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Original Research Article

Dorsal Hand Veins as a Unique Biometric Identifier: A Study in the Omani Population

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ABSTRACT

Background: Dorsal veins form a network on the dorsum of the hand. The dorsal venous arch drains into the basilic and cephalic veins.

Purpose: The study aimed to observe and analyze the characteristics of dorsal metacarpal veins using a descriptive observational approach.

Methods: A total of 99 pairs of hands were analyzed. Inclusion criteria required participants to have no prior hand conditions that would obstruct vein observation. We excluded images of hands with poor quality, no visible veins, or physical obstructions. We used the Vein Scanner mobile application, supported by high-resolution photography with cameras of 48 and 64 megapixel resolution. Photos were captured using a fixed tripod in reflection mode, with the image quality enhanced by increased illumination and image processing techniques. Demographic and activity-related data were collected from all participants.

Results: Among the total 190 hands analyzed, 180 exhibited prominent veins, according to gender, the second vein was the most prominent in males (n = 44) and females (n = 50). Similarly, the third vein was more prominent in males (n = 41) compared to females (n = 27). For the fourth vein, prominence was higher in females (n = 10) than males (n = 5). The overall proportional representation of vein prominence revealed that the second vein accounted for the majority of observations (49.47%), followed by the third vein (35.79%), the fourth vein (7.89%), and the first vein (1.58%). These findings highlight the dominance of the second vein in the dorsal metacarpal region across the studied population and suggest its potential utility as a stable biometric marker.

Conclusion: The study results provide a comprehensive analysis of dorsal metacarpal vein patterns in a cohort of young Omani students, contributing insight into these veins' anatomical and biometric characteristics. The findings reveal that the second dorsal metacarpal vein is the dominant vessel within the dorsal venous network of the hand, emerging as the most prominent vein.

KEYWORDS: Dorsal Hand Veins, Biometrics, Branching Patterns, Vein Prominence, Omani Population, Vein Biometrics.

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INTRODUCTION

The dorsal digital veins of the hand drain into the dorsal metacarpal veins, forming the dorsal venous network. The lateral side of the dorsal venous arch on the posterior part of the hand has the prolongation as the cephalic vein (CV). It then winds around the lateral border of the forearm, ascends into the cubital fossa, and runs up the front of the arm on the lateral side of the biceps. It ends in the deltopectoral triangle at the axillary vein. The cephalic vein receives tributaries from the lateral and posterior surfaces of the limb as it continues up the upper limb [1].

The basilic vein (BV) begins on the medial side of the dorsal venous arch on the back of the hand, travels around the medial border of the forearm, ascends into the cubital fossa, and ends up on the medial side of the biceps on the front of the arm. It joins the venae comitantes of the brachial artery to terminate by forming the axillary vein, which receives the median cubital vein and a variable number of tributaries from the medial and posterior surfaces of the upper limb [2].

The most prevalent types of venous connections are M-, N-, or Y-shaped, depending on their shape [3].

Veins are divided either into superficial and deep veins based on where they are about the deep fascia, which is connected by large caliber communicating veins that connect the deep venous arch with the basilic and cephalic system on the ulnar and radial sides [4]. The digital, metacarpal, and the beginning of the BV on the ulnar side and the CV on the radial side on the dorsum of the hand are the hand's superficial veins [5]. The dorsum of the hand displays the superficial vein network. Located in the subcutaneous tissue near the metacarpophalangeal joints, the dorsal venous arch empties into the BV on the medial side and the CV on the lateral side. The anterior aspect of the forearm is where the CV winds around after crossing the anatomic snuffbox. After that, it rises into the arm and follows the biceps' lateral border. It ends by entering the axillary vein by piercing the deep fascia in the deltopectoral triangle [6].

