Dyeing Technique for Medical Fabrics with Indocyanine Green Exhibiting Near-Infrared Fluorescent Emission

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Introduction Medical fabrics such as surgical gauze are essential and useful tools in the wide range of surgery to stop bleeding, protect organs, and guide surgical destinations. However, gauze is occasionally lost during surgery, or accidents occur where it is retained in the body after surgery. Such problems must be prevented, and it is important to make effective use of the gauze guiding surgeons to an anatomical destination as a marker. Meanwhile, fluorescent emission in the near-infrared (near-IR) region has been widely used in surgery and other medical applications. Medical fabric materials such as the gauze dyed with indocyanine green (ICG) exhibiting near-IR emission, in combination with the fluorescence imaging technique, should make it easier to observe them visually inside the body using their near-IR fluorescence emission, which could be used to prevent the gauze remnant accidents and as a surgical guide. In this study, a novel dyeing technique was developed for medical fabrics with the ICG. Here, the dyeing techniques and conditions as well as the resulting color of surgical gauze are reported for the first time.

Experimental Pure cotton surgical gauze (Hakujuji, Steraze) was dyed with an aqueous solution of ICG (PMRJ) with varying (1) ICG concentration, (2) dyeing time, and (c) dyeing temperature. The gauze samples were immersed in the dyeing solution placed in an autoclave at the prescribed liquor ratio and treated under high temperature and pressure in one dyeing technique. After that the gauze was repeatedly washed and heat-dried, it was then further subjected to high-pressure steam sterilization according to the conditions of use in surgery. The color of the gauze samples was measured with a spectrocolorimeter. The values of L^*, a^*, b^*, and the color difference ΔE^* in the $L^*a^*b^*$ colorimetric system (CIELAB 1976) were calculated.

Results and Discussion Each gauze sample was dyed the same white color as before dyeing or green, depending on the ICG concentration. The relationships between the ICG concentration c_{ICG} and the color difference ΔE^* of the gauze before/after dyeing are plotted in **Fig. 1**. This figure shows that the ΔE^* rapidly increases when the c_{ICG} exceeds 4.50×10^{-5} mol $\mathrm{L^{-1}}$. It was found that the samples were dyed green and deepened above this concentration. This technique was also applied to dye cotton, silk, wool, cellulose acetate, nylon, and acrylic fabrics. The fabrics dyed under optimized conditions emitted bright near-IR fluorescence in the 800 - 860 nm range when irradiated at 740 nm, which can be easily detected and displayed by the fluorescence imaging system in a surgery room. In contrast to the behavior of the dyeing results, the fluorescence intensity of the dyed gauze increased with the c_{ICG} and decreased at the higher concentration.

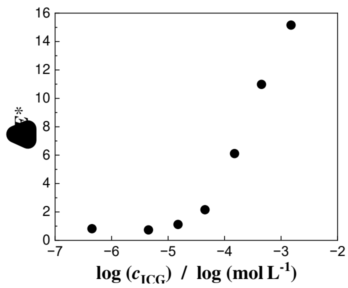

Fig. 1 Plot of ΔE^* between undyed and ICG-dyed gauze against log (c_{ICG}).

The dyeability and the near-IR fluorescence images and spectra with quantum yields will be further discussed in the presentation.

Keywords: Dyeing, Gauze, Indocyanine Green, Fluorescence, Near-infrared, Medical fabric