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# Evaluation of Thermal Imaging in the Diagnosis and Classification of Varicocele

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ABSTRACT

***Introduction***: A varicocele is the abnormal dilation and tortuosity of venous plexus above the testicles. The pattern of abnormal heat distribution in the scrotum can be detected through thermal imaging, which is a distant, non-contact, and non-invasive method. The aim of the present study is to detect and grade varicocele.
***Materials and Methods:*** This study was conducted on 50 patients with high probability of varicocele, who referred to a hospital affiliated to the AJA University of Medical Sciences, Tehran, Iran. The evaluation procedure included thermal imaging, clinical diagnosis, and ultrasound test. The gold standard method was based on ultrasound examination. The thermal imaging was performed using a non-contact infrared camera.
***Results:*** This paper presented two methods for diagnosing and grading varicocele. The first method was based on the patterns and models of thermal asymmetry in the testicles (including three asymmetric and symmetric patterns). The second method was based on the temperature differences. The obtained results demonstrated that the use of temperature differences in the diagnosis of varicocele was better than the other proposed method. In addition, a temperature difference of 0.5°C in the pampiniform venous plexus was an important indicator for the diagnosis of varicocele using thermal imaging. The accuracy of thermography in grading varicocele was 76%.
***Conclusion:*** According to the results of the study, thermography is a useful method for initial varicocele screening and can be applied as a supplement to other diagnostic techniques due to its low cost and lack of radiation exposure. Thermography was concluded to be a precise technique for the diagnosis of varicocele; however, its capability to determine the varicocele grading was comparatively low.

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## Introduction

A varicocele is the abnormal dilation and tortuosity of venous plexus above the testicles. This disease rarely occurs at ages under 10 years; however, it has prevalence rates of 15% and 20-40% among the young adults and fertile males, respectively [1]. Moreover, this rate may reach to 70% among those with secondary infertility [2]. Approximately, 90% of varicoceles occur in the left side, and only 10% of them are bilateral [3]. This is because of the higher length of the vein discharging the left testicle blood into the renal vein and its more vertical angle, compared to that of the right testicle.

One of the main theories explaining the pathophysiology of varicocele is the theory of elevated testicular temperature [4]. However, the etiology of temperature rise in the standing and Valsalva maneuver positions has not still detected [5]. It should be noted that the increased intra-abdominal pressure is considered as a weak risk factor for varicocele [6]. There are still much discussions on the treatment of varicocele by surgery. The majority of the men with varicocele are able to have child; therefore, the spermatic vein ligation is not recommended for all common cases of this disease.

Varicocele is a progressive lesion in some males, which causes the loss of former fertility [7]. The current guidelines recommend surgery for the infertile males diagnosed with this medical condition and semen disorders [8]. However, the recent studies has led to the revision of these suggestions. Accordingly, it has been shown that the surgical treatment option does not increase the chance of fertility in cases that the varicocele is considered as the only proof of infertility [9]. These referred problems will be solved if the males with deteriorating varicocele are diagnosed sooner in order to prevent the reduction of their semen quality.

According to the literature, varicocele has negative toxic effects on the testes. Furthermore, it has been demonstrated that the untreated cases of varicocele can lead to unpleasant results, such as infertility [10]. The surgical operation is performed in case the progressive varicocele results in the deterioration of the semen quality; however, there is no diagnostic criteria for performing surgery in this regard. Semen quality

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analysis is not regarded as a screening method. Currently, varicocele diagnosis depends on physical examination and scrotal ultrasound/Doppler ultrasound [10, 11].