The BV travels from the dorsum of the hand around the forearm's medial side before reaching the anterior aspect, directly below the elbow. The median cubital vein connects the BV and the CV in the cubital fossa. Applying pressure firmly around the upper arm and repeatedly clenching and relaxing the fist will help quickly identify these veins. In this way, the veins become distended by blood [2]. Different courses and communications were observed in the dorsal metacarpal veins (MCVs). While some dorsal MCVs bifurcated into two veins and joined with the adjacent bifurcated vein to form short metacarpal veins, other dorsal MCVs ran between the knuckles of the hand as long dorsal MCVs on the dorsum of the hand. Additionally, it has been noted that certain dorsal MCVs fuse with a nearby vein to form long metacarpal veins or with a vein farther away to form short MCVs. Furthermore, a few dorsal MCVs joined a nearby vein at their origin and traveled parallel to the matching extensor tendon [5].

The unique way of utilizing the dorsal hand veins would be their use in biometrics and identification. Several references have used these veins' variability to categorize them in patterns. Using advanced imaging techniques such as infrared images and combining with palm and finger venous patterns, the possibility of identification is much more significant [6]. Methods of capturing venous images are similar primarily with conventional films, which separate frames are extracted from; however, further processing of these images differs; some studies used feature-level fusion and k-support vector machine classifier, weighted local binary pattern code, or repeated line tracking algorithm [7, 8, 9].

Several studies have found variable statistical parameters gauging accuracy and error rates. Ferrer et al. found an average error rate of 1.43% when looking at dorsal hand veins. Unlike dorsal hand veins, finger veins had a false acceptance rate of 0.375% and a false rejection rate of 1.20%, with identification rates of more than 99.2% [10].

The dorsal MCVs have drawn much attention in computer science as a potential biometric feature [11]. Face recognition, iris, and fingerprint biometric technologies are generally more advanced than recently developed biometrics like veins. Every biometric, nevertheless, has advantages and disadvantages. Recently, there has been a growing interest in hand vein pattern biometrics from the industry and scientific sectors. Anatomically, the vascular patterns on the back of the hand are different from one another and stable throughout adulthood. Veins are invisible to the human eye because they are under the skin. It is hard for someone to change their vein pattern. Its unique features make it a more dependable biometric for person identification [12,13]. There is a paucity of studies in the Arab Gulf region on the anatomy of dorsal hand veins and their biometric applications, and to date, no published research has characterized dorsal metacarpal vein patterns in the Omani population for identification purposes. Hence, the present study aimed to describe the characteristics of dorsal MCV patterns in the Omani population.

MATERIALS AND METHODS

Study Design and Setting

This pilot study was conducted at the College of Medicine & Health Sciences at Sultan Qaboos University. The study aimed to observe and analyze the characteristics of dorsal metacarpal veins using a descriptive observational approach. The participants included 99 medical students from the university.

Participant recruitment and sample size

A total of 99 pairs of hands were analyzed by the authors. Inclusion criteria required participants to have no prior hand conditions that would obstruct vein observation. We excluded images of hands with poor quality, no visible veins, or physical obstructions (e.g., scars, burns, excessive hair) from the analysis. After initial imaging, 8 hands were excluded due to poor quality or obstructions, leaving 190 hands for analysis. Of these, 10 hands showed no prominent vein and were excluded from vein-specific calculations.. While medical students were selected for accessibility and standardization, it is acknowledged that this population may not fully represent the general public. However, the homogeneity of this group helped minimize confounding factors in this pilot phase.

Data collection tools and imaging protocol

The observation of vein patterns was conducted using the Vein Scanner mobile application, supported by high-resolution photography with cameras of 48 and 64-megapixel resolution. Both devices were used for all imaging sessions to evaluate which resolution yielded optimal compatibility and clarity with the application. Images were captured using a fixed tripod in reflection mode, with quality enhanced through increased illumination and post-capture image processing techniques. The use of a mobile app reflects emerging trends in low-cost, real-time biometric imaging; while it lacks the subdermal depth of infrared systems, it proved sufficient for capturing the superficial vein patterns relevant to this study. This approach ensured consistency while minimizing variability between devices.

Two trained individuals independently captured images of participants' hands from a standardized distance of 23.5 cm, using a uniform setup to ensure consistency. Two independent observers interpreted the results. A standard white grid paper was used as the background to facilitate spatial reference and vein mapping. Tourniquet application and vein tapping were employed to improve vein prominence during imaging.

