Progressive Observation of Covid-19 Vaccination Effects on Skin-Cellular Structures by Use of Intelligent Laser Speckle Classification (ILSC) Technique

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Abstract
The recent pandemic showed that the current global research strategies on vaccine development in an emergency period necessitates more optimized supplementary techniques to observe instant progressive vaccines’ subtle effects on human metabolisms to make better and speedy evolutionary health assessments. To fill this gap, we have followed a multi-disciplinary approach exploiting AI, laser-optics, and specific imaging methods. The proposed technique can make progressive observations on Covid-19 Astra Zeneca vaccination effects on skin cellular network by use of the well-established technique—Intelligent Laser Speckle Classification (ILSC), as Covid-19 is a skin-affecting systemic disease. The method also managed to distinguish between three different subject groups via their laser speckle skin image samplings, grouped as early-vaccinated, late-vaccinated and non-vaccinated participants. The results have proven that the ILSC technique, in association with the parametrically optimised Bayesian network, can classify hidden skin changes of vaccinated and non-vaccinated individuals up to 90% accuracy and is also capable of detecting instant progressive developments pertaining to skin cellular properties. The proposed method has also proven that the continuous Covid-19 vaccine effect on the sub-skin layers can be observable by high frequency and speedy non-invasive data collection in real-time with high reliability.

Keywords Skin analysis · Laser speckle imaging · Bayesian Nets · Covid-19 · Vaccines

Introduction
The recent global coronavirus pandemic period’s emergency measures had necessitated very rapid vaccine development, and Covid-19 vaccines were then immediately approved and globally distributed after December 2020. According to the global health studies [1], those vaccines prevented an additional 14.4 million to 19.8 million deaths between 2020 and 2021. Till December 2021, more than 4.49 billion people had received one or more doses of Covid-19 vaccines [2] and the Oxford-AstraZeneca was the most widely used.

The pandemic emergency measures had also proven that the global health research strategies on speedy vaccine development necessitates more optimized supplementary techniques to observe instant progressive vaccines’ subtle effects on human metabolism for better evolutionary assessments. To fill this gap, in this research, we have focused on a multi-disciplinary approach for a non-invasive instant vaccine’s effect observation technique via the skin structure, exploiting AI, laser optics, and a specific imaging method.

Covid-19 infection or its vaccine’s effect on the skin structure and components has already been studied previously and proven by several authors [3–5], as Covid-19 is a systemic disease whose signs are also reflected by the skin. The skin manifestations directly associated with Covid-19 have been studied by [6] in whose details are scrutinized in Section “Covid-19 Effects on Skin” in detail. In another previous study, Magro et al. [4] made a comprehensive analysis of the Covid-19 effects on skin by using light microscopy for skin biopsies, but their method targeted neither an instant disease diagnosis nor an observation of its prognosis. In another work, [5] focused on the adverse effects of

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the Covid-19 vaccine on the skin. Their research was based on basic visual inspection or biopsy techniques. Almost all other global studies on Covid-19 vaccines’ effects [8] mainly rely on visual inspections and biopsies which require highly equipped clinical environments and high-cost medical instrumentation. However, the recent Covid-19 pandemic event has proven that a more effective and speedy diagnosis or detection of such systemic diseases is inevitable, which could only be done by a non-destructive instant skin analysis using optical imaging methods [9, 10] rather than microscopic inspection with biopsies that cannot be applied non-destructively in real-time. Within this research, we propose an alternative non-destructive optical “instant visual observation” technique of Covid-19 vaccine effects by the use of Intelligent Laser Speckle Classification (ILSC) which could be potentially used for the diagnosis and prognosis of Covid-19 disease in a particular period of time-sequence. The novelty of this study is that the Intelligent Laser Speckle Classification (ILSC) technique is applied for the first time to Covid-19 vaccine’s effects, in the context of skin analysis, to unveil the vaccine’s invisible subtle effects on the skin and to make its progressive observation. Some of the earlier studies had very minor overlap with the one introduced here as non-invasive optical methods (e.g., [11, 12]), though their results were not comparable to ours. In their study, Currier et al. focused on the treatment effects of Chronic Transfusion Protocol of Sickle Cell Disease by use of laser speckle contrast imaging, which is the method relying only on visual inspection by the naked eye and is unable to detect invisible content of the skin such as vaccine effects and microscopic cellular changes. The other study [12] investigates treatment observations for specific VKH (Vogt-Koyanagi-Harada) disease caused by the Covid-19 vaccination, by use of laser speckle flowgraph applicable to the eye’s ocular blood flow. As the test results are based on visual prognoses, they are not comparable to the skin analysis results introduced here.