The abnormal thermal patterns can be easily detected by thermal imaging. In the past, the clinical thermal imaging was performed occasionally as an objective diagnostic method [12]. Although it is a non-specific method, which highly depends on the background and environmental factors in some cases, there are several reasons that have made it generally accepted and welcomed in the medical community. First of all, thermal imaging is a distant, non-contact, and non-invasive method [13]. The duration of thermal imaging for varicocele diagnosis is much shorter, compared to other methods. Therefore, this method can be used in a wide range of case detections, which is very useful in the screening process. The colors of thermograms can be easily and quickly interpreted. In addition, this method only records the natural radiations of the skin surface, and there would be no trace of harmful rays. In a study, thermography was reported to be more sensitive than sonography [14].

However, there are multiple factors preventing the routine use of scintigraphy in the diagnosis of varicocele. These factors include the more invasive nature of this method as compared to ultrasonography (due to the administration of intravenous radioisotope), using the methods of the previous studies which had in consistence results with one another, the lack of an entirely clear link between the abnormalities revealed by scintigraphy and treatment outcomes, as well as significantly lower availability [15].

Therefore, this method can be repeatedly used for a long term. Finally, thermal imaging is an immediate method, which can monitor the dynamic changes of temperature. The digital infrared thermal imaging is a non-invasive and sensitive diagnostic method for the detection of primary varicocele using the scrotal skin surface temperature measurement. Despite the objective truth and short duration of this diagnostic method, it was sporadically applied during the clinical procedures in the past. The use of thermography in the detection of varicocele dates back to the late 70s [16, 17]. It has been also demonstrated that the scrotal thermography is a useful diagnostic method for the mild varicocele and the postoperative period [14].

Thermography has been also applied as a successful method for the follow-up [11, 18, 19]. Asymmetry technique is one of the basic principles and methods for the analysis of thermal images. Some researchers have conducted the asymmetry analysis based on the temperature change, skewness, and kurtosis of the image and the study area [20].

According to the studies conducted in other countries, especially those carried out in the field of breast cancer, the thermography imaging systems can have an appropriate performance not only as a precise and absolute method, but also as a supplement to other techniques due to their proper and correct diagnostic results and few false positive or negative responses [14, 21]. Furthermore, [22] and [14] clearly demonstrated the better performance of thermography versus sonography and/or physical examination.

With this background in mind, the present study aimed to identify the strengths and weaknesses of the scrotal thermography imaging in the diagnosis of varicocele. The main assumption was that the scrotal digital infrared thermography is the main tool in the diagnosis of varicocele.

## Materials and Methods

This study was conducted on 50 patients with high probability of varicocele, who referred to a hospital affiliated to the AJA University of Medical Sciences, Tehran, Iran. For the purpose of the study, we used a thermography device with a non-contact infrared camera (VIS-IR 640, Thermoteknix Production Company in England). The technical specifications of the camera are presented in Table 1.

**Table 1.** Technical specifications of the camera used in thermal imaging

| Parameters |
|---|
| 640 × 480 , 25 µm pitch (307, 200 pixels) |
| Uncooled focal plane array (FPA) micro-bolometer |
| Spectral range: 7.5-13 µm |
| Thermal sensitivity: 50 mk |
| Accuracy: ±0.01°C (or ±2% of reading) |
| Field of view: 26° × 20° |
| Temperature range: -20 to 500°C |
| Visible camera: 1.3 M-pixel |

The analysis and presentation of images were performed using the SATIR Wizard software (Thermoteknix Production Company in England). In order to perform the thermography, the patient was placed in a certain distance of about 30 cm (since it resulted in high-resolution and quality images during the experimental work of using the camera) from the infrared thermal camera. The body radiations that are within the range of 0.7-0.9 µm are sent to the image processing system after passing through a focusing lens that acts as a filter. The filter can be of a square or oblong shape and mounted in a holder accessory, or, more commonly, a glass or plastic disk in a metal or plastic ring frame, which can be screwed into the front of or clipped onto the camera lens.

There are multiple points, which must be observed for performing thermal imaging. These points are as follows: 1) the patient must be psychologically relax and comfortable prior to the performance of thermal imaging; 2) the ambient room temperature should be set at approximately 25°C (i.e., neither cold nor warm); 3) it is better to take off the patient's clothes 10 min before shooting and ask him to sit calmly; and 4) the fluorescent lamps in the thermography room must be turned off.