Imaging details

We took images of both hands in two distinct positions: closed fist and open palm. This facilitated the documentation of varying vein patterns across different hand positions, helping increase the visibility of any thin veins. Figures 1 and 2 show examples of the images taken.

Demographic Data

Demographic and activity-related data were collected from all participants. Variables included age and gender, diseases affecting the hands (dermatologic and rheumatologic conditions), injuries to the hands (scars, lacerations, and burns), systemic diseases (hypertension (HTN) and diabetes mellitus (DM)), and lifestyle factors (use of musical instruments and engagement in frequent heavy lifting activities).

Image processing and exclusion criteria

All images were reviewed for quality. We excluded images if veins were not visible, injuries or physical obstructions (scars or burns, impeded vein observation), and if hands were excessively hairy, leading to hidden vein patterns.

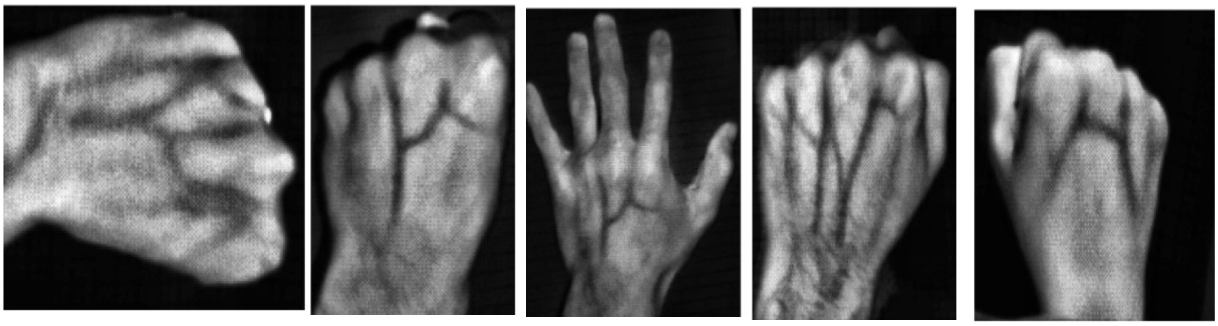

Fig. 1: Enhanced dorsal hand vein images after mobile app processing.

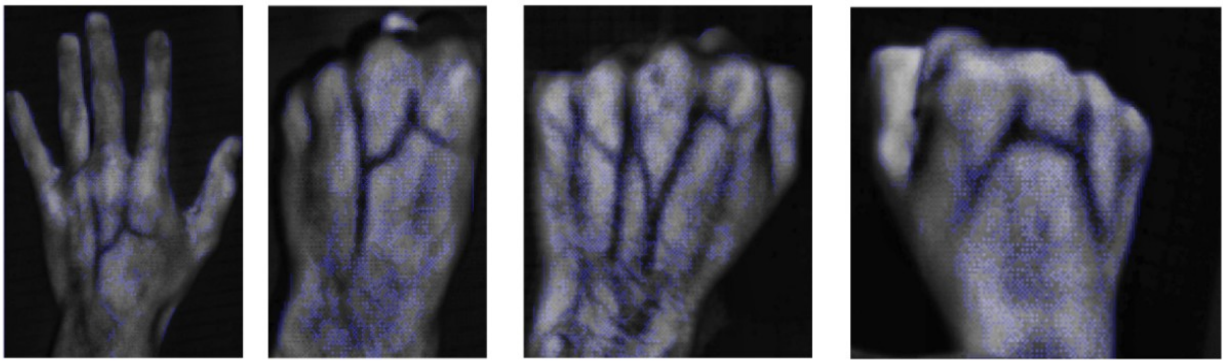

Fig. 2: Highlighted dorsal metacarpal vein patterns in open and closed hand positions.

Data analysis

The vein patterns were analyzed. A grid system was applied to both hands to identify vein patterns and their symmetry. Probabilities and similarities in vein patterns were calculated and visualized using charts. Quantitative results were summarized for descriptive statistical analysis.

