Male factor infertility accounts for 30% to 50% of the total infertile couples seeking for infertility management (1). Among the couples seen for infertility, the most common cause of male infertility is defective spermatozoal function. It may result from testicular pathologies, genetic disorders, and exposure to drugs, toxins, or irradiations, or because of oxidative stress damage (2, 3). The mechanism of action for loss of sperm function may be because of elevated levels of reactive oxygen species (ROS) beyond the available total antioxidant capacity in the semen (3–9).

Seminal plasma has a very effective antioxidant systems that can provide the spermatozoa with a protective environment against oxidative stress (10). This protection compensates for the loss of cytoplasmic sperm enzymes that occurs during maturation and transportation processes, which in turn, diminishes the spermatozoa’s endogenous enzymatic and repair defenses (7, 8, 11–15). Indeed, the total antioxidant capacity of seminal plasma is because of the sum of enzymatic (e.g., superoxide dismutase, catalase, and glutathione peroxidase) and nonenzymatic (e.g., ascorbate, urate, vitamin E, pyruvate, glutathione, taurine, and hypotaurine) antioxidants (7, 16–21).

Low level of seminal total antioxidant capacity (TAC) has a key role in male infertility (8, 22, 23). It is important to ensure that any measurement of seminal TAC is accurate and reliable and yet easy to use as a diagnostic tool in the evaluation and follow-up of male infertility. Total antioxidant capacity levels have been measured by the enhanced chemiluminescence method earlier in patients with clinical diagnosis such as varicocele, varicocele with infection, vasectomy reversal, as well as idiopathic infertility (9, 24, 25). In addition, using the ROS and TAC results, a novel score called the ROS-TAC score was also described earlier by us in subsets of patients with various clinical diagnosis (1, 16, 25–27). This score was described as a better predictor of oxidative stress in patients with various clinical diagnosis compared with ROS or the TAC values alone.

Seminal TAC can be measured as the total available antioxidant protection in the seminal plasma, which is more practical and easy to perform by an enhanced chemiluminescence or the colorimetric assay. In contrast, measuring specific antioxidant assays are expensive and cumbersome in performance (high-pressure liquid chromatography, and so forth) and provide limited information about the assessed antioxidants. Earlier we compared the enhanced chemiluminescence and colorimetric method to assess TAC. We reported that the colorimetric TAC measurement is simple, rapid, cheaper, and accurate (28).

Increase in levels of ROS without a concomitant rise in antioxidant defenses leads to oxidative stress. Oxidative stress...
is involved in the pathogenesis of male and female reproduction. Oxidative stress causes damage to the spermatozoa, oocyte, and embryos. Several reports relate low seminal plasma TAC levels to male infertility, as well as in embryo culture media from the oocytes, cumulus cell mass, and spermatozoa used for insemination in conventional IVF. The potential cellular sources of TAC in an intracytoplasmic sperm injection setting are the spermatozoa and the injected oocytes (8, 22, 23, 29–36). However, a definite cutoff or reference range in infertile patients or proven fertile subjects for a possible use as a diagnostic tool for infertility identification is lacking.

The objectives of our study were to [1] identify a cutoff value for seminal plasma TAC level that can differentiate infertile patients from fertile donors, [2] establish the sensitivity and specificity of the test, and [3] examine the intra- and interobserver variability of the assay to establish the variability between various individuals who may perform the assay in a clinical laboratory setting.

MATERIALS AND METHODS

Subject Selection

This study was approved by the institutional review board of our hospital. Infertile patients (n = 42) as well as normal healthy men (n = 100) were screened and selected on the basis of normal semen analysis according to the World Health Organization (WHO) (37) guidelines.

Semen Collection and Preparation

Semen specimens were collected by masturbation after 48 to 72 hours of sexual abstinence. The specimens underwent complete liquefaction at 37°C for 20 minutes, and 5 µL of each specimen was loaded on a 20-µL Microcell chamber (Conception Technologies, San Diego, CA) where it was analyzed for sperm concentration and motility. Samples were classified according to the results of semen analysis as per the WHO (1999) (37) criteria and history of establishing a pregnancy in the past 2 years.

