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Charnley AK (1992). Mechanisms of fungal pathogenesis in insects with particular reference to locusts. In: Lomer CJ, Prior C (eds) *Biological Controls of Locusts and Grasshoppers: Proceedings of an international workshop held at Cotonou, Benin.* Oxford: CAB International, pp 181-190.

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## Review

# Metamaterials for performance enhancement of patch antennas: A review

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**This review paper focused on the use of metamaterials for the performance enhancement of microstrip patch antennas. In this work, the definition of metamaterials used in literature is first reviewed and then we consider various challenging issues for the microstrip patch antennas. The paper hence concludes some thoughts on the future scope of research in the field of metamaterials, discussing the advantages that metamaterial based technologies offer compared to the conventional patch antennas.**

**Key words:** Metamaterials, microstrip patch antennas (MSA).

## INTRODUCTION

The 21st century was the beginning of a new era of materials called metamaterials that had dramatic impact on physics, optics, and engineering communities. Metamaterials also known as left handed materials (LHM) are artificially constructed materials that exhibit negative permittivity and negative permeability in a certain frequency range. In recent years increasing interest has been focused on the use of metamaterials for improving the performance of conventional patch antennas (Engheta and Richard, 2006).

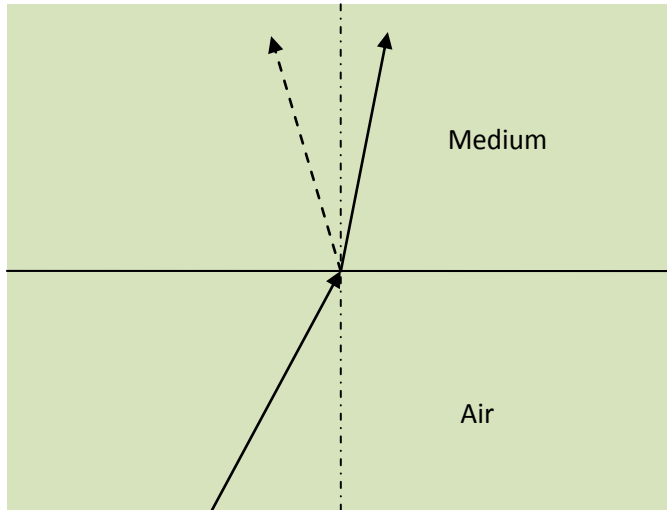
Metamaterials are represented in terms of their medium properties, viz., DNG (Double negative -both  $\epsilon$  &  $\mu$  are negative), DPS (Double positive -both  $\epsilon$  &  $\mu$  are positive), ENG (Epsilon negative) and MNG ( $\mu$  negative). Metamaterials found applications in various fields including sensor detection, remote aerospace applications, public safety, high frequency battle field communication, improving ultrasonic sensors, solar power management and for high gain antennas (Pendry, 2003; Raj, 2007). Veselago speculates that a material whose permittivity and permeability are simultaneously negative, such material if having any measurable degree

of optical transparency, will refract an incident wave on the same side of normal rather than crossing it as shown in Figure 1. If the angle of incidence is still greater than the angle of refraction and assuming that the transmission velocity in the medium is lower than the free space velocity, the object may appear invisible to the observer (Sanderson, 2007). In October 2006, a metamaterial was created by US British team of scientists which rendered an object invisible to microwave radiations (<http://www.dukenews.duke.edu/2006/10/cloakdemo.html>).

## VARIOUS ISSUES IN PATCH ANTENNA DESIGNING

The various challenging issues while designing a patch antenna are – reduction in size, directivity improvement, gain enhancement, bandwidth broadening and backlobe or sidelobe suppression. The key questions thus arise are: (a) How one or more of these performances can be enhanced using metamaterials? And (b) what type of metamaterial should be used to meet these requirements?

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**Figure 1.** Conventional (solid) and metamaterial (dotted) refraction characteristics.

Surface wave propagation is a major problem in patch antennas that reduces antenna gain and efficiency, increases cross polarization, limits the bandwidth, increases end fire radiation, limits the applicable frequency range and hinders the miniaturization of patch antenna. Micromachining technology and photonic band gap structures are two solutions to the surface wave problem.

However, a quick literature survey shows that DNG Materials can be used for directivity enhancement, radiated power enhancement, antenna performance improvement and bandwidth enhancement.