The laser speckle technique has several advantages over the other traditional optical methods [13] for the skin analysis, for example, due to its specifically selected wavelength ($\lambda = 0.65$ µm) which is smaller than skin cells (30 µm), in which the laser light can interact with the skin cellular network to detect its micro changes as a textural phenomenon rather than focusing on a single cell alone [9]. This ability provides the power of ultra-high sensitivity and high spatial resolution to observe a network of very small units like skin cells or even their sub-cellular features (e.g., cells’ nuclei, cell membranes). The advantage of lasers over an ordinary broad spectrum (non-coherent) light source are well known [14], related to the micro level interaction of lasers with skin features and its deeper penetration into biological tissues than ordinary light. The proposed system also consists of basic level instrumentation (e.g., camera at specific spectral sensitivity, specific laser source, auxiliary optical components) and is highly competitive against high-cost and non-real-time techniques like electron microscopy, optical tomography, ultrasound, and Raman microscopy. By the integration of Bayesian AI capability with laser speckle imaging technique as is then called “Intelligent laser speckle classification” (ILSC), the method becomes more efficient for textural features classification. In the current literature, there is only one study [15] which unifies laser speckle contrast imaging with artificial intelligence (neural networks) but differs from our proposed work in terms of its application and outputs. Here, ILSC is an integrated technique [9, 16, 22] which is comprised of different disciplinary methods, providing high sensitivity and discrimination power to detect subtle differences even at the sub-cellular level. The method detects laser speckles’ textural differences, not for only a single cell unit but rather on the whole cellular network, to detect any common property or structural changes in all cells simultaneously, since all cells are naturally identical to each other or react to external effects in the same way. To increase the physical detection sensitivity, the most suitable laser wavelength must be selected. In our case, red laser light ($\lambda = 0.65$ µm) is used as an optimum one for human skin and blood cell analysis [18]. Laser light here provides a high level of spectral accuracy and coherency over the other light sources (e.g., filament bulb, daylight, LED) and directly affects the image data accuracy. The most important advantage of the method is its non-invasive real-time continuous observation by a CCD camera-laser source-based simple optical configuration. Figure 1 depicts the image acquisition setup configuration as is used to acquire laser speckle images of the cellular network with pixel window samplings. The laser wavelength $\lambda = 650$ nm is shorter than individual cell size (~30 µm) or sub-cellular component size (e.g., nucleus) so that the laser light penetrates the skin surface (~0.56 mm), then interacts and causes backscattering by conveying the characteristic information of cellular components back to the image domain. The skin analysis target here is not the deepest penetration into the skin, as all necessary information of skin changes is already available within the 0.5 mm depth of skin layers (as shown in Fig. 1). As a matter of fact, a further depth of skin imaging may even contaminate the purity of targeted skin information provided by the epidermis and papillary dermis skin layers. The surface normally makes $23^\circ$ angles with a laser beam and camera viewing axis. We have to note that the angular degrees are not specifically selected but they have to be kept constant at all times as laser speckle’s physical phenomenon is extremely sensitive against angular changes [19].

The overall organization of this study has been made as follows: In this chapter, generic background information of the proposed research and the most related literature surveys are provided. In Section “Materials and Methods”, the detailed technical information on the materials and methods,
such as laser-optic technique, equipment, image processing, AI methods and light-skin interaction phenomenon are clarified. In Section “Results and Discussion”, experimental results of the proposed research and their conclusions are mentioned.

Like some of the diseases (e.g., diabetes, heart disease, kidney disorder), the Covid-19 disease is also a systemic disease whose effect is reflected by the skin surface [20]. That provides a supportive argument for this study where the Covid-19 vaccination progressive effects (normally invisible to the human eye) can be observed, as it causes cellular structural changes. The other effects, like an increase of antibodies in the blood, changes in blood capillary loops, etc., may also be observable by ILSC technique. According to the AstraZeneca™ report [21], a single dose of vaccination leads to a four-fold increase in antibodies in 95% of participants one month after injection, hence, the tests used in this study covers a 1-month period after the first injection.