Donors or controls (n = 55) were further classified as proven fertile, that is, who had initiated a pregnancy within the past 2 years and had normal semen analysis results according to WHO criteria. Unproven fertile (n = 45) men were those who had normal semen analysis results but had not established a pregnancy in the past 2 years. The infertile patient group (n = 42) consisted of men who had abnormal semen analysis and were presenting for infertility treatment and/or undergoing investigation for various male infertility factors. All samples were centrifuged at 1000 × g for 10 minutes at 4°C. Clear seminal plasma was aliquoted and frozen at −70°C until the time of TAC assay. A total of 142 TAC measures were conducted: 42 for patients, 55 for fertile donors and 45 for donors with unknown fertility status.

Total Antioxidant Assay

Seminal plasma total antioxidant measurement was done using the antioxidant assay kit (Cat #709001; Cayman Chemical, Ann Arbor, MI). The Cayman Chemical antioxidant assay was used to measure the antioxidant capacity of the seminal fluid samples. The principal of the assay is the ability of aqueous and lipid antioxidants in the seminal plasma specimens to inhibit the oxidation of the 2,2′-Azino-di-[3-ethyl-benzthiazoline sulphonate] (ABTS) to ABTS⁺. Under the reaction conditions used, the antioxidants in the seminal plasma cause suppression of the absorbance at 750 nm to a degree that is proportional to their concentration. The capacity of the antioxidants present in the sample to prevent ABTS oxidation was compared with that of standard Trolox, a water-soluble tocopherol analogue. Results are reported as micromoles of Trolox equivalent. This assay measures the combined antioxidant activities of all its constituents including vitamins, proteins, lipids, glutathione, uric acid, and so forth.

The technique for TAC assay used in our study has been described before (38, 39). All seminal plasma samples were diluted 1:10 with the assay buffer before assaying to avoid variability because of interference by the plasma proteins or sample dilution. All reagents and samples were equilibrated to room temperature before beginning the assay. Samples as well as Trolox standards were assayed in duplicate. Trolox standards and reagent were prepared as per the manufacturer’s instructions at the time of the assay. After the plate configuration, 10 µL of Trolox standard and samples were loaded on to the corresponding wells of a 96-well plate. Then 10 µL of metmyoglobin and 150 µL of chromogen were added to all standard/sample wells. The reaction was initiated by adding 40 µL of hydrogen peroxide as quickly as possible. The plate was covered and incubated for 5 minutes on a shaker at room temperature. Absorbance was monitored at 750 nm using ELx800 Absorbance Microplate Reader (BioTek Instruments, Inc., Winooski, VT).

Calculation of Assay Result

Determination of the reaction rate was done by calculating the average absorbance of each standard and sample. The average absorbance of the standards as a function of the final Trolox concentration (µM) was plotted for the standards curve in each run, from which the unknown samples were determined (Fig. 1). The total antioxidant concentration of each sample was calculated using the equation obtained from the linear regression of the standard curve by substituting the average absorbance values for each sample into the equation:

\[
\text{Antioxidant (µM)} = \frac{\text{Unknown average absorbance-Y-intercept}}{\text{Slope}} \times \text{dilution} \times 1000
\]

Precision and Sensitivity of the TAC Assay Kit

According to the manufacturer, the assay precision was: interassay coefficient of variation 3% (n = 20) and intraassay coefficient of variation 3.4% (n = 84). The assay kit could...
measure samples containing antioxidants ranging between 44 and 330 μM without any further dilution.

**RESULTS**

**Receiver Operator Characteristic Curve Analysis**

**Proven fertile donors versus infertile patients** We have examined the association between TAC levels and the status of a subject, as either infertile patient or a fertile donor. We first considered only proven fertile donors who had normal semen analysis results and had fathered a child in the last 2 years. The distribution of TAC levels within the proven fertile and donors of proven fertility is shown in Figure 2 and 3.

The mean ± SD and median (IQR) values were as follows: infertile patients: 1380 ± 430 μM, and 1310 (1040–1600) μM; proven fertile donors: 1830 ± 540 μM and 1700 (1440–2290) μM (Fig. 2). Proven fertile donors showed significant higher seminal plasma TAC levels compared with infertile patients groups (P < .001). The cutoff that maximized the sum of the sensitivity and specificity when using TAC as a predictor of fertility was 1420 μM seminal plasma TAC level. The receiver operating characteristic curve showed 76% sensitivity and 64% specificity for this optimal cutoff (Fig. 4).