### Directivity enhancement

Veselago first introduced DNG materials and demonstrated that a slab of DNG material would act like a lens and it would, thus focus the energy emanating from an antenna (Smith et al., 2000). Metamaterial has inherent property that controls the direction of electromagnetic radiation, in order to collect the emanating energy in a small angular domain around the normal to the surface (Figure 1) A slab of DNG material would improve the directive properties of an antenna than other diffraction-limited systems, such as a convex lens made with a conventional DPS material (Veselago, 1968; Pendry et al., 1999; Pendry, 2000).

### Radiated power enhancement using DNG

With the application of the conventional techniques, such as photonic band gap materials an increased amount of radiated power couples to the space wave (Stefan et al.,

2002). Surface wave coupling effects are also absent. The power radiated by a small antenna can be increased, through the application of DNG metamaterial (Stefan et al., 2002). When the small dipole antenna is surrounded by DNG metamaterial, an increase in radiated power by more than an order of magnitude over free space antenna is obtained (Steve, 2006). The decrease in the reactance of dipole antenna corresponds to the increase in the radiated power.

### Antenna performance improvement using Split Ring Resonators (SRRs)

It was demonstrated that the monopole-SRR metamaterial antenna operates efficiently at  $\lambda/10$  (antenna size) using SRR-wire configuration. Good coupling efficiency and radiation efficiency are thus obtained. The operation of monopole SRR antenna was found to be comparable to the conventional patch antenna at  $\lambda/2$  (which is recommended as an antenna size for efficient coupling and radiation for patch antenna), (Ziolkowski and Allison, 2003) thus it can be used wherever patch antennas are used.

Monopole-SRR antenna becomes an acceptable small antenna at the resonance frequency of SRR. When compared to the conventional monopole antenna, when SRR configuration is added, the characteristics such as radiation pattern are changed. SRR structure employed in the antenna can be modified to obtain an antenna size of about  $\lambda/40$ . Furthermore, by coupling 2, 3, and 4 SRRs a slight shift in the radiation pattern is observed (Mitra, 2007).

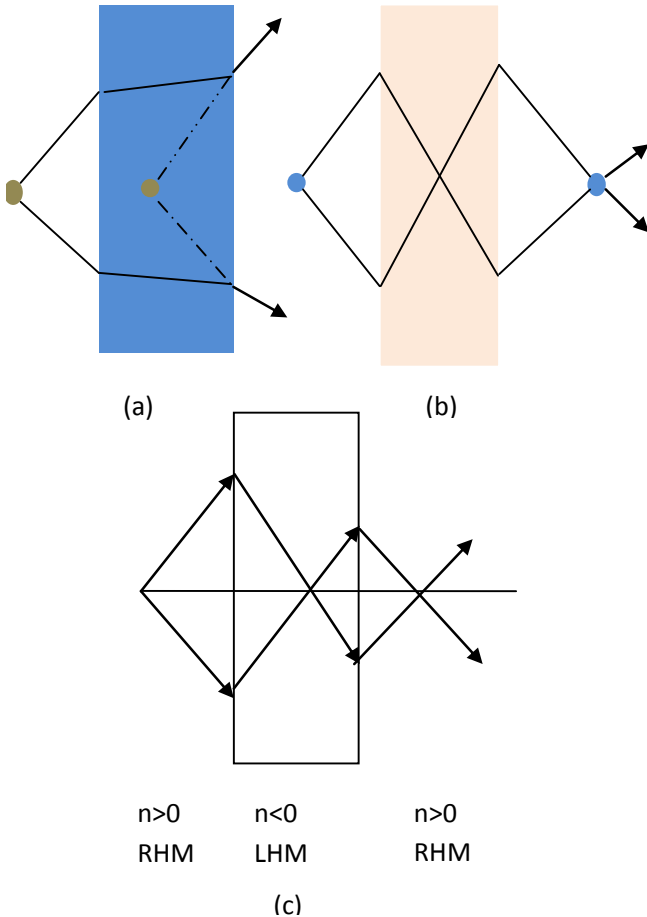
### Bandwidth enhancement

Metamaterials have been shown to enhance specific parameters of low profile and high profile antennas. Metamaterials can be used as covers to increase the bandwidth of printed patch antennas. An example for broadside radiation is metamaterial based planar leaky wave antenna.