Based on the received wavelength, the temperature of each point of the body appears on the display in a certain color after determining the location. The accuracy of detecting the radiations of the skin surface depends on the skill of the specialist in reading the thermography images, operator's skill in setting the visibility window, selected color scale, and patient's distance to the device.

In this study, 50 patients suspected of varicocele were clinically examined by a specialist and the results were recorded. It is worth mentioning that all patients were randomly selected, and all of them had referred to an urologist. The mean age of the patients was 30±7 years. Prior to performing the thermal imaging, some items (e.g., imaging conditions, room temperature, patient's comfort, etc.), which were effective in providing false or true thermography findings, were investigated.

In order to improve the validity of the results, the patients were asked for not having the diseases that can affect the elevation of the testicle temperature. Accordingly, none of the participants suffered from any specific medical conditions that may result in the increase of testicle temperature. Before the testing procedure, the patient was put in a relaxed state in order to avoid the elevation of the temperature in the testicle.

Then, the patients were placed in front of the camera in a standing position, while the lower part of the body was naked. The patients were asked to hold the tip of their penis upward with their fingers so that that the glans penis was kept against the abdominal wall. This was performed, while the patients' legs were stretched, and the testicles hung freely. Finally, the thermography images were taken of the testicles by an operator.

Monitoring the difference of the temperature between the right and left testicles is a part of the diagnostic evaluation. If the average of this temperature difference is more than 0.5°C in the specified areas of the right and left testicles, then it will become an important issue in terms of thermography. The temperature of the testicle is approximately 34°C, which may be different in diverse patients for several reasons. In this regard, the temperature is not considered as the diagnostic criteria, but the temperature difference of the right and left testicles is taken as the evaluating criteria.

The scrotal ultrasound technique is the gold standard method of thermography in varicocele evaluation. After undergoing clinical examination and thermal imaging, the patients were referred to an ultrasound imaging center in order to compare the related results with the proposed method. In digital infrared scrotal thermography, highly sensitive infrared cameras are used for tracking and measuring the temperature of the scrotum area [23].

## Results

As previously mentioned, after receiving and recording the patient's history and results of clinical examinations, and also using the comments and views of a urologist, the thermography images were separately studied by the relevant experts. Based on the previous studies, the temperature of the pampiniform plexus of the testicular veins are points of attention. The visual analysis of these points produces a thermographic pattern sample [24]. The uniform temperature on both sides of the scrotum is regarded as normal. In terms of thermography, the varicocele is an increased temperature of an area that is detected using two major patterns [25].

Based on the collected thermal images, the models and thermal patterns were found to be different in the patients. Therefore, three general patterns were detected, including a symmetric thermal pattern (Figure 1) and two asymmetric thermal ones (Figure 2 and 3). Figure 1 displays a thermal image taken from a patient. As it can be clearly seen, the thermal pattern is uniform and normal on both sides of the scrotum. This was consistent with the relevant doctor's idea, indicating the lack of varicocele.