**All donors versus infertile patients** As a secondary analysis, we compared infertile patients to all donors (whether proven fertile or not). The TAC values in all donors (proven and unproven) was 1740 ± 510 μM and 1670 (1360–2000) μM versus infertile patients: 1380 ± 430 μM, and 1310 (1040–1600) μM; (Fig. 3). The results of this analysis were similar to those that exclude the unproven donors. Significant difference in the TAC values was seen in the two groups when a similar cutoff value of 1420 μM was selected (Fig. 5).

**Intra- and interobserver variability** The intra- and interobserver differences were calculated using the simple difference rather than a standard deviation. Rather than the CV, we used a ratio of a difference to mean (d/m) to represent
the relative difference of two TAC measurements. Next, we assessed the likelihood that such relative differences would exceed 20% value, which is unacceptable. By using this ratio; the mean intraobserver variability was 13.4% for observer 1 and 15% for observer 2. The mean interobserver variability between the two observers was 19%. All the variability measures were in the acceptable ranges (d/m ratio <20%).

DISCUSSION
The link between reactive oxygen species and the male infertility has been established. Irrespective of the clinical manifestation and the results of semen analysis, the presence of abnormal ROS level plays a major role in the pathogenesis of male infertility (27, 30, 36, 41, 42).

Total seminal plasma antioxidants are the most protective defensive mechanism available to spermatozoa against ROS. Low seminal total antioxidant capacity has been shown to be related to male infertility (10, 28, 35, 36). Seminal plasma antioxidant capacity may be influenced by a wide range of the factors such as nutrition, vitamin supply, age, infection, and so forth); therefore, it is important to accurately estimate the total antioxidant amount of the seminal plasma (19, 38). From the methods available for measuring TAC, earlier we compared the more commonly used enhanced
chemiluminescence assay versus the colorimetric assay using for measuring TAC levels in seminal plasma.

For the colorimetric assay we used the TAC kit from Randox (Randox Laboratories Ltd, San Francisco, CA). The measurement of total antioxidant capacity by enhanced chemiluminescent method generally takes approximately 40 to 45 minutes; it requires stringent assay conditions as opposed to the colorimetric assay. The price of an average luminometer with kinetic setting averages $30,000 compared with $6,000 for a simple spectrophotometer. We reported that the colorimetric assay is a reliable, simple, rapid, and accurate assay compared with the chemiluminescence assay (28).

The main objective of our study was to examine the diagnostic value of the seminal plasma TAC assay in infertility clinic in terms of the best cutoff level, assay sensitivity, and specificity using a colorimetric assay. In addition, we examined the inter- and intraobserver variability for this assay to establish the variability between various individuals who may perform the assay in a clinical laboratory setting.

It is important that the technicians are checked off for accuracy especially in routine bench work such as accuracy in pipetting, and so forth. In our study the two observers (R.M. and R.K.S.) were very experienced in routine bench work (>5 years). It is prudent to have more researchers validate our study. The variation is near the acceptable limit. This also depends on the method of calculating the variation. Here we calculated the ratio of the absolute difference to the average value. This is different from the coefficient of variation (CV), which is calculated from the ratio of standard deviation to the average. The d/m ratio is more sensitive to the CV. By using the CV calculations, the inter- and intraobserver variability was around 5%.

In our study, infertile patient group showed lower seminal plasma TAC levels compared with the proven fertile and the overall donor group (Figs. 2 and 3). The proven fertile and all donors groups showed comparable seminal plasma TAC levels. We have established a cutoff value of 1420 μM of Trolox; all infertile men showed TAC levels below this cutoff value, whereas proven fertile men showed TAC levels higher than this cutoff value. Receiver operating characteristic curve showed high sensitivity (76%) and specificity (64%). Interobserver and intraobserver variation were within the acceptable ranges.

Siciliano et al. (21) reported similar total antioxidant status used ABTS-based colorimetric assay in asthenozoospermic (1240 ± 200 μM) and oligoasthenozoospermic patients (1260 ± 210 μM) with normal viscosity compared with normozoospermic healthy donors (1210 ± 160 μM) with proven fertility (21). However significant differences were seen in the TAC levels in these patients with normal viscosity when compared with those that were hyperviscous. They concluded that impaired antioxidants in asthenozoospermic patients may be related to other associated pathologies such as hyperviscosity. Contrary to their findings, low TAC levels were seen in our infertile patient groups, and these levels were significantly lower than in proven as well as unproven fertile donors. None of the samples in our study was hyperviscous.