Such an LWA antenna consists of a metamaterial layer with positive or small values of permittivity and permeability placed on the ground plane and is suitable for producing a narrow beam of radiations at broadside. The directivity increases significantly as the permittivity (or permeability) of the layer decreases (Kamil and Ekmel, 2007).

### DEVELOPMENT AND APPLICATIONS

W.E. Kock developed the first metamaterial in the late 1940s. Up to 2002, the metamaterial structures were impractical for microwave applications owing to narrow



**Figure 2.** (a) Perfect reconstruction (b) high transverse wave vectors imaginary longitudinal component evanescent fields and (c) perfect lens.

bandwidth and low transmission coefficient (Oliner, 1993; Kock, 1946). The various developments include perfect lens and use of metamaterial slab as a cover or as a substrate.

### Perfect lens

John Pendry first postulated that a negative index material would enable a perfect lens because of the property that a wave propagating in LHM exhibits phase advancement instead of phase delay. The superlens is an optical lens which exceeds the diffraction limit but does not rely on negative refraction. The first superlens demonstrated at microwave frequency provided three times better resolution than the diffraction limit as shown in Figure 2. In 2008, two major developments were reported in superlens research and these are:

1. Alternate layers of silver and magnesium fluorides were deposited on the substrate. The nano grids in the layers provided a 3-D structure with a negative refractive

index in near infrared region.

2. Metamaterial from silver nano wires deposited in porous aluminium oxide was formed. This provided negative refraction below 660 nm (Kock, 1949).

The perfect reconstruction through a metamaterial is shown in Figure 2a. Figure 2b and c shows that for a LHM the waves are refracted in such a way to produce a focus inside the material and another just outside. It leads to the creation of highly directional antennas.

### Metamaterial as cover

The unit cells of metamaterial can be combined into a slab to build up a metamaterial cover. A new patch antenna with a metamaterial cover was proposed in 2005, which resulted in enhanced directivity (Chemical and Engineering News, 2008). According to the results, the directivity of patch antenna with metamaterial cover is significantly improved compared to conventional patch antennas. This was cited in 2007, that using metamaterials, efficient design of directive patch antenna can be produced (Fang et al., 2005).

### Other applications

It has been demonstrated at National Institute of Standards and Technology that thin films of metamaterials can reduce the size of the resonating circuits that generates microwaves (Said et al., 2005). Agile antennas have been designed using metamaterials. It has been postulated that because of the subatomic properties of metamaterials, they could be built to bend matter around them. For example a matter cloak could be used to bend a bullet around a person instead of absorbing it. This approach is similar to bullet proof vests (Fang et al, 2005).

### ON-GOING PROJECTS

#### Miniaturized nano- optical devices

An international group Metal Structure for Plasmonics and Nanophotonics aims at developing a new miniaturized nano- optical device based on Plasmonics structures as well as studying the propagation properties of surface plasmons (Pendry et al., 1998).

#### Metamaterial radome designs

Naval Systems Air Command (Navair) is an international group which is applying the concept of metamaterials to improve the performance of radome antenna designs (Alu and Engheta, 2005).

## Antennas with high operational frequency

U.S. Army Research office is working on development of a tunable antenna, capable of operating at high-frequency (30 to 100 GHz) along with GHz Electromagnetic wave Science and Devices for battlefield communications. California and Colorado Universities also collaborated with this project (Smith, 2005).

## High gain antenna applications

The National Geospatial-Intelligence Agency is performing an experimental study on coupling a radiating element with a lens so as to obtain a high-gain antenna. The negative index lenses have shown to possess a much lower geometrical aberration profile as compared to the positive index lenses (<http://people.ee.duke.edu/~drsmith/collaborators.htm>; Air force office of scientific research (AFOSR)).

## DISCUSSION

Researchers studied the different parameters of microstrip patch antennas such as gain, directivity and bandwidth and the use of metamaterials to improve these antenna parameters. For the improvement of directive gain unit cells of omega structure are combined to form a slab which is used as a cover over conventional patch antenna. The conventional antenna without cover has maximum directivity of 8.271 dBi while the antenna with cover has directivity of 11.5 dBi (Ahmad et al., 2010).

Merih et al. (2009) proposed a broadband microstrip antenna based on metamaterials. The proposed antenna has a maximum gain of -1 dBi at 2.5 GHz and a 63% bandwidth over the band of 1.3 to 2.5 GHz.

