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Short Communication

New zeolite-based composite pads with high-volume blood absorption for early warning of postpartum hemorrhage

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Abstract

Medical treatment of severe blood loss during labor is crucial, and the early warning indicator of postpartum hemorrhage (PPH) is essential for labor medical treatment. Measurement of blood loss conventionally looks dirty, reluctant, and less hygienic since some of the blood might be spilled out in the maternity bed, while commercially existing pads have low blood absorption capacity. A new design composite pad composed of absorbent materials, including cellulose rayon, super absorbent polymer (SAP), and zeolite was fabricated and characterized. The SAP and zeolite show properties as crystalline and amorphous materials, respectively. The surface area of natural zeolite was 19.79 (m^2/g). The newly fabricated composite pad showed a high blood absorption capacity (>500–600 mL) with a blood absorption rate of 55.56–85.84 mL/min (depending on the blood volume), showing better performance as compared to the commercial pads. These characteristics suggest that the new composite pad could function not only as a sanitary pad but also as an early warning indicator for PPH if the rate and blood volume reach the dangerous category (≥600 mL or at ≥13 mL/min rate).

Keywords: Natural zeolite, super absorbent polymer, SAP, maternity, labor

Introduction

Dealing with bleeding during and after labor is challenging work for health professionals, including midwives. Under normal circumstances, physiological hemorrhage occurs during the third stage of labor. However, if excessive bleeding occurs, it can result in potential blood loss [1]. Postpartum hemorrhage (PPH) is a critical period of high bleeding rates (often exceeding 500 mL) in the first two hours postpartum, commonly caused by uterine atony, perineal rupture, retained placenta, or other factors during vaginal delivery [2,3]. Despite efforts to prevent childbirth-related bleeding, postpartum hemorrhage (PPH) remains a life-threatening challenge during labor, particularly in recognizing early signs and symptoms, especially in rural areas of developing countries [4]. Approximately 20% of PPH cases occur without risk factors, and delayed clinical decisions often exacerbate the condition [5]. Professional intervention in handling severe PPH increases the chances of survival by 35% [6,7]. Therefore, advocating early warning for PPH is also crucial.

Estimating the blood loss during delivery is critical for early detection and intervention of PPH [8]. In clinical practice, PPH is often anticipated by measuring blood loss using basins, but

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inaccurate measurements may occur due to the lack of volume scaling marks [2,8,9]. While equipment for more accurate measurement has been introduced [10-13], the aim of this study was to develop a more straightforward solution. A new composite pad design was created to not only absorb blood like a standard commercial pad but also serve as an indicator for PPH, which has not been commercially available. Herein, the newly developed sanitary pad employed the combination of super absorbent polymer (SAP) and natural clay-zeolite. Zeolite and SAP are widely studied absorbents with negligible health risks to users [14]. To our knowledge, this is the first study reporting SAP and zeolite as absorbing materials in sanitary pads. A sanitary pad with high and fast absorption capacity is required to hold a large volume of PPH, by which the quantity is easily measured, giving a simple indicator for emergency treatment. Since the material and processing of this new pad are cost-effective and available locally, it shall be contributed to the Indonesian community.

Methods

Study design and blood collection

This study was an experimental design, especially in collecting labor blood samples. Trained midwives were recruited for the postpartum blood sample collection from 15 patients in the maternity clinics, which were randomly sampled. Postpartum blood was collected using sterilized equipment to prevent contamination from dirt, faces, amniotic liquid, and urine. The blood was collected directly into blood bags and stored in a cooler box. Blood viscosity was measured using a portable viscometer (NDJ-8S Rotational Viscometer Adopts Advanced Mechanical).

Studies on characteristics of existing labor sanitary pads

Before the newly fabricated sanitary pad studies, the characteristics of existing and commercially available sanitary pads were explored for comparison. Labor sanitary pads (4 internationally branded sanitary pads) that are available in the Indonesian market were purchased. Each of the sanitary pads was labeled as S1-S4. Their dimensional characteristics (weight, length, width, and thickness) are presented in **Table 1**.