Fingerova et al. (8) reported seminal plasma TAC level to be about 1.4 times higher than those in the blood serum. They measured the seminal plasma TAC levels by using Randox kit. They found significantly lower values (mean ± SD 2.15 ± 0.29 mM) in the infertile patients compared with the control 2.32 ± 0.33 mM; P<.02). When the range and median were compared there appeared to be an overlap between the patients and controls (patients: median and range: 2.11 (1.63–2.64) mM versus control: 2.48 (1.45–2.66) mM. Our results agree with their finding regarding the significantly lower TAC values in patients compared with the controls. However, the difference in our cutoff value between patients and controls is more distinct compared with the values reported in the study by Fingerova et al. (8). This can be attributed to the fact that in their study the patient and control semen analysis results were more or less within normal ranges according to WHO references (37).

Lewis et al. (23) compared the individual antioxidants in serum and in seminal plasma. They reported that in seminal plasma ascorbate, urates, and thiols are the major antioxidant available. However; Donnelly et al. (7) reported that single or combined supplementation of ascorbate and tocopherol is not beneficial for sperm motility improvement. Their findings suggest the importance of the TAC assay instead of measuring individual antioxidants that is complex and inaccurate. It may therefore be important to use TAC assay for monitoring and follow up for infertile patients.

Our inter- and intraobserver variability results were in agreement with our earlier work where we reported the actual average difference of 27.6 μM Trolox equivalent between observers, and interobserver variation of 3 % (95% confidence interval [CI]; −3.6%–9.5%) (28). Benzie et al. (18) reported intraobserver CV of <1.0% and interassay CV of <3.0% using the ferric reducing ability of plasma as a measure of the antioxidant power in the biologic fluid samples.

Using the enhanced chemiluminescence assay for measuring TAC levels we demonstrated the usefulness of this assay in identifying patients with various clinical diagnosis (9, 24, 25). We also defined a novel ROS-TAC score and its usefulness in differentiating the patients from control healthy men (1, 16, 25, 26, 43). Using the enhanced chemiluminescence assay we reported the TAC values in controls 1650.9 ± 532.22 (1, 16, 27) and 1653.98 ± 115.29 molar trolox equivalents (25). All infertile patients with various clinical diagnoses had significantly lower levels of TAC. However, the enhanced chemiluminescence assay probe is no longer available, and the TAC measurement derived from the luminometer are complex and time consuming. The equipment must be simple, easy to use, and cost effective. Although enhanced chemiluminescence involves the luminometer, many labs also use high-pressure liquid chromatography (HPLC) for
measuring vitamin E and C concentrations. This is again time consuming, requires specific instrumentation, and is expensive.

We therefore sought to look for an alternate, easy, and accurate method for measuring the seminal plasma antioxidant status. We demonstrated the ease of using the colorimetric assay (Randox kit) versus the chemiluminescence method for TAC measurement (28). The accuracy, sensitivity, and the specificity was comparable in the two methods. However, this kit is expensive, uses larger assay volumes, and can be used only with a spectrophotometer. Our goal was to use an easy and simple colorimetric assay where multiple samples can be evaluated in smaller volumes simultaneously, and therefore we looked for alternate assay kits. The colorimetric assay described by us is simple, easy, and requires a simple spectrophotometer, which is easily available in most labs. The assay kit used currently in our study is cost effective, requires a smaller assay and reagent volumes, and more importantly, it can be used in a plate reader for simultaneous measurement of large number of samples unlike the Randox kit. In the current study, we included patients and donor based on their semen analysis and fertility status only. In this study, our primary objective was to establish a diagnostic reference values for seminal plasma TAC levels in infertile patients as well as in healthy donors, and hence the abstinence period required was 2–3 days similar to that defined by WHO for routine semen analysis as recommended by WHO (37). It would be interesting to examine the effect of shorter abstinence period of <48 hours, as this may help decrease the amount of time the spermatozoa are subjected to oxidation while in the male reproductive tract and possibly increase the sensitivity. We recommend further studies to not only reproduce our results, but to establish reference values for different age ranges and also with certain diseases such as varicocele and infection, as well as conditions such as hyperviscosity and varying abstinence period.

In conclusion, the simple colorimetric seminal plasma TAC assay used in our study can discriminate proven fertile from infertile patients. It may be used as a diagnostic and prognostic tool in the male infertility clinic. The best cutoff value of seminal plasma TAC level is 1420 μM, with high sensitivity and specificity as seen in this study. Therefore, we can recommend seminal plasma TAC measurement as a quick in-office test for the evaluation of patients with male infertility.

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