Ziolkowski and Erentok (2006) demonstrated that electrically small antenna system can be formed by combining an infinitesimal electrical dipole with ENG spherical shell. Such systems were made to be resonant with a large enhancement of the radiated power in comparison to the antenna alone in free space.

Erentok and Ziolkowski (2008) proposed metamaterial inspired efficient small antennas. The proposed EZ antennas are shown to be naturally matched to a 50 ohm source without matching network. It is demonstrated that EZ antennas have high radiation efficiencies with good impedance matching.

Farad et al. (2005) proposed a compact and low profile metamaterial ring antenna using two unit cells. The antenna offers a 120 MHz -10 dB bandwidth and an efficiency of more than 50%.

All the researchers here premeditated various methods for the improvement of various antenna parameters. Heading in the direction of their aim they achieved the improvement in various antenna parameters using various methodologies.

## FUTURE CHALLENGES

Several challenges must be surpassed before metamaterials make the transitions from theoretical investigation to practical applications in the high frequency regions (visible, IR, THz).

One of the major limitations of metamaterials is their typically narrow band response. The limited bandwidth of metamaterials limits their application in negative-index in the whole visible spectrum.

Moreover, within the next few decades, metamaterial research at microwave and radio frequencies is expected to improve the antenna designing by reducing the antenna size and better performance for satellite antennas and personal mobile devices (Holloway et al., 2008).

## SUMMARY

From this survey, it is clear that metamaterials can be used for improving the performance of conventional patch antennas. In this paper we have taken a brief look at current work and development in the field of metamaterials. We also examined the on-going projects on metamaterial to enhance the performance of antennas. Various future challenges are also considered.

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*Full Length Research Paper*

# Blood glucose level of plasma samples prepared from sodium fluoride and lithium heparin anticoagulants for diabetes mellitus diagnosis

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The aim of this study was to compare blood glucose levels, which were prepared from NaF and lithium heparin anticoagulants for diabetes mellitus (DM) screening test. DM-check up Clinic at Kutchap Hospital, Udonthani province collected the blood samples and filled sodium fluoride (NaF) and lithium heparin tubes (Greiner Bio-One, Austria) from 300 customers. Then, plasma was separated immediately from each blood sample tube by centrifugation and analyzed for blood glucose level by automatic analyzer, Cobas c111 automated chemistry analyzer (Roche Diagnostics GmbH, Mannheim, Germany). Four groups of samples were divided to the all sample group, normal group, prediabetic group and diabetic group according by American Diabetes Association. The result was presented as blood glucose levels of NaF plasma and lithium heparinized plasma in normal and prediabetic groups, which corresponded significantly ( $p < 0.05$ ). This may imply that lithium heparin tube can replace NaF tube and not affect DM diagnosis when immediately analyzing blood glucose levels. In addition, lithium heparin tubes can collect blood samples for other biochemical tests. This may reduce turnaround time, cost, and mistakes from sample overload, and also labour spending on laboratory staff.

**Key words:** Diabetes mellitus, blood glucose, fasting blood sugar, sodium fluoride, lithium heparin.

## INTRODUCTION

Clinical biochemical tests have been performed to diagnose, predict, and monitor disease for patients including annual health checkups for normal people. This investigation should provide beneficial data for the doctor to treat a patient. Sodium fluoride (NaF) is anticoagulant, which is added into blood specimens to inhibit the glycolysis of blood cells (Chan et al., 1989; Young and Bermes, 1999), and then the specimen undergoes centrifugation to separate plasma sample for fasting blood sugar (FBS) test. Recently, lithium heparin (LH) is often used for blood collection in clinical chemistry testing because plasma can be immediately separated from blood cells. Several laboratories used lithium heparin plasma for all routine biochemical testing including

plasma glucose, especially emergency cases (Smith et al., 1987). Moreover, heparin usage trends to decrease spending in laboratory and medical check-up services in Thailand. Recently, lithium heparinized (LH) plasma samples have been used in urgent cases to simultaneously measure glucose and perform routine biochemical analytes in clinical chemistry testing. Shi and co-workers (2009) found that the rapid separation of a plasma sample from blood cells containing lithium heparin is better than using fluoride alone for blood glucose measurements. However, difference in anticoagulant usage for plasma preparation may affect the accuracy of the glucose measurement and lead to misinterpretation for diabetes mellitus diagnosis. For this

