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Scientific Research and Essays

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Full Length Research Paper

Efficacy evaluation of new hemoglobin E screening test in community hospitals

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The objective of the research was to evaluate of the efficacy of new HbE screening test (E-Sure, Mitr Medical, Thailand) compared to the modified 2,6 dichlorophenol indophenols precipitation test (KKU-DCIP) and results were confirmed by capillary electrophoresis. Blood samples were collected from patients who came for physical examinations at Kutchap Hospital and hospitals with inter-laboratory cooperation from October 2013 to February 2014. The samples were screened for those with mean corpuscular volume (MCV) lower than normal (MCV < 80 fl), resulting in 326 samples. After screening and confirming for HbE carriers, 226 cases of HbE carriers were found, including 234 HbE trait and 32 homozygous HbE carriers. When the efficacy of KKU-DCIP screening method was compared to that of the HbE screening test (E-Sure) in community hospitals, it was found that the KKU-DCIP test had sensitivity, specificity, positive predictive, negative predictive and efficiency values of 95.1, 91.6, 98.1, 80.9 and 94.5%, respectively. Whereas, HbE screening test, which had sensitivity, specificity, positive predictive, negative predictive and efficiency values of 99.2, 96.7, 99.2, 96.7 and 98.8%, respectively. The HbE screening test is higher efficacy, as well as being more convenient and easier to interpret, which is suitable for HbE carrier screening in community hospital laboratories.

Key word: Thalassemia, hemoglobin E, screening method, hemoglobin E carrier.

INTRODUCTION

Thalassemia is a genetic abnormality that causes abnormal hemoglobin production by less globin chain protein. The red blood cells are abnormal in size and shape, which prone to destruction. Many abnormal thalassemia gene types are found in Thailand. The convergence of these genes causes abnormality and varying levels of pathological severity, ranging from showing no symptoms at all to the highest severity, which causes fetal death or death at birth (Wasi, 1981; Fucharoen and Winichagoon, 1992). The Public Health

Department announced a national policy to promote the prevention and control of thalassemia and abnormal hemoglobin, considering it a basic right of pregnant women and their husbands to receive screening services and confirmation of whether or not the couple is at risk of having a child with severe thalassemia. Every positive case would receive the service to prenatal diagnose before birth giving. So, each service center must organize the service system according to standard.

HbE, this is structurally abnormal hemoglobin where

the β-globlin chain ($\alpha_2\beta_2^E$) is induced by G-A substitution at codon 26 of the β-globlin gene, causing the amino acids changing the location from glutamate to lysine (Weatherall and Clegg, 2001a; Weatherall and Clegg, 2001b). Generally, heterozygous-type HbE carriers do not have anemia, whereas, their mean corpuscular volume (MCV) value and mean corpuscular hemoglobin (MCH) value are slightly lower (Fucharoen and Winichagoon, 2000). However, if alleles are formed between HbE and β-thalassemia or HbE/β-thalassemia (Vichinsky, 2007; Weatherall and Clegg, 2001b), the patient will have a chronic hemolytic anemia by red blood cell destruction and must receive frequent blood transfusions over lifetime, which may subsequently lead to iron overload. The excess iron may accumulate in various organs, which may cause complications and premature death (Fucharoen et al., 2000). HbE carriers are widely found in Thailand and Southeast Asia (Vichinsky, 2007) and β-thalassemia carriers are also found widely in this region. Thus, the chance of HbE/β-thalassemia may occur very high. The World Health Organization (WHO) estimates that there will be 100,000 HbE/β-thalassemia people in the next twenty years and will also happening in India, Sri Lanka, Malaysia, and South China. This health concerning has also spread to America and Europe as well by resulting from migration and intermarriage with Asian peoples (Vichinsky, 2007; Weatherall and Clegg, 2001a).

HbE/β-thalassemia is classified as thalassemia intermedia, a group of patients with intermediate symptoms including: intermediate pallor with no need frequent blood transfusions, mild jaundice with a possibility they may have gallstones, osteoporosis/low bone mass in the case of iron overload. Some of them can be thalassemia major, which have severe symptoms including: prominent pallor; must receive blood transfusions from childhood, hypersplenism and spleenomegaly (at approximately 6-10 years of age) and need to remove the spleen or spleenoectomy; and iron overload will occur and must be constantly treated with medication. If the patient does not receive appropriate treatment and medication, severe symptoms will occur, such as, characteristic changes of the facial bones and skull, short stature, low body weight, retarded growth, osteoporosis/low bone mass and other complications may occur. Premature death may occur to infections or heart failure (Fucharoen et al., 2000).

HbE screening to prevent the incidence of HbE/β-thalassemia is an important issue to which the government sector should pay attention. Detecting and measuring of HbE can be done through many techniques, such as cellulose acetate electrophoresis (CAE), weak cation-exchange high performance liquid chromatography (HPLC) and capillary zone electrophoresis (CZE) (Clarke and Higgins, 2000; Winichagoon et al., 2008). These techniques are capable of efficiently detecting and measuring HbE; however,

these techniques are not capable of mass population screening. For example, cellulose acetate electrophoresis (CAE) has limitations due to it requiring many steps, from electrophoresis on cellulose acetate sheets, to dying and measuring the intensity of color. Furthermore, this test can only be conducted on 16 samples at a time. The HPLC and CZE methods are more suitable, such as a high throughput, and the HPLC method can present the ratio of hemoglobin A2 and F, which are clearly seen, produce accurate measurement and require a short running time. β-thalassemia carriers have hemoglobin A_2 quantity between 4.0 to 10%. HbE carriers have the EA hemoglobin characteristic and HbE quantity between 25 to 35%. HbE/β-thalassemia has the EF characteristic of hemoglobin, and HbE quantity is between 40 to 60%. Homozygous HbE has the EE hemoglobin characteristic and HbE quantity between 85 to 100%. These techniques require an automatic analyzer, which is expensive. For routine work, the HbE screening method that is easiest performed is the 2,6 dichlorophenol indophenols (DCIP) precipitation test, the basis of which is that the DCIP color will cause unstable hemoglobin, such as hemoglobin E and hemoglobin H to precipitate, which can be accomplished for a mass population. If this method is used together with the 0.36% NaCl osmotic fragility test, the results of the hemoglobin E screening will be easier to interpret, especially in the densely populated or rural areas (Winichagoon et al., 2002; Wiwanitkit et al., 2002). Nevertheless, the DCIP test has issues with reading the results, namely that the dark blue color may make it difficult to read the precipitation and may requiring decolorization (Fucharoen et al., 2004). Furthermore, observing the precipitation may require usage of a light box and solid line written to read the results (Chapple et al., 2006). DCIP testing also requires appropriate temperature and accurate incubation time to avoid false positive results. Additionally, the DCIP color is an oxidizing agent which may deteriorate if stored for a long time (Hughes, 1983; VanderJagt et al., 1986). However, the reading of the results of this method can be improved by a clearing reagent called modified DCIP test (KKU-DCIP), which is widely used at the present (Koranantakul et al., 1998).

The new HbE screening test or E-Sure test (Mitr Medical, Thailand) is based on ion exchange chromatography. After washing by other buffer systems at a different pH it is passed through the column, only hemoglobin E will elute from the column, and is seen as red or pinkish solution in the test tube. This method is quick, specific, highly accurate and simple to perform and does not require any highly skilled technician. It can be used in the rural areas or in a community laboratory with limited resources (Tatu and Kasinrerk, 2012; Sanguansermsri et al., 1998). For the abovementioned reasons, the researcher was interested in the evaluation of the efficacy of the new HbE screening test (E-Sure) compared to the modified DCIP test (KKU-DCIP), which
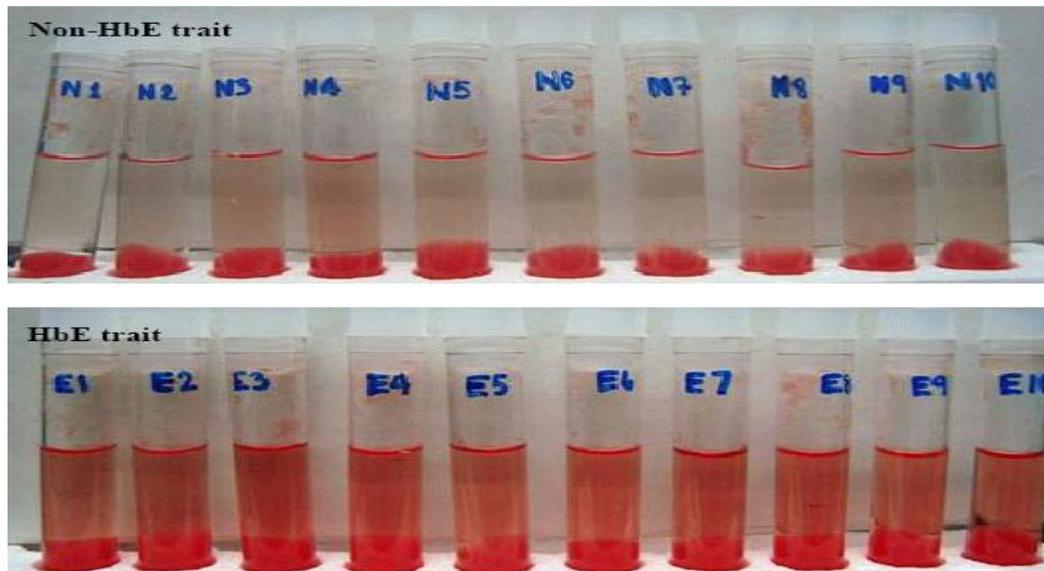
Figure 1. Presenting the results of hemoglobin E carrier testing. The uncolored solution in the top row read as negative results, which interpreted as Non-HbE trait (top row). The reddish-pink colored solution in the bottom row read as positive results and interpreted as HbE trait (Tatu and Kasinrerk, 2012).

is at present the conventional method in community hospitals. The results are confirmed by capillary electrophoresis, which can confirm β-thalassemia carriers as well. The results of this study may be used as a guideline in selecting screening methods for HbE carriers to prevent HbE/β-thalassemia risk at the community level.

MATERIALS AND METHODS

Sample collection and selection for HbE screening test

Ethylenediaminetetraacetic acid (EDTA) blood samples were collected from patients who came for check-ups at Kutchap Hospital and other hospitals with inter laboratory cooperation namely Nong Wuasaw hospital, Nong Saeng hospital and Pen hospital in Udon Thani Province, Thailand. This took place during the normal services of the hospital from October 2013 to February 2014. The research program had to pass the approval of the hospital directors and the Board of Human Research Ethics Committees of the hospital and all subjects gave written consent. The subjects were record the name, surname, AN, HN, ward, time and date of sample collection and clearly label the specimen tubes, as well as correctly giving the details of the specimen for testing in the request form. Before screening for HbE, a complete blood count (CBC) was required as a routine laboratory test. The automatic analyzer was Celltac E MEK-7222 (Nihon Kohden, Japan), and the criterion of sample selection for HbE screening was lower corpuscular volume (MCV< 80 fl).

Evaluation of HbE screening tests and HbE confirmation

The conventional HbE screening was performed by using the modified 2,6 dichlorophenol indophenols (DCIP) precipitation test (KKU-DCIP) method, which was based on that the DCIP will cause

unstable hemoglobin to precipitate. This was conducted by adding 2-3 ml blood to test tubes, which were contained the anti-coagulant, EDTA and centrifuged at 100 g for 10 min. The plasma was removed and 20 μl of red blood cells was added to the test tube containing 5 ml of DCIP reagent (KKU-DCIP Clear Reagent Kit). The blood and reagent were mixed by gently turning the test tubes and then warmed to 37°C for 1 h. The results were then accurately read. Positive result was turbid solution and clear solution was negative result.

The new HbE screening test or E-Sure test is based on ion exchange chromatography according by characteristics, charge, and structure of each type of hemoglobin, which has different anions and cations. When the hemoglobin is placed in a particular buffer solution, the hemoglobin becomes electrically charged and then hemoglobin solution is passed through the column (diethyl aminoethyl [DEAE]) each hemoglobin molecules will be captured by the column. After washing by another buffer system at different a pH, it is passed through the column, only hemoglobin E will elute from the column, and is seen as red solution in the test tube. Color intensity is dependent on the quantity of Hb E. It is notable that homozygous HbE (EE) gives a dark red color to the solution and heterozygous HbE (EA) gives a pinkish red color (Figure 1). The procedures of E-Sure were done by 1) open micro-column cap and then, put the micro-column in 13 × 100 mm test tube 2) pipette 2 ml of buffer A to micro-column 3) pipette 20 μl of whole blood to buffer A in micro-column 4) adding the stick of test kit to micro-column, press the stick to elute buffer A into test tube until it will be finished and throw away buffer A from test tube) 5) pipette 4 ml of buffer B to micro-column 6) adding the stick of test kit and press the stick to elute buffer B into test tube and 7) read and interpret to results as describe on above.

Hemoglobin typing was used to distinguish normal, thalassemia and other types of hemoglobin abnormalities especially between β-thalassemia, heterozygous HbE (EA) and homozygous HbE (EE) and also to diagnose patients and carriers. The capillary electrophoresis was performed by an automatic analyzer, Capillarys II hemoglobin (Sebia electrophoresis, USA), which gave a high electrical charge to capillary tubes inside of the vessel. Both ends
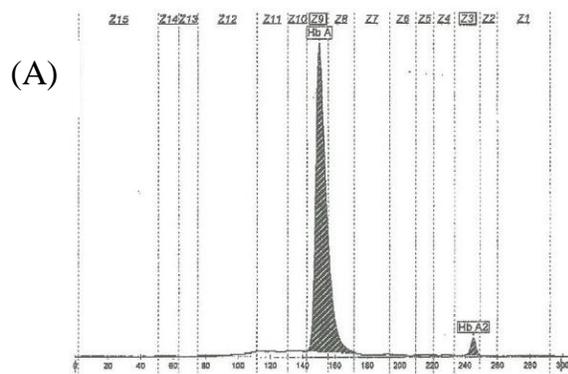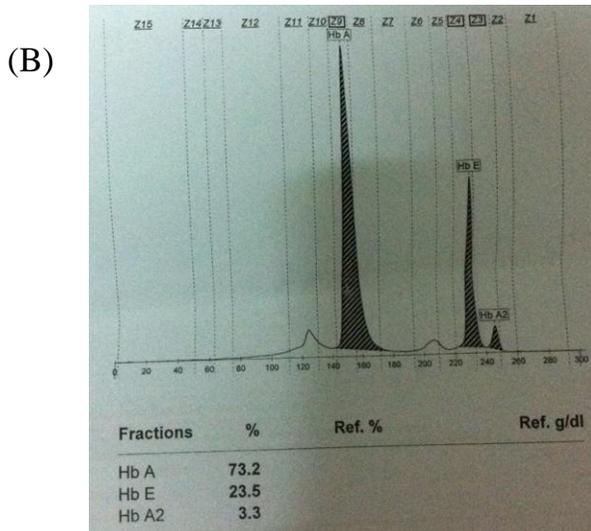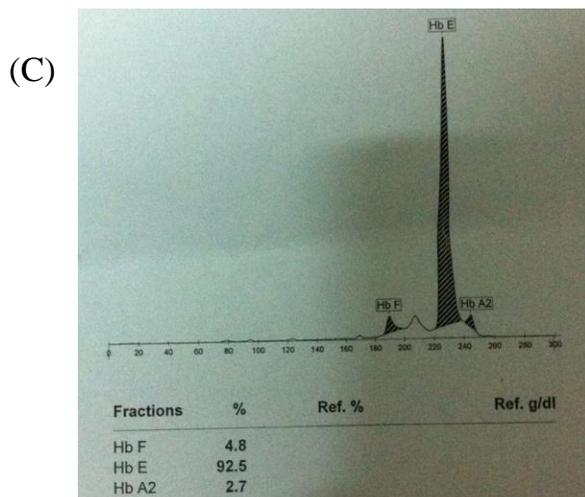
Figure 2. Electropherogram of hemoglobin typing by capillary electrophoresis. The results read as follows: A) A$_2$A; B) EA; C) EE, which were interpreted as normal, Heterozygous HbE and Homozygous HbE, respectively.

were immersed in electrolyte solution and caused the ions inside the sample to run from the positive to negative pole according to the strength of the electroosmotic flow (EOF). The zones of the separated solution after the electrical charge will pass the detection window and the changing of the signal from the detector (deuterium lamp) is sent to the data processor. This result is called an electropherogram. A report using a normal person's values as a reference is: Hb A = 79.4-93.4, Hb A$_2$ < 4.0, Hb F = 0.0-1.2. When each sample has been confirmed by hemoglobin typing, the new HbE screening (E-Sure) test is evaluated for sensitivity, specificity, positive predictive value, negative predictive value and efficiency (accuracy) of the analysis compared to modified DCIP (KKU-DCIP) method. The calculation of sensitivity, specificity, positive predictive value, negative predictive value and efficiency of tests were done by following formulae (TP = number of true positive; TN = number of true negative; FP = number of false positive and FN = number of false negative):

%Sensitivity = [TP/ TP+FN] x 100
%Specificity = [TN/ TN+FP] x 100
%PPV = [TP/ TP+FP] x 100
%NPV = [TP/ TP+FP] x 100
%Efficiency = [TP+TN/ TP+FP+TN+FN] x 100

RESULTS

326 HbE carriers (MCV < 80 fl) were screened by the modified 2,6 dichlorophenol indophenols precipitation test (KKU-DCIP) and HbE screening test (E-Sure) test and confirmed with Hb typing by capillary electrophoresis to find false positives and false negatives from both screening methods. The hemoglobin electropherograms were presented as the A$_2$A, EA and EE and interpreted to normal, heterozygous HbE and homozygous HbE, respectively (Figure 2). After screening and confirming for HbE carriers, 226 cases of HbE carriers were found, including 234 HbE trait and 32 homozygous HbE carriers (Table 1). When the efficacy of the KKU-DCIP screening method was compared to that of the HbE screening test (E-Sure) in community hospitals, it was found that the KKU-DCIP test had sensitivity, specificity, positive predictive, negative predictive and efficiency values of 95.1, 91.6, 98.1, 80.9 and 94.5%, respectively. Whereas, HbE screening test, which had sensitivity, specificity, positive predictive, negative predictive and efficiency values of 99.2, 96.7, 99.2, 96.7 and 98.8%, respectively (Table 2).

DISCUSSION

For the EDTA blood samples with low MCV (< 80 fl) values were presented anemic condition. MCV is one of the regular blood indices from CBC when applied together with screening test. There can increase the sensitivity of screening test to diagnose hemoglobin E carriers (Yeo et al., 1994; Nadarajan et al., 2010; Sharma et al., 2013) and other thalassemia (Alkindi et al., 2011; Italia et al., 2014), such as, alpha-thalassemia carriers (Pornprasert et al., 2013). However, the many studies of

Table 1. The numbers of normal and HbE carriers after confirmation (N = 326).

Hb typing	Interpretation	Number of cases
A_2A	Normal or Non clinical significant	60
EA	Heterozygous HbE	234
EE	Homozygous Hb E	32

Table 2. Two-by-two table showing diagnostic indices of KKU-DCIP and E-Sure screening tests to identify the hemoglobin E trait among low MCV samples (N = 326).

Test	Test result	Hb trait status		Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
		Normal	HbE trait					
KKU-DCIP	Negative	55	13	95.1	91.6	98.1	80.9	94.5
	Positive	5	253					
E-Sure	Negative	58	2	99.2	96.7	99.2	96.7	98.8
	Positive	2	264					

screening test for efficacy did not use the MCV value as the "cut off" before comparing between each screening methods. MCV can be used generally to screen thalassemia, which has long been widely practiced in eastern countries (Cao et al., 2002). At present, many hospitals use automatic red blood cell analyzer to test CBC, which also gives MCV and Mean Corpuscular Hemoglobin (MCH) values as it is convenient for laboratory work. Furthermore, red cell distribution width value, RDW of blood indices can screen thalassemia carriers and hemoglobin E carriers as well (Sharma et al., 2013). Nevertheless, using MCV and MCH values to screen thalassemia carriers or thalassemia were limited as far as results interpretation and distinguishing them from other conditions that were lower MCV and MCH, e.g., iron deficiency anemia and chronic blood loss. Thalassemia screening by MCV values lower than 80 fl and/or MCH 27 pg were lower in sensitivity and specificity than screening by the one tube osmotic fragility test, OF and DCIP, because the Thai population has a number of HbE carriers with values MCV $\geq$ 80 fl and MCH $\geq$ 27 pg (Sanchaisuriya et al., 2005). In this study, 60 samples were interpreted to normal, but had low MCV values and interpreted to be a non- hemoglobin E trait but possibly a heterozygous alpha thalassemia-1 trait with hemoglobin typing as A_2A (normal). It was necessary to run further confirmatory tests by multiplex polymerase chain reaction (PCR) (Chang et al., 1991; Tongsong et al., 2000; Panyasai et al., 2002; Tungwiwat et al., 2006). Furthermore, other anemic conditions, such as chronic blood loss and iron deficiency anemia can also give low MCV results.

Wanapirak et al. (2009) compared the efficacy of the CMU-E method (Chiang Mai University-HbE, Thailand) and KKU-DCIP. The CMU-E method uses microcolumn chromatography, which is similar to E-Sure. The study

results showed that CMU-E method produced less false positives because the results were easier to read and interpret than KKU-DCIP method, which must read positive results from murky solution, even though clearing reagent is used. Sometimes, false positive may be produced arising from the time to warm the solution and blood at 37°C, which is too long, and may also give positive results for other unstable Hb, such as, HbH disease.

HbE screening by the E-Sure test was newly developed by Tatu and Kasinrerk (2012) as a method with high sensitivity and specificity; however, this method has never been tested in community hospitals. This study used blood indices of MCV (< 80 fl) before using hemoglobin E E-Sure screening test kits, compared to the widely used method, KKU-DCIP. Community hospitals with limited highly skilled laboratory technician can also use the latter method; however, the reading and interpreting of results by E-Sure tests is easier and gives less false positives. The sensitivity, specificity, positive predictive, negative predictive and efficiency values are all higher than that of the KKU-DCIP method. However, results from hemoglobin E screening by the E-Sure method still presented 2 false positives and 2 false negatives. This may have occurred from reusing columns too many times, or from the reading and interpretation of the technician performing the test.

The capital cost for E-Sure screening is lower (0.78-0.94 USD/test) than the KKU-DCIP method (1.56-1.88 USD/test). If the E-Sure method would be used in place of the KKU-DCIP method, the capital costs for hospital labs would be reduced, especially community hospitals with limited budgets. Furthermore, hospitals with Quality Assurance (QA) policies, such as Hospital Accreditation (HA), ISO 15189 and Laboratory Accreditation (LA), among others, using the E-Sure method in place of the

KKU-DCIP method could report results faster. The E-Sure test is takes 5 to 10 min turnaround time; whereas, the KKU-DCIP method takes an approximately 30 min turnaround time. This could increase the quality of health services. The government sector and relevant agencies support SMEs that conduct business involving biomedical material and health science appliances to develop the biomedical material and industry. E-Sure tests were developed under the support of the National Innovation Agency (NIA), Thailand. The researcher perceives that there are benefits of this study to provide information to support the quality of products currently on the market, and also support Thai innovations.

Conclusion

The new HbE screening test, E-Sure test is a screening test with higher efficacy, as well as being more convenient and easier to interpret than the KKU-DCIP test. Furthermore, no additional special appliances are needed to conduct the test. This method is suitable for hemoglobin E carrier screening in community hospital laboratories.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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REFERENCES

Alkindi S, Pathare A, Al-Madhani A, Al-Zadjali S, Al-Haddabi H, Al-Abri Q, Gravell D, Mathew M, Krishnamoorthy R (2011). Neonatal Screening: Mean haemoglobin and red cell indices in cord blood from Omani neonates. Sultan Qaboos Univ. Med. J. 11(4):462-469. PMid:22087394 PMCid:PMC3206748

Cao A, Rosatelli MC, Monni G, Galanella R (2002). Screening for thalassemia: a model of success. Obstet. Gynecol. Clin. North Am. 29(2):305-328. http://dx.doi.org/10.1016/S0889-8545(01)00006-7

Chang JG, Lee LS, Lin CP, Chen PH, Chen CP (1991). Rapid diagnosis of alpha-thalassemia-1 of southeast Asia type and hydrops fetalis by polymerase chain reaction. Blood 78(3):853-854.PMid:1859898

Chapple L, Harris A, Phelan L, Bain BJ (2006). Reassessment of a simple chemical method using DCIP for screening for haemoglobin E. J. Clin. Pathol. 59(1):74-76. http://dx.doi.org/10.1136/jcp.2005.027961; PMid:16394284 PMCid:PMC1860247

Clarke GM, Higgins TN (2000). Laboratory investigation of hemoglobinopathies and thalassemias: Review and update. Clin. Chem. 46(8):1284-1290. PMid:10926923

Fucharoen G, Sanchaisuriya K, Sae-ung N, Dangwibul S, Fucharoen S (2004). A simplified screening strategy for thalassaemia and haemoglobin E in rural communities in South-east Asia. Bull. World Health Organ. 82(5):364-372. PMid:15298227 PMCid:PMC2622836

Fucharoen S, Ketvichit P, Pootrakul P, Siritanaratkul N, Piankijagum A, Wasi P (2000). Clinical manifestation of beta-thalassemia/hemoglobin E disease. J. Pediatr. Hematol. Oncol. 22(6):552-557. http://dx.doi.org/10.1097/00043426-200011000-00022;PMid:11132229

Fucharoen S, Winichagoon P (1992). Thalassemia in Southeast Asia: problem and strategy for prevention and control. Southeast Asian J. Trop. Med. Public Health. 23(4):647-655. PMid:1298071

Fucharoen S, Winichagoon P (2000). Clinical and hematologic aspects of hemoglobin E beta-thalassemia. Curr. Opin. Hematol. 7(2):106-112. http://dx.doi.org/10.1097/00062752-200003000-00006; PMid:10698297

Hughes DE (1983). Titrimetric determination of ascorbic acid with 2,6-dichlorophenol indophenols in commercial liquid diets. J. Pharm. Sci. 72(2):126-129. http://dx.doi.org/10.1002/jps.2600720208; PMid:6834248

Italia K, Upadhye D, Dabke P, Kangane H, Colaco S, Sawant P, Nadkarni A, Gorakshakar A, Jain D, Italia Y, Ghosh K, Colah R (2014). Clinical and hematological presentation among Indian patients with common hemoglobin variants. Clin. Chim. Acta. 431:46-51. http://dx.doi.org/10.1016/j.cca.2014.01.028; PMid:24508621

Kor-anantakul O, Suwanrath CT, Leetanaporn R, Suntharasaj T, Liabsuetrakul T, Rattanaprueksachart R (1998). Prenatal diagnosis of thalassemia in Songklanagarind Hospital in southern Thailand. Southeast Asian J. Trop. Med. Public Health 29(4):795-800. PMid:10772567

Nadarajan VS, Sthaneshwar P, Jayaranee S (2010). RBC-Y/MCV as a discriminant function for differentiating carriers of thalassaemia and HbE from iron deficiency. Int. J. Lab. Hematol. 32(2):215-221. http://dx.doi.org/10.1111/j.1751-553X.2009.01174.x; PMid:19566741

Panyasai S, Sringam P, Fucharoen G, Sanchaisuriya K, Fucharoen S (2002). A simplified screening for alphathalassemia1 (SEA type) using a combination of a modified osmotic fragility test and a direct PCR on whole blood cell lysates. Acta Haematol. 108(2):74-78. http://dx.doi.org/10.1159/000064746; PMid:12187024

Pornprasert S, Punyamung M, Treesuwan K (2013). Criteria for detection of alpha-thalassemia-1 Thai type deletion in routine laboratory. Clin. Lab. 59(11-12):1423-1427. PMid:24409681

Sanchaisuriya K, Fucharoen S, Fucharoen G, Ratanasiri T, Sanchaisuriya P, Changtrakul Y, Ukosanakarn U, Ussawaphark W, Schelp FP (2005). A reliable screening protocol for thalassemia and hemoglobinopathies in pregnancy: An alternative approach to electronic blood cell counting. Am. J. Clin. Pathol. 123(1):113-118. http://dx.doi.org/10.1309/FUF9EVGQ24V1PKTP; PMid:15762286

Sanguansermsri T, Sankapreecha C, Steger HF (1998). Hb E screening test. Thai J. Hematol Transfus. 8(2):215-21.

