INTRODUCTION

Although tissue tolerance to ischemia is highly variable, ischemia may progress quickly to tissue necrosis unless an immediate intervention is performed to remedy the situation. Ischemia-induced complications following flap reconstruction can lead to functional and cosmetic morbidities due to additional or repeated operations [1-3]. In free flaps alone, ischemic necrosis, either partial or total, still occurs in 5% to 10% of cases, even when performed by an experienced operator [1,2]. Furthermore,
hand surgery, full formal repair of all structures sometimes may not be possible during replantation and complex hand injuries due to the duration of ischemia and the nature of the injury. Hence, patients undergoing replantation have demonstrated increased rates of secondary surgical revisions [4-6].

Interestingly, the timing of secondary procedures does not differ tremendously between cases of traumatic injuries and replantation. No fixed period has been universally accepted in terms of secondary procedures. Instead, the prime determinant of timing is the status of the soft tissue or skin cover at the proposed surgery site, including subsidence of edema, infection, induration, and delayed wound healing as a result of ischemia [4,6,7]. Generally, secondary procedures should not be considered until survival of the replanted finger can be guaranteed [6].

In the non-tourniquet technique of hand surgery, one needs to infiltrate tumescent solution into tissues that already have survived an ischemic injury, both as local anesthesia and to create a bloodless surgical field. The benefits and safety of the tumescent technique using epinephrine-containing local anesthesia have been documented [8-10]. Through retrospective studies, the use of a very diluted concentration of epinephrine (i.e., the one-per-mil tumescent technique) has also been confirmed as effective and safe for a wide range of indications and several different procedures [9,11,12]. With reference to the recommended timing of secondary surgery, which is determined based on tissue status, the authors posed the question of whether it is safe to apply the tumescent technique to facilitate such procedures.

METHODS

This study was conducted to assess the safety of infiltrating one-per-mil tumescent solution into tissue that has already survived ischemic conditions. A randomized experimental study was conducted in 20 Wistar rats (12 males and 8 females, weighing 220–270 g) at the Animal Laboratory, Faculty of Medicine, Universitas Indonesia. Randomization by simple random sampling was conducted regarding the use of the right and left sides of the groin. All rats were housed with a 12-hour light/dark schedule and received stock diet and water ad libitum for 7 days before surgery. Approval was obtained from the Ethics Committee of Faculty of Medicine, Universitas Indonesia (No. 258/UN2.F1/ETIK/2016) before conducting this study.

Anesthesia was provided by intramuscular injection of 35 mg/kg of ketamine and 5 mg/kg of xylazine. Bilateral groin flaps, each sized 3 x 2 cm, were designed with a projection of the superficial inferior epigastric artery on their surface. Each groin flap was subjected to an ischemic state by clamping the pedicle of the vessel for 15 minutes before the flaps were sutured back into place (Fig. 1).

The area of flap survival was then evaluated and assessed clinically on day 7 after surgery through photographs was taken with a Leica D-Lux Type 109 digital camera (Leica, Wetzlar, Germany). The photos were captured frontally, from a 30-cm distance, in automatic mode. The photos were then analyzed with the Analyzing Digital Image software (Lawrence Hall of Science, Berkeley, CA, USA) to calculate the percentage of necrotic area. Flaps that experienced either partial or total necrosis were excluded. Only flaps that totally survived (100% of its dimensions) underwent the second surgical procedure, for which they were randomly assigned to three groups.

Flaps in group A were gently infiltrated subcutaneously with 3 mL of one-per-mil tumescent solution using a 1-mL syringe and a 26-gauge needle at 10 minutes before elevation. The one-per-mil tumescent solution was a mixture of 1:1,000,000 epinephrine in normal saline. The same injection technique was used in group B, but with 3 mL of normal saline. Group C served as the control group, in which the flap was harvested without any injection in advance. Likewise, as in the first surgical procedure, the flap was immediately sutured back to the donor site with 5-0 silk sutures, while the animals were kept alive for further observation.

All flaps in groups A and B were measured with a TCM CombiM module version 903-111 (Radiometer Medical ApS, Copenhagen, Denmark) to quantify the oxygen tension level (TcPO₂). The sensor used was the tc Sensor 84 version 945-737 (Radiometer Basel AG, Copenhagen, Denmark). The same test was applied to all flaps in group C pre-surgically.

Seven days after the second surgical procedure, the viability of the flaps was re-assessed, using the same technique that was de-
scribed earlier for the assessment at day 7 after the first surgical procedure.

Using SPSS Statistics version 20.0 for Mac (IBM Corp., Armonk, NY, USA), the data were analyzed using the paired t-test, analysis of variance, and the unpaired t-test. Homogeneity was tested with the Shapiro-Wilk test.

**RESULTS**

The mean weight of the rats was 232 ± 17.7 g. Only one flap was excluded due to total necrosis following the first surgical procedure. Thus, the study proceeded with 39 flaps, which were equally distributed among all groups. An analysis of flap survival before and after the second surgical procedure is presented in Fig. 2. As can be seen, the flap area did not differ across the groups. Furthermore, no flap showed a significant change in area before and after the second surgical procedure. The mean flap areas for groups A, B, and C were 5.11 ± 0.13, 4.96 ± 0.12, and 4.94 ± 0.15 cm², respectively.

The mean TcPO₂ at 7 days after the first surgical procedure was 99.9 ± 5.7, 103 ± 8.5, and 102 ± 5.3 mmHg in groups A, B, and C, respectively. Following one-per-mil tumescent and normal saline infiltration, the TcPO₂ readings (group A, 37.2 ± 6.3 mmHg; group B, 48.7 ± 5.9 mmHg) decreased significantly (P < 0.05) compared to the pre-injection state (Table 1).