Table 1. Dimensional characteristics of commercially available labor sanitary pads

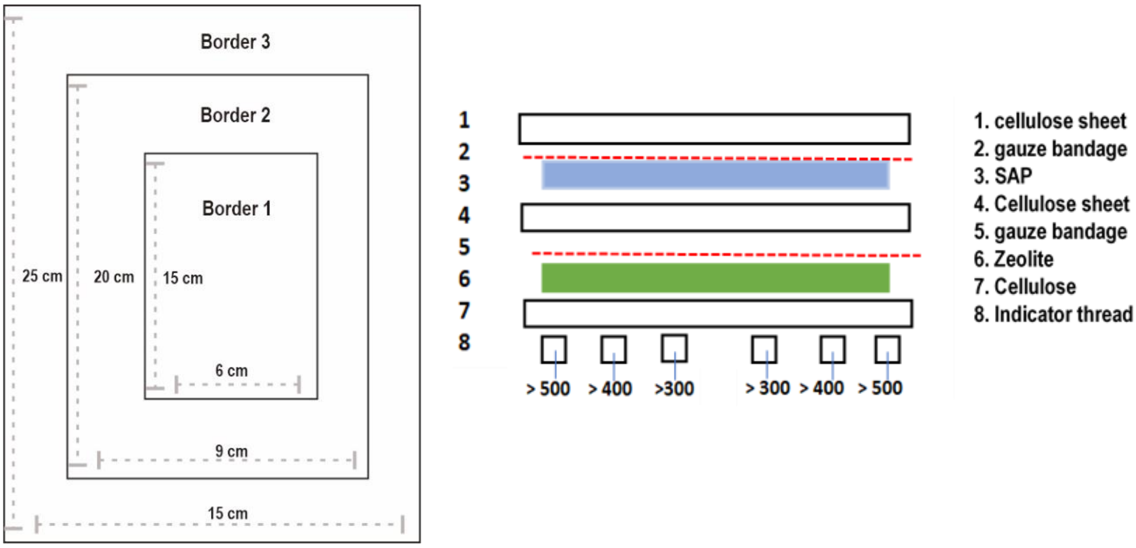
Pad's label	Weight (g)	Length (cm)	Width (cm)	Thickness (cm)
S1	40	48.5	18.0	0.77
S2	20	30.0	19.5	0.43
S3	30	45.0	12.0	0.58
S4	10	35.0	9.50	0.36

Preparation and physical characterization of the absorbent materials of the newly fabricated sanitary pad

Superabsorbent (SAP; sodium polyacrylate, commercial grade) and natural zeolite experience were procured from local suppliers. Zeolite was ground and sieved, then the particles that passed through 100 mesh were collected and then dried at 105°C until they reached a constant weight. The porosity was analyzed using BET methods with Micromeritics TriStar II 3020 instrument. The zeolite crystallinity was characterized with the X-ray Diffraction (XRD) method using the Shimadzu XRD 7000 instrument (CuKα radiation, 40 kV, and 40 mA). Surface area analysis was performed on QuadraSorb Station 1 (ver. 5.06) based on the adsorption-desorption of nitrogen at 77.3 K. The values were calculated using Brunauer-Emmett-Teller (BET) and Barret-Joyner-Halenda (BJH) isotherm models.

Design and fabrication of the new composite pad

The new assembly pad was reverted to the size of commercial products (45 cm × 15 cm). At the bottom of the new design pad, we drew three rectangular images on the water-proof non-woven cloth (propylene fabric) with a pencil (**Figure 1A**). Indicator threads were stuck on each side of the rectangular pictures using double tape. The second layer was a viscose rayon (cellulose) sheet with a 22 cm × 15 cm size and about 0.5 cm thinness. Natural zeolite (52 g; ≥100 mesh particles) was spread on the cellulose layer, as illustrated in **Figure 1B**. The surface was leveled with a PVC pipe rolling pin (37 cm length and 4 kg weight). Above the natural zeolite layer, the gauze bandage sheet was placed and leveled again with the rolling pin before the second cellulose sheet was assembled on the gauze surface. On the surface gauze bandage, 52 grams of SAP was spread and flattened with the rolling pin. Before the upper level was covered with a cellulose sheet, the SAP was covered with a gauze bandage layer, and the surface was pressed with the rolling pin. The cellulose upper level was flatted with the rolling pin again and the seal all sides of the package with paper tape.