Sharma A, Marwah S, Buxi G, Yadav R (2013). Hemoglobin e syndromes: emerging diagnostic challenge in north India. Indian J. Hematol. Blood Transfus. 29(1):21-25. http://dx.doi.org/10.1007/s12288-011-0140-9; PMCid:PMC3572259

Tatu T, Kasinrerk W (2012). A novel test tube method of screening for hemoglobin E. Int. J. Lab. Hematol. 34(1):59-64. http://dx.doi.org/10.1111/j.1751-553X.2011.01357.x; PMid:21883965

Tongsong T, Wanapirak C, Sirivatanapa P, Sanguansermsri T, Sirichotiyakul S, Piyamongkol W, Chanprapaph P (2000). Prenatal control of severe thalassaemia: Chiang Mai strategy. Prenat. Diagn. 20(3):229-234. http://dx.doi.org/10.1002/(SICI)1097-0223(200003)20:3<229::AID-PD790>3.0.CO;2-3

Tungwiwat W, Fucharoen S, Fucharoen G, Ratanasiri T, Sanchaisuriya K (2006). Development and application of a real-time quantitative PCR for prenatal detection of fetal alpha(0)-thalassemia from maternal plasma. Ann. N. Y. Acad. Sci. 1075:103-107. http://dx.doi.org/10.1196/annals.1368.013; PMid:17108198

VanderJagt DJ, Garry PJ, Hunt WC (1986). Ascorbate in plasma as measured by liquid chromatography and by

dichlorophenolindophenol colorimetry. Clin. Chem. 32(6):1004-1006. PMid:3708799

Vichinsky E (2007). Hemoglobin E syndromes. Hematology Am. Soc. Hematol. Educ. Program. 79:79-83. http://dx.doi.org/10.1182/asheducation-2007.1.79; PMid:18024613

Wanapirak C, Sirichotiyakul S, Luewan S, Srisupundit K, Tongsong T (2009). Comparison of the accuracy of dichlorophenolindophenol (DCIP), modified DCIP, and hemoglobin E tests to screen for the HbE trait in pregnant women. Int. J. Gynaecol. Obstet. 107(1):59-60. http://dx.doi.org/10.1016/j.ijgo.2009.04.020; PMid:19477441

Wasi P (1981). Haemoglobinopathies including thalassemia. Clin. Haematol. 10(3):707-729. PMid:7030550

Weatherall DJ, Clegg JB (2001a). Inherited haemoglobin disorders, an increasing global health problem. Bull. World Health Organ. 79(8):704-712. PMid:11545326 PMCid:PMC2566499

Weatherall DJ, Clegg JB (2001b). The Thalassaemia Syndromes, 4th edn. Blackwell Scientific, Oxford. http://dx.doi.org/10.1002/9780470696705

Winichagoon P, Svasti S, Munkongdee T, Chaiya W, Boonmongkol P, Chantrakul N, Fucharoen S (2008). Rapid diagnosis of thalassemias and other hemoglobinopathies by capillary electrophoresis system. Translational Res. 152:178-84. http://dx.doi.org/10.1016/j.trsl.2008.08.004; PMid:18940720

Winichagoon P, Thitivichianlert A, Lebnak T, Piankijagum A, Fucharoen S (2002). Screening for the carriers of thalassemias and abnormal hemoglobins at the community level. Southeast Asian J. Trop. Med. Public Health. 33(Suppl. 2):145-150. PMid:12755285

Wiwanitkit V, Suwansaksri J, Paritpokee N (2002). Combined one-tube osmotic fragility (OF) test and dichlorophenol-indolphenol (DCIP) test screening for hemoglobin disorders,an experience in 213 Thai pregnant women. Clin. Lab. 48(9-10):525-528. PMid:12389713

Yeo GS, Tan KH, Liu TC (1994). Screening for beta thalassaemia and HbE traits with the mean red cell volume in pregnant women. Ann. Acad. Med. Singapore 23(3):363-366. PMid:7944251

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Prevalence and clinical characteristics of irritable bowel syndrome (IBS) in police officers in Istanbul

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This study was undertaken to determine the prevalence and clinical characteristics of irritable bowel syndrome (IBS) in police officers. The retrospective study was carried out by applying a questionnaire including Rome II criteria in a study population of 1750 police officers who were selected by systematic sampling method among those admitted to Istanbul Police Hospital between 2000 and 2008. We determined IBS prevalence and their clinical characteristics. The IBS prevalence of police officers was 38%. Among the 1750 patients participating in the study, 722 were admitted with gastrointestinal symptoms (GIS). 54.1% of IBS patients were constipation-dominant, 3% of them were diarrhea-dominant and 42.9% of them had alternating bowel habits. We found the prevalence of IBS to be related with previous infections, abdominal operations, chronic laxative use, absence of reguler diet, lack of fiber foods in nutrition and daily tea or coffee consumption. A negative statistical relationship between IBS prevalence and smoking or alcohol intake was found. No association was found between the prevalence of IBS and psychological events. Distribution of IBS patients among age groups was not different. There were both similar and different results about prevalence and clinical characteristics of IBS in police officers from the other studies. IBS prevalence (38%) in our study was higher than usually estimated. It was around 6.2 to 19.1% in previous studies. The prevalence of IBS with alternating constipation and diarrhea was significantly higher too. The factors having a positive correlation with IBS were similiar to the results of other studies. More studies should be carried out to explain the reasons of the differences.

Key words: Irritable bowel syndrome (IBS), prevalence, police.

INTRODUCTION

Irritable bowel syndrome (IBS) is a functional gastrointestinal disorder characterized by symptoms of abdominal pain, discomfort or bloating associated with changes in bowel habit without any organic symptom (Thompson et al., 1999; Talley and Spiller, 2002). The most common diagnosis of functional gastrointestinal disorders include functional dyspepsia and irritable bowel disease successively (Unalan, 2010).

In the absence of biological disease marker, diagnosis of IBS have been made by using symptom based criteria like Manning, Roma I, Roma II or Rome III (Manning et al., 1978; Longstreyh et al., 2006). The prevalence of IBS

Table 1. Distribution of IBS patients according to age groups.

Age group (years)	IBS [+] {n (%)}	IBS [-] {n (%)}	Total (n)
20 - 29	302 (39)	469 (61)	771
30 - 39	167 (37)	283 (63)	450
40 - 49	196 (37)	333 (63)	529
Total	665 (38)	1085 (62)	1750

in population based studies was around 10% in most studies (Talley et al., 1991; Sandler, 1990; Ballou and Keefer, 2013). IBS prevalence was found to vary between 6.2 and 19.1% in studies from Turkey (Celebi et al., 2004; Karaman et al., 2003; Akpinar et al., 1999; Yilmaz et al., 2005). The prevalence of IBS varies with age and can be seen in all age groups (Talley et al., 1995). It was found to be around 14% between 15 to 44 years in previous studies and goes down to 9% over 45 years (Drossman et al., 1993). Although it was found to be significantly more common, sometimes to be 2 or 3 times higher in females than males, an equal prevalence of men and women was reported in some studies (Talley et al., 1995; Drossman et al., 1993).

Identification of the physiological basis for symptoms of IBS is known but pathophysiologic mechanism is not understood. It is unlikely that a single unifying factor will explain it. Many factors such as gut dysmotility, visceral hypersensitivity, mucosal inflamation, alteration in fecal microflora, psychosocial factors such as stressful life and anxiety disorders affect the clinical course (Simren et al., 2000; Bouin et al., 2002; Törnblom et al., 2002; Kassinen et al., 2007; Nicholl et al., 2008; Drossman et al., 2002). Some recent reports have found an interesting correlation between obesity and IBS (Delgado-Aros et al., 2004). There is an association between the daily stress factors of police work with obesity and metabolic syndrome. The 'Buffalo Cardio-Metabolic Occupational Police Stress (BCOPS) study revealed that compared with 32% of the general population, 40% of police officers were obese and that over 25% suffered from metabolic syndrome compared with 18.7% of the general population (Hartley et al., 2011). The study was initiated because of the assumption that the daily stress factors that police officers endure during their work, such as danger, high demands and exposure to human misery and death, are contributing factors to a higher risk of chronic health outcomes.

In this study, we aimed to determine the prevalence and clinical characteristics of IBS on police officers.

MATERIALS AND METHODS

1750 police officers selected by systematic sampling method among those admitted to Istanbul Police Hospital (Uskudar State Hospital, the new name) between 2000 and 2008 were enrolled in the study. These patients were evaluated by experts in gastroenterology and internal medicine. Due to lack of reliable biological markers for the diagnosis of IBS, symptom-based criteria were used. IBS was diagnosed with the exclusion of other diseases with similar clinical picture. After listening to the story of the patients and physical examination, complete blood count, erythrocyte sedimentation rate, biochemical tests, sigmoidoscopy and especially in elderly patients, colonoscopy were performed. In patients with the alarm signs such as weight loss, advanced age of onset, night waking symptoms, family history (cancer, inflammatory bowel disease) further research was done. Patients with an abdominal mass, hepatomegaly, fever, arthritis, dermatitis, signs of malabsorption found on physical examination; abnormalities on initial laboratory tests including anemia, thyroid dysfunction, increased sedimentation rate, leukocytosis, presence of occult blood in stool or other abnormal biochemical findings were evaluated further. Rome II criteria were used for the diagnosis of IBS.

Laxative use, history of previous infection, previous abdominal surgery, physiological stress, diet, eating habits and lack of fibrous foods, daily consumption of tea and coffee, smoking, regular alcohol intake in persons diagnosed with IBS were investigated retrospectively. Deficiencies have been completed by telephone or face-to-face interviews.

SPSS 11 statistical program for Windows was used for statistical analysis. Chi-square test and Fisher exact Chi-square test was performed to compare qualitative data in IBS patients and in control groups without IBS. Level of statistical significance of the data were interpreted by "p" value. P < 0.05 values were statistically different.

RESULTS

The study involved 1750 patients, 665 patients (38%) were diagnosed with IBS. 722 of patients participating in the study had gastrointestinal complaints, 1028 patients had non-gastrointestinal symptoms (GIS). Almost all of the patients due to the nature of the occupation were male. There were very few women. Distribution of IBS patients according to age group is shown in Table 1.

IBS prevalence according to age did not show any significant difference (p > 0.05). 54.1% of patients were constipation dominant, 3% of them were diarrhea dominant, 42.9% of them were IBS with alternating constipation and diarrhea.

Characteristics of the patients with and without IBS are shown in Table 2. Laxative usage was sinificantly high in IBS group (P < 0.0001). We found a significant difference between IBS and previous abdominal operation too (p < 0.05). IBS had a positive correlation with previous infection history (p < 0.05). The statistical relationship between the stress and the prevalence of IBS was not

Table 2. Characteristics of the patients with and without IBS.

Patients characteristics		IBS [-] (%)	IBS [+] (%)	P
Laxative use	(+)	24 (1)	122 (7)	P < 0.0001
	(-)	1061 (61)	543 (31)	
Previous infection	(+)	124 (7)	102 (6)	P < 0.05
	(-)	961 (55)	563 (32)	
Previous psychological stres	(+)	846 (48)	540 (31)	P > 0.05
	(-)	239 (14)	125 (7)	
previous abdominal operation	(+)	72 (4)	68 (4)	P < 0.05
	(-)	1013 (58)	597 (34)	
Reguler diet (three meals per day)	(+)	884 (51)	328 (19)	P < 0.0001
	(-)	201 (11)	337 (19)	
Fiber consumption	(+)	826(47)	316 (18)	P < 0.0001
	(-)	259 (15)	349 (20)	

Table 3. The relationship between IBS and smoking-drinking materials.

IBS prevalence		IBS [-] (%)	IBS [+] (%)	P
Daily tea consumption	1 - 2 cups/day	622 (36)	201 (11)	P < 0.0001
	3+	463 (26)	464 (27)	
Daily coffee consumption	1 - 2 cups/day	1054 (60)	486 (28)	P < 0.0001
	3+	31 (2)	179 (10)	
Reguler alcohol intake	(+)	103 (6)	22 (1)	P < 0.0001
	(-)	982 (56)	643 (37)	
Smoking	(+)	819 (47)	421 (24)	P < 0.0001

significant (p > 0.05). IBS was observed to be significantly increased in persons not eating three regular meals per day, and in subjects without fiber in their diet (p < 0.0001).

The relationship between IBS and smoking-drinking materials are given in Table 3. IBS prevalence increased as the daily consumption of tea and coffee increased (p < 0.0001). We found a negative correlation between IBS and smoking (p < 0.0001). There was a negative correlation between IBS and alcohol intake too (p < 0.0001).

DISCUSSION

The diagnosis of IBS ranks 7th among all medical diagnoses (Everhart and Renault, 1991; Russo et al.,

1999). The disease that gastroenterologists diagnosed most frequently was IBS. The IBS prevalence of the police officers admitted to the hospital was found to be 38% and was higher than most of the other studies. IBS prevalence may vary between 2.9 to 17% in different studies (Sandler, 1990; Talley et al., 1991; Full-Young et al., 2010). Its prevalence in Turkish society ranges from 6.2 to 19.1% (Celebi et al., 2004; Karaman et al., 2003; Akpinar et al., 1999; Yilmaz et al., 2005); 54.1% of IBS patients were constipation-dominant (C-IBS), 3% of them were diarrhea-dominant (D-IBS) and 42.9% of IBS patients had an alternating bowel habit (A-IBS). Although C-IBS prevalence were higher in our population, a recent review for asian population showed diarrhea predominance for males (Full-Young et al., 2010). Another population based study from Turkey showed the subtype prevalences of IBS as 48.1% (D-IBS), 38.9%

(C-IBS), 13% (A-IBS) (Yilmaz et al., 2005). Although A-IBS prevalence was remarkebly high and D-IBS prevalence was low in our study, we should consider that A-IBS prevalences ranges = from 20 to 65% in different studies (Full-Young et al., 2010).

Among age groups, there was no statistically significant difference (p > 0.05). Unlike the studies involving the community, very young and elderly patients were not included in the statistical survey because there are a certain age range of the police officers. We did not review any statistical link with educational level and gender status on IBS because the patients educational status and gender status were almost the same.

In our study, the statistical relationship between the stress and the prevalence of IBS was not significant (p > 0.05). In a prospective study, psychosocial factors such as anxiety, sleep problems, somatic symptoms were shown to be independent risk factors for the development of IBS (Nicholl et al., 2008). Stress is also known to play a role in exacerbation of IBS (Whitehead et al., 1992). Since stress is found in the nature of police job, it may explain why we could not find any differences between each group in our study.

Laxative drug use was common among our patients (p < 0.0001). Chronic laxative use usually exists in constipation-predominant patients (Olden and Scuhuster, 1998). The result of our study is compatible with previous research results.

In our study, we found a significant correlation between IBS and previous abdominal operation (p < 0.05). According to the literature, lifetime abdominal operation prevalence of IBS was higher than healthy subjects. Results are compatible with the literature (Saito et al., 2002).

We found a positive correlation between IBS and previous infection history (p < 0.05). In the literature it has been demonstrated that infection and other harmful agents have enhanced the precision of receptors causing symptoms (Karaman and Turkay, 2002).

In our study, we observed the IBS prevalence to be higher in individuals who did not eat regular meals and who had insufficient fiber in their diet (p < 0.0001). The habit of feeding with insufficient fiber foods have been shown to contribute to chronic constipation even in children (Akyildiz et al., 2005).

IBS prevalence increased as the daily consumption of tea and coffee increased (p < 0.0001). The symptoms of IBS and functional gastrointestinal disorders are usually together and may cause the current situation (Holtmann et al., 1997; Agreus et al., 2001). In the literature, although some of the studies show that smoking is one of the possible reason that increase dyspeptic complaints and IBS, there are also studies without any differences (Ozkan et al., 1992; Karaman et al., 2003). In our study, we found a negative correlation between IBS and smoking (p < 0.0001). There was negative correlation between IBS and alcohol intake too (p < 0.0001).

Police officers with vocational and socio-economic features constitute a special group of society. Our research results have both similarity and differences from the results of other studies. We found the IBS prevalence to be related with previous infections, abdominal operations, chronic laxative use, absence of reguler diet, lack of fiber foods in nutrition and daily tea or coffee consumption. Negative statistical relationship between IBS prevalance and smoking or alcohol intake was found. No relationship was found between the prevalence of IBS and psychological events. We think that more studies with different job groups should be carried out to explain the reasons of the differences.

Conflict of interests

The author(s) have not declared any conflict of interests.

REFERENCES

Agreus L, Svardsudd K, Talley NJ, Jones MP, Tibblin G (2001). Natural history of gastro-esophageal reflux disease and functional abdominal disorders: a population-based study. Am. J. Gastroenterol. 96(10):2905-2914. http://dx.doi.org/10.1016/S0002-9270(01)03242-7

Akpinar H, Kilic B, Amanvermez D, Aslan O, Sonmez I (1999). Prevalence of irritable bowel syndrome in İzmir Narlidere region. Turk. J. Gastroenterol. 10(2):21.

Akyildiz BN, Uranci N, Nuhoglu A (2005). The evaluation of patients with chronic constipation. Turkiye Klinikleri J. Pediatr. 14(2):66-69.

Ballou SK, Keefer L (2013). Multicultural considerations in the diagnosis of irritable bowel syndrome: A selective summary. Aur. J. Gastroenterol. Hepatol. 25(10):1127-1133.

Celebi S, Acik Y, Deveci SE, Ayar A, Demir A, Durukan P (2004). Epidemiological features of irritable bowel syndrome in a Turkish urban society. J. Gastroenterol. Hepatol. 19(7):738-743. http://dx.doi.org/10.1111/j.1440-1746.2004.03367.x; PMid:15209618

Delgado-Aros S, Locke GR, Camilleri M, Talley NJ, Fett S, Zinsmeister AR, Melton LJ (2004). Obesity is associated with increased risk of gastrointestinal symptoms: a population-based study. Am. J. Gastroenterol. 99:1801-1806. http://dx.doi.org/10.1111/j.1572-0241.2004.30887.x; PMid:15330922

Drossman DA, Li Z, Andruzzi E, Temple RD, Talley NJ, Thompson WG, Whitehead WE, Janssens J, Funch-Jensen P, Corazziari E, et al (1993). US householder survey of functional gastrointestinal disorders. Prevalance, sociodemography and health impact. Dig. Dis. Sci. 38(9):1569-1580. http://dx.doi.org/10.1007/BF01303162; PMid:8359066

Drossman DA, Camilleri M, Mayer EA, Whitehead WE (2002). AGA technical review on irritabl bowel syndrome. Gastroenterology 123(6):2108-2131. http://dx.doi.org/10.1053/gast.2002.37095; PMid:12454866

Everhart JE, Renault PF (1991). Irritable bowel syndrome in Office-based practice in the United States. Gastroenterology 100(4):998-1005. PMid:2001837

Hartley TA, Burchfiel CM, Fekedulegn D, Andrew ME, Violanti JM (2011). Health disparities in police officers comparisons to the U.S. general population. Int. J. Emerg. Ment. Health 13(4):211-220. PMid:22900455

Holtmann G, Goebell Hi, Talley NJ (1997). Functional dyspepsia and irritable bowel syndrome.İs there a common pathophysiologic basis? Am. J. Gastroenterol. 92(6):954-959. PMid:9177509

Karaman C, Turkay C (2002). Irritabl bowel syndrome. Curr. Gastroenterol. 6(2):96-102.

Karaman N, Türkay C, Yönem Ö (2003). Irritable bowel syndrome prevalence in city center of Sivas. Turk. J. Gastroenterol. 14(2):128-131. PMid:14614640

Kassinen A, Krogius-Kurikka L, Mäkivuokko H, Rinttilä T, Paulin L, Corander J, Malinen E, Apajalahti J, Palva A (2007). The fecal microbiota of irritable bowel syndrome patients differs significantly from that of healthy subjects. Gastroenterology 133(1):24-33. http://dx.doi.org/10.1053/j.gastro.2007.04.005; PMid:17631127

Longstreyh GF, Thompson WG, Houghton LA, Mearin F, Spiller RC (2006). Functional bowel disorders. Gastroenterology 130(5):1480-1491. http://dx.doi.org/10.1053/j.gastro.2005.11.061; PMid:16678561

Manning AP, Thompson WG, Heaton KW, Morris AF (1978). Towards positive diagnosis of irritable bowel. Br. Med. J. 2(6138):653-654. http://dx.doi.org/10.1136/bmj.2.6138.653; PMid:698649 PMCid:PMC1607467

Nicholl BI, Halder SL, Macfarlane GJ, Thompson DG, O'Brien S, Musleh M, McBeth J (2008). Psychosocial risk markers for new onset irritable bowel syndrome--results of a large prospective population-based study. Pain 137(1):147-155. http://dx.doi.org/10.1016/j.pain.2007.08.029; PMid:17928145 PMCid:PMC2441776

Ozkan H, Ucan S, Meydanli M, Yilmaz E, Koyuncu N, Sahin G, Comcuoglu C, Yagmurlu A, Tanriverdi A, Selvi E, Cetinkaya H, Donderici O, Sarioglu M, Isitan F, Cetin F, Dumlu S, Bahar K, Ozden A (1992). The frequency of smoking in various areas of Ankara citizens and dyspepsia in those who smoke. Turk. Klinikleri J. Med. Sci. 12(3):258-263.

Russo MW, Gaynes BN, Drossman DA (1999). A national survey of practice patterens of gastroenterologists with comparison to the past two decades. J. Clin. Gastroenterol. 29(4):339-343. http://dx.doi.org/10.1097/00004836-199912000-00009 ; PMid:10599638

Sandler RS (1990). Epidemiology of irritabl bowel syndrome in the United States. Gastroenterology 99(2):409-415. PMid:2365191

Simren M, Castedal M, Svedlun J, Abrahamsson H, Björnsson E (2000). Abnormal propagation pattern of duodenal pressure waves in the irritable bowel syndrome (IBS). Dig. Dis. Sci. 45(11):2151-2161. http://dx.doi.org/10.1023/A:1010770302403; PMid:11215731

Talley NJ, Zinsmeister AR, Van Dyke C, Melton LJ (1991). Epidemiology of colonic symptoms and irritable bowel syndrome. Gastroenterol. 101(4):927-934.

Talley NJ, Zinsmeister AR, Melton LJ (1995). Irritabl bowel syndrome in a community:symptom subgroups, risk factors and health care utilization. Am. J. Epidemiol. 142(1):76-83. PMid:7785677

Talley NJ, Spiller R (2002). Irritable bowel syndrome: a little understood organic bowel disease? Lancet. 360(9332):555-564. http://dx.doi.org/10.1016/S0140-6736(02)09712-X

Thompson WG, Longstreth GF, Drossman DA, Heaton KW, Irvine EJ, Müler-Lissner SA (1999). Functional bowel disorders and functional abdominal pain. Gut. 45(2):43-46.

Törnblom H, Lindberg G, Nyberg B, Veress B (2002). Full-thickness biopsy of the jejunum reveals inflammation and enteric neuropathy in irritable bowel syndrome. Gastroenterol. 123(6):1972-1979. http://dx.doi.org/10.1053/gast.2002.37059; PMid:12454854

Unalan PC (2010). Approach to the functional gastrointestinal disorders in primary care. Türk. Klinikleri J. Fam. Med-Special Topic 1(3):76-82.

Yilmaz S, Dursun M, Ertem M, Canoruc F,Turhanoglu A (2005). The epidemiological aspects of irritable bowel syndrome in Southeastern Anatolia:a stratified randomised community-based study. Int. J. Clin. Pract. 59(3):361-369. http://dx.doi.org/10.1111/j.1742-1241.2004.00377.x; PMid:15857337

Saito YA, Schoenfeld P, Locke GR (2002). The epidemiology of irritable bowel syndrome in North America: A Systemic Review. Am. J. Gastroenterol. 97(8):1910-1914. PMid:12190153

Whitehead WE, Crowell MD, Robinson JC, Heller BR, Schuster MM (1992). Effects of stressful life events on bowel symptoms: subjects with irritable bowel syndrome compared with subjects without bowel dysfunction. Gut 33(6):825-830; http://dx.doi.org/10.1136/gut.33.6.825; PMid:1624167 PMCid:PMC1379344

Full Length Research Paper

Analysis of changes in grain production on fruit and vegetable cultivation areas in Turkey through geographically weighted regression

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The main purpose of this paper is to address the question of whether and how farmers have tried to increase agricultural productivity after the regulatory role of governments on the agricultural industry has been reduced due to financial crises. The relationship between agricultural sowing area shifts (grain to fruit, grain to vegetables, vegetables to fruit) were explored by using geographically weighted regression model. This model showed how the decrease of grain sowing areas led to an increase of fruit and vegetable sowing area in Turkey. It was demonstrated that farmers tended to choose more productive agricultural crops in order to address agricultural sustainability problems. Geographical information system data sets regarding the years between 2000 and 2010 were obtained from 923 districts. The results of the analysis showed a strong relationship between changes in grain, vegetable and fruit areas. According to geographically weighted regression, the variation of local coefficients ranged from - 0.62 to 0.34. Because of the productivity factors, grain and vegetable areas have been replaced by fruit production. However, Turkey will be faced with food security problems in the future due to the decrease of grain cultivation. The increasing opportunity for irrigation has had a profoundly important role in shifting from grain to vegetable and fruit production.

Key words: Geographically weighted regression, geographical information system, sustainable agriculture, farm policy, food security.

INTRODUCTION

Statist policies have been replaced by liberal agricultural and trade policies in Turkey after 1980 (Ediger and Huvaz, 2006; Özmucur, 2007; Hasanov et al., 2010; Türkekul and Unakıtan, 2011). The agricultural support policy, which underpinned agricultural policies in Turkey during the planned period between 1960 and 1980, consisted of three main headings: The government's purchase of farmers' products for a base price above the market price; the availability of state subsidies for agricultural inputs such as fertilizer, pesticide and seed; and privileged loan interest rates for farmers (Önal, 2007). After the introduction of liberal policies, the

Table 1. Agricultural planted areas and changes between 2000 and 2010.

Agricultural planted area (decare)	2000	2010	Percent of change
Total Agricultural	263.790.670	243.942.052	-7.52
Grain planted	180.377.820	163.303.020	-9.47
Vegetables planted	9.043.770	8.015.980	-11.36
Fruit planted	26.109.420	30.105.797	1531

regulatory role of the state on prices was left to the market's own operation (Kepenek and Yentürk, 2000).

In the post-1980 period, Turkey frequently experienced economic crises followed by decreases in agricultural supports. Within six years following the financial crisis in 1994, institutions operating in main areas that contributed to the regulation of products such as milk, forage, meat, fish, forest products, tractors and fertilizer were privatized (Önal, 2007). Significant structural transformations were also experienced following the financial crisis in 2001. The most important agricultural change experienced in this period was the initiation of membership negotiations with the European Union (EU). Thus, in Turkish agriculture, a process of comprehensive transformation that included legislative activities aimed at adjusting with the EU Common Agricultural Policies began. After the agricultural reform in 2001, employment in agriculture declined, the share of agriculture in Gross Domestic Product became smaller, internal migration increased as small farmers withdrew from agriculture, and employment opportunities could not be offered to these newcomers with low educational levels in cities (BSB, 2008).

Agricultural production has decreased because of the radical transformations in agriculture in the post-1980 period. The state regulations in favor of farmers in important areas such as meat, fish, forage, seed, fertilizer and tractors has diminished rapidly (Önal, 2007). Important changes have also been observed in the structure of agricultural ownership after the 2001 crisis. While the share of those with an enterprise size of more than 10 ha was 34% in 2001, it rose to 65.7% in 2006 (TUIK, 2008). This increase shows that traditional family enterprises have been increasingly vanishing, leaving mainly large enterprises. Further, agricultural crop type has been influenced by this transformation in order to increase productivity. Table 1 demonstrates that in agrıcultural sowing areas there have been some notable changes; while total fruit areas rose, grain and vegetables areas decreased (TUIK, 2011).