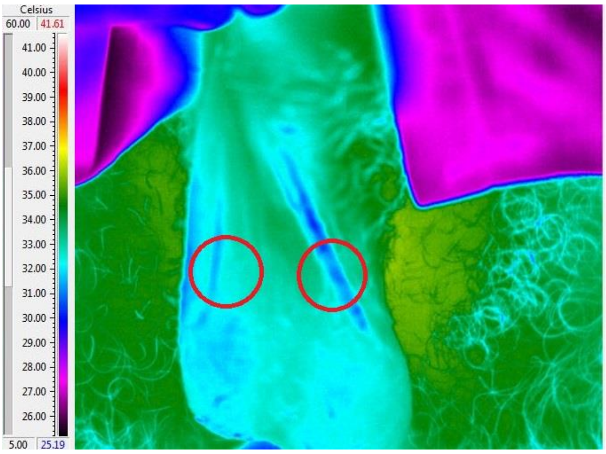



**Figure 1.** Thermographic image of the testicles in a healthy person

The first pattern with asymmetric temperature distribution is shown in the pampiniform venous plexus of scrotum, which exclusively engages the upper part of the testicles. An example of this pattern is presented in Figure 2. As it can be observed, an asymmetric thermal pattern can be observed in the pampiniform venous plexus area at the top of the right and left testicles. According to the specialist's opinion, this indicates a grade II varicocele. In some cases, a high scrotal temperature was only observed in the pampiniform venous plexus, while there was no temperature elevation in the testicle of the same side.

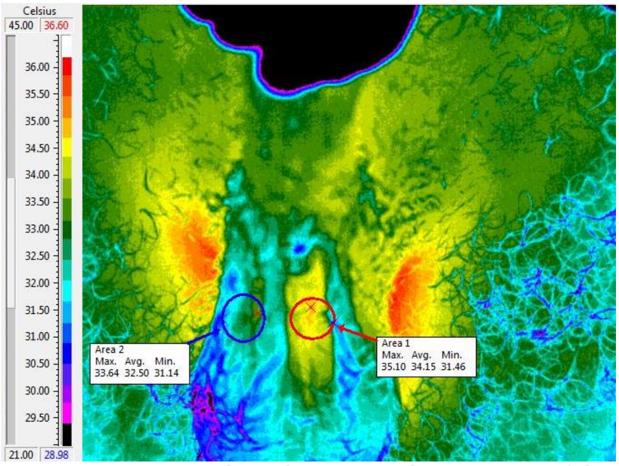
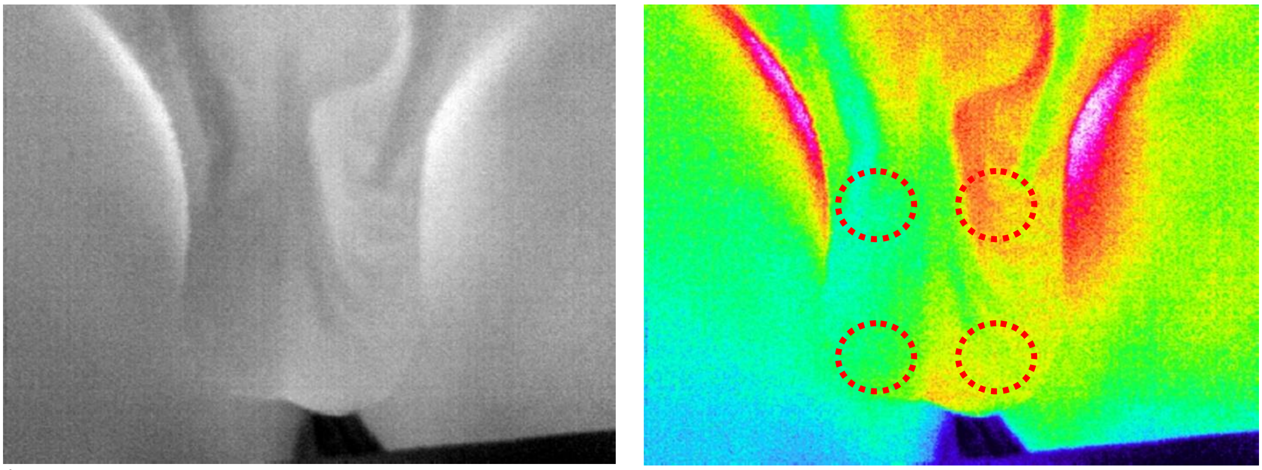



**Figure 2.** Asymmetric thermal pattern in the upper part of the testicles in thermography image of grade II varicocele

The second pattern with asymmetric temperature distribution was in the pampiniform venous plexus that was expanded towards the testis of the same side or involved the hyperthermia of the whole testicle. Although the full bilateral hyperthermia of the scrotum is a rare medical condition, it is a definite symptom of varicocele. As previously indicated, the determination of the localization and extension of hyperthermia area is very important in the interpretation of the thermographic findings. An example of this pattern is illustrated in Figure 3. As can be seen in this figure, the increased temperature involves both pampiniform venous plexus and scrotum.



