Machine Learning-Based Evaluation of Skin Prick Tests using Photoplethysmography Imaging

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***Abstract*— Skin prick testing (SPT) is widely used to diagnose immediate allergic hypersensitivity, but conventional visual assessment may be affected by interobserver variability and neighboring reactions. This study investigated photoplethysmography imaging (PPGI) combined with machine learning for the objective classification of SPT reactions. Skin perfusion was monitored in 18 subjects before allergen application and at 1, 5, 10, 15, and 20 minutes afterwards. Following motion compensation and signal filtering, perfusion parameters were calculated for 324 samples, including 134 positive and 190 negative reactions. Individual parameters were evaluated using receiver operating characteristic analysis, while their combination was assessed using a support vector machine (SVM) with subject-wise cross-validation. Discriminatory performance improved over time, with individual parameters achieving area under the curve (AUC) values above 0.90 at later measurement points. Excluding spatially influenced samples increased the maximum AUC to approximately 0.96. Using the complete dataset, the SVM achieved strong discrimination from 5 minutes onwards. Its best performance occurred at 10 minutes, with an AUC of 0.937, accuracy of 0.867, sensitivity of 0.812, and specificity of 0.909. PPGI combined with machine learning may therefore provide a non-contact, quantitative complement to conventional SPT assessment.**

Keywords—skin prick testing, photoplethysmography imaging, skin perfusion, allergy diagnostics, machine learning

I. Introduction

Allergic diseases affect hundreds of millions of people worldwide, and their prevalence continues to increase. Their symptoms can substantially impair patients' quality of life and daily functioning, emphasizing the need for reliable diagnostic methods [1]. Skin testing plays an important role in allergy diagnostics because the skin acts not only as a physical barrier but also as an immunologically active organ that responds to allergen exposure [2].

In clinical practice, the skin prick test (SPT) is widely used to identify immediate hypersensitivity due to its safety, simplicity, low cost, and rapid availability of results [3-5]. SPT evaluates immunoglobulin E-mediated reactions following the application of allergen extracts to the superficial layers of the skin [3]. In sensitized individuals, allergen exposure activates mast cells and induces the release of inflammatory mediators, including histamine [3]. This process results in a characteristic wheal-and-flare response associated with local edema, vasodilation, and increased skin perfusion [3], [4]. SPT reactions are typically evaluated 15–20 minutes after allergen application by visually inspecting and manually measuring the wheal [4]. Although this approach is well established, its reliability depends on the applied technique, allergen extracts, medication status, individual skin reactivity, control responses, and interpretation criteria [3-5]. Conventional assessment may also be affected by interobserver variability, irregular reaction geometry, and vascular responses extending from neighbouring test sites [5, 6]. These limitations motivate the development of objective and spatially resolved methods for evaluating SPT reactions.

Photoplethysmography imaging (PPGI) is a non-contact optical technique that enables spatial mapping of blood-volume and perfusion changes across the skin surface [7], [8]. Unlike conventional SPT assessment based primarily on wheal dimensions, PPGI provides information about the temporal and spatial development of the underlying vascular response. Previous applications of PPGI in dermatology and allergy testing have demonstrated its ability to visualize local perfusion changes and identify frequency-dependent microvascular responses following histamine or allergen application [8-11]. These studies collectively support the potential of PPGI as a quantitative complement to conventional SPT evaluation.

Automated and machine-learning approaches have also been investigated to improve the objectivity of SPT evaluation. Earlier systems primarily focused on the digital measurement of wheal dimensions, whereas more recent deep-learning methods have been developed to segment wheals and support image-based interpretation of test results [12, 13]. However, these approaches rely mainly on the visible geometry of skin reactions and do not directly characterize the underlying microcirculation perfusion response. This suggests that physiological information obtained using PPGI could provide a complementary basis for automated SPT assessment.

The present study investigates whether parameters derived from PPGI measurements can be used to objectively distinguish positive and negative SPT reactions in clinical practice. The extracted perfusion parameters are evaluated using statistical methods and a supervised machine learning approach based on a support vector machine (SVM). The proposed method could complement conventional visual assessment and pave the way for more objective and standardized interpretation of SPT evalutation.

II. Methods

A. Experimental Protocol and Data Aquisition

The PPGI method was used to monitor changes in skin perfusion during SPT in 18 subjects with a mean age of (33 ± 11) years. Measurements were performed on both forearms using a camera-based PPGI system comprising a Blackfly S BFS-U3-28S5M monochrome camera (FLIR Systems, Wilsonville, OR, USA) and two-panel white LED illumination with a color temperature of 5500 K. A band-pass optical filter with a central wavelength of 540 ± 2 nm and a bandwidth of 10 ± 2 nm (Edmund Optics, Barrington, NJ, USA), together with a