Agricultural production is unevenly distributed in Turkey. Farmers living in the coast of Aegean and Mediterranean who have higher income levels concentrated on fruit production. Farmers living in the Southeastern Anatolia who have irrigation opportunities concentrated grain, vegetable and fruit production, since these regions have lower income levels compared to rest of the regions. Large scale irrigation projects change not only agriculture production, but also income structure

(Eraydın, 1992). With regard to agricultural production, any location is linked to the rest of the world through three broad channels; production, trade and climate. That is why agricultural production should be handled in a multifaceted manner. Many studies have tried to answer the question of which factors affect agricultural production and productivity. For example, fertilizer usage (Marinoa et al., 2011; Shengli et al., 2012) efficient irrigation area, (Yujian et al., 2013; Guang-Cheng et al., 2014) drought (Keating and Meinke, 1988; Venuprasad et al., 2008; Chris and Budde, 2009; Ananda et al., 2011; Jana et al., 2013) affects grain production. The main purpose of this paper is to address the question of whether and how productivity plays role in the agricultural production of grains, vegetables and fruits.

METHODOLOGY

The data between the years 2000 and 2010 was obtained from the Turkish Statistical Institute; 923 districts were used for geographically weighted regression analyses. Districts were taken as the units of analysis. Regions are shown in Figure 1. The year 2000 was selected as the starting point in this research due to the financial crisis, after which striking differences have been observed in spatial organization. ArcGIS was employed as the geographical information system (GIS) program in the analyses. Grain, fruit and vegetables crop variables consist of the total sowing areas (decare) in districts. It was investigated in this study if decreasing of grain crop has a spatial distribution effect or if it contributes to fruit crop and vegetables crop because of the productivity. In this study, in order to explain spatial variability in agricultural production across Turkey, GWR was used instead of OLS.

GWR extends the global regression ordinary least squares (OLS). For each location, regression coefficient can be estimated by using a GWR model (Fotheringham et al., 1996, 2002). GWR method allows for analyzing the spatial variability of the local coefficients of independent variable or variables. Geographically weighted regression is a powerful tool to explain the spatial heterogeneity. OLS creates a regression coefficient which assumes that the relationship between the variables are constant across regions. The OLS can be written as:

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \varepsilon$$

(1)

Where y is a dependent variable, xi are exploratory variables; k is the number of independent variables; β_1 and β_0 represent and coefficient and intercept respectively; and ε is the error term.

As a local regression technique, GWR is an extension of global regression technique (Fotheringham et al., 2002). GWR assumes that relationships between the change in grain, vegetable and fruit area may vary over space. It can be formulated as:
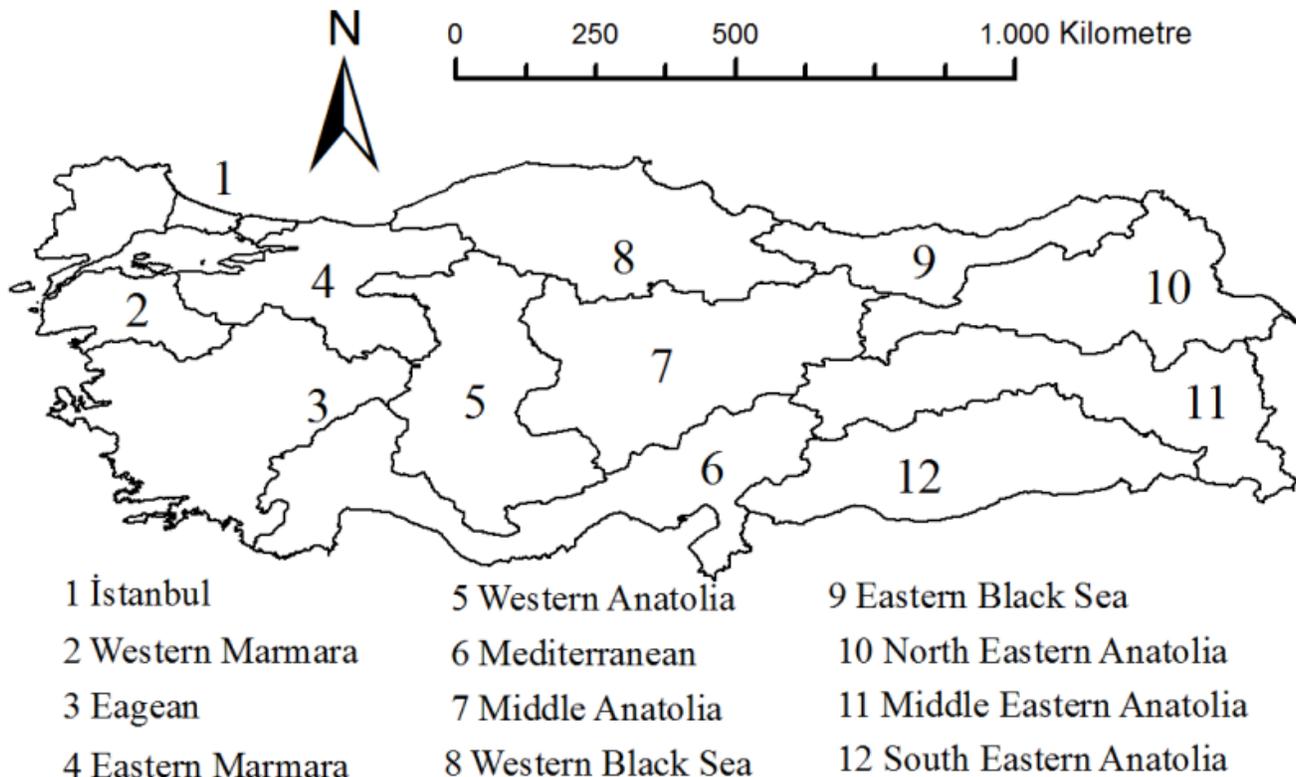
Figure 1. Map of Turkey's regions.

$$y_i = \beta_0 \left(u_j, v_i \right) + \sum_{i=1}^{k} \beta_i \left(u_j, v_i \right) x_{ij} + \varepsilon_j \tag{2}$$

where u_j and v_i denote the spatial positions of location j; β_0 (u_j,v_j) is the intercept for location j; $\beta_{ik}(u_j,v_j)$ is the local estimated coefficient for the exploratory variable; x_k at point i, and ε_j is the random error term at location i.

In case of spatial heterogeneity, local model performance is better than that of the global model. Even if there is a significant relationship between the dependent and independent variable, the result of the global model would be insignificant since there is a positive or negative relation in different regions. In other words, spatially heterogeneous structure can be represented by just one coefficient by a global model, whereas a local model estimates a set of parameters containing independent variable or variables for each spatial unit. During the past five years a considerable amount of literature has been published on GWR in a variety of fields: the regional spillover effect (Rasekhi et al., 2013), land use and water quality (Tu, 2011), agriculture (Su et al., 2012), cancer risks (Gilbert and Chakraborty, 2011), traffic levels (Selby and Kockelman, 2013), migration (Lehtonen and Tykkyläinen, 2010) and grain production (Yang et al., 2013).

RESULTS

This study is based on the assumption that as long as total agricultural sowing area remains almost constant, when either grain or vegetable sowing areas decrease and fruit area increases in the same district, it can be said that grain or vegetable area are replaced by fruit area.

The maps in Figure 2 were created so that the remarkable difference between 2000 and 2010 in terms of change of grain, fruit and vegetable sowing areas can be seen. Figure 2 also demonstrates the wide range of agricultural sowing areas between districts. Figure 2a shows that grain areas were concentrated in the Middle Anatolia (Figure 1 no: 7) and South Eastern Anatoliain 2000 in Turkey. It can be seen that grain production in Middle Anatolia is dramatically losing its importance. The other important change is that grain area rose in Southeastern Anatolia and Eastern Anatolia (Figure 1 no: 10-11), while it was declining sharply in Middle Anatolia. The grain area decrease in Middle Anatolia will have dramatically effects on Turkey's agricultural production.

The distribution of fruit areas at the coast is more dense than at the center of the Turkey (Figure 2c and f). Fruit areas were concentrated in the Aegean (Figure 1 no:3), western part of Southeastern Anatolia, Eastern part of the Mediterranean (Figure 1 no: 6), the Black Sea (Figure 1 no: 8-9) coast and the Eastern part of Marmara (4). Vegetable area is widespread in the Aegean, Mediterranean, western part of Southeastern Anatolia and Western Anatolia (Figure 2b and e). The increase in fruit area from 2000 to 2010 across Turkey in contrast to grain area is profoundly important for Turkey's agricultural production process because in fruit is more productive than grain. On the other hand, grain plays a crucial role in food security.
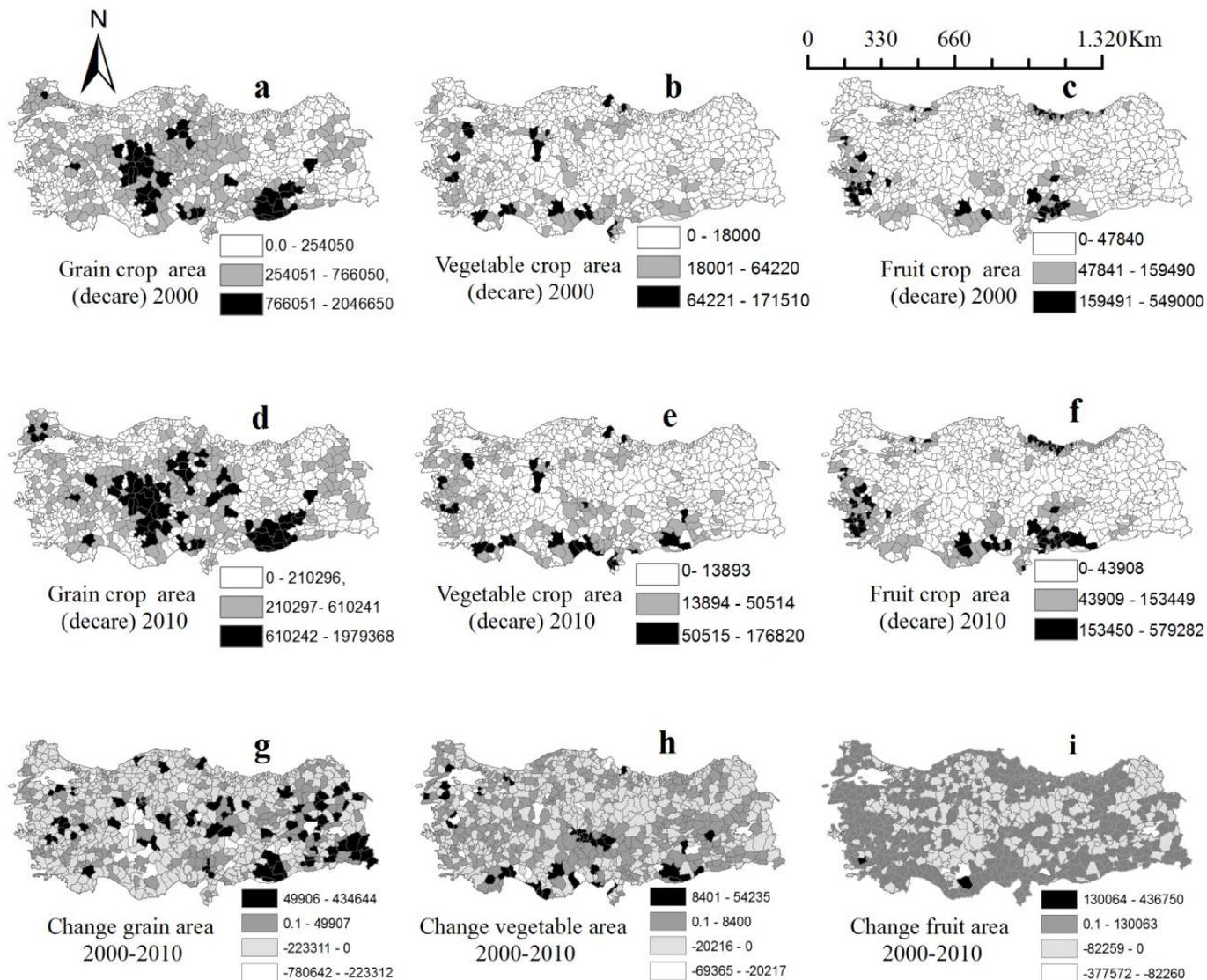
Figure 2. Spatial mapping of grain, fruit and vegetable areas between 2000 and 2010 in Turkey.

Figure 2 can be briefly summarized such that after 2000 among the Turkish agricultural crop types, many transitions such as from grain to fruit production have occurred. In this study, how grain areas are replaced by fruit and vegetable areas is explained by using spatial econometric model. As seen in Figure 2, there are so many spatial transitions from one crop type to another that it can be very difficult to see without using spatial econometric model.

GWR model, which estimates a set of parameters of independent variable for each districts was used to characterize transitions from either grain or vegetable to fruit sowing areas. Local model GWR was performed to determine whether there was a significant spatial non-stationary relationship between the change in grain and fruit area variables over the period. GWR presented

better solutions than OLS (Table 2). The AIC results from the GWR model were lower than those from the OLS model, which suggests that the GWR model was a better fit than OLS (Fotheringham et al., 2002; Tuand and Xia, 2008).

The considerable spatial variability in grain, vegetable and fruit sowing area indicates that there is a significant spatial non-stationary relationship between dependent and independent variables. Spatial non-stationery means that the relationship between independent and dependent variables are not constant over space (Fotheringham et al., 2002). The fact that the variation of local coefficients ranges from negative to positive indicates that the relationship between independent and dependent variables is non-stationary. At the same time, the variation of local R-squared, which explains different

Table 2. Model performance as judged by AIC$_{GWR}$ and AIC$_{OLS}$.

Dependent variable	Independent variable	AIC$_{GWR}$		AIC$_{GWR}$	
Fruit	Grain	AIC$_{GWR}$	21543,9	AIC$_{OLS}$	21554
Vegetable	Grain	AIC$_{GWR}$	18824,1	AIC$_{OLS}$	19036
Vegetable	Fruit	AIC$_{GWR}$	18898,4	AIC$_{OLS}$	19045
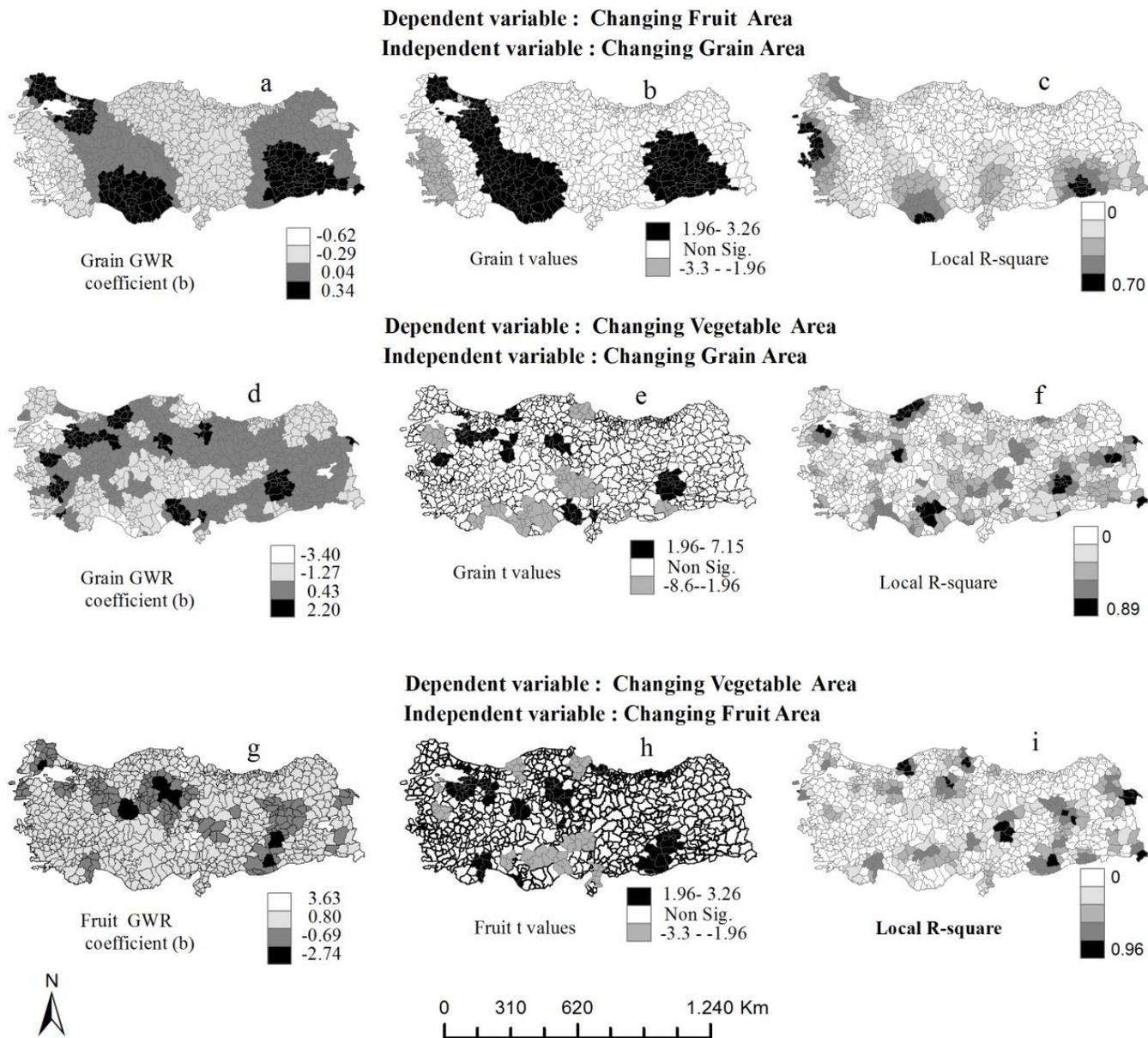
Figure 3. Spatial distribution of local coefficients, R-squared and t-statistics from the GWR. T-values are significant in some districts at a 0.05 level (t-values above 1.96 and lower than -1.96).

localization, shows the relationship between grain, vegetable and fruit variables (Table 3). Figure 3 shows the results of the GWR analysis that was performed to determine the relationship of spatial variability between changing grain, vegetable and fruit sowing areas.

Here, we show how there is a relationship between the agricultural sowing types shift by taking into account GWR results. The share of fruit among arable areas

Table 3. Variation of local R-squared.

Dependent variable	Independent variable	Coefficient			
Fruit	Grain	Grain coefficient	-0.64-0.34	Local R-squared	0.0-0.70
Vegetable	Grain	Grain coefficient	0.06-2.67	Local R-squared	0.0-0.89
Vegetable	Fruit	Fruit coefficient	-2.74-3.63	Local R-squared	0.0-0.96

increased in all regions. Figure 3a, d and g show the spatially varying coefficients. In those maps, white and light-gray district clusters indicate a negative relation between independent and dependent variables and dark-gray and black colors represent that both independent and dependent variables increased. Some of the t-values that are represented by white color in the Figure 3b, e and h were insignificant at a 0.05 level (t-values above -1.96 or lower than 1.96). Figure 3c, f and i show R-squared variables for each district. There are of course black and dark gray clusters, indicating a strong relationship between the variables.

Grain coeffients range from -0.62 to 0.34 (Figure 3a). The fact that the variation of local coefficients range from negative to positive account for relationships between changing grain and fruit sowing area spatial heterogeneity distributions. Positive coefficient values are found in Mediterranean, Southeastern Anatolia (SEA) and western Marmara. Considering fruit productivity, those regions have advantages of sustainable development of agricultural areas. In addition, they have a relative advantage in terms of irrigation systems. In particular, the SEA region is the site of the important Southeastern Anatolia irrigation project that is likely to be a contributing factor in increasing both grain and fruit area (Akpınar and Kaygusuz, 2012; Çelik and Gülersoy, 2013).

Black color clusters in Figure 3a reflect how farmers meet sustainability conditions after government regulations in the agricultural industry have been reduced. The negative coefficients are highly concentrated in the coast of Aegean. This negative spatial relationship is evidence of how the grain area was replaced by fruit area. The reason why the agricultural area shifted from grain to fruit is likely due to irrigation opportunities. Another reason in SEA is that farmers have large arable areas which have both sunshine duration and irrigation advantages. The reason that fruit area is increasing while grain area is decreasing is based on the fact that fruit is definitely more productive than grain.

Unlike fruit, vegetable and grain planting and production cycle is less than 1 year. Since it takes about 3 to 10 years to reach the first fruit harvest, it is very difficult for poor farmers to shift from grain to fruit. Even if poor farmers have enough arable land to produce fruit, they have to continue to crop grain. Apart from the Black Sea region, regions in the coast of Turkey have relatively higher income levels. Therefore, in those regions,

agricultural sowing areas have shifted from grain to fruit smoothly.

Figures 3d, e and f show the results of the GWR analysis that was performed to show the relationship of spatial variability between changing grain and vegetable areas. Grain coefficients variable ranged from -3.40 to 2.20 (Figure 3d). Therefore we can say that relationship between changing grain and vegetable area spatially heterogeneously distributed. Negative coefficients, concentrated on the coast of Aegean, Eastern Black Sea, Mediterranean, Southwest Marmara. Middle Anatolia and Southeastern Anatolia are a very clear demonstration of how the grain area was replaced by vegetable. Shift from grain to vegetable is easier than shift from grain to fruit because of the long amount of time to first harvest for fruit cultivation. In this reason negative coefficients between the grain to vegetable are more widespread than grain to fruit. The reason that grain production is being replaced by vegetables in the coastal regions of Turkey is that those regions have irrigation advantages compared to the rest of the Turkey.

Figure 3g shows that grain coefficients variable ranged from -2.74 to 3.63. Coefficients ranging from negative to positive indicate how well the local regression model is obtained. Negative coefficients represent shifts from vegetable to fruit and positive coefficients represent that both vegetable and fruit increased. The negative relationship between vegetable and fruit area is concentrated in the SEA, north of Mediterranean, north of Aegean and west Black Sea. Because both vegetable and fruit need irrigate systems, the shift from vegetable to fruit is relatively easily. Significant positive relationships suggest that changing vegetable sowing area from 2000 to 2010 is associated with higher changing fruit sowing area.

DISCUSSION

Many farmers are beginning to recognize the need to increase agricultural productivity. In order to cope with and adapt to agricultural productivity challenges, farmers prefer fruit production instead of grain. Farmers attempted to overcome and adapt after new economic crisis conditions by raising sustainability limits through new spatial organizations. In the coastal regions of Turkey, it is obvious that agriculture has shifted from grain area to fruit area. The reason why there is a spatial

transition from grain and vegetable area to fruit area is based on the fact that fruit productivity is much higher than vegetable and grain. There is a controversial situation here in that this process may lead to new food security problem. The shift from grain to fruit may solve the farmers' sustainable agriculture problem but cause a food security problem for the nation because grain is such an essential food.

Fruit agriculture crop requires high amount of water compared to grain areas. Middle Anatolia has disadvantages in irrigated agriculture compared to the coast of Turkey. SEA is one of the poorest regions in Turkey. Accordingly, there are many districts in which per capita income is far below the average in the east of Turkey. In 2010, the richest province (Istanbul) had a per capita income more than 3 times than that of the poorest provinces (Mardim, Batman, Siirt, Sırnak). The probability that in the SEA region, positive agricultural changes will contribute towards catching up to wealthier provinces is very high.

Conclusions

The purpose of this study was to determine how farmers have tried to increase agricultural productivity. This paper shows that agricultural productivity can play an important role in grain production. One of the more significant findings to emerge from this study is that Turkey's types of agricultural production have changed drastically. Striking evidence shows that grain production is moving from the center of Turkey to the east and southeast. The second major finding was that agricultural productivity can play important role in the shift from grain and vegetable to fruit production. There is a spillover effect between agricultural production types, because grain is crucial for human life. The decline of government support for farmers and economic crises make sustainable agriculture extremely difficult. It can be said that sustainable agricultural production is at risk in Turkey since droughts have increased in central Anatolia, which is an important region for grain production. It is understood that farmers prefer fruit, but we do not know what kinds of fruit have replaced grains and vegetables. Further research needs to be done to establish how climate conditions influence types of agricultural production and to analyze which kind of fruit has been preferred in order to more comprehensively characterize the current situation and trends.

REFERENCES

Akpınar A, Kaygusuz K (2012). Regional sustainable water and energy development projects: A case of Southeastern Anatolia Project in Turkey. Renew. Sustain. Energy Rev. 16:1146-1156. http://dx.doi.org/10.1016/j.rser.2011.11.015
Ananda N, Vadlani PV, Prasad PVV (2011). Evaluation of drought and heat stressed grain sorghum (Sorghum bicolor) for ethanol production. Ind. Crops Prod. 33:779-782.

http://dx.doi.org/10.1016/j.indcrop.2011.01.007
BSB (2008).2008 Kavşağında Türkiye siyaset iktisat ve toplum. Yordam, Istanbul. pp. 169-183.
Chris F, Budde ME (2009). Phenologically-tuned MODIS NDVI-based production anomaly estimates for Zimbabwe. Remote Sensing of Environment. 113:115-125. http://dx.doi.org/10.1016/j.rse.2008.08.015
Çelik MA, Gülersoy AE (2013). An examination of the effects of Southeastern Anatolia Project on agricultural patterns changes using remote sensing. J. Int. Soc. Res. 28(5):46-54.
Ediger VS, Huvaz O (2006). Examining the sectoral energy use in Turkish economy (1980–2000) with the help of decomposition analysis. Energy Conver. Manage. 47(6):732-745. http://dx.doi.org/10.1016/j.enconman.2005.05.022
Eraydın A (1992). Post-FordizmveDeğişenMekansalÖncelikler. ODTÜ, Ankara.
Fotheringham AS, Charlton ME, Brundson C (1996). The geography of parameter space: and investigation into spatial non-stationarity. Int. J. GIS. 10:605-627.
Fotheringam AS, Brunsdon C, Charlton M (2002). Geographically Weighted Regression: The Analysis of Spatially Varying Relationships. Wiley, Chichester.
Gilbert A, Chakraborty J (2011). Using geographically weighted regression for environmental justiceanalysis: Cumulative cancer risks from air toxics in Florida. Soc. Sci. Res. 40:273-286. http://dx.doi.org/10.1016/j.ssresearch.2010.08.006
Guang-Cheng S, Sheng D, Na L, Shuang-En Y, Ming-Hui W, Dong-Li S (2014). Effects of controlled irrigation and drainage on growth, grain yield and water use in paddy rice. Eur. J. Agron. 53:1-9. http://dx.doi.org/10.1016/j.eja.2013.10.005
Hasanov M, Ayşen A, Telatar F (2010). Nonlinearity and structural stability in the Phillips curve: Evidence from Turkey. Econ. Model. 27(5):1103-1115. http://dx.doi.org/10.1016/j.econmod.2010.03.009
Jana K, Greg M, Vincent V, Peter C, Graeme LH (2013). Drought stress characterization of post-rainy season (rabi) sorghum in Indi. Field Crops Res. 141:38-46. http://dx.doi.org/10.1016/j.fcr.2012.10.020
Keating BA, Meinke H (1988). Assessing exceptional drought with a cropping systems simulator: A case study for grain production in Northeast Australia. Agric. Syst. 3:315-332.
Kepenek Y, Yentürk N (2000). Türkiye Ekonomisi. RemziKitapevi, Isanbul. pp. 197-198.
Lehtonen O, Tykkyläinen M (2010). Self-reinforcing spatial clusters of migration and socio-economic conditions in Finland in 1998-2006. J. Rural Stud. 26:361-373. http://dx.doi.org/10.1016/j.jrurstud.2010.02.003
Marinoa S, Tognettib R, Alvinoa A (2011). Effects of varying nitrogen fertilization on crop yield and grain quality of emmer grown in a typical Mediterranean environment in central Italy. Eur. J. Agron. 34:172-180. http://dx.doi.org/10.1016/j.eja.2010.10.006
Önal NE (2007). 1980 sonrasıdevletpolitikalarınınTürkiye'nin tarımsal dönüşümüne etkileri. Marmara Universitesi. Unpublished PHD thesis.
Özmucur S (2007). Liberalization and concentration: Case of Turkey. Q. Rev. Econ. Financ. 46(5):762-777. http://dx.doi.org/10.1016/j.qref.2006.08.005
Rasekhi S, Anousheh S, Ranjbar H, Moghimi M (2013). Regional spillover research and development investment: A geographically weighted. Afr. J. Bus. Manage. Regression Approach 7(33):3212-3219.
Selby B, Kockelman KM (2013). Spatial prediction of traffic levels in unmeasured locations: applications of universal kriging and geographically weighted regression. J. Transp. Geo. 29:24-32. http://dx.doi.org/10.1016/j.jtrangeo.2012.12.009
Shengli G, Hanhua Z, Tinghui D, Jinshui W, Wenzhao L, MingdeH., Yong L, Keith JS (2012). Winter wheat grain yield associated with precipitation distribution under long-term nitrogen fertilization in the semiarid Loess Plateau in China. Goderme 189-190:442-450. http://dx.doi.org/10.1016/j.geoderma.2012.06.012
Su S, Xiao R, Zhang Y (2012). Multi-scale analysis of spatially varying relationships between agricultural landscape patterns and urbanization using geographically weighted regression. Appl. Geo. 32:360-375. http://dx.doi.org/10.1016/j.apgeog.2011.06.005
Tu J (2011). Spatially varying relationships between land use and water

quality across an urbanization gradient explored by geographically weighted regression. Appl. Geo. 31:376-392. http://dx.doi.org/10.1016/j.apgeog.2010.08.001

Tuand J, Xia ZG (2008). Examining spatially varying relationships between land use and water quality using geographically weighted regression I: Model design and evaluation. Sci. Total Environ. 407:358-378. http://dx.doi.org/10.1016/j.scitotenv.2008.09.031; PMid:18976797

TUIK (2008). The research of agricultural business structure, number: 196 newsletter.