A B

Figure 1. Diagram of new design composite pad; (A) rectangle images at the bottom of the new pad; (B) Layer structure of the new pad. Numerical numbers (>500, >400, and >300) represented border markers for maximum blood volume absorbed by the newly fabricated pad.

Absorption and diffusion rate of pad component and the new pad package

Blood was filled in a graduated separation funnel and hung at a stative equipped with a ring clamp (**Figure 2A** and **2B**). A centimeter-sized paper was drawn on a transparent polyethylene film, and a square (3 cm × 3 cm) hole was made in the middle of the transparent film (**Figure 2B**). Several types of pads, pad components of the new design pad and the new pad package were tested individually for horizontal blood absorption (blood diffused horizontally) [16]. The blood flow rate (from the funnel, measured by blood volume flew down per minute) was studied to adjust with the blood wetted rate (measured by the number of wetted squares below the centimeter-sized transparent film, as shown in **Figure 2C**) in the pad, which was 13 mL/min. Then, the suitable blood flow rate was maintained in all experiments. The area covered by blood rectangular (**Figure 1A**) under the pad was monitored at every 100 mL of blood absorbed. The absorption capacity of the pad was expressed as the volume of the absorbed blood divided by the time required for the overload. The volume of the absorbed blood was estimated based on the number of square marks on the pad covered with blood (**Figure 2C**).

Results

Characteristics of the absorbing materials

The XRD diffractogram, along with the bulk appearances of the zeolite and SAP used as the absorbing material, are presented in **Figure 3A**. The diffractogram appears with amorphous patterns, suggesting the presence of impurities in zeolite. Nonetheless, crystalline peaks were clear in SAP, which was assigned to the presence of sodium polyacrylate salt (the main component of SAP). Further, based on BET, the adsorption of nitrogen onto the zeolite revealed its surface area to be 19.79 m^2/g. As for the BJH-based pore distribution, the results are presented in **Table**

2. The pore size ranged from 20–1.8 nm. The adsorption and desorption patterns of the nitrogen are presented in **Figure 3B**.

Figure 2. Experiment method for blood absorption capacity of various pads: (A) pad blood absorption capacity test; (B) blood wetted area test on the pad; and (C) measurement of blood wetted area on the pad.

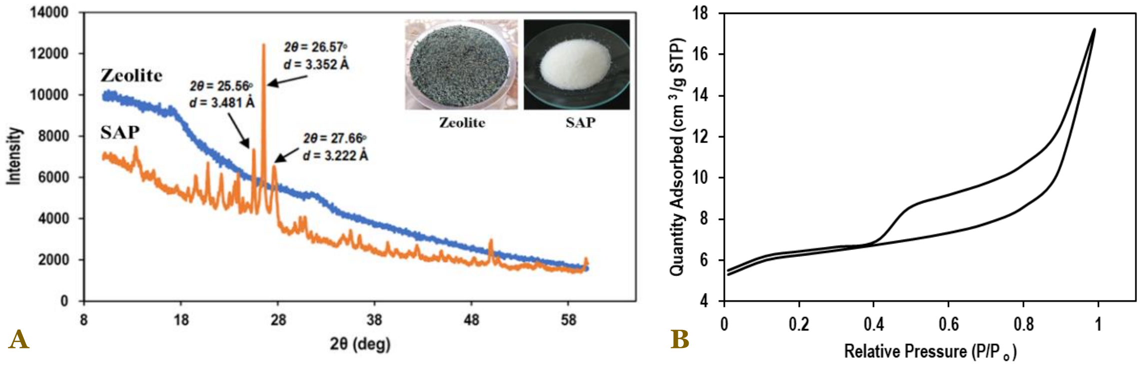


Figure 3. XRD diffractograms and photographed images of zeolite and super absorbent polymer (A). Hysteresis of gas adsorption-desorption of the zeolite (B).