Ethical approval

Ethical approval was obtained from the Medical Research Ethics Committee (MREC) of the College of Medicine and Health Sciences at Sultan Qaboos University (MREC #3131).

RESULTS

Demographic Characteristics

The study included 99 participants, comprising 50 males and 49 females, with an average age of 21 years (median: 21 years; age range: 17–25 years). Participants were further characterized by their history of hand-related conditions or activities. A total of 5 participants reported prior hand injuries (3 males and 2 females), and 1 participant (male) had undergone hand surgery. Nine participants reported hand diseases (4 males, 5 females), while one participant (male) had a metabolic disease. Activities impacting hand usage included playing musical instruments (n = 8; 5 males, three females) and heavy lifting or gym activities (n = 16; 12 males, four females).

Frequency and distribution of the most prominent dorsal metacarpal veins

Among the total 190 hands analyzed, the most prominent dorsal metacarpal vein was predominantly the second vein, observed in 94 hands (49.47%). This was followed by the third vein, which was prominent in 68 hands (35.79%), the fourth vein in 15 hands (7.89%), and the first vein in 3 hands (1.58%). The proportional distribution and frequency of vein prominence are summarized in Table 3. Ten hands (5.3%) exhibited no prominent vein and are excluded from vein-specific counts Figure 3 shows the frequency of venous prominence.

Gender and laterality analysis

When stratified by gender, the second vein was the most prominent in males (n = 44) and females (n = 50). Similarly, the third vein was more prominent in males (n = 41) compared to females (n = 27). For the fourth vein, prominence was higher in females (n = 10) than males (n = 5). Laterality analysis included 95 left and 95 right hands. Vein prominence distribution was similar across both sides Figure 4 shows the gender distribution of prominent veins.

Table 1: Demographic Characteristics of Participants (N = 99).

Characteristic	Total (n = 99)	Male (n = 50)	Female (n = 49)
Age (years)			
Mean (SD)	21 (±1.9)	—	—
Median (Range)	21 (17–25)	—	—
Hand Injuries	5 (5.1%)	3 (6.0%)	2 (4.1%)
History of Hand Surgery	1 (1.0%)	1 (2.0%)	0 (0.0%)
Hand Diseases	9 (9.1%)	4 (8.0%)	5 (10.2%)
Metabolic Disease	1 (1.0%)	1 (2.0%)	0 (0.0%)
Musical Instrument Use	8 (8.1%)	5 (10.0%)	3 (6.1%)
Heavy Lifting / Gym Activities	16 (16.2%)	12 (24.0%)	4 (8.2%)

Table 2: Participant Demographics and Most Prominent Dorsal Metacarpal Vein Distribution.

Characteristic	n (%)	Second Vein	Third Vein	Fourth Vein	First Vein
Total Participants	99 (100%)	94 (49.5%)	68 (35.8%)	15 (7.9%)	3 (1.6%)
Sex					
Male	50 (50.5%)	44	41	5	0
Female	49 (49.5%)	50	27	10	3
Age (years)					
Mean (SD)	21 (±1.9)	—	—	—	—
Range	17–25	—	—	—	—
Hand Conditions					
Prior hand injury	5 (5.1%)	3	2	0	0
History of hand surgery	1 (1.0%)	1	0	0	0
Hand disease	9 (9.1%)	4	4	1	0
Metabolic disease	1 (1.0%)	0	1	0	0
Hand-Related Activities					
Musical instrument use	8 (8.1%)	4	3	1	0
Heavy lifting / gym	16 (16.2%)	10	5	1	0

Vein counts (second, third, fourth, first) reflect 180 hands with prominent veins from 99 participants.