TUIK (2011). Statistical Indicators, 1923-2010. Turkish Statistical Institute, Ankara.

Türkekul B, Unakıtan G (2011). A co-integration analysis of the price and income elasticities of energy demand in Turkish agriculture. Energy Policy 39:2416-2423. http://dx.doi.org/10.1016/j.enpol.2011.01.064

Venuprasad R, Sta Cruz MT, AmanteM, Magbanua R, Kumar A, Atlin GN (2008). Response to two cycles of divergent selection for grain yield under drought stress in four rice breeding populations. Field Crops Res. 107:232-244. http://dx.doi.org/10.1016/j.fcr.2008.02.004

Yang Y, Tong X, Zhu J (2013). A geographically weighted model of the regression between grain production and typical factors for the Yellow River Delta. Math. Comput. Model. 58:582-587. http://dx.doi.org/10.1016/j.mcm.2011.10.062

Yujian Y, XueqinT, Jianhua Z (2013). A geographically weighted model of the regression between grain production and typical factors for the Yellow River Delta. Math. Comput. Model. 58:582-587. http://dx.doi.org/10.1016/j.mcm.2011.10.062

Full Length Research Paper

Effects of an additional pharmaceutical care intervention versus usual care on clinical outcomes of Type 2 diabetes patients in Nigeria: A comparative study

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The aim of this study was to evaluate the impact of an additional pharmaceutical care intervention on clinical outcomes of Type 2 diabetes patients receiving care in tertiary hospitals. This study was a randomized, controlled and longitudinal study with a 12-month patient follow-up. This study was conducted in two Nigerian University Teaching Hospitals. Patients in 'usual care' received the usual/conventional care offered by the hospitals. Patients in 'intervention' received usual care and pharmaceutical care for 12 months. This additional pharmaceutical care included a stepwise approach: setting priorities for patient care, assessing patient's specific educational needs and identification of drug related problems (DRPs), development of a comprehensive and achievable pharmaceutical care plan in collaboration with the patient and the doctor, implementation of the this plan, monitoring and review of the plan from time to time. By end of 12 months, there were significant reductions in the following clinical outcomes (control vs. intervention): glycosylated haemoglobin (%) (7.77 ± 1.12 vs. 7.23 ± 1.09; P = 0.0009), fasting glucose (mg/dL) (168.7 ± 11.49 vs. 129.34 ± 9.97; P < 0.0001). The results for LDL-C, HDL-C, Triglycerides and Total Cholesterol were 116.28 ± 9.64 vs. 101.43 ± 8.35; P < 0.0001, 45.29 ± 6.68 vs. 53.82 ± 5.81; P < 0.0001, 159.59 ± 8.91 vs. 154.37 ± 10.34; P = 0.0002, 203.75 ± 25.96 vs. 188.71 ± 19.41; P < 0.0001 respectively. The intervention resulted in beneficial improvement of clinical outcomes of Type 2 diabetes patients receiving treatment in tertiary hospitals.

Key words: Pharmacist, pharmaceutical care, intervention, diabetes outcomes, clinical outcomes, Type 2 diabetes, randomized, controlled study.

INTRODUCTION

Diabetes mellitus is associated with considerable morbidity and mortality. Diabetes is also a major risk factor for cardiovascular disease, stroke, and kidney failure (Akanji and Adetunji, 1990). Diabetes mellitus (DM) was once regarded as a disease of the affluent but is now vastly visible as a growing health problem in

developing economics as almost 80% diabetes death occurs in low and middle income countries (International diabetes federation; Odili et al., 2010). The national standardized prevalence rate of DM in Nigeria is 2.2%, while the crude prevalence rate is 7.4% in those aged 45 years and above who live in urban areas (Nyenwe et al., 2003). Global estimates of the prevalence of diabetes for 2010 and 2030 showed that prevalence of diabetes in Nigeria in 2010 was 4.7% and 3.9% and it would be 5.5% and 4.3% in 2030 when compared with world population and national population, respectively (Shaw et al., 2010).

Pharmaceutical care is the direct, responsible provision of medication related care with the purpose of achieving definite outcomes that improve a patient's quality of life (Hepler and Strand, 1990). The principal elements of pharmaceutical care are that it is medication related; it is care that is directly provided to the patient by pharmacist; it is provided to produce definite outcomes; these outcomes are intended to improve the patient's quality of life; and the provider (pharmacist) accepts personal responsibility for the outcomes (Hepler and Strand, 1990). Diabetes is a disease that desperately needs more pharmacist involvement. Pharmacists who are specialized in this growing chronic condition can make a significant, positive impact on the patient, the health care system and themselves (Davis et al., 2005). Health-care professionals are becoming increasingly aware of the need to assess and monitor the quality of life (QoL) as an important outcome of diabetes care.

Health related quality of life HRQoL is an important outcome on its own right and, because it may influence the patient's self-care activities, which may consequently impact on the diabetes control (Khan et al., 2004). Many pharmaceutical care programs have been established in various countries to enhance clinical outcomes and the health-related quality of life (HRQoL). These programs were implemented by pharmacists, with the cooperation of the physicians and other health care professionals. Pharmaceutical care and the expanded role of pharmacist are associated with many positive diabetes-related outcomes, including improved clinical measures (Jaber et al., 1996), improved patient and provider satisfaction (Sadur et al., 1999; Majumdar et al., 2003), and improved cost of management (Sadur et al., 1999; Coast-Senior et al., 1998). The pharmacist can therefore, in collaboration with physicians and other health care professionals, contribute to the improvement of diabetic patients' quality of life by informing and educating patients, answering their questions and, at the same time monitoring the outcomes of their treatment (Hawkins et al., 2002). Currently in Nigeria, there is no available evidence of impact of pharmaceutical care intervention on clinical outcomes of patients with Type 2 receiving treatment in tertiary hospital.

The aim of this study was to evaluate the impact of an additional pharmaceutical care intervention on clinical diabetes outcomes of patients with Type 2 diabetes receiving care in tertiary hospitals.

METHODS

Study design

This study was a randomized, controlled, and longitudinal prospective study with a 12-month patient follow-up.

Study setting

The study protocol was approved by the Research Ethical Committees of the University of Nigeria Teaching Hospital, ItukuOzalla (UNTH) and NnamdiAzikiwe University Teaching Hospital, Nnewi (NAUTH) in which this study was conducted. These hospitals are tertiary hospitals that serve as referral centers to most of the hospitals in Nigeria.

Inclusion/exclusion criteria

Patients with Type 2 diabetes mellitus who fulfilled the recruitment criteria were identified and included in the study. The inclusion criteria were: patients that were diagnosed of Type 2 diabetes mellitus and/or patients that were receiving oral hypoglycemic therapy, patient who provided written informed consent, patients who expressed willingness to abide by the rules of study, patients who were certified fit for the study by their consulting doctors.

Exclusion criteria were patients who were diagnosed of Type 1 diabetes (to avoid complexity in the study scope), patients who were less than 18 years (they are legally regarded as minor and consequently they cannot take decision of their own), patients who were pregnant (they are generally not allowed to participate in the study of this nature by the institutions used for the study), patients who expressed willingness to withdraw from the study (participation is voluntary). These criteria were according to the guiding principles of the institutional review boards of the hospitals used in this study.

Patients' selection

Following sample size power calculation, a sample size of at least 104 patients in each of the control and intervention groups was required. Based on these data, to ensure sufficient statistical power and to account for 'drop-outs' during the study, a target sample size of 220 patients were recruited (110 patients from each of the hospitals).

The folders of the 110 selected patients in each hospitals (UNTH and NAUTH) were assigned numbers 1 to 110 which represented individual patient, patients were randomly assigned to one of two sub-groups (intervention group-PC or control group-UC) based on the number on their folders using online 'random sequence generator' (Mads-Haahr, 1998) with sequence boundaries of 1 to 110 (boundaries inclusive) set in two columns format: first column was priori designated to sub-intervention group (55 patients) and second column sub-control group (55 patients) see the flow chart in the Figure 1.

Data collection

Each recruited patient was interviewed face-to-face (for approximately 20 min) by the research clinical pharmacist to obtain details of their socio-demographics, family history of diabetes. Patients' files were reviewed to obtain information on medications being used, co-morbidities, patients' hospital visits and admissions. The recruitment lasted for three months. Pharmaceutical care diary
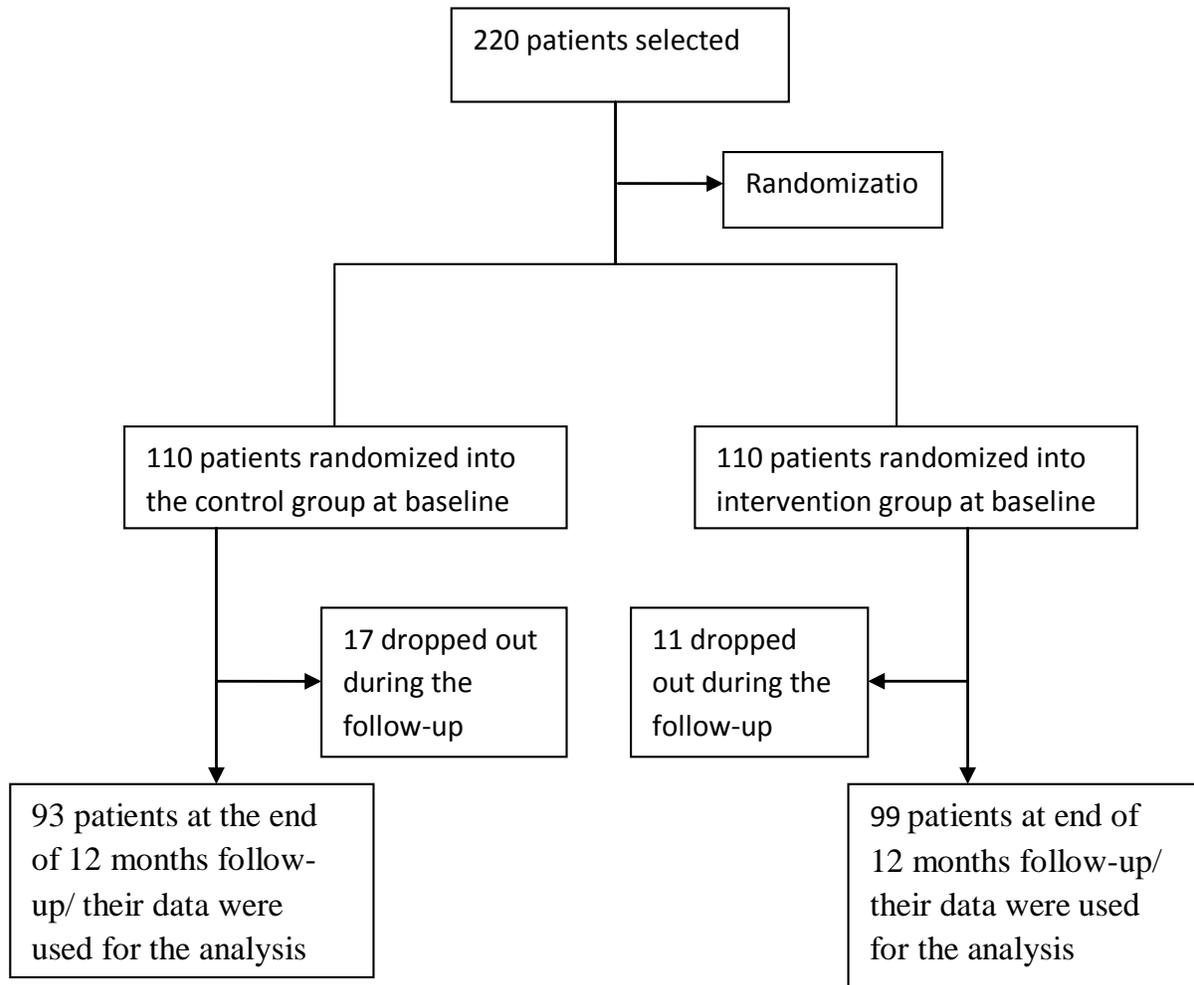
Figure 1. Flow chart of the participants.

was given to each patient to gather data on frequency of continuous home blood glucose monitoring, fasting blood glucose, systolic and diastolic blood pressure, drug-related problems and adherence to medication. There were routine measurements of body weight and body mass index (BMI), HbA1c, serum total cholesterol, serum creatinine, serum HDL-C, serum low density lipoprotein-cholesterol (LDL-C) and serum triglycerides.

Evaluation of training course and teaching materials

The medical and educational contents of the training materials were evaluated by the doctors and nurses in diabetes clinics before the administration of the materials to the patients. They were asked to rate the materials as being excellent, very good, good, fair, poor, and unsuitable for use.

Study procedures

Patients in UC received the usual/conventional care offered by the hospitals which included: hospital visits on appointment or on a sick day, consultations with the doctors, prescription of drugs and routine laboratory tests, review of diagnosis and medications, refilling of prescriptions by patients and referral. This usual care was offered with little or no education/training of the patients on their diseases and drugs and without empowerment of the patients to be fully involved in the self-management of their illnesses.

Patients in PC received usual care and pharmaceutical care for 12 months. This additional pharmaceutical care included a stepwise approach: setting priorities for patient care, assessing patient's specific educational needs and identification of drug related problems (DRPs), development of a comprehensive and achievable pharmaceutical care plan in collaboration with the patient and the doctor, implementation of the this plan, monitoring and review of the plan from time to time (Hepler and Strand, 1990).

The nurses collaborated with the pharmacist in terms of organizing the patients and patients' folders, taking point of care testing, counseling the patients, and reinforcing the information given to the patients during training sections. The physicians provided the visitation/appointment schedule for the patients, and prescription of laboratory tests. They were also involved in implementation of consensus strategies in managing drug related problems in areas of changing, substitution, and withdrawal of medications. All the members of the health care team were trained before the implementation of the intervention.

Table 1. **The treatment goals/targets and therapeutic protocol.

S/N	Parameter	Goals/ Targets
1	HbA$_{1c}$	< 7%
2	FBG	70-130 mg/ dL
3	RBG	< 200 mg/dL
4	2h-postprandial blood glucose	< 180 mg/ dL
5	BP	< 130/80 mmHg
6	Total cholesterol	< 200 mg/ dL
7	LDL-C	< 100 mg/ dL or ~ 30-40% reduction.
8	HDL-C	>50 mg/dL (Women), > 40 mg/dL (men)
9	Triglycerides	< 150 mg/dL
10	Waist circumference	Male < 94 cm, female < 82 cm
11	Physical activity	1 h brisk walking ≥ 3 times/ week
12	Weight loss	~ 5-10% if overweight
13	Alcohol intake	< 1 (men) and < 0.5 (women) bottle of beer/day (3 units of alcohol per bottle)
14	Smoking cessation	100%
15	Medication adherence	100%
16	Continuous self-monitoring of glucose and BP	100%
17	Medication adherence	100%
18	Appointments/follow-up	100%
	Therapeutic protocol	**Actions**
19	Patient with Hypertension	ACEI/ ARB therapy
20	Dyslipidaemia or age > 40 years with CVD risk.	Statin therapy
21	If HbA$_{1c}$ > 8.5%	Basal insulin therapy
22	Age > 40 years with CVD risk	Aspirin/clopidogrel therapy

** These targets and protocols could be adjusted to meet individual needs of the patients.

The educational/training program for the patients consisted of 4 sessions of 90 to 120 min. The program covered the following areas: diabetes overview and its complications, self-monitoring blood glucose techniques and interpretation of diabetes related tests, medications and their side-effects, life style modification, counseling and effective interaction with health providers. Pharmaceutical care provided ground for the patients to monitor and react to changes in their blood glucose levels, allowing them to integrate their diabetes into the lifestyle

they preferred. Glucometer and strips were given to the patients as motivation and to encourage continuous self blood glucose monitoring. Data were collected on baseline (first 3 months), 6, 9 and 12 months. The treatment goals/targets and therapeutic protocol used during the study is shown in Table 1.

Data analysis

Statistical analyses were performed using the SPSS

version16. An intention-to-treat approach was used. Two-sample comparisons were made using Student's t-tests for normally distributed variables or Mann–Whitney U-tests for non-normally distributed data. Comparisons of proportions were done using Chi square or Fisher's exact. The differences in PC and UC were assessed at baseline and 12 months. An a priori significance level of $P < .05$ was used throughout.

Since we used two hospitals, we initially made comparisons of the sub-UC of UNTH and NAUTH, also

sub-PC of UNTH and NAUTH to determine their similarity, or, more specifically, to uncover any problems related to selection, history, or maturation effects. If major differences were identified, we planned to analyze and report the group findings separately. If the groups were found to be essentially similar in these respects, we planned to combine the groups for baselines and 12 months assessments of the effects of PCs (Cranor and Christensen, 2003). The latter condition was applicable to this study.

RESULTS

The medical and educational contents of the training course were rated positively by the 17 doctors and 29 nurses: the majority 38 (82.6%) rated the contents as 'Excellent' and remaining 8 as 'very good' or 'good' and only 3 (6.5%) of them suggested little modification or changes which were effected before the materials were administered.

The number of patients who completed the study and whose data were analysed at 12 months in UC and PC were 93 (84.55%) vs. 99 (90.0%), respectively. With the exception of patients' variables 'number of participants taking hypertensive drugs' and 'smoking', we found no other variable differing significantly at baseline when the sub-UC and sub-PC arms of the two hospitals were compared (Table 2).

The number of patients who completed the study and whose data were analyzed at 12 months in UC and PC were 93(84.55%) vs. 99 (90.0%) respectively. There were significant improvements in all the clinical parameters measured after 12 months of intervention (Table 3).

There were significant changes in number of patients that achieved 'control' in the following parameters (change, % change) after 12 months of intervention: HbA1c < 7%: 17 (18.28%); $P = 0.0466$; Obesity: -10 (10.75%); $P = 0.0364$, Overweight: -16 (-17.2%); $P = 0.0067$, and high-density lipoprotein cholesterol (HDL-C) > 40 mg/dl: 19 (20.43%); $P = 0.0195$ (Table 4). (For this study, we defined "control" as the normal ranges as reported by ADA (2011).

DISCUSSION

This study revealed that there were significant changes in number of patients that achieved 'control' in the following parameters after 12 months of intervention: HbA1c, overweight, and high-density lipoprotein cholesterol (HDL-C), LDL-C, Triglyceride and total cholesterol.

Patients with Type 2 diabetes are more likely to die from cardiovascular disease than people without diabetes, and modifiable risk factors such as hyperglycemia, dyslipidemia, and hypertension can be targeted to reduce this risk (UKPDS, 1998; Gaede et al., 2000). In addition to community-based care, there is a need for simple, cost-effective programs implemented in the hospital that allows the benefits of improved metabolic and blood pressure control to be realized more widely (Viberti, 2003). Pharmacists could contribute to

such programs through pharmaceutical care (PC). This PC intervention comprised elements that are parts or extensions of existing diabetes management namely: individualized patient education and follow-up reinforcement through additional written educational material; use face-to-face interview and appointments; provision of a regularly updated, goal-directed, patient-specific medication profile designed to improve patient compliance and understanding. It was tailored to promote communication of drug-related information between patient, pharmacist, primary care physician, and other health care professionals. Although, the clinical benefits of PC intervention in the present study cannot be assessed in relation to the individual contributions of these factors, they reflect effects of combined strategies (Kennie et al., 1998).

This study demonstrated that a 12-month PC program implemented for Type 2 diabetes patients can produce beneficial reductions in modifiable vascular risk factors, most notably glycemic control (HbA1C), blood pressure and dyslipidaemias. Pharmacist-administered diabetes education and management services have been shown to improve glycemic control over standard treatment, as well as to improve control of blood pressure, hyperlipidemia and increase in the frequency of aspirin use (Keil and McCord, 2005). Garrett and Bluml (2005) demonstrated that patients who participated in the pharmaceutical care intervention had significant improvement in clinical indicators of diabetes management, higher rates of self-management goal setting and achievement, and increased satisfaction with diabetes care.

Glycosylated Haemognobin (HbA1c)

A significant higher mean reduction was noted in PC group when 12-month value was compared to baseline value while there was no significant change in the UC group. This suggests that regular pharmacist contact was beneficial perhaps through encouraging adherence with blood glucose–lowering therapy and a prudent diet.

The HbA1C test is subject to certain limitations: conditions that affect erythrocyte turnover (haemolysis, blood loss) and haemoglobin variants must be considered, particularly when the HbA1C result does not correlate with the patient's clinical situation (DCCT, 1993; Stratton et al., 2000; Sack et al., 2002). In addition, HbA1C does not provide a measure of glycemic variability or hypoglycemia. For patients prone to glycemic variability (especially Type 1 patients, or Type 2 patients with severe insulin deficiency), glycemic control is best judged by the combination of results of self monitoring blood glucose (SMBG) testing and the HbA1C (ADA, 2011).

Blood pressure

This study demonstrated a positive effect of the pharmaceutical care intervention on blood pressure

Table 2. Baseline characteristics of the patients in PC and UC arms.

Demographic data	UC (N=110)	PC (N=110)	p-value
Mean Age (years)	52.8 ± 8.2	52.4 ± 7.6	0.708
Grouped Age: > 53 years, no (%)	81(73.64)	75 (68.18)	0.373
Sex: Male, no (%)	49 (44.55)	44 (40)	0.495
Level of education (%)			0.406
Primary school, no (%)	3 (2.72)	6 (5.45)	
Secondary school, no (%)	71 (64.55)	63 (57.27)	
University, no (%)	36 (32.73)	41 (37.27)	
Marital status (%)			0.409
Currently married, no (%)	37 (33.64)	46 (41.82)	
Widowed, no (%)	71 (64.54)	63 (57.27)	
Single, no (%)	2 (1.82)	1 (0.91)	
Occupation (%)			0.611
Self employed, no (%)	37 (33.64)	34 (30.91)	
Employee, no (%)	35 (31.82)	42 (38.18)	
Retired, no (%)	38 (34.54)	34 (30.91)	
Smoking status: Smoker, no (%)	34 (30.91)	21 (19.09)	0.043*
Dignostic Time- Mean (SD)	4.5±2.2	4.8±2.8	0.378
Dignostic Time: ≥ 5 years, no (%)	62 (56.36)	71 (64.55)	0.215
Family hx of diabetes, no (%)	71(64.55)	62 (56.36)	0.214
Physical Activity/Exercise no (%)	18 (16.36)	23 (20.91)	0.387
Co-morbidities			
Hypertension	60 (54.55)	73 (66.36)	0.073
Congestive heart failure	11 (10.00)	15 (13.64)	0.404
Ischemic heart disease	7 (6.36)	8 (7.27)	0.789
Arthritis	37 (33.64)	43 (39.09)	0.400
≥ 2 co-morbidities: no (%)	72 (65.45)	81 (73.64)	0.187
Overnight hospitalization, no (%)	9 (8.18)	7 (6.36)	0.604
Emergency Room, no (%)	1(0.91)	2 (1.82)	0.561
Use of insulin, no (%)	17 (15.45)	13 (11.82)	0.432
Anti-diabetic medication, no (%)	103 (93.64)	107 (97.27)	0.195
Other medications			
Daily Aspirin, no (%)	43 (39.09)	57 (51.82)	0.058
Diuretics, no (%)	71 (64.55)	84 (76.36)	0.055
Anti-Hypertensives, no (%)	98 (89.91)	78 (70.91)	0.0007*
Lipid lowering, no (%)	23 (20.91)	14 (12.73)	0.105
Complications			
Myocardial infarction, no (%)	2 (1.82)	4 (3.64)	0.408
Stroke, no (%)	9 (8.18)	6 (5.45)	0.422
Foot ulcer, no (%)	2 (1.82)	3 (2.73)	0.651
Blindness, no (%)	1 (0.91)	1 (0.91)	1.000
Renal failure, no (%)	3 (2.73)	8 (7.27)	0.122

levels. The reduction observed in the PC was more pronounced despite having the higher number of patients with hypertension who were in anti hypertensive drugs at baseline. This could be attributed to the effectiveness of pharmaceutical care in identifying and resolving drug-related problems and in optimizing adherence to lifestyle modifications (Machado et al., 2007; Krass et al., 2005; Al-Mazroui et al., 2009). The Fremantle Diabetes Study identified a reduction in mean SBP and DBP values over 12 months (Clifford et al., 2005). Significant reductions in SBP and DBP over 12 months were also reported by Al-Mazroui et al. (2009). In a study conducted by Lee et al. (2006), patients who submitted to a pharmaceutical care program for 18 months significantly reduced their mean

Table 3. Comparison of mean clinical data of PC and UC arms at baseline and 12 months.

Clinical outcomes	Baseline		12 Months		p-value	
	UC (n = 110)	PC (n = 110)	UC (n = 93)	PC (n = 99)	Baseline	12 months
Mean HbA1c (%)	7.785 ± 1.03	7.985 ± 1.06	7.77 ± 1.12	7.23 ± 1.09	0.318	0.0009*
Mean weight (kg)	66.5 ± 5.7	65.05 ± 4.7	66.20 ± 3.24	61.40 ± 5.37	0.148	<0.0001*
Mean body mass index (kg/m^2)	26.6 ± 3.5	27.2 ± 2.8	26.10 ± 4.29	25.28 ± 2.79	0.162	<0.1159
Mean SBP (mmHg)	140.84 ± 10.3	143.91 ± 12.8	141.82 ± 7.84	127.76 ± 6.98	0.051	<0.0001*
Mean DBP (mmHg)	87.32 ± 4.2	88.92 ± 7.9	86.32 ± 4.60	78.45 ± 4.97	0.062	<0.0001*
Mean FBG (mg/dL)	177.43 ± 11.8	180.61 ± 13.5	168.74 ± 11.49	129.34 ± 9.97	0.064	<0.0001*
Mean LDL-C (mg/dL)	112.43 ± 7.9	113.10 ± 10.6	116.28 ± 9.64	101.43 ± 8.35	0.596	<0.0001*
HDL-C (mg/dL)	44.65 ± 4.7	44.85 ± 5.1	45.29 ± 6.68	53.82 ± 5.81	0.763	<0.0001*
Triglycerides (mg/dL)	161.40 ± 11.4	162.41 ± 13.8	159.59 ± 8.91	154.37 ± 10.34	0.555	0.0002*
Total Cholesterol (mg/dL)	211.56 ± 22.3	204.4 ± 24.5	203.75 ± 25.96	188.71 ± 19.41	0.024*	<0.0001*

Table 4. Comparison of percentage of patients that achieved control at 12 months.