Table 2. Pore distribution of the zeolite based on Barret-Joyner-Halenda (BJH) isotherm

Adsorption		Desorption	
Pore diameter range (nm)	Average diameter (nm)	Pore diameter range (nm)	Average diameter (nm)
170.3–19.5	21.10	170.2–19.5	21.16
19.5–10.6	12.49	19.5–10.3	12.12
10.6–7.0	8.00	10.3–7.0	8.00
7.0–5.2	5.80	7.0–5.1	5.70
5.2–4.1	4.46	5.1–3.8	4.25
4.1–3.2	3.54	3.8–3.1	3.39
3.2–2.6	2.85		
2.6–2.1	2.32		
2.1–1.6	1.80		

Absorption and diffusion rate

The absorption rate of postpartum blood into the pad and wetted pad area is presented in **Table 3**. The commercial pads had absorption and wetted area rates of 9.9–14.7 mL/min and 58.70±1.5–162.0±5.3 cm², respectively. Faster absorptions were observed in newly fabricated pads with SAP, zeolite, or their combination. Larger blood-wetted areas were also larger in newly fabricated pads than in commercial ones. The combination of zeolite and SAP yielded the best performance with blood absorption and wetted area of 25.8±3.3 mL/min and 317.67±11.24 cm², respectively.

Table 3. Mean blood absorption rate and mean area of pad wetted with labor blood

Sample	Blood absorption, mean±SD (mL/min)	Area of the blood-wetted pad, mean±SD (cm²)
S1	14.7±0.7	162.0±5.3
S2	11.2±0.8	142.3±4.0
S3	13.9±0.1	58.70±1.5
S4	9.9±0.9	135.7±5.5
SAP+cellulose rayon	17.4±0.2	198.3±8.5
Zeolite+cellulose rayon	18.3±0.3	218.6±7.7
SAP+zeolite+cellulose rayon	25.8±3.3	317.6±11.2

SAP: super absorbent polymer

Blood absorption capacity

The commercial pad (S1) was found to be unable to retain 150 mL postpartum blood, as indicated by the inundation at border 3 (**Table 4**). As for the newly fabricated pad, the inundation only reached border 1 even when the blood volume was 350 mL. Inundation at border 3 was only observed after the blood volume increased to 600 mL.

Table 4. The blood absorption capacity of the newly designed pad and indicator threads

Blood volume (mL)	Blood absorption (mL/min)	Blood inundation		
		Border 1	Border 2	Border 3
S1*				
150	56.18	Yes	Yes	Yes
250	NA	NA	NA	NA
350	NA	NA	NA	NA
500	NA	NA	NA	NA
600	NA	NA	NA	NA
SAP+zeolite+cellulose rayon				
150	55.56	Yes	No	No
250	74.63	Yes	No	No
350	97.76	Yes	No	No
500	96.15	Yes	Yes	No
600	85.84	Yes	Yes	Yes

NA: not applicable; SAP: super absorbent polymer

*Having the highest absorption rates and largest dispersion among commercial pads

Discussion

In our study, the zeolite-based pad has been successfully prepared and tested for its potential as an early indicator of PPH. The zeolite was revealed to consist of SiO2 and other metal oxides such as Al_2O_3, CaO, K_2O Fe_2O_3 MgO, Na_2O, and TiO_2. The composition profile of the natural zeolite was in line with that reported previously [15]. The presence of these metal oxides determines the ability of the zeolite to absorb various substances, including the whole blood [10-13]. The findings from surface area analysis in the present study also suggest that the natural zeolite had a fairly good adsorption capacity. The gap area between the desorption and adsorption curves indicates the gas absorption capacity [16,17]. Similar to those reported previously, zeolite-based materials tend to possess such gas adsorption-desorption profiles [18-20].

We found that the zeolite-based pads were found to have faster absorption rates as well as larger blood-covered areas, where the combination of zeolite and SAP had the most optimum values. These findings suggest that the newly fabricated pads were effective in absorbing postpartum blood that was well-dispersed on the pad surface. In terms of the absorption capacity, the inundation was only observed when the volume of the blood loss reached 600 mL. A total blood loss volume of 600 mL indicates a life-threatening condition. These characteristics exhibit the potential of the new pad as the early indicator for PPH.