**Table 1.** Demographic data of customers who joined in this study (N = 300).

| Parameters           | Number        |
|----------------------|---------------|
| Age (years)          | 60±11 (16-87) |
| Gender               |               |
| - Male               | 80            |
| - Female             | 220           |
| DM                   | 202           |
| Hypertension         | 13            |
| DM with hypertension | 85            |

**Table 2.** Numbers of normal, prediabetic and diabetic customers who were screened for DM (N = 300).

| Sample group | FBG (mg/dL)     | Amount |
|--------------|-----------------|--------|
| Normal       | 70-110          | 48     |
| Prediabetic  | > 110 and < 126 | 62     |
| Diabetic     | > 126 mg/dL     | 190    |

reason, the aim of this study was to compare fasting blood glucose concentration between NaF and lithium heparinized plasma from 300 customers who were admitted at DM-check up Clinic, Kutchap Hospital, Udonthani province.

## MATERIALS AND METHODS

### Subjects

DM-check up Clinic, Kutchap Hospital, Udonthani province collected blood samples and filled sodium fluoride (NaF) and lithium heparin tubes (Greiner Bio-One, Austria) from 300 customers. The health data demographic was based on their medical history and a physical examination. All subjects gave written consent, and the study protocol was approved by the Institutional Review Board for Research Ethic of Kutchap hospital, Udonthani, Thailand.

### Specimen collection and handling

All samples were obtained from venous blood. For each sample, six milliliters of fasting blood samples was collected and then, divided to three milliliters of blood sample was drawn into NaF and the remaining was drawn into lithium heparinized plasma commercial tubes (Greiner Bio-One, 2002; Young and Bermes, 1994).

### Blood glucose analysis

The samples were separated for plasma by centrifugation at 1,542 × g (~3,000 rpm)/5 min (room temperature) and interval time of plasma separation was 2 h for NaF treated tubes and Li heparin treated tubes (Thompat et al., 2011). Each obtained plasma sample

was measured for blood glucose level, using Cobas c111 automated chemistry analyzer (Roche Diagnostics GmbH, Mannheim, Germany) *in vitro* test kits for the qualitative test of human serum and plasma using two levels of control material. Analyses were used and performed following procedures from the manufacturer. The room temperature ranged from 26 to 28°C under the air condition control at Laboratories of Clinical Pathology Unit, Kutchap Hospital, Udonthani, Thailand. The internal quality control for the automatic analyzer was performed using two levels of control materials purchased from manufacturer to calculate standard deviation (SD) and coefficient variance (%CV) of glucose.

### Data analysis

Statistic analysis was performed using the SPSS computer program version 11.0 (SPSS, Chicago, IL). The Kolmogorov-Smirnov test was statistically used for normal distribution test and paired *t*-test statically tested for difference between the blood glucose level of NaF and lithium heparinized plasma after 8 to 12 h fasting among 4 groups: all sample group, normal group (fasting blood glucose = 70 to 110 mg/dL), prediabetic group or impaired glucose tolerance (fasting blood glucose > 110 mg/dL and < 126 mg/dL) and diabetic group (fasting blood glucose >126 mg/dL) according to the American Diabetes Association diagnostic criteria (American Diabetes Association, 2007). In the case of non normal distribution data, we used non parametric test, Wilcoxon signed rank test. The analysis of differences was judged by using  $\alpha < 0.05$  (two-tailed) as the significant statistic.

## RESULTS

The demographic data of healthy volunteers who joined in this study is shown in Table 1. The parameters included age, gender, and clinically diagnosis including diabetes mellitus, hypertension and diabetes mellitus with hypertension. The diagnosis of clinical customers into the normal group (fasting blood glucose = 70 to 110 mg/dL), the prediabetic group or impaired glucose tolerance (fasting blood glucose > 110 mg/dL and < 126 mg/dL) and the diabetic group (fasting blood glucose > 126 mg/dL) was done according to the blood glucose level after 8 to 12 h fasting accorded to American Diabetes Association diagnostic criteria (Table 2). The fasting blood glucose level of NaF and lithium heparinized in the all sample groups and diabetic were not normally distributed, whereas, normal group and prediabetic group was normally distributed after tested by Kolmogorov-Smirnov test (data not shown). Then, we tested statically different between fasting blood glucose level of NaF and lithium heparinized plasma by Wilcoxon signed rank test for the all sample group and diabetic group, and paired *t*-test for normal group and prediabetic group. Blood glucose levels in NaF and lithium heparinized plasma were statically compared for each group, the all sample groups (NaF1/Heparin1), the normal group (NaF2/Heparin2), the prediabetic group (NaF3/Heparin3) and the diabetic group (NaF4/Heparin4). We found that blood glucose levels in NaF and lithium heparinized plasma from normal group (NaF2/Heparin2) and