Clinical outcomes	Baseline		12th Month		p-value	
	UC(n=110)	PC (n=110)	UC (n=93)	PC (n=99)	baseline	12 months
HbA1c < 7%, no, (%)	42(38.18)	38(34.55)	44(47.31)	61(61.62)	0.575	0.0466*
Obese, no. (%)	17(15.45)	20(18.18)	22(23.66)	12(12.12)	0.589	0.0364*
Overweight, no, (%)	48(43.64)	51(46.36)	51(54.84)	35(35.35)	0.684	0.0067*
BP < 130/80 (mmHg), no. (%)	22(20.00)	17(15.45)	23(24.73)	33(33.33)	0.377	0.1900
LDL-C < 100 mg/dL, no. (%)	76(69.09)	71(64.55)	81(87.10)	86(86.87)	0.474	0.9626
HDL-C > 40 mg/dL, no. (%)	59(53.64)	61(55.45)	58(62.37)	77(77.78)	0.787	0.0195*
Triglycerides < 150 mg/dl), no. (%)	29(26.36)	31(28.18)	27(29.03)	39(39.39)	0.7621	0.1309
Total-C < 200 mg/dL, no. (%)	25(22.73)	28(25.45)	26(27.96)	38(38.38)	0.6362	0.1256

UC = Usual care and PC = Pharmaceutical care intervention.

SBP values but demonstrated no significant differences in DBP. Castro et al. (2006) reported a trend for better blood pressure control in uncontrolled hypertensive patients enrolled in a pharmaceutical care program over 6 months, although the differences were not statistically significant. These variations in results may be attributed to different characteristics of patients enrolled in the studies (age, baseline blood pressure levels, diseases presented, education level, and socio-economic status), study duration, and the characteristics of the health systems where the studies were conducted (availability of medications, availability of medical and nursing consultation, and others).

Lipid profile

The percentage change in number of patients who achieved HDL-C goal in the intervention group was significant after 12 months in comparison with the control group. Interventions to optimize adherence to lifestyle modifications, identify and resolve drug-related problems, particularly the drug-related problems concerning the

need for additional therapy such as statins and fibrates (Al-Mazroui et al, 2009; Mazzolini et al., 2005) supported to this result. Other studies had also demonstrated the effectiveness of pharmaceutical care programs in lowering lipid levels, but with varying figures in the results (Al-Mazroui et al, 2009; Clifford et al., 2005; Mazzolini et al., 2005).

Body Mass Index

Significant change in proportion of patients that achieved control in 12 months was observed in the intervention group compared with the control group. Obesity is a well-known risk factor for cardio-vascular diseases and it is associated with increased mortality. Obese (with BMI ≥ 30 kg/m^2) and overweight people (i.e., BMI of 25.0 to 29.9) have an increased risk of death from heart disease, stroke, and cancers. (Al-Mazroui et al., 2009) reported a smaller reduction in BMI (-1.05 kg/m^2) over 12 months in the United Arab Emirates health system. Another study demonstrated that a pharmaceutical care program reduced BMI from 30.0 to 29.4 kg/m^2 in 12 months

(Clifford et al., 2002). These studies demonstrated the effectiveness of pharmaceutical care in reducing BMI though with considerable variability, which may be due to a variety of factors such as diverse health system settings, different patient characteristics, and different study durations.

Limitations

Studies of this kind must address inherent potential threats to internal validity (Campbell and Stanley, 1963; Cook and Campbell, 1979). Several such threats were possible in this study: Missing data presented the most daunting challenge. Among the clinical outcomes measured, HbA1c concentration was the most important. Fortunately, this measure suffered the least from missing data, so it served well as the focus of clinical outcome assessments. Selection bias was a threat because participation was voluntary though the groups were randomized. It remains possible that patients who chose to participate in the program may have differed in some important way from those who did not participate.

Conclusion

The additional pharmaceutical care intervention resulted in beneficial improvement of the clinical outcomes over usual care in the following areas glycoslated haemoglobin (HbA$_{IC}$), glycemic control, blood pressure control, and lipid profile. The results of this study illustrate a convincing rationale for improving standards of care for patients with Type 2 diabetes through pharmaceutical care intervention. However, further research is needed to improve on the current pharmaceutical care intervention strategies such that the recorded improvements in clinical outcomes will be sustained for a very long time after an intervention.

Conflict of interest

The authors declare that they have no competing interests.

Authors' contributions

MOA and CNA designed the study. MOA carried out the statistical analysis. All the authors were involved in articles write-up. All authors read and approved the final manuscript.

REFERENCES

ADA (2011), American Diabetes Association. Standards of medical care in diabetes [Position Statement]. Diabetes Care 34 (Suppl. 1): S11-S61. PMid:21193625 PMCid:PMC3006050

Akanji A, Adetunji A (1990). The pattern of presentation of foot lesions in Nigerian diabetic patients. W. Afr. J. Med. 9:1-4. PMid:2271417

Al-Mazroui N, Kamal M, Ghabash N, Yacout T, Kole P, McElnay J (2009). Influence of pharmaceutical care on health outcomes in patients with Type 2 diabetes mellitus. Brit. J. Clin. Pharmacol. 67: 547-557. http://dx.doi.org/10.1111/j.1365-2125.2009.03391.x; PMid:19552750 PMCid:PMC2686072

Campbell D, Stanley J (1963). Experimental and Quasi-Experimental Designs for Research. Chicago, Illinois: Rand McNally College Publishing Company.

Castro MS, Fuchs FD, Santos MC, Maximiliano P, Gus M, Moreira LB, Ferreira MB (2006). Pharmaceutical care program for patients with uncontrolled hypertension: Report of a double-bind clinical trial with ambulatory blood pressure. Am. J. Hypertens. 19:528-533. http://dx.doi.org/10.1016/j.amjhyper.2005.11.009; PMid:16647628

Clifford R, Batty K, Davis T, Davis W, Stein G, Stewart G, Plumridge RJ (2002). A randomised controlled trial of a pharmaceutical care programme in high-risk diabetic patients in an outpatient clinic. Int. J. Pharm. Pract. 10:85- 89. http://dx.doi.org/10.1111/j.2042-7174.2002.tb00592.x

Clifford R, Batty K, Davis T, Davis W (2005). Effect of a Pharmaceutical Care Program on Vascular Risk Factors in Type 2 Diabetes (The Fremantle Diabetes Study). Diabetes Care 28:771-776. http://dx.doi.org/10.2337/diacare.28.4.771; PMid:15793171

Coast-Senior E, Kroner B, Kelley C, Trili L (1998). Management of patients with type 2 diabetes by pharmacists in primary care clinics. Ann. Pharmacother. 32:636-641. http://dx.doi.org/10.1345/aph.17095; PMid:9640480

Cook T, Campbell D (1979). Quasi-experimentation. Design and Analysis Issues for Field Studies. Chicago, Illinois: Rand McNally College Publishing Company.

Cranor C, Christensen D (2003). The Asheville Project: short-term outcomes of a community pharmacy diabetes care program. J. Am. Pharm. Assoc. 43:149-159. http://dx.doi.org/10.1331/108658003321480696; PMid:23945854

Davis TM, Clifford RM, Davis WA, Batty KT (2005). The role of pharmaceutical care in diabetes management. Br. J. Diabetes Vasc. Dis. 5(6):352-356. http://dx.doi.org/10.1177/14746514050050061001

DCCT (1993). The Diabetes Control and Complications Trial Research Group: The effect of intensive treatment of diabetes on the development and progression of long-term complications in insulin-dependent diabetes mellitus. New Engl. J. Med. 329:977-986. http://dx.doi.org/10.1056/NEJM199309303291401; PMid:8366922

Gaede P, Vedel P, Larsen N, Jensen G, Parving H, Pedersen O (2000). Multifactorial intervention and cardiovascular disease in patients with type 2 diabetes. New Engl. J. Med. 348:383393.

Garrett D, Bluml B (2005). Patient self-management program for diabetes: first-year clinical, humanistic, and economic outcomes. J. Am. Pharm. Assoc. 45:130-137. http://dx.doi.org/10.1331/1544345053623492

Hawkins D, Bradberry JC, Cziraky MJ, Talbert RL, Bartles DW, Cerveny JD (2002). National Pharmacy Cardiovascular Council treatment guidelines for the management of type 2 diabetes mellitus: Toward better patient outcomes and new roles for pharmacists. Pharmacotherapy 22(4):436-444. http://dx.doi.org/10.1592/phco.22.7.436.33667; PMid:11939679

Hepler C, Strand L (1990). Opportunities and responsibilities in pharmaceutical care. Am. J. Hosp. Pharm. 47:533-543. PMid:2316538

International diabetes federation: Diabetes atlas. http://da3.diabetesatlas.org/newsc269.html.

Jaber L, Halapy H, Fenret M, Tummalapalli S, Diwakaran H (1996). Evaluation of a pharmaceutical care model on diabetes management. Ann. Pharmacother. 30:238-243. PMid:8833557

Keil P, McCord A (2005). Pharmacist impact on clinical outcomes in a diabetes disease management program via collaborative practice. Ann. Pharmacother. 39: 1828-1832. http://dx.doi.org/10.1345/aph.1G356; PMid:16219894

Kennie N, Schuster B, Einarson T (1998). Critical analysis of the pharmaceutical care research literature. Ann Pharmacother. 32:17-26. PMid:9475815

Khan CR, Weir GC, King GL, Moses AC (2004). Joselin's Diabetes Mellitus. 14th ed. Philadelphia: Lippincott Williams & Wilkins.

Krass I, Taylor S, Carlene S, Armour C (2005). Impact on medication use and adherence of Australian Pharmacist's Diabetes Care Services. J. Am. Pharm. Assoc. 45: 33-40. http://dx.doi.org/10.1331/1544345052843093

Lee J, Grace K, Taylor A (2006). Effect of a pharmacy care program on medication adherence and persistence, blood pressure, and low-density lipoprotein cholesterol. J. Am. Med. Assoc. 296: 2563-2571. http://dx.doi.org/10.1001/jama.296.21.joc60162; PMid:17101639

Machado M, Bajcar J, Guzzo G, Einarson T (2007). Sensitivity of patient outcomes to pharmacist interventions. Part II: Systematic review and meta-analysis in hypertension management. Ann. Pharmacother. 41: 1770-1781. http://dx.doi.org/10.1345/aph.1K311; PMid:17925496

Mads-Haahr Random Sequence Generator (1998-2011). Available from: http://www.random.org/sequences/

Majumdar SR, Guirguis LM, Toth EL, Lewanczuk RZ, Lee TK, Johnson JA (2003). Controlled trial of a multifaceted intervention for improving quality of care for rural patients with type 2 diabetes. Diabetes Care 26: 3061-3066. http://dx.doi.org/10.2337/diacare.26.11.3061; PMid:14578240

Mazzolini T, Irons B, Schell E, Seifert C (2005). Lipid levels and use of lipid-lowering drugs for patients in pharmacist-managed lipid clinics versus usual care in 2 VA Medical clinics Centers. J. Manage Care Pharm. 11: 763-771. PMid:16300420

Nyenwe E, Odia O, Ihekwala A, Ojule A, Babatunde S (2003). Type 2 diabetes in adult Nigerians: A study of its prevalent and risk factors in Port Harcourt, Nigeria. Diab. Res. Clin. Pr. 62:177-185. http://dx.doi.org/10.1016/j.diabres.2003.07.002

Odili VU, Ugboka LU, Oparah AC (2010). Quality of life people with diabetes in Benin City as measured with WHOQoL-BREF. Internet J. Law Healthc. Ethics 6(2). http://www.ispub.com/journal/the-internet-journal-of-law-healthcare-and-ethics/volume-6-number-2/quality-of-life-of-people-with-diabetes-in-benin-city-as-measured-with-whoqol-bref.html.

Sack D, Bruns D, Goldstein D, Maclaren N, McDonald J, Parrott M (2002). Guidelines and recommendations forlaboratory analysis in the diagnosis and management of diabetes mellitus. Clin. Chem. 48:436-472.

Sadur C, Moline N, Costa M. Michalik D, Mendlowitz D, Roller S, Watson R, Swain BE, Selby JV, Javorski WC (1999). Diabetes management in a health maintenance organization. Efficacy of care management using cluster visits. Diabetes Care 22:2011-2017. http://dx.doi.org/10.2337/diacare.22.12.2011; PMid:10587835

Shaw J, Sicree R, Zimmet P (2010). Global estimates of the prevalence of diabetes. Diab. Res Clin. Pr. 87:4-14. http://dx.doi.org/10.1016/j.diabres.2009.10.007; PMid:19896746

Stratton I, Adler A, Neil H, Matthews D, Manley S, Cull C, Hadden D, Turner RC, Holman RR (2000). Association of glycaemia with macrovascular and microvascular complications of type 2 diabetes (UKPDS 35): Prospective observational study. Brit. Med. J. 321:405-412. http://dx.doi.org/10.1136/bmj.321.7258.405; PMid:10938048

UKPDS (1998). UK Prospective Diabetes Study Group: Intensive blood glucose control with sulphonylureas or insulin compared with conventional treatment and risk of complications in patients with type 2 diabetes (UKPDS 33). Lancet 352:837-853. http://dx.doi.org/10.1016/S0140-6736(98)07019-6

Viberti G (2003). The need for tighter control of cardiovascular risk factors in diabetic patients. J. Hypertens. 21(Suppl. 1):S3-S6.

Full Length Research Paper

Analytical solution of the steady state condensation film on the inclined rotating disk by a new hybrid method

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In this paper, a similarity transformation is used to reduce the three-dimensional steady state condensation film on an inclined rotating disk by a set of nonlinear boundary value problems. This problem is solved using a new hybrid technique based on differential transform method (DTM) and Iterative Newton's Method (INM). The differential equations and its boundary conditions are transformed to a set of algebraic equations, and the Taylor series of solution is calculated. After finding Jacobian matrix, the unknown parameters computed using Multi-Variable Iterative Newton's Method. These techniques are used to obtain an approximate solution of the problem. In this solution, there is no need to restrictive assumptions or linearization. The results compared with the numerical solution of the problem, and a good accuracy of the proposed hybrid method observed. Finally, the velocity and temperature profiles demonstrated for different values of problem parameters.

Key words: Condensation film, rotating disk, nonlinear boundary value problem, differential transform method, iterative Newton's method, Jacobian matrix.

INTRODUCTION

Usually scientific problems and phenomena in our world are essentially nonlinear and modeled by the nonlinear differential equations. Most of them do not have an exact analytical solution. So, numerical and approximate methods are used by researchers to solve such equations. The numerical methods are often costly and time consuming to get a complete form of results, because it gives the solution at the discrete points. Furthermore, in the numerical solution the stability and convergence should be considered to avoid divergence or inappropriate results.

Approximate techniques like Decomposition Method (DM), Homotopy Analysis Method (HAM), Homotopy Perturbation Method (HPM), Variational Iteration Method (VIM) are good substitutes for numerical methods. During the recent years, some of the nonlinear engineering problems have been solved using some of these methods, such as HAM (Rashidi et al., 2008; Dinarvand
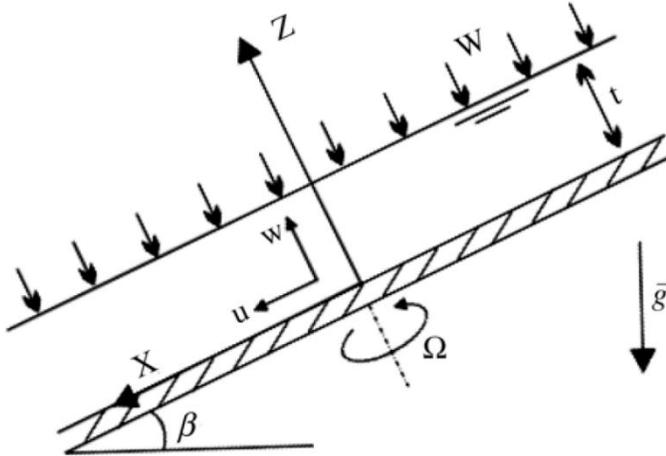
Figure 1. The schematic diagram of the problem (Rashidi and Dinarvand, 2009).

et al., 2009; Rashidi et al., 2008, 2009; Liao, 2009; Ziabakhsh and Domairry, 2009; Abbasbandy and Hayat, 2009), HPM (Raftari and Yildirim, 2010; Esmaeilpour and Ganji, 2007; Fathizadeh and Rashidi, 2009; Bararnia et al., 2012), VIM (Mohyud-Din et al., 2010; Rashidi and Shahmohamadi, 2009; Wazwaz, 2007) and DM (Wazwaz 2006; Alizadeh et al., 2009; Kechil and Hashim, 2007). In most of the researches, some modifications introduced to overcome the nonlinearity. Also, the fractional differential equations are investigated using some approximate solution in Yang (2012), Yang and Baleanu (2013) and Yang et al. (2013a, b).

Differential transform method is also one of the other approximate methods to solve differential equations. This method was introduced by Zhou (1986) to solve initial value problems in analysis of the electrical circuits. After that, DTM applied to differential algebraic equation (Ayaz, 2004; Liu and Song, 2007) partial differential equation (Ayaz, 2003, 2004; Ravi-Kanth and Aruna, 2008; Yang et al., 2006; Chang and Chang, 2009), integral equation (Odibat, 2008; Arikoglu and Ozkol, 2005, 2008), ordinary differential equation (Mosayebidorcheh, 2014; Mosayebidorcheh and Mosayebidorcheh, 2012; Torabi and Aziz, 2012; Joneidi et al., 2009) and fractional differential equation (Nazari and Shahmorad, 2010; Odibat et al., 2008; Erturk et al., 2008; Arikoglu and Ozkol, 2007). The method is an iterative technique to find the Taylor series solution of the problem. In this method, there is no need to the high calculation cost to determine the coefficients of Taylor series.

Removing a condensate liquid from a cooled, saturated vapor is applicable in engineering phenomena. First work with this subject is done by Von Karman (1921) about a rotating disk in an infinite fluid. The motion of the condensate film using centrifugal forces on a cooled rotating disk is considered by Sparrow and Gregg (1959). They transformed the Navier-Stokes equations into a system of nonlinear boundary value problems and

numerically integrated for some finite film thicknesses. Their work was extended by considering vapor drag by Beckett et al. (1973) and considering suction on the plate by Chary and Sarma (1976). The problem is also related to chemical vapor deposition, when a thin fluid film is deposited on a cooled rotating disk (Jensen, 1991).

The main goal of this paper is to present an analytical approximate solution of the steady three-dimensional problem of condensation film on the inclined rotating disk. This problem was studied by Wang (2007) and Rashidi and Dinarvand (2009).

MATHEMATICAL FORMULATION

Consider a disk rotating in its plane with angular velocity Ω (Figure 1). The angel between disk and horizontal axis is β. A fluid film with the thickness t is formed by spraying, with a velocity W. Assume the disk radius is large compared to the thickness of fluid film. So, the end effects can be neglected. The gravity acceleration $\bar{g}$ acts downward. The temperatures on the disk and on the film are T_w and T_0, respectively. We can consider the pressure as a function of z only, because the ambient pressure on the film surface is constant p_0. Ignoring the viscous dissipation term, the continuity, momentum and energy equations for the steady state are given in the following form:

$$u_x + v_y + w_z = 0, \tag{1}$$

$$uu_x + vu_y + wu_z = \nu\left(u_{xx} + u_{yy} + u_{zz}\right) + \bar{g}\sin\beta, \tag{2}$$

$$uv_x + vv_y + wv_z = \nu\left(v_{xx} + v_{yy} + v_{zz}\right), \tag{3}$$

$$uw_x + vw_y + ww_z = \nu\left(w_{xx} + w_{yy} + w_{zz}\right) - \bar{g}\cos\beta - p_z/\rho, \tag{4}$$

$$uT_x + vT_y + wT_z = \alpha\left(T_{xx} + T_{yy} + T_{zz}\right). \tag{5}$$

In these equations u, v and w denote the velocity components in the x, y and z directions, respectively and T indicates the temperature, ρ, ν and α are the density, kinematic viscosity and thermal diffusivity of the fluid, respectively. Assuming zero shears on the film surface and zero slip on disk, the following boundary conditions exist

$$u = -\Omega y, \quad v = \Omega x, \quad w = 0, \quad T = T_w \quad \text{at } z = 0,$$
$$u_z = 0, \quad v_z = 0, \quad w = -W, \quad T = T_0, \quad p = p_0 \quad \text{at } z = t. \tag{6}$$

The following transforms used for this problem (Wang, 2007).

$$u = -\Omega y g(\eta) + \Omega x f'(\eta) + \bar{g}p(\eta)\sin\beta/\Omega,$$
$$v = \Omega x g(\eta) + \Omega y f'(\eta) + \bar{g}s(\eta)\sin\beta/\Omega, \tag{7}$$
$$w = -2\sqrt{\Omega\nu}f(\eta),$$
$$T = (T_0 - T_w)\theta(\eta) + T_w,$$

Where

$$\eta = z\sqrt{\Omega/\nu}.\tag{8}$$

The conservation law (Equation (1)) is automatically satisfied. The Equations (2) to (5) can be written as follow:

$$f''' - \left(f'\right)^2 + g^2 + 2f\,f'' = 0,\tag{9}$$

$$g'' - 2g\,f' + 2f\,g' = 0,\tag{10}$$

$$p'' - p\,f' + sg + 2f\,p' + 1 = 0,\tag{11}$$

$$s'' - g\,p - s\,f' + 2f\,s' = 0,\tag{12}$$

$$\theta'' + 2\Pr f\,\theta' = 0.\tag{13}$$

Where $\Pr = \nu/\alpha$ is the Prandtl number. The boundary conditions for Equations (9) to (13) are

$$
\begin{aligned}
&f\left(0\right)=0, \quad f'\left(0\right)=0, \quad f''\left(\delta\right)=0,\\
&g\left(0\right)=1, \quad g'\left(\delta\right)=0,\\
&p\left(0\right)=0, \quad p'\left(\delta\right)=0,\\
&s\left(0\right)=0, \quad s'\left(\delta\right)=0,\\
&\theta\left(0\right)=0, \quad \theta\left(\delta\right)=1.
\end{aligned}\tag{14}
$$

Where δ is constant normalized thickness

$$\delta = t\sqrt{\Omega/\nu}.\tag{15}$$

DIFFERENTIAL TRANSFORM METHOD

The differential transform is defined as follows:

$$X(k) = \frac{1}{k!}\left[\frac{d^k x(t)}{dt^k}\right]_{t=t_0},\tag{16}$$

where, $x(t)$ is an arbitrary function, and $X(k)$ is the transformed function. The inverse transformation is as follows:

$$x\left(t\right) = \sum_{k=0}^{\infty} X\left(k\right)\left(t - t_0\right)^k.\tag{17}$$

Substituting Equation (16) into Equation (17), we have

$$x\left(t\right) = \sum_{k=0}^{\infty} \frac{\left(t - t_0\right)^k}{k!}\left[\frac{d^k x\left(t\right)}{dt^k}\right]_{t=t_0}.\tag{18}$$

The function $x(t)$ is usually considered as a series with limited terms and Equation (17), can be rewritten as:

$$x\left(t\right) \approx \sum_{k=0}^{m} X\left(k\right)\left(t - t_0\right)^k.\tag{19}$$

Where, m represents the number of Taylor series' components. Usually, through elevating this value, we can increase the accuracy of the solution. Some properties of the DTM are shown in Table 1. These properties are extracted from Equations (16) and (17).

SOLUTION OF THE PROBLEM

Here, we try to solve the Equations (9) to (13) using a new hybrid technique. The solution consists of two stages, first through mathematical relations and applying DTM, the Taylor series of solution is found. After that, the iterative Newton's method applied to obtain the unknown parameters.

Applying DTM

Each boundary value problem (Equations (9) to (13)) can be transformed to an initial value problem with the replacement of the unknown initial conditions instead of the boundary conditions at end.

$$f''(0)=a_1, \quad g'(0)=a_2, \quad p'(0)=a_3, \quad s'(0)=a_4, \quad \theta'(0)=a_5.\tag{20}$$

By applying the DTM on Equations (9) to (13) at $\eta = 0$, the following recursive relations obtained for calculating the series solutions' coefficients

$$
\begin{aligned}
F\left(k+3\right) = \frac{1}{(k+1)(k+2)(k+3)}\Bigg\{&\sum_{r=0}^{k}(r+1)F(r+1)(k-r+1)F(k-r+1)\\
&-\sum_{r=0}^{k}G(r)G(k-r)-2\sum_{r=0}^{k}(r+1)(r+2)F(r+2)F(k-r)\Bigg\},
\end{aligned}\tag{21}
$$

$$G\left(k+2\right) = \frac{2}{(k+1)(k+2)}\left\{\sum_{r=0}^{k}(r+1)F(r+1)G(k-r)-\sum_{r=0}^{k}(r+1)G(r+1)F(k-r)\right\},\tag{22}$$

$$
\begin{aligned}
P\left(k+2\right) = \frac{1}{(k+1)(k+2)}\Bigg\{&\sum_{r=0}^{k}(r+1)F(r+1)P(k-r)\\
&-\sum_{r=0}^{k}S(r)G(k-r)-2\sum_{r=0}^{k}(r+1)P(r+1)F(k-r)-\delta(k)\Bigg\},
\end{aligned}\tag{23}
$$

$$
\begin{aligned}
S\left(k+2\right) = \frac{1}{(k+1)(k+2)}\Bigg\{&\sum_{r=0}^{k}G(r)P(k-r)\\
&+\sum_{r=0}^{k}(r+1)F(r+1)S(k-r)-2\sum_{r=0}^{k}(r+1)S(r+1)F(k-r)\Bigg\},
\end{aligned}\tag{24}
$$

$$\Theta\left(k+2\right) = \frac{1}{(k+1)(k+2)}\left\{-2\Pr\sum_{r=0}^{k}(r+1)\Theta(r+1)F(k-r)\right\}.\tag{25}$$

The differential transform of the conditions at $\eta = 0$ in Equations (14) and (20) is:

$$
\begin{aligned}
&F(0)=0, \quad G(0)=1, \quad P(0)=0, \quad S(0)=0, \quad \Theta(0)=0,\\
&F(1)=0, \quad G(1)=a_2, \quad P(1)=a_3, \quad S(1)=a_4, \quad \Theta(1)=a_5,\\
&F(2)=a_1.
\end{aligned}\tag{26}
$$

Table 1. The properties of the DTM.