The main contributions of this research to the earlier studies would be as follows:

- Within this research, we have proven that the Covid-19 vaccine effect and possibly Covid-19 infection can be observed at a high frequency of data collection, with high reliability. “Multi-Classifier System” (MCS) is also applicable by the addition of more laser sources with different wavelengths (e.g., red, IR) [22–24].
- Speedy image acquisition and processing provide real-time skin analysis, thus enabling a continuous skin observation by successive data collection.
- Texture-based laser speckle image classification provides very high spatial resolution with “scalability” for the analysis of sub-cellular features (depending on specifically selected laser wavelength).
- The laser speckle effect is a physical phenomenon which is very sensitive against the subtle changes in any textural features like skin cellular network, whose potential is exploited within this work.
- Even though the classification capability of the system is proven by Bayesian networks here, such AI components can easily be replaced by other methods (e.g., deep learning – Convolutional NN, etc.).
- Skin penetration of the laser light would also be depending on its selected wavelength. This provides a filtering capability of unwanted skin layers’ obstruction for the ideal image data acquisition [25].

Covid-19 Effects on Skin

The skin structural (cutaneous) effects associated with Covid-19 have been studied by many researchers, with the most comprehensive analysis by Solak et al. [6]. The study concluded that the cutaneous symptoms of Covid-19 patients may prove a link between the disease and skin changes. In the experiments 18% of the patients exhibited dermatological symptoms. The other study [7] indicated that the variability of Covid-19 related skin findings is substantial (20% of patients) compared to other viral infections which are typically present with characteristic skin signs. Those studies substantially concluded the
presence of a link between the Covid-19 infection and its specific skin signs such as rash, redness, bruising and wounds. Those signs associated with Covid-19 obviously appear at the advanced stage of the disease rather than the signs to be used for an early diagnosis. They have also not had any invisible characteristics, having very subtle skin effects detected only by biopsies [5].

**Covid-19 and Its Vaccine Effects on Skin**

After the coronavirus global spreading affected nearly 145 million people at the time of April 2021, the first doses of the human Covid-19 vaccine were started to be tested in March 2020 [26]. Meanwhile, the UK was the first country to approve and test Pfizer-BioNTech vaccine [27] and it was followed by vaccination of Oxford-AstraZeneca in January 2021 after approval of the World Health Organisation [28]. Meanwhile, the vaccines’ side effects onto the skin have been recently studied with the worldwide coverage [3]. Some of the conclusions suggested that the most common skin reactions cited by the clinical trial data were as follows: delayed large local reactions (4 days or more after vaccination), pityriasis-rosea-like eruptions, reactivation of herpes simplex, and varicella zoster [29]. According to the trial reports, Oxford-AstraZeneca (AZD1222) vaccine caused very rare skin side effects of severe cellulitis, psoriasis, rosacea, vitiligo, and Raynaud phenomenon [30]. The studies have also proven that the cutaneous (skin) reactions like eruptions caused by Covid-19 vaccine have similarity with the mild and moderate Covid-19 skin symptoms [4]. It was reported that up to 20% of patients with Covid infection also suffered from skin eruptions [31].

**Materials and Methods**

The methodology covers three main tasks within this research such as the following: (1) specification of laser reflection parameters to optimize light-skin interaction which involves fundamental light physics. According to fundamental principles, the frequency of light \( f = \frac{C}{\lambda} \) where \( C \): light speed, \( \lambda \): light wavelength) must be different than the atomic (electrons) frequency of skin properties for its reflection from the skin; otherwise, light is absorbed. Meanwhile, laser speckle modelling is a more complex one than normal light reflection as described by Eqs. (1), (2), and (3) in Section “Laser Speckle Phenomenon”. (2) Laser speckle image (LSI) analysis includes optimized image sampling at the best energy band (broad enough with max number of laser speckle primitives) as shown in Figs. 2 and 3, as well as the selection of the most suitable texture measures for LSI texture analysis, for the image quantisation process. (3) The final task refers to Bayesian (AI) classification technique, which is a qualitative process to make a comparison between the subject groups.

**Laser Speckle Imaging Camera System**

For the laser speckle image data acquisition, a high resolution (3840 × 2880 pixels) commercial CCD sensor image camera is used where each CCD pixel corresponds to a 2.8 µm² area on the image domain. The camera is utilized after a moderate modification by attaching a low-level laser source (1 mW power) with approximately 23° of angle to the skin surface normal, which is fixed arbitrarily at the system design stage where such incident/reflection angle degree level has no quality effect on the measurements unless they are extremely wide or narrow, but those angles must be kept...
constant permanently (Fig. 1). The laser source is a collimated red laser diode at 650 nm wavelength [25] whose power is much less than maximum permissible exposure, which is 2000 Wm$^{-2}$ for human skin (at 400–700 nm wavelength range) for long-term exposure, i.e., between 5 and 10 h. The laser source is used in our tests only for short-term illuminations (approx. 3–5 s) over approximately a 10-mm-diameter area on the upper-hand skin of each participant to generate a speckle effect on the skin surface and sub-skin layers. The skin imaging location of the upper hand is selected since the same body region has been used in our earlier skin-related (non-Covid) studies yielding the accurate results [9, 16].