A B

**Figure 3.** Asymmetric thermal pattern in the pampiniform venous plexus and scrotum in the thermography image of a patient with grade III varicocele; A. Gray, B. Colorful

**Table 2.** Measured temperature by thermal cameras in different areas

| Temperature (°C) | LP | RP | LT | RT | LTH | RTH | ΔLPRP | ΔLPLTH | ΔRPLTH |
|---|---|---|---|---|---|---|---|---|---|
| Mean | 34.15 | 32.23 | 33.40 | 32.22 | 33.10 | 33.11 | 1.92 | 1.05 | 0.87 |
| Median | 34.15 | 32.32 | 33.65 | 32.22 | 33.10 | 33.21 | 1.83 | 1.05 | 0.78 |
| Standard deviation | 0.74 | 0.65 | 1.21 | 0.51 | 0.89 | 0.52 | 0.09 | 0.15 | 0.24 |
| Minimum | 33.10 | 31.10 | 31.20 | 31.30 | 33.30 | 32.20 | 2.00 | 0.20 | 2.20 |
| Maximum | 36.00 | 33.50 | 35.55 | 33.20 | 34.88 | 34.40 | 2.50 | 1.12 | 1.38 |

L: left; R: right; P: pampiniform plexus; T: testicle; TH: thigh; Δ: temperature difference

The measured temperatures of the pampiniform plexus, scrotum, and thigh are presented in Table 2. According to this table, the thermal mean, median, standard deviation, maximum, and minimum differences are the values that can reveal the thermal asymmetry. For example, the ΔRPLTH corresponds the temperature difference between RP and LTH, or ΔLPLTH signifies the temperature difference between LP and LTH.

This table demonstrates the descriptive statistics of the temperature in the respective areas in a patient with left grade III varicocele. The mean temperature difference between the pampiniform plexus of the right and left testicular veins was 1.92°C, which follows the parameters of the model III proposed in this study. The temperature differences in venous plexus pampiniform among the patients with varicocele is shown in Table 3.

Initially, all the patients were tested with Doppler ultrasound. Out of the 50 patients, 35 cases were diagnosed to have testicular diseases. The results of the ultrasound are shown in Table 4.

**Table 3.** Temperature differences in venous plexus pampiniform among the patients with varicocele

| Samples | Temperature differences in venous plexus pampiniform |
|---|---|
| Healthy case | ΔT<0.5 |
| Grade I | 0.5<ΔT<0.75 |
| Grade II | 0.75<ΔT<1 |
| Grade III | 1<ΔT |

**Table 4.** Scrotal abnormalities detected by scrotal ultrasonography in thirty five infertile males

| Properties | Number of cases (%) |
|---|---|
| Left varicocele | 30(66.7) |
| Epididymal cyst | 2(4.45) |
| Right varicocele | 2(4.45) |
| Unilateral testicular cyst | 1(2.22) |

Subsequently, the results of the ultrasound methods were compared with those of the thermal imaging method. The results of the thermography and ultrasonography in diagnosing and grading varicocele are presented in Table 5. In addition, the diagnostic functions of thermography were evaluated according to the patterns presented in this study (including a pattern of thermal symmetry as shown in Figure1 along with two patterns of thermal asymmetry as displayed in Figures 2 and 3). It is worth mentioning that out of the 50 participants, five patients were excluded from the study due to having cystic masses, etc.