Original function	Transformed function
$f(t) = g(t) \pm h(t)$	$F(k) = G(k) \pm H(k)$
$f(t) = cg(t)$	$F(k) = cG(k)$
$f(t) = \dfrac{d^n g(t)}{dt^n}$	$F(k) = \dfrac{(k+n)!}{k!} G(k+n)$
$f(t) = g(t)h(t)$	$F(k) = \displaystyle\sum_{r=0}^{k} G(r)H(k-r)$
$f(t) = t^n$	$F(k) = \delta(k-n) = \begin{cases} 1 & if\ k = n \\ 0 & if\ k \neq n \end{cases}$

Substituting Equation (26) into Equations (21) to (25) for $k=0,1,\dots$, we have:

$$f(\eta) = \frac{a_1}{2}\eta^2 - \frac{1}{6}\eta^3 - \frac{1}{12}a_2\eta^4 - \frac{1}{60}a_2^2\eta^5 - \frac{1}{360}a_1\eta^6 + \left(\frac{1}{2520} - \frac{1}{630}a_2a_1\right)\eta^7 + \cdots, \tag{27}$$

$$g(\eta) = 1 + a_2\eta - \frac{1}{3}a_1\eta^3 + \left(\frac{1}{12}a_1a_2 - \frac{1}{12}\right)\eta^4 - \frac{1}{15}a_2\eta^5 - \left(\frac{1}{90}a_1^2 + \frac{1}{45}a_2^2\right)\eta^6 + \cdots, \tag{28}$$

$$p(\eta) = a_3\eta - \frac{1}{2}\eta^2 - \frac{1}{6}a_4\eta^3 - \frac{1}{12}a_2a_4\eta^4 + \left(\frac{1}{40}a_1 - \frac{1}{60}a_3\right)\eta^5 - \left(\frac{1}{720} + \frac{1}{72}a_2a_3\right)\eta^6 + \cdots, \tag{29}$$

$$s(\eta) = a_4\eta + \frac{1}{6}a_3\eta^3 + \left(\frac{1}{12}a_2a_3 - \frac{1}{24}\right)\eta^4 - \left(\frac{1}{60}a_4 + \frac{1}{40}a_2\right)\eta^5 - \frac{1}{72}a_2a_4\eta^6 + \cdots, \tag{30}$$

$$\theta(\eta) = a_5\eta - \frac{1}{1200}a_1a_5\eta^4 + \frac{1}{6000}a_5\eta^5 + \frac{1}{18000}a_2a_5\eta^6 + \frac{1}{126000}\left(a_1^2 + a_2^2\right)a_5\eta^7 + \cdots. \tag{31}$$

Applying Iterative Newton's method

Now, we have to obtain the unknown parameters from the boundary conditions at the end (Equation (14)) and substituting $\eta = \delta$ in Equations (27) to (31). Regarding this, we define the following residual functions to minimize them for obtaining the unknown parameters:

$$R_1 = f''(\delta, a_1, a_2, a_3, a_4, a_5) = \sum_{k=2}^{m} k(k-1)F(k)\delta^{k-2},$$

$$R_2 = g'(\delta, a_1, a_2, a_3, a_4, a_5) = \sum_{k=1}^{m} kG(k)\delta^{k-1}, \tag{32}$$

$$R_3 = p'(\delta, a_1, a_2, a_3, a_4, a_5) = \sum_{k=1}^{m} kP(k)\delta^{k-1},$$

$$R_4 = s'(\delta, a_1, a_2, a_3, a_4, a_5) = \sum_{k=1}^{m} kS(k)\delta^{k-1},$$

$$R_5 = \theta(\delta, a_1, a_2, a_3, a_4, a_5) - 1 = \sum_{k=0}^{m} \Theta(k)\delta^k - 1.$$

The above functions must be zero to get the values a_1 to a_5. To obtain the roots of the Equation (32), we use the following multi-variable iterative Newton's method:

$$\begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix}_{n+1} = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix}_n - \begin{bmatrix} \dfrac{\partial R_1}{\partial a_1} & \cdots & \dfrac{\partial R_1}{\partial a_5} \\ \vdots & \ddots & \vdots \\ \dfrac{\partial R_5}{\partial a_1} & \cdots & \dfrac{\partial R_5}{\partial a_5} \end{bmatrix}_n^{-1} \begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \\ R_5 \end{bmatrix}_n, \qquad n = 0,1,2,\cdots. \tag{33}$$

After guessing the initial values for a_1 to a_5, we have to calculate the residual vector (*R*) and Jacobian Matrix ($\frac{\partial R_i}{\partial a_j}$). The residual vector can be obtained by substituting $(a_1,\dots,a_5)^n$ in Equation (32). The elements of the Jacobian matrix in Equation (33) can be computed by differentiating analytically with respect to a_1 to a_5 and then substituting $(a_1,\dots,a_5)^n$ in that equation. The Jacobian elements are presented in the appendix A for $\delta = 1$ and *Pr*=1.

RESULTS

The accuracy chosen for computing a_1 to a_5 by Newton's method was 10^{-6}. Figures 2 and 3 demonstrate graphical representation of the presented results and numerical solution to show the efficiency and accuracy of the hybrid proposed method. In these figures, the present results compared with the numerical solution by the Runge-Kutta method. The approximate solution of the problem is presented in Table 2 for *Pr*=1. The values of the unknown parameters a_1, a_2, a_3, a_4 and a_5 presented in Table 3 for *Pr*=5 and different thickness numbers. These values can be substituted in Equations (27) to (31) to obtain the approximate solution of the problem. All of the initial guesses for a_1 to a_5 considered 1. The history of the convergence is shown in Figure 4 for a special case. As we can see in Figure 6 the problem converged rapidly
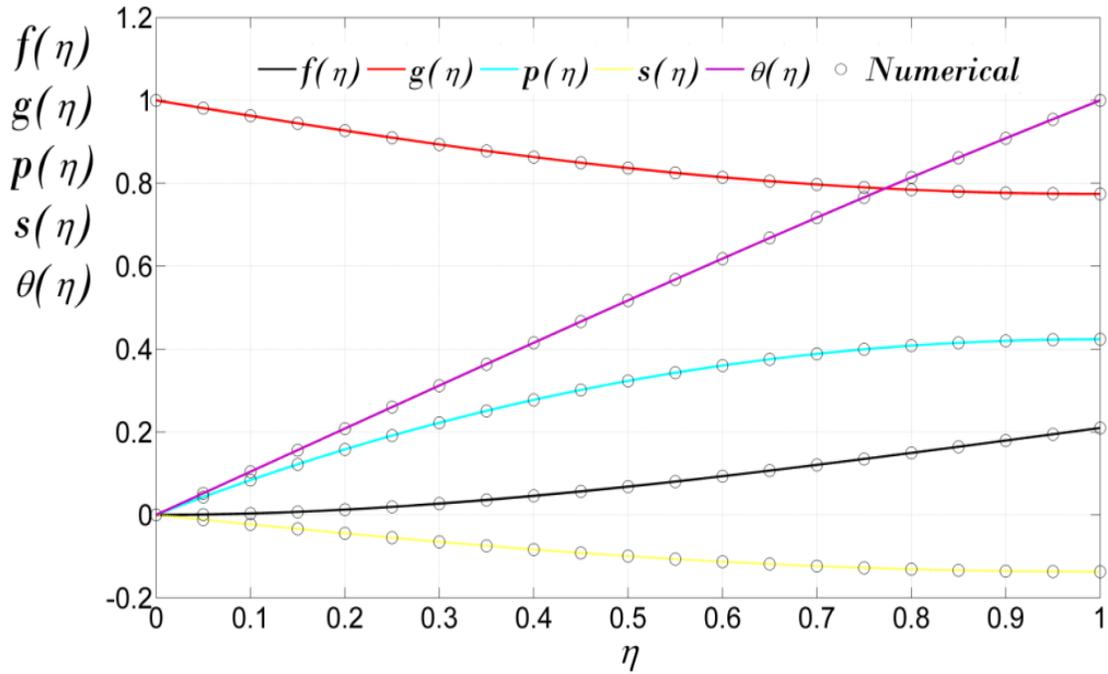
Figure 2. The profiles $f(\eta), g(\eta), p(\eta), s(\eta)$ and $\theta(\eta)$ when $\delta = 1$ and *Pr*=1.
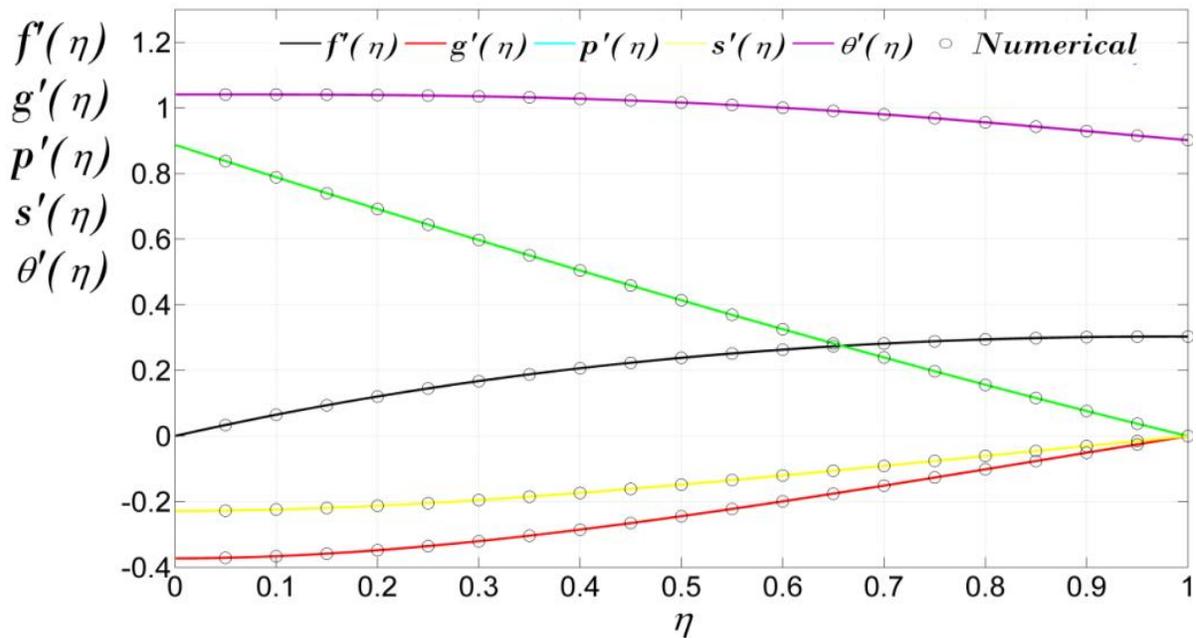
**Figure 3.** The profiles $f'(\eta), g'(\eta), p'(\eta), s'(\eta)$ and $\theta'(\eta)$ when $\delta = 1$ and *Pr*=1.

with only 5 iterations. This is because the Jacobian matrix obtained by differentiating analytically with respect to a_1 to a_5.

DISCUSSION

Most physical problems in fluid mechanics and heat transfer usually converted to a system of boundary value

Table 2. The approximate solutions $f(\eta), g(\eta), p(\eta), s(\eta)$ and $\theta(\eta)$ when Pr=1.

Solutions	Approximate solution
$\delta = 0.5$	$f(\eta) = 0.2412\eta^2 - 0.1667\eta^3 + 0.0066\eta^4 - 0.0001\eta^5 - 0.0013\eta^6 + 0.0004\eta^7 - 0.0000\eta^8$ $g(\eta) = 1 - 0.0787\eta + 0.1608\eta^3 - 0.0865\eta^4 + 0.0052\eta^5 - 0.0027\eta^6 + 0.0016\eta^7 - 0.0004\eta^8$ $s(\eta) = -0.0401\eta + 0.0823\eta^3 - 0.0449\eta^4 + 0.0026\eta^5 - 0.0000\eta^6 - 0.0003\eta^7 + 0.0000\eta^8$ $p(\eta) = 0.4941\eta - 0.5\eta^2 + 0.0067\eta^3 - 0.0002\eta^4 + 0.0038\eta^5 - 0.0008\eta^6 - 0.0001\eta^7 - 0.0004\eta^8$ $\theta(\eta) = 2.0080\eta - 0.0807\eta^4 + 0.0335\eta^5 - 0.0009\eta^6 + 0.0037\eta^7 - 0.0033\eta^8$
$\delta = 1$	$f(\eta) = 0.3489\eta^2 - 0.1667\eta^3 + 0.0311\eta^4 - 0.0023\eta^5 - 0.0019\eta^6 + 0.0008\eta^7 - 0.0001\eta^8$ $g(\eta) = 1 - 0.3720\eta + 0.2355\eta^3 - 0.1052\eta^4 + 0.0248\eta^5 - 0.0086\eta^6 + 0.0031\eta^7 - 0.0009\eta^8$ $p(\eta) = 0.8933\eta - 0.5\eta^2 + 0.0380\eta^3 - 0.0071\eta^4 + 0.0028\eta^5 + 0.0032\eta^6 - 0.0008\eta^7 - 0.0008\eta^8$ $s(\eta) = -0.2281\eta + 0.1489\eta^3 - 0.0693\eta^4 + 0.0131\eta^5 - 0.0012\eta^6 + 0.0004\eta^7 - 0.0003\eta^8$ $\theta(\eta) = 1.0445\eta - 0.0615\eta^4 + 0.0174\eta^5 - 0.0022\eta^6 + 0.0042\eta^7 - 0.0025\eta^8$

Table 3. The values of a_1, a_2, a_3, a_4 and a_5 obtained by iterative Newton's method when Pr=5.

Solutions	a_1	a_2	a_3	a_4	a_5
$\delta = 0.1$	0.0999	-0.0006	0.0999	-0.0003	10.0003
$\delta = 0.2$	0.1998	-0.0053	0.1999	-0.0027	5.0026
$\delta = 0.3$	0.2986	-0.0178	0.2995	-0.0089	3.3422
$\delta = 0.4$	0.3940	-0.0416	0.3980	-0.0210	2.5209
$\delta = 0.5$	0.4825	-0.0787	0.4941	-0.0401	2.0399
$\delta = 0.6$	0.5594	-0.1285	0.5862	-0.0667	1.7329
$\delta = 0.7$	0.6208	-0.1879	0.6726	-0.1003	1.5279
$\delta = 0.8$	0.6647	-0.2519	0.7522	-0.1395	1.3885
$\delta = 0.9$	0.6921	-0.3149	0.8249	-0.1823	1.2956
$\delta = 1$	0.7057	-0.3730	0.8910	-0.2272	1.2423

problems (BVPs) and it is essential to find the powerful analytical, approximate and numerical methods for solving this type of differential equations. The steady state condensation film on the inclined rotating disk is one of the mechanical problems which governing equations of it can be formulated as nonlinear system of boundary value problems. Here, a hybrid procedure is proposed to solve the differential equations of problem. This technique is based on differential transform method and Newton's iterative method as a combination of analytical and numerical methods. The results of this technique can be obtained as a polynomial function (Taylor series with limited terms). This is one of the advantages of method. The rapid convergence of solution is also significant.

Conclusion

In this paper, a similarity transformation is used to reduce the governing equations of condensation film on an inclined rotating disk by a set of nonlinear boundary value problems. This problem is solved using a new hybrid technique based on differential transform method (DTM) and Iterative Newton's Method (INM). Using the method,
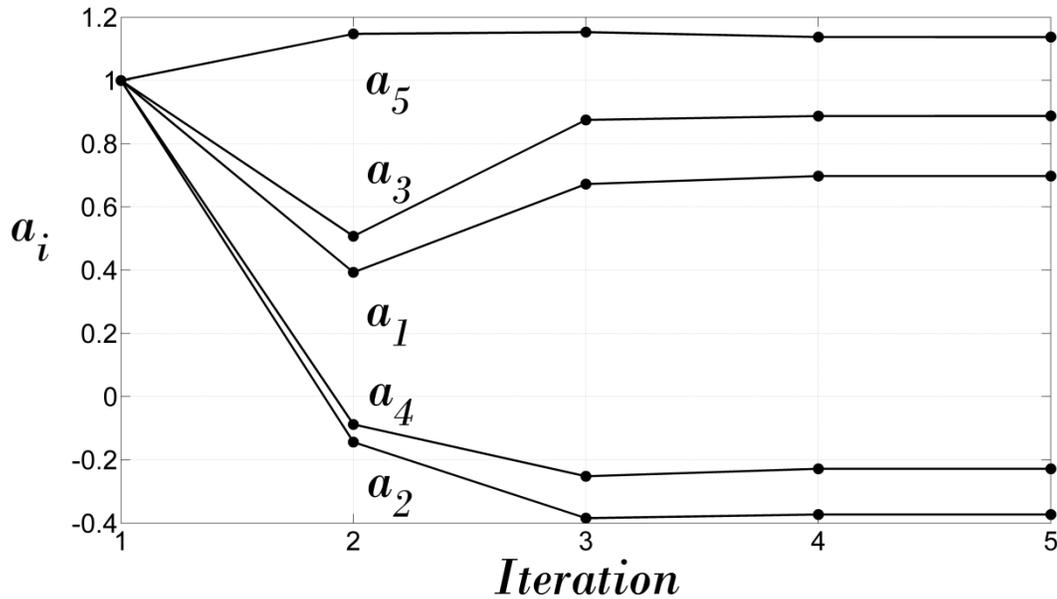
Figure 4. The history of the iterative Newton's method when $\delta = 1$ and *Pr*=5.

the differential equations and boundary conditions are transformed into a recurrence set of equations. After finding Jacobian matrix, the unknown parameters computed using multi-variable iterative Newton's method. Finally, the approximate solution is obtained. The main objective of the present research paper is to introduce a powerful and simple technique as a high accuracy and efficient method for solving a set of nonlinear boundary value problems. The accuracy and efficiency of proposed technique is verified by the numerical results.

NOMENCLATURE

DTM: Differential transformation method
$\bar{g}$: Gravity acceleration

p_0 : Pressure on the film surface

Pr : Prandtl number
T: Temperature

T_w : Disk temperature

T_0 : Film temperature

t: Thickness
u: Velocity component in *x* direction
v: Velocity component in *y* direction
w: Velocity component in *z* direction

Greek symbols

Ω : Angular velocity
β : Angel between disk and horizontal disk

ρ : Density
ν : Kinematic viscosity
α : Thermal diffusivity
δ : normalized thickness

REFERENCES

Abbasbandy S, Hayat T (2009). Solution of the MHD Falkner-Skan flow by homotopy analysis method. Commun. Nonlin. Sci. Num. Simul. 14:3591-3598. http://dx.doi.org/10.1016/j.cnsns.2009.01.030

Arikoglu A, Ozkol I (2007). Solution of fractional differential equations by using differential transform method, Chaos Solit. Fract. 34:1473–1481. http://dx.doi.org/10.1016/j.chaos.2006.09.004

Arikoglu A, Ozkol I (2008). Solutions of integral and integro-differential equation systems by using differential transform method. Comput. Math. Appl. 56:2411–2417. http://dx.doi.org/10.1016/j.camwa.2008.05.017

Arikoglu A,Ozkol I (2005).Solution of boundary value problems for integro-differential equations by using differential transform method. Appl. Math. Comput. 168:1145–1158. http://dx.doi.org/10.1016/j.amc.2004.10.009

Alizadeh E, Sedighi K, Farhadi M, Ebrahimi-Kebri HR (2009). Analytical approximate solution of the cooling problem by Adomian decomposition method. Commun. Nonlin. Sci. Num. Simul. 14 462–472. http://dx.doi.org/10.1016/j.cnsns.2007.09.008

Ayaz F (2004). Solutions of the system of differential equations by differential transform method. Appl. Math. Comput. 147:547–567. http://dx.doi.org/10.1016/S0096-3003(02)00794-4

Ayaz F (2004). Applications of differential transform method to differential-algebraic equations. Appl. Math. Comput. 152 649–657. http://dx.doi.org/10.1016/S0096-3003(03)00581-2

Ayaz F (2003). On the two-dimensional differential transform method. Appl. Math. Comput. 143:361–374. http://dx.doi.org/10.1016/S0096-3003(02)00368-5

Beckett PM, Hudson PC, Poots G (1973).Laminar film condensation due to a rotating disk, J. Eng. Math. 7:63–73.

http://dx.doi.org/10.1007/BF01535269

Bararnia H,Ghasemi E, Soleimani S, Ghotbi AR, Ganji DD (2012). Solution of the Falkner–Skan wedge flow by HPM–Pade' method. Adv. Eng. Soft. (43):44–52.

Chang SH, Chang IL (2009). A new algorithm for calculating two-dimensional differential transform of nonlinear functions. Appl. Math. Comput. 215:2486–2494. http://dx.doi.org/10.1016/j.amc.2009.08.046

Chary SP, Sarma PK (1976). Condensation on a rotating disk with constant axial suction. J. Heat Transf. 98:682–684. http://dx.doi.org/10.1115/1.3450624

Dinarvand S, Rashidi MM, Doosthoseini A (2009). Analytical approximate solutions for two dimensional viscous flow through expanding or contracting gaps with permeable walls. Cent. Eur. J. Phys. 7(4). http://dx.doi.org/10.2478/s11534-009-0024-x

Esmaeilpour M, Ganji DD (2007). Application of He's homotopy perturbation method to boundary layer flow and convection heat transfer over a flat plate. Phys. Lett. A. 372:33–38. http://dx.doi.org/10.1016/j.physleta.2007.07.002

Erturk VS, Momani S, Odibat Z (2008). Application of generalized differential transform method to multi-order fractional differential equations. Commun. Nonlin. Sci. Numer. Simul. 13:1642–1654. http://dx.doi.org/10.1016/j.cnsns.2007.02.006

Fathizadeh M, Rashidi F (2009). Boundary layer convective heat transfer with pressure gradient using Homotopy Perturbation Method (HPM) over a flat plate. Chaos Solit. Fract. 42:2413–2419. http://dx.doi.org/10.1016/j.chaos.2009.03.135

Joneidi AA, Ganji DD, Babaelahi M (2009). Differential Transformation Method to determine fin efficiency of convective straight fins with temperature dependent thermal conductivity. Int. Commun. Heat Mass Transf. 36:757–762. http://dx.doi.org/10.1016/j.icheatmasstransfer.2009.03.020

Jensen KF (1991). Flow phenomena in chemical vapor deposition of thin films. Ann. Rev. Fluid. Mech. 23:197–232. http://dx.doi.org/10.1146/annurev.fl.23.010191.001213

Kechil SA, Hashim I (2007). Non-perturbative solution of free-convective boundary-layer equation by Adomian decomposition method. Phys. Lett. A 363:110–114. http://dx.doi.org/10.1016/j.physleta.2006.11.054

Liu H, Song Y (2007). Differential transform method applied to high index differential–algebraic equations. Appl. Math. Comput. 184:748–753. http://dx.doi.org/10.1016/j.amc.2006.05.173

Liao SH (2009). A general approach to get series solution of non-similarity boundary-layer flows. Commun. Nonlin. Sci. Num. Simul. 14:2144–2159. http://dx.doi.org/10.1016/j.cnsns.2008.06.013

Mohyud-Din ST, Yildirim A,Sezer SA, Usman M (2010). Modified Variational iteration method for free-convective boundary-layer equation using Pade approximation. Math. Problems Eng. Article ID 318298, 11.

Mosayebidorcheh S (2014). Analytical investigation of the micropolar flow through a porous channel with changing walls. J. Mol. Liq. 196:113–119. http://dx.doi.org/10.1016/j.molliq.2014.03.022

Mosayebidorcheh S, Mosayebidorcheh T (2012). Series solution of convective radiative conduction equation of the nonlinear fin with temperature dependent thermal conductivity. Int. J. Heat Mass Transf. 55:6589–6594. http://dx.doi.org/10.1016/j.ijheatmasstransfer.2012.06.066

Mosayebidorcheh S, Ganji DD, Farzinpoor M (2014). Approximate solution of the nonlinear heat transfer equation of a fin with the power-law temperature-dependent thermal conductivity and heat transfer coefficient. Propul. Power Res. 3(1):41–47. http://dx.doi.org/10.1016/j.jppr.2014.01.005

Nazari D, Shahmorad S (2010). Application of the fractional differential transform method to fractional-order integro-differential equations with nonlocal boundary conditions. J. Comput. Appl. Math. 234:883–891. http://dx.doi.org/10.1016/j.cam.2010.01.053

Rashidi MM, Shahmohamadi H, Dinarvand S (2008). Analytic Approximate Solutions for Unsteady Two-Dimensional and Axisymmetric Squeezing Flows between Parallel Plates. Math. Problems Eng. Article ID 935095, p. 13.

Rashidi MM,Shahmohamadi H (2009). Analytical solution of three-dimensional Navier–Stokes equations for the flow near an infinite rotating disk. Commun. Nonlin. Sci. Numer. Simul. 14:2999–3006.

http://dx.doi.org/10.1016/j.cnsns.2008.10.030

Rashidi MM, Domairry G, Dinarvand S (2009). Approximate solutions for the Burger and regularized long wave equations by means of the homotopy analysis method. Commun. Nonlin. Sci. Num. Simul. 14:708–717. http://dx.doi.org/10.1016/j.cnsns.2007.09.015

Rashidi MM, Ganji DD, Dinarvand S (2008). Approximate Traveling Wave Solutions of Coupled Whitham-Broer-Kaup Shallow Water Equations by Homotopy Analysis Method. Diff. Equ. Nonlin. Mech. Article ID 243459, P. 8.

Ravi Kanth ASV, Aruna K (2008). Differential transform method for solving linear and non-linear systems of partial differential equations. Phys. Lett. A. 372:6896–6898. http://dx.doi.org/10.1016/j.physleta.2008.10.008

Raftari B,Yildirim A (2010). The application of homotopy perturbation method for MHD flows of UCM fluids above porous stretching sheets. Comput. Math. Appl. 59:3328–3337. http://dx.doi.org/10.1016/j.camwa.2010.03.018

Rashidi MM, Dinarvand S (200). Purely analytic approximate solutions for steady three-dimensional problem of condensation film on inclined rotating disk by homotopy analysis method. Nonlin. Anal.: Real World Appl. 10:2346–2356.

Odibat ZM (2008). Differential transform method for solving Volterra integral equation with separable kernels. Math. Comput. Modell. 48:1144–1149. http://dx.doi.org/10.1016/j.mcm.2007.12.022

Odibat Z, Momani S, Erturk VS (2008). Generalized differential transform method: Application to differential equations of fractional order. Appl. Math. Comput. 197:467–477. http://dx.doi.org/10.1016/j.amc.2007.07.068

von Karman TV (1921). Uberlaminare und turbulentereibung, Z. Angew. Math. Mech. 1:233–252.

Sparrow EM, Gregg JL (1959). A theory of rotating condensation. J. Heat Transf. 81:113–120.

Torabi M, Aziz A (2012). Thermal performance and efficiency of convective–radiative T-shaped fins with temperature dependent thermal conductivity, heat transfer coefficient and surface emissivity. Int. Commun. Heat. Mass Transf. 39(8):1018-1029. http://dx.doi.org/10.1016/j.icheatmasstransfer.2012.07.007

Wazwaz AM (2007). The variational iteration method for solving two forms of Blasius equation on a half-infinite domain. Appl. Math. Comput. 188:485-491. http://dx.doi.org/10.1016/j.amc.2006.10.009

Wazwaz AM (2006). The modified decomposition method and Pade´ approximants for a boundary layer equation in unbounded domain. Appl. Math. Comput. 177:737–744. http://dx.doi.org/10.1016/j.amc.2005.09.102

Wang CY (2007). Condensation film on an inclined rotating disk. Appl. Math. Modell. 31:1582–1593. http://dx.doi.org/10.1016/j.apm.2006.05.013

Yang XJ, Baleanu D (2013). Fractal heat conduction problem solved by local fractional variation iteration method. Therm. Sci. 17(2):625-628. http://dx.doi.org/10.2298/TSCI121124216Y

Yang AM, Yang XJ, Li ZB (2013a). Local fractional series expansion method for solving wave and diffusion equations on cantor sets. Abstr. Appl. Analysis. Article ID 351057, p. 5.

Yang XJ, Baleanu D, Zhong WP (2013b). Approximate solutions for diffusion equations on Cantor space-time. Proc. Roman. Acad. Ser. A. 14(2):127-133.

Yang XJ (2012). Local Fractional Functional Analysis and Its Applications. Asian Academic Publisher Limited, Hong Kong; Advanced Local Fractional Calculus and Its Applications, World Science Publisher, New York.