**Laser Speckle Phenomenon**

As far as the basic principle of “laser light-skin surface interaction” is concerned, when a skin surface is illuminated by a coherent light like laser, then the light itself penetrates the skin and scatters from the skin layers, exhibiting a particular intensity distribution as it covers the skin surface with a granular structure. The very fundamental formula of laser speckle image includes its pixel intensity statistics (1), where the standard deviation of spatial intensity variations $\sigma_{s}$ is equal to the mean intensity $\langle I \rangle$ for a fully developed (ideal) speckle pattern. This would be stated by the basic formula (1):

$$K = \frac{\sigma_s}{\langle I \rangle}$$

where $K$ is the speckle contrast, and its value is between 0 and 1. If the speckle pattern is ideal, then $K = 1$, but if the speckle pattern becomes non-ideal, e.g., blurred by a diffuser or surface motion, the value of $K$ will be shifted towards zero. The laser speckle effect image formation and its statistical analysis at the skin observation domain by the use of a digital camera (e.g., CCD ideally or CMOS at lower cost but with less accuracy) is a multi-parametric task. The laser speckle image’s statistical property heavily depends on its system geometry like laser illumination angle or camera orientation. In the image formation domain, a basic light amplitude at point $A$ (e.g., at a single pixel of CCD camera matrix) may be formulized as in Formula (2) and (3) [32]:

$$I_{j}(A) = |I_{j}|e^{i\phi_{j}}$$

$$I_{com}(A) = \frac{1}{\sqrt{N}} \sum_{j=1}^{N} |I_{j}|e^{i\phi_{j}}$$

where

- $I_{j}$: basic light amplitude of a surface element $j$.
- $A$: point on image domain (single pixel of CCD matrix).
- $\phi_{j}$: random phases of light at $j$th surface element.
- $i$: imaginary part.
- $N$: total surface elements.

**Texture Analysis of LSI**

Image texture analysis [33] utilizing specific texture measures is the essential and initial part of the Intelligent laser speckle classification (ILSC) technique that was...
tested and used successfully in the last two decades with high accuracy [22, 32]. The formulations are described by Eqs. (4), (5), (6), (7), and (8). The nine types of texture measures used based on Formulas (4), (5), (6), (7), and (8), including five texture measures with 3×3 pixel image scanning kernel, and four texture measures with 5×5 pixel kernel in association with all those formulas. The texture measures are applied on a 30×30 pixel image segment of each laser speckle image, where the laser speckle effect appears to be at maximum level (Fig. 3). Sampling process of the laser speckle images has great importance where the uniform textural characteristics of image segment should be justified. To optimize this task, each 30×30 pixel sampling area should have a sufficient number of texture primitives and also textural uniformity all over the area [9].

\[
\text{variance}_{\text{Russ}} = \sqrt{\sum (\text{centerpixel} - \text{neighbor})^2} \quad (4)
\]

\[
\text{variance}_{\text{Levine}} = \frac{1}{\text{area}} \sum (\text{centerpixel} - \text{mean})^2 \quad (5)
\]

\[
\sigma = \sqrt{\text{variance}_{\text{Levine}}} \quad (6)
\]

\[
\text{skewness} = \frac{1}{\sigma^3} \frac{1}{\text{area}} \sum (\text{centerpixel} - \text{mean})^3 \quad (7)
\]

\[
\text{Std.Deviation} = \sqrt{\frac{\sum (x - x')^2}{n}} \quad (8)
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\]

The original data set has been utilized within this work, which consists of the quantized form of laser speckle images as acquired by LSI camera system. The quantization of LS images (Section “Laser Speckle Imaging Camera System”) is achieved by the use of 8 texture measures whose details are already explained in this chapter and also in Section “Conclusion”. (Table 1).
Bayesian Networks as Applicable AI Method