Table 3: Frequency and proportion of the most prominent dorsal metacarpal veins

Veins	Frequency (n)	Proportion (%)
1st vein	3	1.58
2nd vein	94	49.47
3rd vein	68	35.79
4th vein	15	7.89

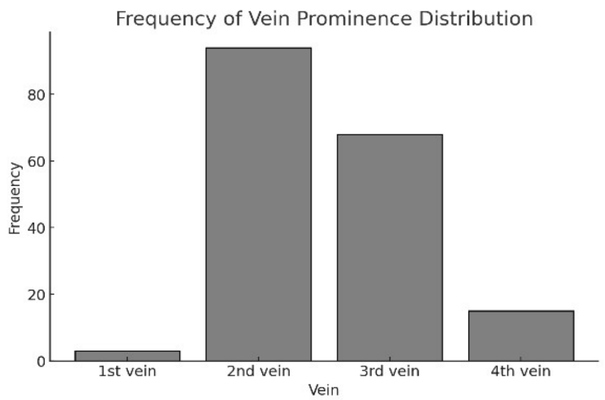

Fig. 3: Distribution of prominent dorsal metacarpal veins across all hands.

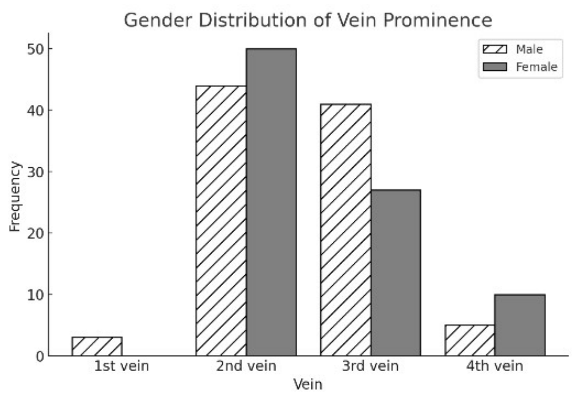

Fig. 4: Gender-wise distribution of the most prominent dorsal metacarpal veins.

Proportional representation

The overall proportional representation of vein prominence revealed that the second vein accounted for the majority of observations (49.47%), followed by the third vein (35.79%), the fourth vein (7.89%), and the first vein (1.58%). These findings highlight the dominance of the second vein in the dorsal metacarpal region across the studied population.

Impact of activities on vein prominence

Those who engaged in heavy lifting or gymnasium activities (n = 16) and musical instrumentation (n = 8) were more likely to have prominent veins.

DISCUSSION

Our study provides a comprehensive analysis of dorsal MCV patterns in a cohort of young undergraduate medical students, contributing insight into these veins' anatomical and biometric characteristics. To our knowledge, this represents the first dataset specifically examining dorsal hand vein patterns in the Omani population with implications for biometric identification. Critically, we found that the second dorsal MCV was the dominant vessel within the dorsal venous network of the hand, emerging as the most prominent vein in nearly half (49.47%) of the cases studied. Analysis based on gender revealed subtle differences: the second vein was consistently dominant in both sexes, but males exhibited greater prominence in the third vein, while females showed higher prominence in the fourth vein. The equal distribution of vein prominence between left and right hands suggests symmetrical venous drainage. Additionally, participants engaged in heavy lifting/gymnasium activities (n = 16) and musical instrumentation (n = 8) were more likely to have prominent veins.

These findings contextualize prior work. The observed prominence of the second dorsal MCV corroborates existing anatomical descriptions of the dorsal venous arch draining into cephalic/basilic veins [1, 3, 6]. Previous studies highlighted interindividual variability in venous patterns, including the M-, N-, or Y-shaped configurations identified by Kulus et al. Additionally, Salameh et al. classified venous patterns into six categories, as depicted in Figure 5 [3, 5]. This aligns with our observation of secondary prominence in the third dorsal MCV (35.79%) and infrequent dominance of the fourth/first veins. The gender-based variations in vein prominence add nuance to established bilateral symmetry principles [2]. While associations between activities and vein prominence were noted, sample size limitations preclude direct comparison to prior biomechanical studies.