**Table 5.** Comparison of the findings of thermography and ultrasonography in diagnosing and grading varicocele

| | Grading (%) | | | | |
|---|---|---|---|---|---|
| | I | II | III | Healthy | Total |
| Ultrasonography | 8 | 12 | 10 | 15 | 45 |
| Thermography detection | 5 | 10 | 8 | 22 | 45 |

The values related to the left spermatic vein diameter are illustrated in Table 6.

**Table 6.** Left spermatic vein diameter

| | Diameter of left pampiniform lexus vein (mm) |
|---|---|
| Left varicocele Health (No) | 3.0±0.9 |
| Grade I | 3.7±1.2 |
| Grade II | 4.1±1.3 |
| Grade III | 5.1±1.5 |

It is noteworthy to indicate that thermography is only able to detect the temperature changes of the skin surface. Table 7 presents the number of the patterns observed in our study population based on the three proposed thermal models for grades II and III varicocele as well as the healthy state.

**Table 7.** Varicocele diagnosis through the proposed thermal patterns regardless of the temperature difference

| Proposed pattern | Number |
|---|---|
| Healthy pattern | 22 |
| Grade II of thermal pattern | 7 |
| Grade III of thermal pattern | 5 |

As can be noticed, the number of the people who were diagnosed by the proposed thermal pattern are less than the actual number identified by the temperature difference. In other words, the temperature difference along with the proposed thermal pattern can enhance the accuracy of diagnosis. However, the proposed thermal pattern was correct and error-free for the healthy subjects in all cases.

According to the results of the independent sample t-test, there was a significant difference between the two groups of healthy samples and those with varicocele (P<0.001). The distribution of the mean thermal differences in the healthy and varicocele cases is displayed in Figure 4. Based on the results of the ANOVA test, a significant difference was observed among the three different grades of varicocele (P<0.002).

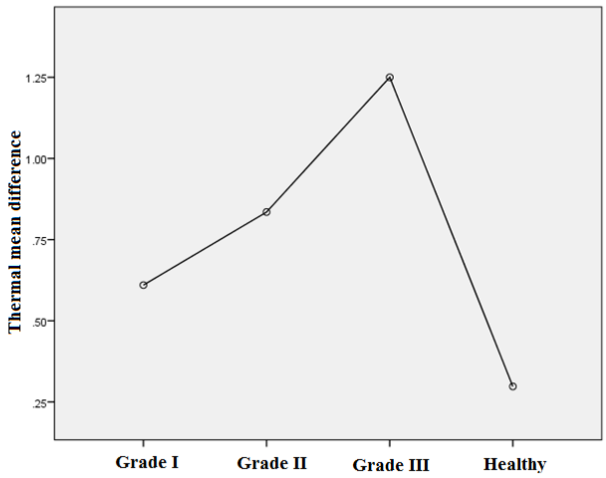



**Figure 4.** The distribution of mean thermal differences of the healthy and varicocele cases

## Discussion

Currently, varicocele diagnosis depends on physical examination and scrotal ultrasonography/Doppler ultrasound. However, the physical examination is a subjective method and cannot be helpful alone in the diagnosis of subclinical varicocele [22]. Furthermore, the role of the examiner's and interpreter's clinical experience in interpreting the findings of the ultrasonography/Doppler ultrasound is one of the disadvantages of these methods. In addition, the use of ultrasound in the postoperative stage (i.e., during the follow-up) is restricted [26].

On the other hand, thermography allows the imaging of the surface temperature distribution. Skin temperature depends on complex relationships of heat exchange in the skin, internal, and local vascular tissues with metabolic activity. Testis temperature is about 3°C lower than the body temperature (37◦C) [27]. If varicocelectomy is performed in the early stages of the disease and at a young age, it will produce better results regarding the fertility [28].