**Table 3.** The correlation of blood glucose levels in NaF and lithium heparinized plasma from normal group (NaF2/Heparin2) and prediabetic group (NaF3/Heparin3).

| Group         | Paired correlation |              |
|---------------|--------------------|--------------|
|               | Correlation        | Significance |
| NaF2/Heparin2 | 0.984              | 0.001*       |
| NaF3/Heparin3 | 0.946              | 0.001*       |

\* = significance at  $\alpha = 0.05$ .

prediabetic group (NaF3/Heparin3) were significantly correlated (Table 3). However, blood glucose levels in NaF and lithium heparinized plasma from all sample group (NaF1/Heparin1) and diabetic group (NaF4/Heparin4) were significantly different ( $p < 0.0001$ ).

## DISCUSSION

Loss of glucose from sample containers is a serious and underappreciated problem. Decreases in glucose concentrations in whole blood *ex vivo* are due to glycolysis. The rate of glycolysis—reported to average 5 to 7%/h [approximately 0.6 mmol/L (10 mg/dL)] varies with the glucose concentration, temperature, leukocyte count, and other factors. Such decreases in glucose concentration will lead to missed diabetes diagnoses in the large proportion of the population who have glucose concentrations near the cut-points for diagnosis of diabetes.

This study demonstrated that blood glucose levels in NaF and lithium heparinized plasma from normal and prediabetic were corresponded ( $p < 0.05$ ) when prepared by NaF and lithium-heparin anticoagulants. This implies that lithium heparin tube can replace NaF tube and not affect DM diagnosis when immediately analyzed for blood glucose level. Because the physicians and medical technologists need to “cut-off” or separate normal from abnormal, then correlating blood glucose levels in NaF and lithium heparinized plasma and noting normal group is important. This is also important in prediabetic or impaired glucose tolerant persons to intervene with food consumption and life style. In addition, lithium heparinized plasma can be appropriated for other biological analysts more than NaF plasma, which analyses only blood glucose. Use of lithium heparin tube can save cost, reduce turnaround time (TAT) and decrease mistakes labelling multiple blood collection tubes. In case of blood glucose levels in NaF and lithium heparinized plasma from the all sample group and diabetic group were significantly different ( $p < 0.0001$ ). This may have been because the majority of cases had visited to our DM check-up clinic were diabetics. High blood glucose levels in DM prepared from NaF and lithium-heparin can be different by several factors, such

as, high blood glucose affect to linearity of test, lipidemic plasma in some DM persons with high blood lipid complication.

A previous study showed that heparin can preserve sugar level and can be used in other biochemical tests (Landt, 2000). Lithium heparin (LH) plasma would be desirable for point of care tests (POCT) biochemical analysis because the specimen can be centrifuged immediately after collection, and without fibrin strand formation for serum preparation. Biochemical tests using heparinized plasma trends to is increasing in many laboratories and mobile public medical services in Thailand.

Factors may affect laboratory results including blood glucose, such as race, age, gender, diet, use of drugs (prescribed, over the counter and herbal remedies), stress, specimen collection (e.g., time of day, tourniquet time, tube type, and anticoagulants), sample handling (e.g., clotting, centrifugation, and storage) and method validation (Horowitz, 2008). Time and temperature condition for plasma preparation and storage will be concern, because lithium heparin is unable to inhibit glycolysis in the same way that NaF can inhibit and as a result blood glucose level will decrease after long time storage at room temperature. This point should be a concern for future study.

## Conclusion

Blood glucose levels, which were prepared by NaF and lithium heparin anticoagulants were not significantly different within the normal and the prediabetic groups when analyzed by Cobas c111 automated chemistry analyzer. Therefore, the Lithium heparinized tube can replace NaF, if plasma is analyzed immediately, this can save cost, reduce turnaround time (TAT) and decrease mistakes labelling of multiple blood collection tubes.

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