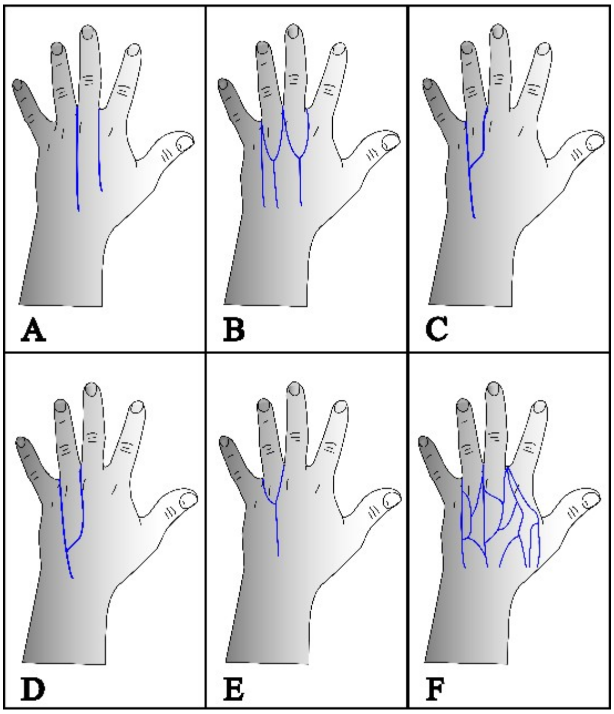

Fig. 5: Representative venous pattern configurations**.** Adapted from Salameh et al. [5] with prior permission.

Collectively, these observations have various implications. The variability and stability of dorsal MCVs underscore their biometric utility. Vein patterns are unique, stable in adulthood, and resistant to superficial changes [12,13]. Compared to fingerprints/iris scans, hand vein recognition offers enhanced security due to subcutaneous invisibility [11]. Our population-specific data (e.g., 49.47% second-vein dominance) support Ferrer et al.'s low error rate (1.43%) for dorsal vein recognition, highlighting feasibility for Omani biometric systems [10]. We advise that for practical adoption, future work should address limitations like sample diversity and infrared imaging integration to optimize real-world reliability.

Study limitations

Despite its strengths, this study has some limitations. First, the relatively small sample size and limited demographics of undergraduate medical students restrict the generalizability of the findings to other populations or age groups. Second, the manual imaging techniques used potentially increase variability in image quality despite standardizing efforts. Moreover, manual methods may limit reproducibility compared to automated infrared-based vein imaging systems, which offer higher consistency in large-scale biometric applications. Third, while associations between vein prominence and activities were explored, causal inferences cannot be made without longitudinal or experimental data. Additionally, cultural factors such as clothing norms, especially in conservative settings, may affect the visibility and accessibility of dorsal hand veins in broader population studies, limiting the practicality of imaging protocols in certain contexts.

Future directions

Future studies should focus on expanding the sample size to include a more diverse population of age and ethnicity to capture the full spectrum of dorsal venous variability. Advanced imaging techniques, such as infrared imaging, could provide improved visualization and accuracy in detecting these venous patterns, which can be used to replicate a similar study. Collaborations with biomedical engineers and computer scientists are encouraged to develop Omani-specific vein recognition algorithms tailored to the biometric traits observed in this population. A multidisciplinary approach involving anatomy, biology, physics, optics, and artificial intelligence can be planned. In addition, longitudinal studies are needed to evaluate the stability of dorsal vein patterns over time, which is critical for the long-term reliability of vein-based identification systems.

CONCLUSION

This study highlights the prominence and variability of dorsal MCVs in the Omani population, with the second dorsal vein being the most consistently observed. Our findings contribute to the growing field of advanced biometrics on hand vein anatomy and its potential applications for medico-legal purposes. By utilizing the stability of these unique patterns, future advancements in identification technologies can enhance current biometrics to be used for identification purposes.

Abbreviations

BV– Basilic Vein
CV– Cephalic Vein
DM– Diabetes Mellitus
HTN– Hypertension
MCV– Metacarpal Vein
MREC– Medical Research Ethics Committee

Conflicts of Interests: None

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Interpretation: AAH, AAL, SD
Writing: AAH, AAL, FAH, MAS, TAS, SD
Supervision: MAM, SD
Editing: AAL, MAM, SD

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