Yang X, Liu Y, Bai S (2006). A numerical solution of second-order linear partial differential equations by differential transform. Appl. Math. Comput. 173:792–802. http://dx.doi.org/10.1016/j.amc.2005.04.015

Ziabakhsh Z, Domairry G (2009). Analytic solution of natural convection flow of a non-Newtonian fluid between two vertical flat plates using homotopy analysis method. Commun. Nonlin. Sci. Numer. Simul. 14:1868–1880. http://dx.doi.org/10.1016/j.cnsns.2008.09.022

Zhou JK (1986). Differential transformation and its applications for Electrical Circuits. Huazhong University Press, Wuhan, China (in Chinese). PMCid:PMC341339

Appendix A

Here, the elements of the Jacobian matrix $\partial R_i / \partial a_j$ presented for $\delta = 1$ and $Pr=1$:

$$J(1,1) = \frac{1}{180} a_2^2 - \frac{1}{15} a_2 + \frac{11}{12} + \cdots,$$

$$J(1,2) = \frac{1}{90} a_1 a_2 - \frac{1}{15} a_1 - \frac{2}{3} a_2 - \frac{44}{45} + \cdots,$$

$$J(1,3) = 0,$$

$$J(1,4) = 0,$$

$$J(1,5) = 0,$$

$$J(2,1) = -\frac{1}{18} a_1 a_2 - \frac{2}{15} a_1 + \frac{221}{630} a_2 + \frac{46}{45} + \cdots,$$

$$J(2,2) = -\frac{1}{15} a_2^2 - \frac{1}{36} a_1^2 - \frac{4}{15} a_2 + \frac{221}{630} a_1 + \frac{2}{3} + \cdots,$$

$$J(2,3) = 0,$$

$$J(2,4) = 0,$$

$$J(2,5) = 0,$$

$$J(3,1) = -\frac{1}{35} a_1 + \frac{1}{36} a_4 a_2 + \frac{1}{8} + \cdots,$$

$$J(3,2) = -\frac{1}{3} a_4 - \frac{1}{12} a_3 + \frac{1}{36} a_4 a_1 - \frac{2}{45} a_2 a_3 + \frac{1}{105} a_2 + \frac{1}{90} + \cdots,$$

$$J(3,3) = -\frac{1}{45} a_2^2 - \frac{1}{12} a_2 + \frac{11}{12} + \cdots,$$

$$J(3,4) = \frac{1}{36} a_1 a_2 - \frac{1}{3} a_2 - \frac{179}{360} + \cdots,$$

$$J(3,5) = 0,$$

$$J(4,1) = \frac{1}{84} a_2 - \frac{1}{36} a_2 a_3 - \frac{1}{360} + \cdots,$$

$$J(4,2) = \frac{1}{3} a_3 - \frac{1}{12} a_4 - \frac{2}{45} a_4 a_2 - \frac{1}{36} a_1 a_3 + \frac{1}{84} a_1 - \frac{1}{8} + \cdots,$$

$$J(4,3) = \frac{1}{3} a_2 - \frac{1}{36} a_1 a_2 + \frac{179}{360} + \cdots,$$

$$J(4,4) = -\frac{1}{12} a_2 - \frac{1}{45} a_2^2 + \frac{11}{12} + \cdots,$$

$$J(4,5) = 0,$$

$$J(5,1) = \frac{1}{63} a_5 a_1 - \frac{437}{5040} a_5 + \cdots,$$

$$J(5,2) = \frac{1}{630} a_5 a_2 + \frac{1}{180} a_5 + \cdots,$$

$$J(5,3) = 0,$$

$$J(5,4) = 0,$$

$$J(5,5) = -\frac{437}{5040} a_1 + \frac{1}{180} a_2 + \frac{1}{1260} a_2^2 + \frac{1}{126} a_1^2 + \frac{61}{60} + \cdots.$$

Full Length Research Paper

Seamless transition of domain name system (DNS) authoritative servers

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The domain name system (DNS) resolution service often migrates from the one set of authoritative servers to another. The basic requirements for such transition are to ensure zero down time and minimize the transition delay. The optimum transition schemes are proposed favoring seamless and fast DNS resolution service migration. The transition of DNS authoritative servers may take place horizontally or vertically. For the horizontal case, the delegated authority is handovered from the old set of authoritative servers to the new one. For the vertical case, a zone cut is initiated from the parent zone to a newly delegated set of authoritative servers. For the DNSSEC signed zones, the DNSSEC-aware transition schemes are proposed to ensure the continuity of the trust chain. The transition delays as well as how to optimize them are discussed.

Key words: Domain name system (DNS), authoritative server, service migration

INTRODUCTION

The domain name system (DNS) is a fundamental component of the modern Internet, providing a critical link between human users and Internet routing infrastructure by mapping host names to IP addresses.

The DNS uses a tree (or hierarchical) name structure. The top of the tree is the root node followed by the top-level domains (TLDs), then the Second-Level Domains (SLD) and any number of lower levels. Each node within the domain name hierarchy is assigned to an authority - an organization or person responsible for the management and operation of that node. Such an organization or person is said to administer the node authoritatively. The authority for a particular node can in turn delegate authority for lower levels of that node within the domain name hierarchy. When a parent zone

delegates part of its namespace to a child zone, the parent zone stores a list of NS resource records for the authoritative servers of the child zone. This list of NS resource records are kept both at the parent and the child zone. As shown in Figure 1, com. zone delegates example.com. zone to a child zone. The authoritative servers of the child zone are listed in a set of NS resource records. And normally the same set of NS resource records are also contained in the zone file of the child zone- example.com. zone here.

The DNS resolution service often migrates from the one set of authoritative servers to another. The basic requirements for the transition are to ensure zero down time and minimize the transition time. Service continuity is the key objective of the transition of DNS authoritative

```
$ORIGIN com.
example.com.    IN   NS   ns1.example.com.
example.com.    IN   NS   ns2.example.com.
example.com.    IN   NS   ns3.example.com.
$ORIGIN example.com.
example.com.    IN   NS   ns1.example.com.
example.com.    IN   NS   ns2.example.com.
example.com.    IN   NS   ns3.example.com.
```

Figure 1. DNS delegation example.

Figure 2. Recursive resolution procedure.

servers, and any resolvers should be served with response in compliance with DNS specifications during the transition. For the efficiency consideration, the transition time should be minimized in order to reduce the cost of simultaneous service of the predecessor and the successor.

The service migration problem has been addressed in the past particularly in the area of generic networks. Oikonomou and Stavrakakis (2010) proposed to determine the optimal location of a service facility in a way that is both scalable and deals inherently with network dynamicity. Shayani et al. (2010) applied techno-economic analysis to model and study the service migration between platforms. Gabner et al. (2011) investigated service component migration between the mobile client and the infrastructure-based cloud as a means to avoid service failures and improve service performance. Vanbever et al. (2011) proposed router grafting, where parts of a router are seamlessly removed from one router and merged into another, allowing a network operator to rehome a customer with no disruption. To improve the reliability and efficiency of a system in the pervasive computing domain, Cai et al. (2013) proposed a service-oriented intelligent seamless migration (SOISM) mechanism and algorithm. However, all of them cannot be directly applied to the problem of seamless transition of authoritative servers, which requires specific DNS protocol compliance.

With the introduction and deployment of DNSSEC, sustaining trust chain in parallel with the transition of DNS authoritative servers is non-trivial for the DNSSEC signed zones. An overview of challenges and potential pitfalls of DNSSEC was presented in Herzberg and Shulman (2013). Yang et al. (2011) provided a systematic examination of the design, deployment, and operational challenges encountered by DNSSEC. While key rollover was discussed as a component of DNSSEC service transition, the authoritative server transition has not been examined in combination with trust chain transition in previous works.

This work provides the following two major contributions. 1) The seamless transition of authoritative servers is analyzed and solved based on two categories: delegation transition and authority transition. 2) The DNSSEC solution for secure seamless transition of authoritative servers is proposed.
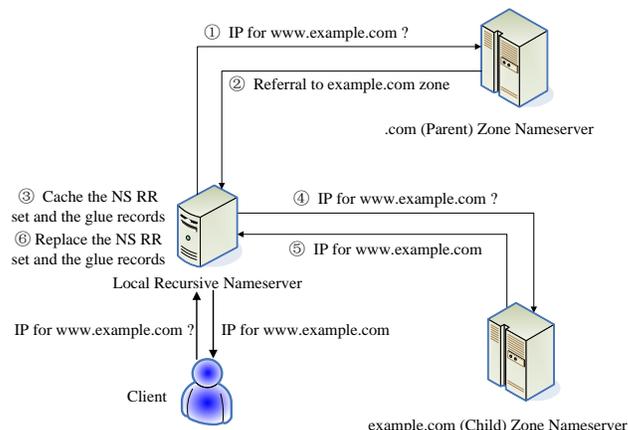
DNS RECURSIVE RESOLUTION

Figure 2 illustrates the recursive resolution procedure. The client's browser uses a resolver and queries a local recursive server for a name (say example.com). The query may miss the DNS cache in this server, that is there is no cached A records for "www.example.com". Moreover, if the NS record set for the queried domain also expired at this time (otherwise, the server can go to the authoritative server of the "example.com" zone directly), the recursive server has to request the parent zone of "example.com" by contacting the authoritative server of ".com" zone. The ".com" authoritative server answers with a referral to the servers responsible for the example.com domain. This is in the form of NS records of servers in the authority section of the DNS message. Though technically we asked only for the NS records, the servers also give us the IP address of each in the additional section of the DNS message: this is known as "glue" and is provided to avoid "query loop" and save us from having to look it up. The recursive server chooses one of the authoritative servers and sends off the same query: "what's the A record for www. example.com?". The authoritative server's reply message contains the A record in the answer section, the NS records and glue records in authority and additional section respectively.

TRANSITION SCHEME OF DNS AUTHORITATIVE SERVERS

Delegation transition

The typical transition of DNS authoritative servers is
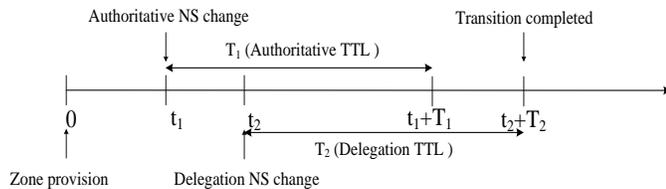
Figure 3. The time line of delegation transition.

$ORIGIN com.
www.example.com.   IN A   128.0.0.1
ns1.example.com.   IN   A   128.0.0.2
ns2.example.com.   IN   A   128.0.0.3
ns3.example.com.   IN   A   128.0.0.4

Figure 4. The original parent zone records prior to the delegation.

migration from one set of authoritative servers to another. The delegation relationship between the parent zone and the child zone does not change but the authoritative servers of the child zone changes.

According to the analysis above, the NS RRset cached by the resolvers can be the authoritative one from the child zone or the delegating one from the parent zone. This is dependent on the implementations of the child zone's name servers and the resolvers. Considering the diversity of DNS implementations, the transition mechanism should fit both cases for the guarantee of consistent service. That is, the resolvers have to wait enough time for the expiration of the old NS RRset from the cache.

Technically, migrating the delegation in the parent zone is enough for the authoritative server transition since the resolvers have to contact the parent zone for the referral information after the relevant NS RRset in the cache expires. For the child zone's nameservers which include the apex NS RRset in responses, migrating the apex NS RRset also allows for the speeding of the authoritative server transition. This is due to the possibility that some resolvers may follow the migrated apex NS RRset to reach the new authoritative server before they have the opportunity to refresh their referral information.

Let the TTL of the authoritative NS RRset in the child zone be T_1 and the TTL of the delegation NS RRset in the parent zone be T_2. Let the zone provision of the new DNS authoritative servers be launched at time 0. Let the authoritative NS RRset in the child zone be changed at t_1 and the delegation NS RRset in the parent zone be changed at t_2.

During the transition, there are three repositories of NS RRset, the parent zone, the old child zone and the new child zone. We discuss them respectively as follows.

If the old NS RRset is fetched from the parent zone by the resolvers, the resolver will get the new delegation NS RRset after t_2+T_2, which is expiration time of the old NS RRset from the cache. If the old NS RRset is fetched from the old child zone by the resolvers, the resolver will get the new authoritative NS RRset after t_1+T_1, which is expiration time of the old NS RRset from the cache.

After t_1 or t_2, the new NS RRset may be fetched from the new child zone by the resolvers. This is due to either the new delegation NS RRset at the parent zone or the new authoritative NS RRset at the old child zone.

In summary, after $\max\{t_1+T_1, t_2+T_2\}$, all resolvers have their caches refreshed by the new NS RRset. Since that time, all resolvers will not send DNS requests to the old child zone. So the Old DNS Authoritative Servers can come to the end of service. The time line is shown in Figure 3.

Authority transition

In the case of authority transition, some name space, once resolvable in the zone, is delegated as its child zone. It is the generation of a new child zone from its parent zone. Compared with the delegation transition, the migration does not move horizontally, but vertically. The original zone records related to the example.com subzone is illustrated in Figure 4. In the transition, the parent zone adds delegation records and at the same time removes all authoritative records of the delegated zone. The parent zone records and the child zone records posterior to the delegation is shown in Figure 5. If the delegated zone is provisioned at the new DNS authoritative servers prior to the delegation, any afterward requests for the delegated zone arriving at the parent zone is answered with the referral information directing to the new DNS authoritative servers. Let the zone provision of the new DNS authoritative servers start at time 0 and the delegation records adding and authoritative records of the delegated zone removing in the parent zone happen at time t_1.

DNSSEC TRANSITION SCHEME

DNSSEC provides acryptographic solution to the original DNS specifications. Public/private key pairs are used for the authentication of each zone. The public keys are stored in DNSKEY RRset, and all the sig-natures are stored in RRSIG RRset. In response to a query, an authoritative server returns both the requested data and its associated RRSIGRRset.

```
$ORIGIN com.
example.com.    IN   NS   ns1.example.com.
example.com.    IN   NS   ns2.example.com.
example.com.    IN   NS   ns3.example.com.
$ORIGIN example.com.
example.com.    IN   NS   ns1.example.com.
example.com.    IN   NS   ns2.example.com.
example.com.    IN   NS   ns3.example.com.
www.example.com.  IN A   128.0.0.1
ns1.example.com.    IN   A   128.0.0.2
ns2.example.com.    IN   A   128.0.0.3
ns3.example.com.    IN   A   128.0.0.4
```

Figure 5. The parent zone records and the child zone records posterior to the delegation.
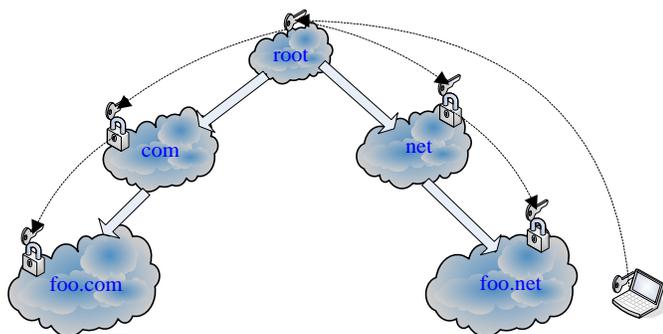

Figure 6. Record verification through the chain of trust by resolvers.

A resolver that has learned the DNSKEY of the requested zone can verify the origin, authenticity and integrity of the reply data. To resist replay attacks, each signature carries a definitive expiration time.

In order to authenticate the DNSKEY for a given zone, say www.foo.com, the resolver needs to construct a chain of trust that follows the DNS hierarchy from a trusted root zone key down to the key of the zone in question (this is shown in Figure 6). In the ideal case, the public key of the DNS root zone would be obtained offline in a secure way and stored at the resolver, so that the resolver can use it to authenticate the public key of com.; the public key of com. would then be used to authenticate the public key of foo.com.

A parent zone must encode the authentication of each of its child zone's public keys in the DNS. To accomplish this, the parent zone creates and signs a Delegation Signer (DS) RR that corresponds to a DNSKEYRR at the child zone, and creates an authentication link from the parent to child. It is the child zone's responsibility to request an update to the DSRR every time the child's DNSKEY changes.
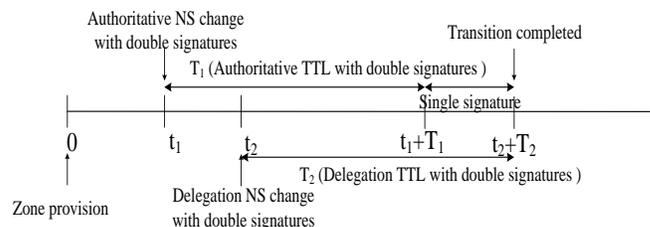
Figure 7. The time line of DNSSEC-aware delegation transition.

For the signed zone, the main objective of transition is to maintain any records verifiable through the chain of trust.

DNSSEC-aware delegation transition

In the case of authority transition, some name space, once resolvable in the zone, is delegated as its child zone. It is the generation of a new child zone from its parent zone. Compared with the delegation transition, the migration does not move horizontally, but vertically. The original zone records related to the example.com subzone is illustrated in Figure 4. The delegation relationship between the parent zone and the child zone does not change but the authoritative servers of the child zone changes.

When the authoritative NS records or the delegation NS records change, their signatures or RRSIG records should be generated by resigning the NS records with the DNSKEY. But the previously fetched NS records are still retained in the cache until they expire from the cache according to the TTL. The resolver follows the cached NS records to request the old authoritative servers for the NS records' signatures. This makes it necessary to maintain the signatures of old NS records together with those of the new ones. Otherwise, the cached NS records would lose their signatures and fail verifications because the replied RRSIG RR set only contains the RRSIG for the new NS records. Therefore, the double signatures, for both new and old NS records, should be kept in the old authoritative servers and parent servers for the TTL of the NS records. However, for the new authoritative servers, the double signature scheme is unnecessary. When a query is sent to the new authoritative servers, the cached NS records in the resolver must be the ones referring to the new authoritative servers. So the signature for the new NS records is enough for the successful verification. The time line is shown in Figure 7.

DNSSEC-aware authority transition

Compared with DNSSEC-oblivious authority transition,

the zone provision of the new DNS authoritative servers should be conducted along with the submission of DS records to the parent zone and zone signing. The parent zone should add the submitted DS records and sign them with its DNSSEY to establish a chain of trust linking the new child zone.

TRANSITION DELAY AND ITS OPTIMIZATION

For the delegation transition, the transition delay is $\max\{ t_1+T_1, t_2+T_2 \}$. To accelerate the transition, the authoritative NS RRset in the child zone and the delegation NS RRset in the parent zone should change as soon as possible after the zone provision of the new DNS authoritative servers. Minimizing the TTL of the authoritative NS RRset in the child zone and the TTL of the delegation NS RRset in the parent zone also helps to speed up the transition.

For the authority transition, the transition delay is t_1. To accelerate the transition, the authoritative NS RRset in the child zone and the delegation NS RRset in the parent zone should change as soon as possible after the zone provision of the new DNS authoritative servers. Minimizing the TTL of the authoritative NS RRset in the child zone and the TTL of the delegation NS RRset in the parent zone also helps to speed up the transition.

For the DNSSEC-aware delegation transition, the transition delay is $\max\{ t_1+T_1, t_2+T_2 \}$, which determines the resolution service duration of the old authoritative servers. Note that if $t_1+T_1<t_2+T_2$, a single signature time window emerges for the old authoritative severs. In that period, the old authoritative severs only need to keep the RRSIG records for the new NS records because the old NS records have already expired from the cache. But the old authoritative severs should continue its resolution service because the old delegation NS records have not expired from the cache. In the scenario, the resolver may still send its queries to the old authoritative servers following the references in its cache (the old delegation NS records). So if the old authoritative severs is unresponsive, the queries will get the failure response. For the DNSSEC-aware authority transition, the transitiondelay is t_1.

Conclusions

DNS operators are under increasing pressure to make their resolution service highly reliable and continuous to avoid service disruptions. But operators often need to change the authoritative servers to upgrade faulty equipment, deploy new servers, or transfer services. Unfortunately, unexamined authoritative server changes may cause disruptions. In this paper,

seamless transition schemes are presented allowing an operator to migrate DNS authoritative servers with no disruption. In addition, the transition schemes are examined in the DNSSEC cases aiming at sustaining trust chains. The transition delay and its optimization are discussed.

Conflict of interests

The author(s) have not declared any conflict of interests.

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REFERENCES

Cai H, Chao P, Robert HD, Linhua J (2013). A novel service-oriented intelligent seamless migration algorithm and application for pervasive computing environments. Future Gener. Comput. Syst. 29(8):1919-1930. http://dx.doi.org/10.1016/j.future.2013.02.008

Gabner R, Hans-Peter S, Karin AH, Gunter H (2011). Optimal Model-Based Policies for Component Migration of Mobile Cloud Services. In Proceedings of the 2011 IEEE 10th International Symposium on Network Computing and Applications (NCA '11). pp.195-202. http://dx.doi.org/10.1109/NCA.2011.33

Herzberg A, Shulman H (2013). DNSSEC: Interoperability Challenges and Transition Mechanisms. In Proceedings of the 2013 International Conference on Availability, Reliability and Security (ARES '13). pp. 398-405. http://dx.doi.org/10.1109/ARES.2013.53; PMid:23186151

Oikonomou K, Stavrakakis I (2010). Scalable service migration in autonomic network environments. IEEE J. Sel. A. Commun. 28(1):84-94. http://dx.doi.org/10.1109/JSAC.2010.100109

Shayani D, Machuca CM, Jager M (2010). A techno-economic approach to telecommunications: the case of service migration. IEEE Trans. on Netw. Serv. Manage. 7(2):96-106.

Vanbever L, Stefano V, Cristel P, Pierre F, Olivier B (2011). Seamless network-wide IGP migrations. SIGCOMM Comput. Commun. Rev. 41(4):314-325. http://dx.doi.org/10.1145/2043164.2018473

Yang H, Eric O, Dan M, Songwu L, Lixia Z (2011). Deploying Cryptography in Internet-Scale Systems: A Case Study on DNSSEC. IEEE Trans. Dependable Secur. Comput. 8(5):656-669. http://dx.doi.org/10.1109/TDSC.2010.10

Full Length Research Paper

Haar Wavelet-Picard technique for fractional order nonlinear initial and boundary value problems

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In this article, a technique called Haar wavelet-Picard technique is proposed to get the numerical solutions of nonlinear differential equations of fractional order. Picard iteration is used to linearize the nonlinear fractional order differential equations and then Haar wavelet method is applied to linearized fractional ordinary differential equations. In each iteration of Picard iteration, solution is updated by the Haar wavelet method. The results are compared with the exact solution.

Key words: Fractional differential equations, Wavelet analysis, Caputo derivative, Haar wavelets, Picard iteration.

MSC 2010: 34Bxx, 65Lxx.

INTRODUCTION

Haar wavelet is the lowest member of the Daubechies family of wavelets and is convenient for computer implementations due to the availability of explicit expression for the Haar scaling and wavelet functions (Daubechies, 1990). Operational approach is pioneered by Chen (Chen and Hsiao, 1997) for uniform grids. The basic idea of Haar wavelet technique is to convert differential equations into a system of algebraic equations of finite variables.

Boundary value problems are considerably more difficult to deal with than the initial value problems. The Haar wavelet method for boundary value problems is more complicated than for initial value problems. Second-order boundary value problems are solved in Siraj-ul-Islam et al. (2010) by the Haar wavelets; they considered the six sets of different boundary conditions for the solution. Boundary value problems for fractional differential equations are solved in Mujeeb and Khan (2012) which considers the numerical solution by the Haar wavelet for different boundary value problems of fractional order.

The Picard approach (Bellman and Kalaba, 1965) is used to linearize the individual or system of nonlinear ordinary and partial differential equations. In this paper, we consider the case of fractional order nonlinear ordinary differential equations which contain various forms of nonlinearity. The main aim of the present paper is to get the numerical solutions of nonlinear fractional order initial ad boundary value problems over a uniform grids with a simple method based on the Haar wavelets and Picard technique.

THE HAAR WAVELETS

The Haar functions contain just one wavelet during some

subinterval of time and remains zero elsewhere and are orthogonal. The Haar wavelets are useful for the treatment of solution of differential equations (Chen and Hsiao, 1997). The ith Haar wavelet $h_i(x), x \in [a, b]$ is defined as

$$h_i(x) = \begin{cases} 1, & a + (b-a)\frac{k}{m} \leq x < a + (b-a)\frac{k+0.5}{m}; \\ -1, & a + (b-a)\frac{k+0.5}{m} \leq x < a + (b-a)\frac{k+1}{m}; \\ 0, & otherwise. \end{cases} \quad (1)$$

where $i = 2^j + k + 1; j = 0,1,2,\cdots,J$ is the dilation parameter, where $m = 2^j$ and $k = 0,1,2,\cdots,2^j - 1$ is translation parameter. J is maximal level of resolution and the maximal value of i is $2M$, where $M = 2^J$. In particular $h_1(x) = \chi_{[a,b]}(x)$, where $\chi_{[a,b]}$ is the characteristic function on interval [a, b], is the Haar scaling function. For the Haar wavelet, the wavelet collocation method is applied. The collocation points are usually taken as $x_j = \left(\frac{b-a}{2}\right)\left(\frac{j+0.5}{2M}\right) + \left(\frac{b+a}{2}\right), j = 1,2,\cdots,2M.$

Fractional integral of the uniform Haar wavelets

Any function $y \in L_2[a,b]$ can be represented in term of the uniform Haar series

$$y(x) = \sum_{i=1}^{\infty} b_i h_i(x), \quad (2)$$

where b_i are the Haar wavelet coefficients given as $b_i = \int_{-\infty}^{\infty} y(x)h_i(x)dx.$

The Riemann-Liouville fractional integral of the Haar scaling function is given as

$$I_a^\alpha h_i(x) = \frac{(x-a)^\alpha}{\Gamma(\alpha+1)}, \quad (3)$$

and

$$I_a^\alpha h_i(x)$$
$$= \frac{1}{\Gamma(\alpha+1)}\begin{cases} (x-a(i))^\alpha, & a(i) \leq x < b(i); \\ (x-a(i))^\alpha - 2(x-b(i))^\alpha, & b(i) \leq x < c(i); \\ (x-a(i))^\alpha - 2(x-b(i))^\alpha + (x-c(i))^\alpha, & x \geq c(i) \end{cases} \quad (4)$$

CONVERGENCE ANALYSIS

As our work is based on Picard technique and Haar wavelet method, we thus analyze the convergence of both schemes.

Convergence of Picard technique

Consider the nonlinear second order differential equation

$$y''(x) = f(y), y(0) = y(b) = 0. \quad (5)$$

Application of Picard technique to (5) yields

$$y_{n+1}''(x) = f(y_n), \quad y_{n+1}(0) = y_{n+1}(b) = 0. \quad (6)$$

Let $y_0(x)$ be some initial approximation. Each function $y_{n+1}(x)$ is a solution of the linear equation (6), where y_n is always considered known and is obtained from the previous iteration.
   According to Picard iteration:

$$|y_{n+1} - y_n| \leq k|y_n - y_{n-1}|, \text{ where } k < 1. \quad (7)$$

This shows that there is linear convergence, if there is convergence at all.

Convergence of Haar wavelet method

Let $y(x)$ be a differentiable function and assume that $y(x)$ have bounded first derivative on $(0,1)$, that is, there exists $K > 0$; for all $x \in (0,1)$

$$|y'(x)| \leq K.$$

Haar wavelet approximation for the function $y(x)$ is given by $y_M(x) = \sum_{l=1}^{2M} b_l h_l(x)$.
   Babolian and Shahsavaran (2009) gave L_2-error norm for Haar wavelet approximation, which is

$$\|y(x) - y_M(x)\|^2 \leq \frac{K^2}{3}\frac{1}{(2M)^2},$$

or

$$\|y(x) - y_M(x)\| \leq O\left(\frac{1}{M}\right), \quad (8)$$

where $M = 2^J$ and J is the maximal level of resolution. From inequality (8), we conclude that error is inversely proportional to the level of resolution. Equation (8) ensures the convergence of Haar wavelet approximation at higher level of resolution, that is, when M is increased.

APPLICATIONS

Here, we solve nonlinear differential equations of

fractional order by the Haar wavelets-Picard technique and compare the results with the exact solution. Throughout this work we use Caputo derivatives and for the details of fractional derivatives and integrals we refer the readers to Podlubny (1999).

Example 1: Consider the ath order fractional nonlinear Bratu type equation,

$$^cD^\alpha y(x) - 2e^{y(x)} = 0, \quad 1 < \alpha \leq 2, \tag{9}$$

subject to the initial condition $y(0) = 0, y'(0) = 0$.

The exact solution, when $\alpha = 2$, is given by (Kiymaz, 2010)

$$y(x) = -2\ln(cosx). \tag{10}$$

Applying the Picard iteration to the Equation 9, we get

$$^cD^\alpha y_{r+1}(x) = 2e^{y_r(x)}, \ 1 < \alpha \leq 2, \tag{11}$$

with the initial condition $y_{r+1}(0) = 0, y'_{r+1}(0) = 0$.