Merla *et al*. (2004) stated that temperatures above 34°C and 32°C in the pampiniform plexus and/or scrotum are indicative of varicocele, respectively [29]. In our studied samples, 83% and 92% of the patients had a temperature above 34°C and 32°C, respectively. Tucker reported that the retention of breath could help the diagnosis of varicocele, and in a normal mode (i.e. the absence of venous reflux), this leads to a decrease in the temperature by 0.5°C [30]. However, no similar effect was observed in this study and further studies should be conducted to determine the usefulness of this parameter.

Nogueira *et al*. (2009) and Yamamoto *et al*. stated that the temperature differences of 0.3 and 0.8 in the right and left sides of the upper part of the pampiniform plexus are indicative of unilateral varicocele [18, 31]. However, this clinical sign alone cannot be taken into account. The temperature of the scrotum skin is lower than that of the upper part of the thigh [32]. In this study, the temperature of the central part of the upper thigh was measured as the calibration temperature. In all patients, the temperature of the left pampiniform plexus was higher than that of the upper part of the thigh. In a study conducted by Merla *et al*., the researcher raised the possibility of measuring the difference in the speed of temperature return after scrotal cooling [29].

Due to the complexities of grading varicocele in the thermography method, the proposed method is mostly focused on the diagnosis of varicocele. The obtained results could provide models for varicocele grading; nonetheless, they have some mistakes. This paper presented two methods for diagnosing and grading varicocele. The first method was based on the patterns and models of thermal asymmetry in the testicles (including three asymmetric and symmetric patterns that were presented in Figures 1, 2, and 3). The second method was based on the temperature differences (Table 3). The obtained results showed that the use of temperature differences in the diagnosis of varicocele was better than the other proposed method.

## Conclusion

With respected to the findings of the present study, thermography has both advantages and disadvantages in the detection of varicocele. With the advent of new generations of infrared detectors, infrared thermal imaging has become a thorough medical diagnostic tool for measuring the abnormal areas in the thermal pattern. In addition, sensitivity to temperature, spatial resolution, non-contact nature, and safety of thermal imaging are among the beneficial features of this method. Moreover, thermal images can be digitally stored, and then processed using different software packages.

Thermography does not provide information on the morphology of testicular structures; however, it presents information on temperature function and vascular conditions of testicular tissues. The results of this study suggested that thermography can be used in the primary diagnosis or quick screening of varicocele. In addition, it can be applied as a supplement to ultrasound. In other words, although thermography can be helpful in the initial screening for obtaining the positive or negative result of affliction with varicocele, determining the grade of this disease requires higher accuracy and more studies. However, a pattern for grading can be reached with a large number of images.

Another point is that asymmetry has a key role in early diagnosis of varicocele, which can be achieved through primary settings of the camera. The results of this study can be used to identify two parameters indicating varicocele, including temperature difference in pampiniform venous plexus and thermal pattern. In this regard, if the temperature difference is noticed in pampiniform venous plexus, varicocele can be suspected. Due to the value of the temperature difference, varicocele grade can be recognized. The potential defect of scrotal thermography is the inseparability of varicocele from other pathological states of scrotum (e.g., testicular tumors and inflammation of the epididymis).

In summary, the diagnosis of varicocele through thermography entails several steps, including taking a thermal image from the patient, evaluation of the thermal patterns (asymmetry) of the testicular and venous plexus, and diagnosis of varicocele in case of observing asymmetric thermal pattern. In addition, the grading of varicocele can be determined through the evaluation of the temperature difference of the testicles. Accordingly, higher temperature difference and level of involvement indicate higher grading of varicocele.

More studies are recommended to be conducted on larger sample size, including both patients and healthy subjects, to investigate the sensitivity of thermography method as well as its respective features and diagnostic parameters. Furthermore, to improve the proposed method for future works, the neural network techniques can be employed for clustering and grading of varicocele.

The limitation of this study was the sensitivity of thermal cameras to sunlight and fluorescent. Regarding this, the performers are recommended to set the ambient light prior to the imaging procedure.

In addition, they should try to take images in the dim light.

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