Bayesian Network (BN) is a well-established artificial intelligent method whose details and statistical description are already given in several publications [17, 34, 35]. The most remarkable characteristics and advantages of Bayesian Networks are that it can demonstrate knowledge representation and reasoning even under high uncertainties, and it also provides a graphical representation of links between the related attributes. In BN, each node refers to a data attribute (or called variable), as those variables are connected to each other via links (arcs) representing dependency relationships between them. BN’s structure can be explained as follows: if \( A = \{X_1, \ldots, X_n\} \) is a random variable denoting the patterns covering the \( n = N \times M \) dimensional vector space, then joint probability distribution \( P = (X_1, \ldots, X_n) \) will be a product of all conditional probabilities whose Eq. (9) would be:

\[
P(X) = \prod_i P(X_i | pa(X_i))
\]  

(9)

where \( pa(X_i) \) is the parent set of \( X_i \). As a brief, Bayesian algorithm examines the information of two related variables from a data set and decides if two variables are dependent. It also investigates how close the relationship is between those variables. This information is called conditional mutual information of two variables \( X_i, X_j \) which may be denoted as:

\[
I(X_i, X_j | C) = \sum_{x_i, x_j, c} P(x_i, x_j, c) \log \frac{P(x_i, x_j | c)}{P(x_i | c)P(x_j | c)}
\]  

(10)

In Eq. (10), \( C \) is a set of nodes and \( c \) is a vector (one instantiation of variables in \( C \)). If \( I(X_i, X_j | C) \) is smaller than a certain threshold \( t \), then we can say \( X_i \) and \( X_j \) are conditionally independent. Bayesian networks are also called belief networks, casual probabilistic networks or directed Markov fields. The utilities called PowerPredictor™ and PowerConstructor™ are used within the experiments in this study as they refer to Bayesian Classifier (Figs. 4, 5, and 6) and Bayesian Inference system (Fig. 7) respectively.
Laser-Optical Skin Analysis

Optical imaging methods in association with a coherent light like lasers are very efficient tools for skin and sub-skin analysis and progressive observation as utilized by earlier applications [9]. As far as the coherent light and its skin interaction are concerned, the laser light has the potential to penetrate deep into skin layers while keeping its constant wavelength and causes specular reflection, diffraction and diffuse reflection from the skin layers which come back to the skin surface. The generic physical phenomenon of light-surface interaction has been studied by several researchers previously [36]. In the skin-laser interaction case, the diffusely reflected laser light from the sub-skin layers can convey the skin’s structural information back to the surface and be detected by the camera imaging, referred to as the laser speckle effect, whereas the specularly reflected and diffraction (mixed effect) laser light produces very bright image area reflection (Fig. 3) which contains no information. The depth of laser light’s skin penetration depends on its wavelength as such light characteristics have previously been studied by Bashkatov et al. [25]. In regard to their experiments, the red laser (0.6 nm) light has nearly 2-mm penetration capability into the skin and the skin cellular network to be observed by this study is located at the basal layer at approximately 0.1 mm depth of skin [37].

Results and Discussion

Classification Test of Different Subject Groups

The experimental stage includes laser speckle image (LSI) data collection from three different subjects groups, such as the following: early-vaccinated (starting at 13th February 2021), late-vaccinated (starting at 6th March 2021) and non-vaccinated individuals for a 1-month period. Camera images are collected from the participants’ back-of-hand (dorsal) region at a specific time of the day (midnight). Each image sampling size was 30×30 pixels targeting a specific laser speckle-effect region on the images and a single image pixel corresponds to 2.8 microns. Image data set includes 60 cases in total as collected from three subject groups (20 cases for each group) for a 1-month period. The subject groups are labelled as follows: S: early-vaccinated, A: late-vaccinated, and E or EM: non-vaccinated. Laser speckle image samples taken are quantized by textural analysis [33] as tested earlier [9], and then build data sets are processed by Bayesian network for the classification after a training session (by 50/50 ratio of data sets). In the second type of tests, the link...
discriminate between those groups whose automatically con-
structed Bayesian network is shown in Fig. 6. This meant
with two groups of late-vaccinated (group A) and early-
vaccinated individuals (65% vaccinated individuals (80–90% classification accuracy) and
display the equality between vaccinated individuals (65%
classification accuracy). The maximum classification accuracy has been
achieved between the group A and group EM which are early
vaccinated and non-vaccinated respectively with 90% clas-
sification accuracy (sensitivity = 100%, specificity = 80%)
results as shown in Fig. 5.

The results show that the parametrically optimized Bayesian classifier called PowerPredictor™ (e.g., by attribute links threshold, discretisation method, single-multi net options) is capable of discriminating between vaccinated and non-vaccinated individuals (80–90% classification accuracy) and display the equality between vaccinated individuals (65% classification accuracy).