During surgery, the adjunctive use of epinephrine in the one-
The benefits of local infiltration with a solution containing epinephrine in the field of reconstructive surgery for the facial region and beyond have been established for many decades. The benefits of the tumescent technique are especially convincing for liposuction, as a way of administering a greater dose of lidocaine, reaching as high as 45 mg/kg [13]. The tumescent technique is also well accepted for its safety when applied properly in the finger, hand, and upper extremity, especially regarding its vasoconstrictive effects [11,12].

Concerns about the possible deleterious effects of epinephrine-containing local anesthesia could be addressed by confirming its safety in tissue that has survived previous ischemic insults. The outcomes of this experimental study are promising for the future, as all flaps survived after being infiltrated with epinephrine-containing solution using the tumescent technique. It was also proven that every flap successfully maintained its dimensions without any size reduction caused by small partial necrotic areas within, the presence or absence of which was not specifically determined.

The first TcPO2 measurements of the flaps, made a week after the first surgical procedure in which the flaps suffered an ischemic insult, showed no significant differences across all groups. All flaps had TcPO2 values exceeding 60 mmHg (Table 1), which are associated with good perfusion. These values were compatible with the clinical assessment that all the flaps were eligible to undergo the second surgical procedure.

It might be debatable whether the clamping time (15 minutes) was sufficient to create ischemia, as no standard clamping time exists. Small animal skin flaps that undergo arterial clamping may be undetectable by oxygen saturation measurements after only 20 seconds [14]. Another animal study showed that changes in tissue oxygen saturation were time-dependent, with oxygen saturation in both arteries and veins dropping to its lowest level after 15 minutes and plateauing for the next 15 minutes [15]. A clinical study in humans even used 4-minute vessel occlusions to delineate the pattern of reperfusion [16]. Regardless, the main idea of the current study was to represent the actual circumstances of free flaps and revascularization. In real clinical settings, free flaps are transferred with the shortest ischemic time possible. The same concept is applied for revascularization.

The 1:1,000,000 epinephrine caused a significant decrease of the skin perfusion in the flaps; the mean TcPO2 was 37.2 ± 6.3 mmHg, almost half of 60 mmHg. All flaps in group A showed a marked difference in tissue color, as shown in Fig. 3, wherein the flaps look pale. Nonetheless, the TcPO2 of all flaps but one was still greater than 30 mmHg (one flap had a reading of 29 mmHg), which could be normatively associated with partial or complete survival [17]. In fact, no flap suffered from any necrosis whatsoever.

Interestingly, the mean TcPO2 level of group B (48.7 ± 5.9 mmHg) also decreased significantly from the baseline (103 ± 8.5 mmHg; P < 0.05) (Table 1). The fact shows that a 1:1,000,000 concentration of epinephrine caused a significant decrease of tissue perfusion through its role as an α/β-adrenergic vasoconstrictor [5,12]. When compared to the relatively small tissue volume, the massive amount of solution injected into the tissue plays an important role in causing hydrostatic vasocompression [5,12,18]. Although further research is needed to explain the exact mechanism through which the oxygen perfusion level is reduced, this study indicates that epinephrine is a potential contributing factor.

In assessing flap perfusion, TcPO2 levels were measured as an adjunct to clinical observation that allowed an immediate evaluation of ischemia. Epinephrine has been demonstrated to cause effective vasoconstriction even at concentrations as low as 1:1,000,000 [5,12]. In normal saline infiltration, the excessive accumulation of isotonic fluid through interstitial subcutaneous infiltration can predispose to hemodilution and produce edema, which in turn reduces the vascular transmural pressure gradient and physically compresses capillaries, thereby reducing nutritive tissue perfusion [19,20]. Therefore, the TcPO2 values decreased to a lesser extent after infiltration in the normal saline group than in the one-per-mil tumescent group, since both mechanical compression and the action of epinephrine contributed to the effect. However, the TcPO2 readings in both groups after infil-
In general, the results demonstrate that one-per-mil tumescent infiltration into viable groin flap tissue did not have deleterious effects on flap perfusion. This study confirms that the vasoconstrictive effect of 1,000,000 epinephrine in the tumescent infiltration technique does not completely restrict blood perfusion, even in flap tissue that has previously suffered from an ischemic condition. Regarding precautions that must be taken in applying tumescent local anesthesia, it must be stressed that the one-per-mil tumescent application in this study was only performed on groin flaps that showed total clinical survival. It is not advisable to infiltrate tissue that shows problems with viability.

Based on our results for the tissue response to one-per-mil tumescent application in viable flaps, we can assume that one-per-mil tumescent solution is unlikely to cause any harm to flaps as long as the perfusion of the flap is established. Thus, it may be possible to consider one-per-mil tumescent application in future secondary procedures, such as flap revision and refinement surgery after replantation.

In summary, infiltration of one-per-mil tumescent solution into viable groin flaps did not yield any clinical signs of flap failure, even though the flaps had previously suffered from an ischemic condition. Although flap failure is the most feared complication when employing the tumescent technique due to the adjunctive action of epinephrine, this study showed that the epinephrine in the one-per-mil tumescent solution can be considered safe and beneficial as an adjunctive agent when used properly.

NOTES

Conflict of interest
No potential conflict of interest relevant to this article was reported.

Ethical approval
The study was approved by the The Ethics Committee of Faculty of Medicine, Universitas Indonesia (No. 258/UN2.F1/ETIK/2016).

Author contribution
Concept and design of the study, performing the analysis and data interpretation, and approving the final manuscript: Prasetyono TO. Conducting the acquisition and analysis of the data and drafting the article to present important results: Nindita E.

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