In our previous study [10], high-risk postpartum hemorrhage (600 mL blood loss) occurred with the blood flow rate from the vagina reaching up to 13 mL per minute. This newly fabricated pad can absorb 600 mL of blood with a higher absorption rate, which is up to 25.8±3.3 mL/min. This rate means the new pad is still applicable even with the higher bleeding flow rate (>13 ml/min). The new pad is reasonable to be used as an early warning indicator for postpartum hemorrhage since it can retain the blood volume up to 600 mL, where the covered area was still within the rectangle indicator thread line without overflowing from the new pad. High absorption capacity could be attributed to the properties of the zeolite and SAP components as powerful absorbents that were used to fabricate the new pad [21,22]. Additionally, the gauze bandage, which was used to hold the zeolite powder and SAP crystal within the new pad, also absorbs the blood [23]. SAP contains sodium polyacrylate, which immediately coagulates and holds water molecules in its matrix. Since blood contains 51% water, SAP interacts with the water within the blood, forming a chemical reaction that results in coagulation [24]. The illustrated interaction between SAP and water molecules in the postpartum blood is presented in **Figure 4**.

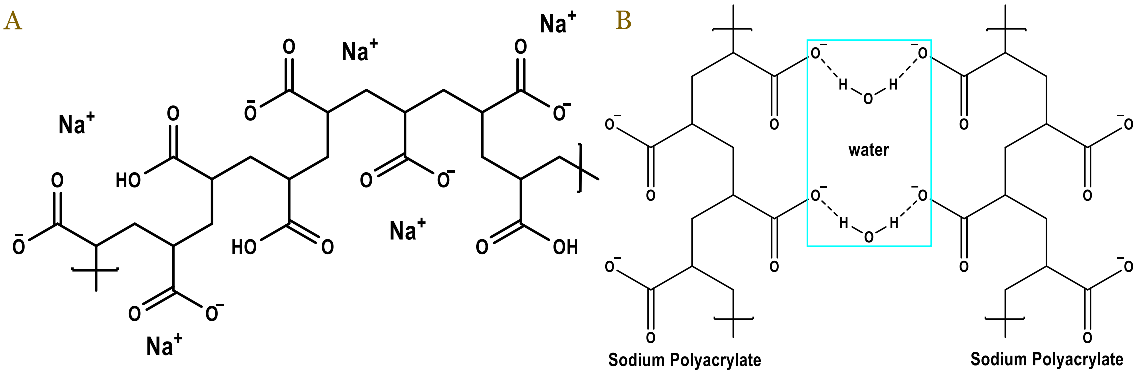


Figure 4. Super absorbent polymer made of sodium polyacrylate with the chemical structure before (A) and after in contact with water (B).

The present study was still preliminary, thus possessing numerous limitations. Though the blood samples were collected from 15 different individuals, the number was insufficient to include the variability of the samples. Implementation of the new zeolite-based pad in clinical settings still requires a lot of measures. A standardized procedure should be designed to ensure the safety of the patients when the new pad is used. Further, we did not perform a diagnostic analysis to determine whether the new pad could be used as an early indicator for PPH. This analysis is particularly important, considering the blood volume calculation requires manual reading, which can vary depending on the birth attendants. The blood thickness variations across patients could result in a bias during the blood loss volume estimation. Moreover, patients' eligibility criteria were not strictly controlled, contributing to possible deviations in its implementation in clinical settings. Future research should consider these factors and employ a robust methodology to assess the new zeolite-based pad's ability to indicate PPH occurrence.

Conclusion

A new labor sanitary pad comprised of zeolite and SAP has been successfully designed and fabricated. Zeolite and SAP, as part of pad essential components, showed beneficial characteristics for blood absorption, including porosity and crystallinity. The newly fabricated pad had higher blood absorption capacity than the commercial pad, suggesting improved performance as the labor sanitary pad and potential early-warning indicator for PPH. Our findings warrant future research aimed at the implementation of the new pad in clinical settings.

Ethics approval

The study was carried out in 40 clinics following the retrieval of ethical clearance (No. LB.02.03/6.7/02.08/2020).

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Competing interests

All the authors declare that there are no conflicts of interest.

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Underlying data

Derived data supporting the findings of this study are available from the corresponding author on request.

How to cite

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