To prove the identical effects of the vaccinations on cellular network structures, similar tests have been carried out with two groups of late-vaccinated (group A) and early-vaccinated (group S) with the results of 65% classification accuracy (sensitivity = 80%, specificity = 50%). This meant that the system (with the same network options) could not discriminate between those groups whose automatically con-
structed Bayesian network is shown in Fig. 6.

**Cellular Progressive Changes (CPC) Observation Test**

In the progressive observation test, an artificial progression attribute (e.g., series of numbers between 1 and 60) is added to each data set to see whether any network link to any other vaccinated individuals’ attribute will be established auto-
matically by the specific Bayesian tool PowerConstructor™ to prove that there is a progress of changes on a cellular network or cellular properties. This would be any change in cellular network structure in shape, an increase of antibodies in the blood (micro-veins) or any other cellular/subcellular content. In the results, the system establishes a link between the progression attribute and vaccinated groups (S, A) but not displays any link between the progression attribute and the non-vaccinated group (E), as shown in Fig. 7.

The partial data set shown in Table 1 includes texture \(t_1-t_9\) calculations referring to pixel-based statistics formulated in Fig. 3 with two arithmetic operator (pixel kernel) groups as are 3 × 3 and 5 × 5 pixels. Table 1 also includes an artificially built "progressive change" attribute in the last column to investigate if there is any link between any of the attributes and progression measures.

**Conclusion**

The proposed potential use of Intelligent laser Speckle Classification (ILSC) in association with the Bayesian inference and classification techniques is the unique one among the other conventional methods like immunoglobulin tests, as ILSC optimally unifies different disciplinary fields like light physics, texture analysis, and AI method to outperform the other conventional techniques in terms of speed, non-invasiveness, and real-time functionality. The most common methods used to observe Covid-19 vaccine effects rely on the immuno-
globin test which checks the number of certain antibodies called immunoglobulins generated progressively in the body. The antibodies are proteins that immune cells produce to fight against viruses. The proposed ILSC technique may also be utilized to observe the prognosis period of Covid-19 disease with the possible healing effect of particular substances (e.g., Dexamethasone [38], Remdesivir [39], Regn-Covz [40], etc.) at a high frequency of tests. It can also potentially be used to select the most effective vaccine type for the individual (in the concept of personalised medicine [41], by a frequent observation of the vaccine effect on the body tissue cells. The proposed system is getting more inevitable by its unique characteristics, like its instant use even at real-time speeds, as well as its flexible re-design capacity of instrumentation such as specific selection of its laser wavelength suitable with the size of observation features (e.g., sub-cellular components), power of laser source to adjust its light penetration into the skin layers, camera resolution, and usage of an AI method (e.g., Convolutional neural networks). The system reliabil-
ity would be further increased by the next advanced version of the proposed technique called “Multi-Classifier System” (MCS) by the addition of more laser sources with different wavelengths (e.g., red, IR). The proposed method can also be used in more comprehensive research with more than one vaccine simultaneously. Then the highest accurate result of a vaccine would be selected as the most effective one. Furt-
ther improvement of the system capability (e.g., blood clot development risk assessment after vaccination) would depend on such data collection procedure from the specific patient groups who suffer from the blood clot development issue, as the technical configuration of proposed systems would be capable enough to overcome such tasks with minor system modifications like laser wavelength selections sensitive to subtle changes of blood content, circulation velocity, etc. The low-cost and highly portable characteristics of the system are promising for its broad usage in the health community, transport environments, leisure centres, schools, etc.

**Author Contribution** Ahmet Orun has made the experiments, data analysis, and prepared the manuscript. Fatih Kurugollu has made the final review and contributed with additional techniques and references.
Declarations

Ethical Approval  Ethical Approval had been obtained for this Laser image sampling system used for the human participants for their skin image acquisitions, FREC Amendments was approved in 16/5/2013 by De Montfort University Health & Life Sciences Faculty Research Ethics Committee (Ref. 1112) with reference to Guidelines of Helsinki Declaration of Human Rights. Contact details: HLSFRO@dmu.ac.uk. The research has been conducted so that the participants are NOT identifiable from the data set.

Consent to Participate  Participants’ consents have been obtained and they were free to withdraw at any time.

Consent for Publication  The results of research can be published at any form of domain and media.

Conflict of Interest  The authors declare no competing interests.

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