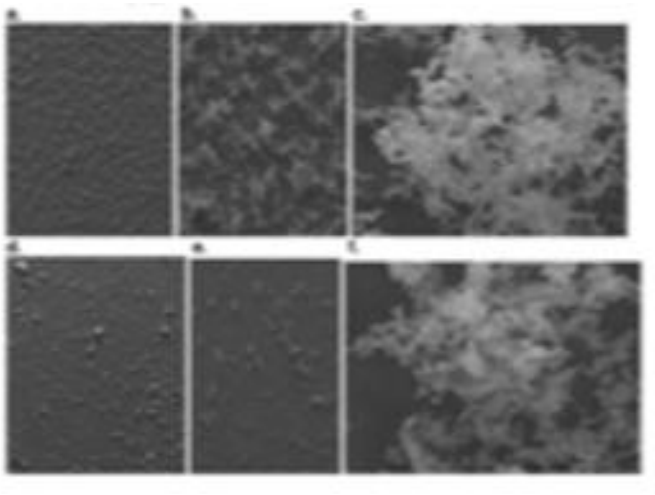

***Figure 5:*** *Samples from arterial filter, view by scanning electron microscopy (voltage 10.00 kv, sample-objective lens distance 9.1 mm and magnification 250x (a), magnification 1000x (b), magnification 10000x (c)) with an phosphorylcholine coated oxygenator following pulseless cardiopulmonary bypass flow. Samples from arterial filter, view by scanning electron microscopy (voltage 10.00 kv, sample-objective lens distance 9.1 mm and magnification 250x (d), magnification 600x (e), magnification 40000x (f)) with a phosphorylcholine coated oxygenator following pulsatile cardiopulmonary bypass flow.*

Analysis of arterial filter by SEM did not show any particle that was hold by the filter during the pulsatile or nonpulsatile flow.

## 3. Results and Discussion

Cardiopulmonary bypass (CPB) is fundamental for open heart surgery. Despite improvements of biotechnology, multiple organ dysfunction, CPB induced systemic in flammatory response (SIRS) and endothelial dysfunction are still major clinical drawbacks (Tanaka et all, 2000, Rabe et all, 2011). The most interesting part of the CPB is oxygenator, which had a huge surface area. Plasma proteins and cellular elements stick on the oxygenator fibers as soon as the CPB flow begins (Guan et all, 2009, Tabesh et all, 2012). Much effort was undertaken in recent years to reduce CPB related adverse events and to prevent adhesion on the artificial surfaces (Gourlay, 2001). Heparin coated and more recently, phosphorylcholine coated (PC) oxygenators have been demonstrated to reduce inflammatory response and better biocompatibility (Wendel, 1999). Karakisi SO., demonstrated that a more prominent cellular immune response was observed on using PC oxygenators (Karakisi et all, 2016). A PC cardiopulmonary bypass circuit was tested by using SEM for biocompatibility. Neither thrombus formation nor organized cellular deposits were found on the inner housing, heat exchanger, and outer surface of the hollow fibers (De Somer et all, 1999). A PC oxygenator had lesser protein adsorption and lower cellular adhesion even without anticoagulation (Iwasaki et all, 2003).

There are many studies also searching pulsatile flow, although it is not widely accepted. It has beneficial effects on tissue perfusion, diffusion, and metabolism [18]. We compare pulsatile flow and non-pulsatile flow with PC oxygenators. We studied not only blood analysis of patients but also SEM analysis

of the oxygenators and arterial filters according to flow type. In our study, haematocrit value, platelet counts, fibrinogen, prothrombin, and d-dimer levels slightly changed in both groups insignificantly. There is not any significant difference between the groups. Moreover, it was previously mentioned that pulsatile flow is responsible for the decrease of platelet count but also protection of fibrinolytic system elements (Agirbasli et all, 2014). Lorussoa R. could not find any difference in terms of demographics, operative, and haematological profiles between the PC and uncoated groups. Postoperatively, PC group showed only reduced platelet consumption (Lorussoa et all, 2009). Blood urea nitrogen, serum creatinine, bilirubin, AST, ALT, protein, and albumin levels were also differed insignificantly and return to initial values in both groups in our study. Inflammatory biomarkers increased during CPB but decreased during the further measurements without having any significant differences in between the groups. On the other hand, Abramov D., could not be able to find out beneficial effects of pulsatile perfusion in a study over 1800 patients with CABG. Both mortality and morbidity including renal dysfunction did not differ in pulsatile and non-pulsatile groups (Abramov et all, 2003). A cochrane based search also could not define supportive data for or against pulsatile perfusion to reduce mortality, myocardial infarction, stroke, or renal insufficiency (Alghamdi and Latter, 2006). Studies shown release of cytokines during the CPB several times (Frering et all, 1994). A reduced cytokine levels and protected pulmonary and renal functions on pulsatile flow were mentioned by Sezai A. (Sezai et all, 2005, Nam et all, 2015, Lim et all, 2015).

The biocompatibility of the oxygenator according to the flow type was evaluated by SEM analyses. The coated oxygenators had lower level of activated platelet, complement and coagulation cascades caused by the decreased surface activation. In our study, both flow type had similar results of adhesion on fiber surfaces. This reveals that coating of oxygenators is more important than the flow type. Axial sections of the fiber samples were analysed on non-used oxygenator to obtain reference value by SEM. The difference of thickness on fibers in between the reference value and measurement following CPB, was calculated as protein adsorption value. This value was 0.84 μm in pulsatile group and 1.54 μm in non-pulsatile group. The difference is 0.70 μm in between the groups. The protein adsorption on oxygenator fibers is not statistically significant on both pulsatile and non-pulsatile perfusion flow. Superficial view of fiber samples was also analyzed by using SEM. Although, the analysis is qualitative, the platelet, leukocyte and erythrocyte amount are also similar at both groups.

CPB activates the inflammatory response and the leukocytes. Filters usually prevent the activated leukocytes which were bigger, but they cannot stop small leukocytes. Evaluation of the blood samples that were extracted from the arterial filter bring out fibrin network and blood cells on fibers. The images of the SEM provide the very nice images of the arterial filter fibers that involve fibrin and cellular content. Those results are comparable with the literature (Simons et all, 2010, Undar et all, 2019). It is possible to get an impression of lower level of cellular content and haemoglobin adsorption at pulsatile group during the CPB in our study.

Our study limitations can be mentioned as; pulsatile perfusion quantification could not have described in terms of energy equivalent pressure and hemodynamic energy. It was well defined previously for the precise evaluation of the pulsatile flow (Undar et all, 2003, Undar et all, 2006). Pulseless flow circulates with a constant velocity and pressure in the body, but it is not physiological (Sperling et all, 2009). Pulsatile flow maintains a physiological flow that is similar with heart. This needs additional energy and pressure. This extra energy enhances a better microcirculation (Undar et all, 1999, Kocakulkak et all, 2004, Demirkilic et all, 2004).
On the other hand, mechanical effects of pulsatile perfusion may lead a particle embolization that may occur around pump head. Our analysis of arterial filter by SEM did not show any particle (related with CPB lines as silicone particles etc.) that was hold by the filter during the pulsatile flow or nonpulsatile flow.

In our study, both flow type had similar results of adhesion on fiber surfaces. There is lesser amount of blood components on the fibers of arterial filter at pulsatile flow and no particles related with CPB lines at both groups. Coating of oxygenators is beneficial in case of surface biocompatibility and pulsatile perfusion develops lower amount of blood elements on arterial filter.

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