Now we apply the Haar wavelet method to Equation 11; we approximate the higher order derivative term by the Haar wavelet series as

$$^cD^\alpha y_{r+1}(x) = \sum_{l=1}^{2M} b_l h_l(x) \tag{12}$$

Lower order derivatives are obtained by integrating Equation 12 and using the initial condition

$$y_{r+1}(x) = \sum_{l=1}^{2M} b_l p_{\alpha,l}(x), \ y'_{r+1}(x) = \sum_{l=1}^{2M} b_l p_{\alpha-1,l}(x). \tag{13}$$

Substituting Equations 12 and 13 in Equation 11, we get

$$\sum_{l=1}^{2M} b_l h_l(x) = 2e^{y_r(x)}, \tag{14}$$

with the initial approximation $y_0(x) = 0$.

We fix the order of the differential Equation (9), $\alpha = 2$ and the level of resolution, $J = 5$. The graph in Figure 1 shows the exact and approximate solutions by proposed method at four iterations. The absolute error reduces with the increasing iterations.

Results at fifth iteration of proposed method at fixed level of resolution, $J = 3$ and at different values of α are shown in Figure 2 with exact solution at $\alpha = 2$. Figure 2 showed that numerical solutions converge to the exact solution when α approaches to 2.

Example 2: Consider the fractional nonlinear Duffing equation

$$^cD^\alpha y(x) + y'(x) + y(x) + y^3(x) = \cos^3(x) - \sin(x), 1 < \alpha \leq 2, \tag{15}$$

subject to the initial conditions $y(0) = 1, y'(0) = 0$.

The exact solution, when $\alpha = 2$, is

$$y(x) = cos(x) \tag{16}$$

Applying the Picard iteration to Equation 15

$$^cD^\alpha y_{r+1}(x) + y'_{r+1}(x) + y_{r+1}(x) = \cos^3(x) - \sin(x) - y_r^3(x), 1 < \alpha \leq 2, \tag{17}$$

with the initial condition $y_{r+1}(0) = 1, y'_{r+1}(0) = 0$.

Applying the Haar wavelet method to Equation (17), we approximate the higher order derivative term by the Haar Wavelet series as

$$^cD^\alpha y_{r+1}(x) = \sum_{l=1}^{2M} b_l h_l(x) \tag{18}$$

Now to get the Haar wavelet series for lower order derivatives terms we integrate Equation 18 and use the initial condition

$$y_{r+1}(x) = \sum_{l=1}^{2M} b_l p_{\alpha,l}(x) + 1, \ y'_{r+1}(x) = \sum_{l=1}^{2M} b_l p_{\alpha-1,l}(x). \tag{19}$$

Substituting Equations 18 and 19 in Equation 17, we get

$$\sum_{l=1}^{2M} b_l [h_l(x) + p_{\alpha-1,l}(x) + p_{\alpha,l}(x)] = \cos^3(x) - \sin(x) - y_r(x)^3 - 1, \tag{20}$$

with the initial approximations $y_0(x) = 1, y'_0(x) = 0$.

We fix the level of resolution, $J = 3$ and order of differential Equation (15), $\alpha = 2$. The exact and numerical solutions by proposed method at different iterations along with the absolute error are shown in Figure 3. We observe that error reduces with increase in iterations.

Exact solution at $\alpha = 2$ and the Haar solution at different values of α, are displayed in Figure 4. It is observed that solutions of fractional nonlinear Duffing Equation (15) converge to the solution of second order nonlinear Duffing equation, when α approaches to 2.

**Example 3:** Consider the αth order nonlinear Lane-Emden type Equation:

$$^cD^\alpha y(x) + \frac{2}{x} y'(x) + 8e^{y(x)} + 4e^{\frac{y(x)}{2}} = 0, \ 1 < \alpha \leq 2, \tag{21}$$

subject to the initial conditions $y(0) = 0, y'(0) = 0$.

The exact solution, when $\alpha = 2$, is
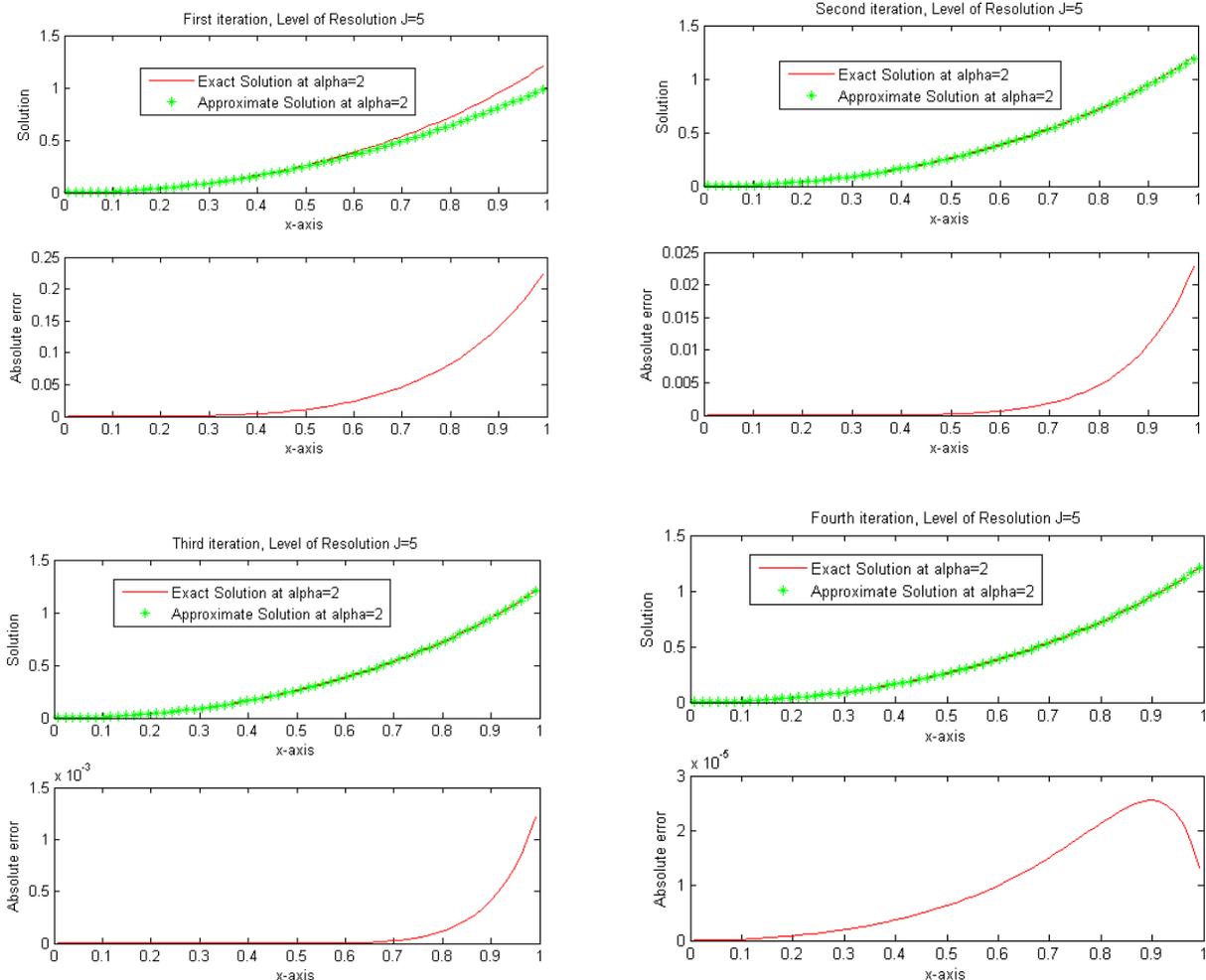
Figure 1. Comparison of exact solution and solutions by Haar wavelet-Picard technique at $J = 5$; for different iterations, and α=2.
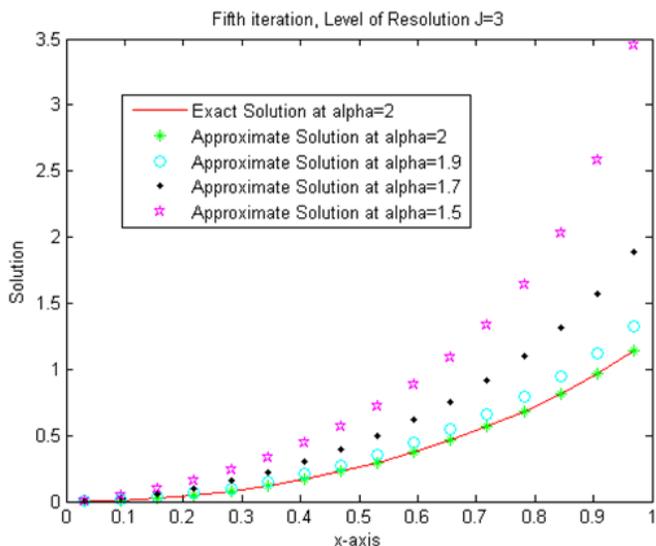
Figure 2. Exact solution at α = 2 and the Haar wavelet-Picard solution at α = 2, α = 1.9, α = 1.7, and α = 1.5.

$$y(x) = -2\ln(1 + x^2). \tag{22}$$

Picard iteration to Equation 21 implies

$$^{c}D^{\alpha}y_{r+1}(x) + \frac{2}{x}y'_{r+1}(x) = -8e^{y_r(x)} - 4e^{\frac{y_r(x)}{2}} , \ 1 < \alpha \le 2, \tag{23}$$

with the initial conditions $y_{r+1}(0) = 0, y'_{r+1}(0) = 0$.

Applying the Haar wavelet method to equation

$$^{c}D^{\alpha}y_{r+1}(x) = \sum_{l=1}^{2M} b_l h_l(x) \tag{24}$$

Lower order derivatives are obtained by integrating Equation 25 and using the initial condition

$$y_{r+1}(x) = \sum_{l=1}^{2M} b_l \ p_{\alpha,l}(x), \tag{25}$$

$$y'_{r+1}(x) = \sum_{l=1}^{2M} b_l p_{\alpha-1,l}(x). \tag{26}$$
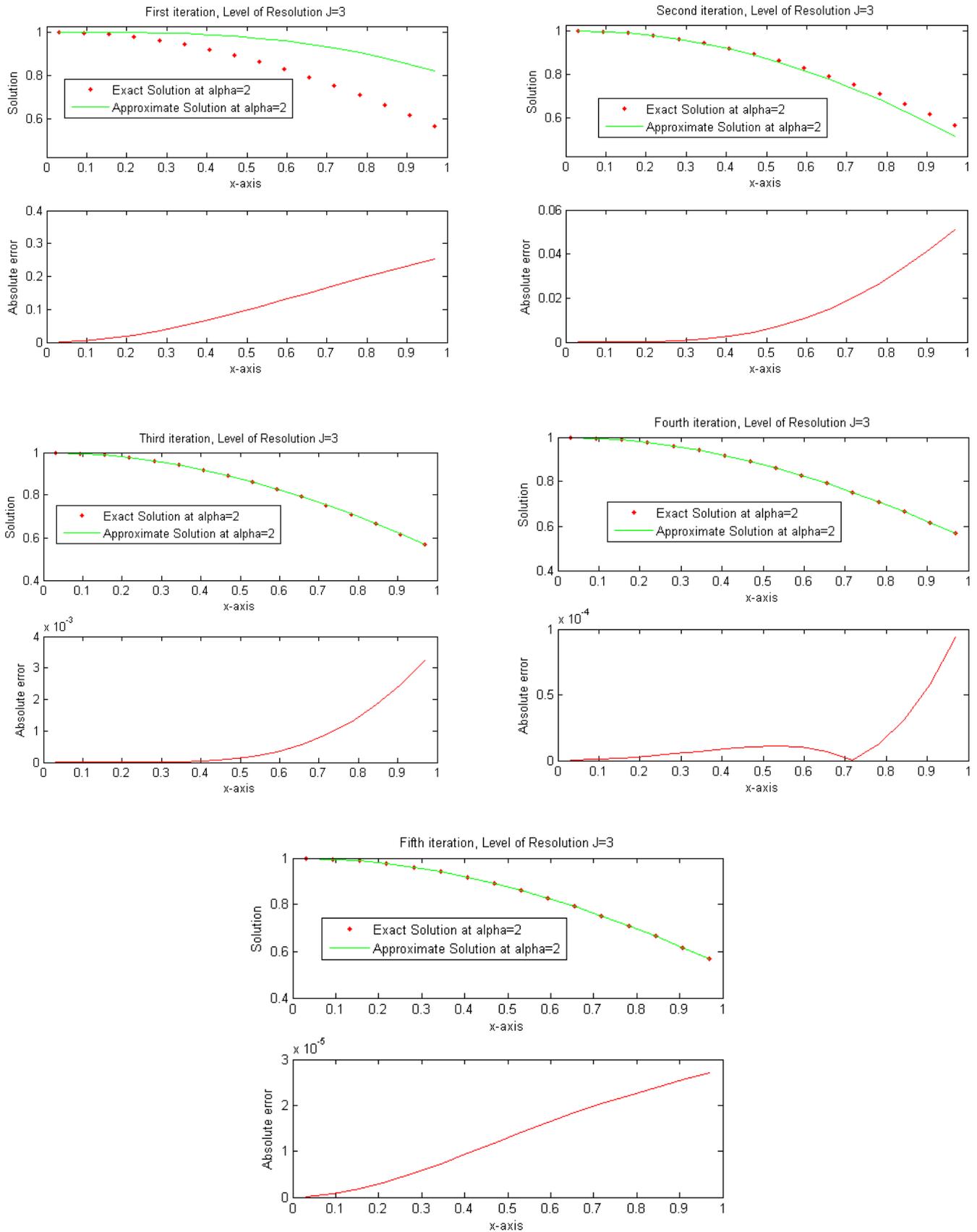
Figure 3. Comparison of exact solution and solutions by Haar wavelet-Picard technique at *J* = 3, for different iterations, and α =2.
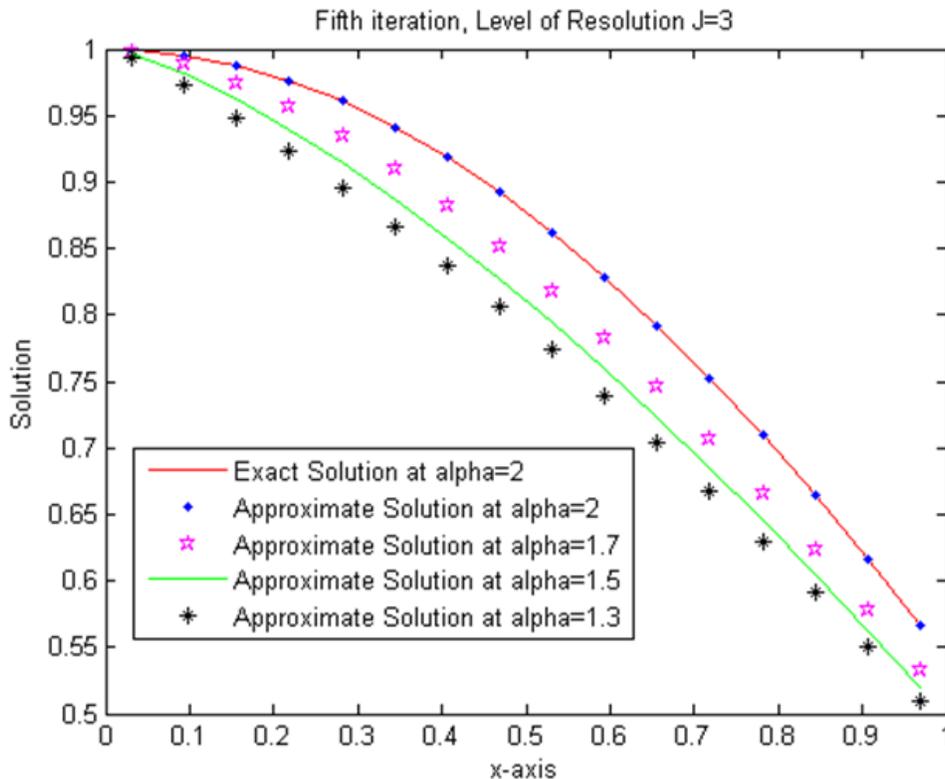
Figure 4. Exact solution at α = 2 and the Haar wavelet-Picard solution at α = 2, α = 1.8, α = 1.5, and α = 1.3.

Substituting Equations 24, 25 and 26 in Equation 23, we get

$$\sum_{l=1}^{2M} b_l \left[h_l(x) + \frac{2}{t} p_{\alpha-1,l}(x) \right] = -8e^{y_r(x)} - 4e^{\frac{y_r(x)}{2}} \quad (27)$$

with the initial approximations $y_0(x) = 0, y'_0(x) = 0$.

Here we fix the order of differential Equation (21), $\alpha = 2$ and level of resolution, $J = 5$. The graph in Figure 5 shows the exact and approximate solutions by proposed method at six iterations. The absolute error reduces with increasing iterations.

Results of sixth iteration by Picard iteration at fixed level of resolution, $J = 5$, are shown in Figure 6 with exact solution at $\alpha = 2$ and the proposed solution at different values of α. Figure 6 showed that the proposed numerical solutions converge to the exact solution when α approaches to 2.

Example 4: Consider the αth order fractional nonlinear boundary value problem,

$$^{c}D^{\alpha}y(x) + a(x)y'^{2}(x) + b(x)y(x)y'(x) = f(x), \ 1 < \alpha \leq 2, \quad (28)$$

subject to the boundary conditions $y(0) = 0, y(1) = 0$.
The exact solution is given by

$$y(x) = x^3 - x^2. \quad (29)$$

where

$$f(x) = \frac{\Gamma(4)}{\Gamma(4-\alpha)} x^{3-\alpha} - \frac{\Gamma(3)}{\Gamma(3-\alpha)} x^{2-\alpha} + a(x)(3x^2 - 2x)^2 + b(x)(3x^2 - 2x)(x^3 - x^2).$$

Applying the Picard technique to Equation (28), we get

$$^{c}D^{\alpha}y_{r+1}(x) = f(x) - a(x)y_r^2(x) - b(x)y_r(x)y'_r(x), \ 1 < \alpha \leq 2, \quad (30)$$

with the boundary conditions $y_{r+1}(0) = 0, y_{r+1}(1) = 0$.

Now applying the Haar wavelet method to Equation (30), we approximate the higher order derivative term by the Haar wavelet series as

$$^{c}D^{\alpha}y_{r+1}(x) = \sum_{l=1}^{2M} b_l h_l(x) \quad (31)$$

Lower order derivatives are obtained by integrating Equation 31 and using the initial conditions

$$y_{r+1}(x) = \sum_{l=1}^{2M} b_l (p_{\alpha,l}(x) - xC_{\alpha,l}), \quad (32)$$
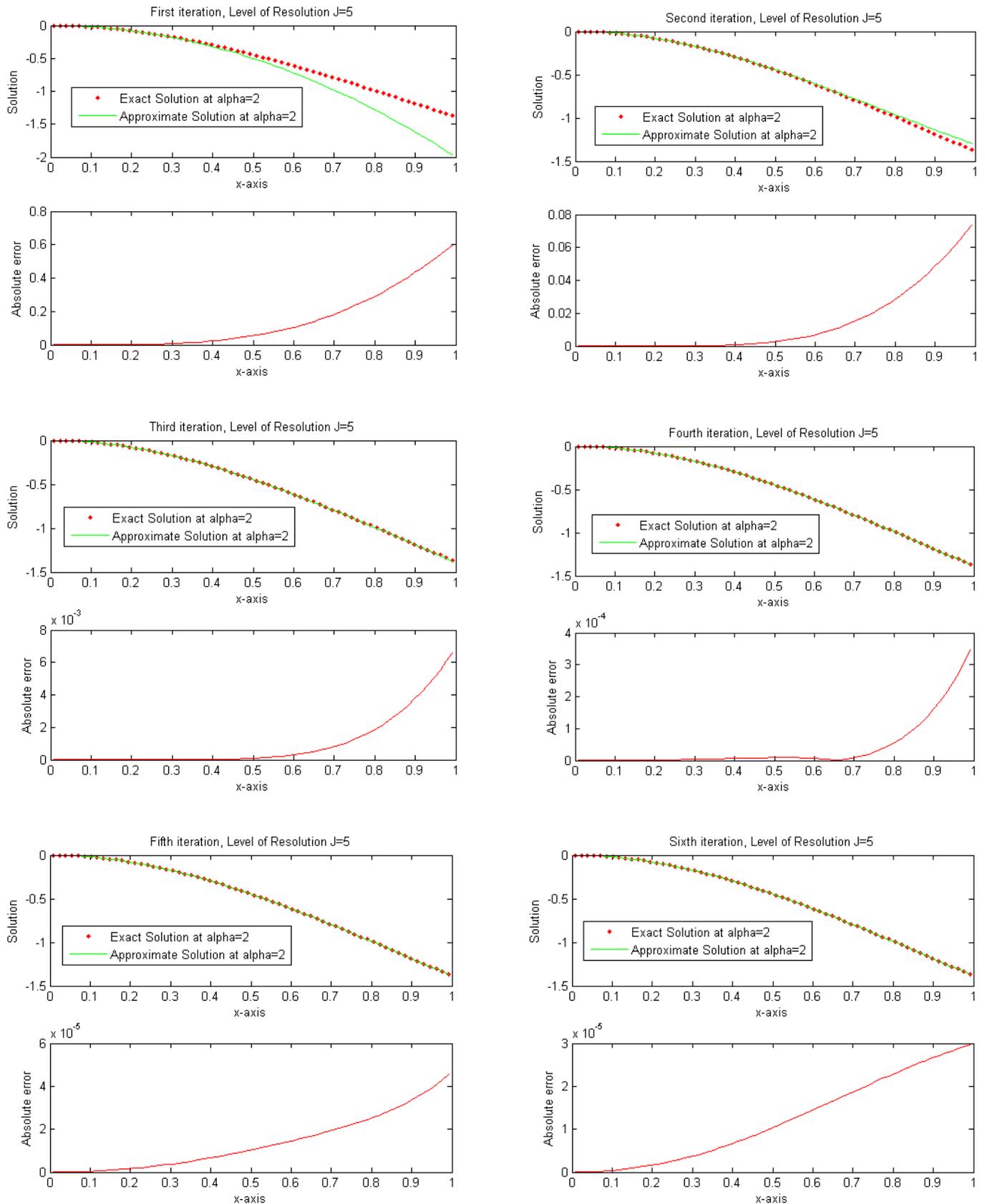
Figure 5. Comparison of exact solution and solutions by Haar wavelet-Picard technique at *J* = 5, for different iterations, and α = 2.
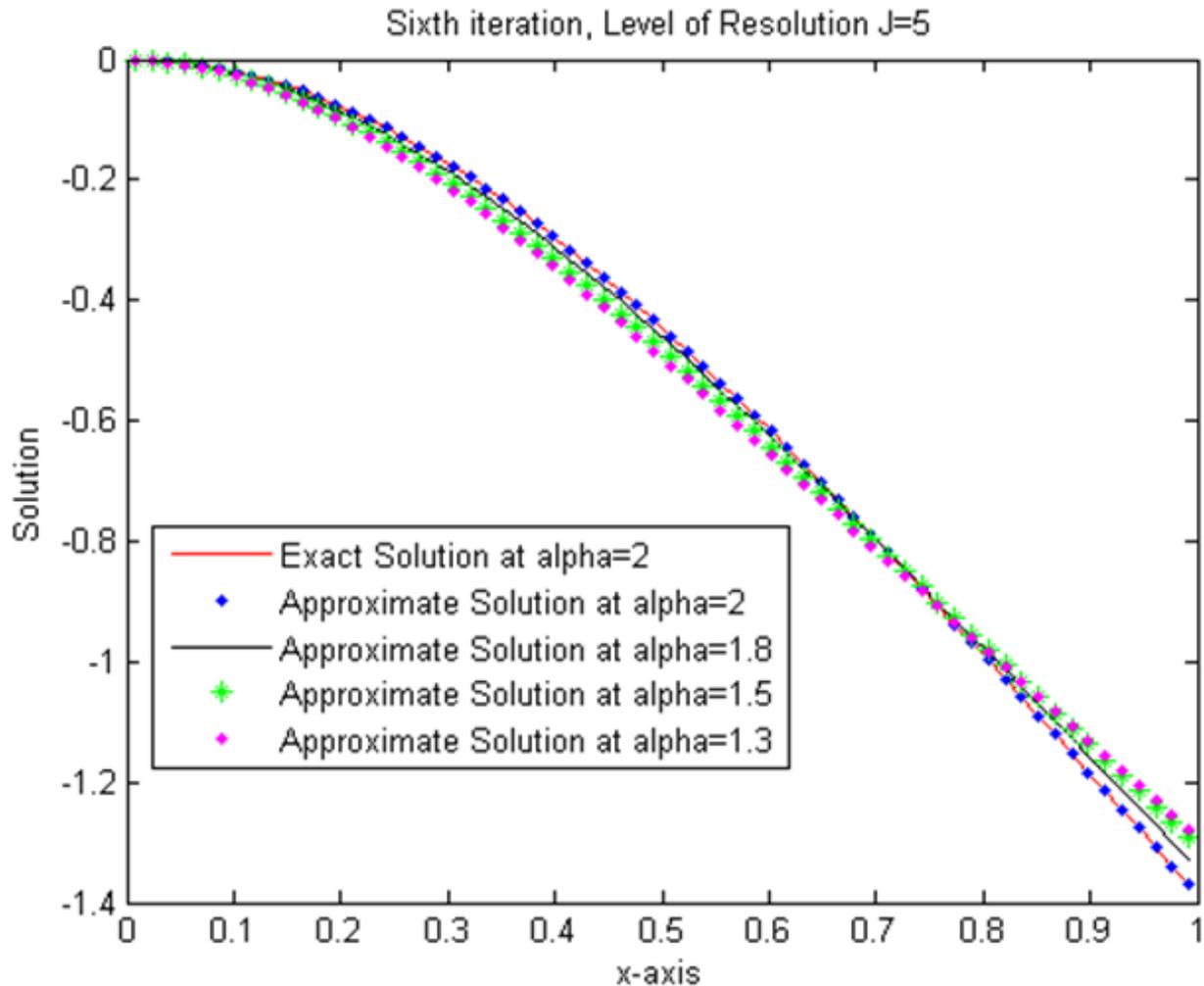
Figure 6. Exact solution at α = 2 and the Haar wavelet-Picard solution at α = 2, α = 1.8, α = 1.5, and α = 1.3.

$$y'_{r+1}(x) = \sum_{l=1}^{2M} b_l(P_{\alpha-1,l}(x) - xC_{\alpha,l}), \qquad (33)$$

where $C_{\alpha,l} = \int_0^1 P_{\alpha,l}(x)\,dx.$ Substituting Equations 31, 32 and 33 in Equation 30, we get

$$\sum_{l=1}^{2M} b_l h_l(x) = f(x) - a(x)y_r'^2(x) - b(x)y_r(x)y'_r(x), \quad 1 < \alpha \le 2 \qquad (34)$$

with the initial approximation $y_0(x) = 0, y_0'(x) = 0.$ Here we consider $a(x) = e^x$ and $b(x) = x.$

We fix the order of the differential Equation 28, $\alpha = 2$, and level of resolution, $J = 5$. The graph in Figure 7 shows the exact and approximate solutions by proposed method at six iterations. The absolute error reduces with increasing iterations.

Results at sixth iteration of proposed method at fixed level of resolution, $J = 5$, and at different values of α are shown in Figure 8 with the exact solution at $\alpha = 2$. Figure 8 showed that the numerical solutions converge to the exact solution when α approaches to 2.

Conclusion

This study showed that Haar wavelet-Picard technique gives excellent results when applied to different fractional order nonlinear initial and boundary value problems.

The solution of the fractional order, nonlinear differential equation converge to the solution of the integer order differential equation as shown in Figures 2, 4, 6 and 8.

Other Figures shows that approximate solution converge to the exact solution while iterations are increased and absolute error goes down.

Different type of nonlinearities can easily be handled by the Haar wavelet-Picard technique.
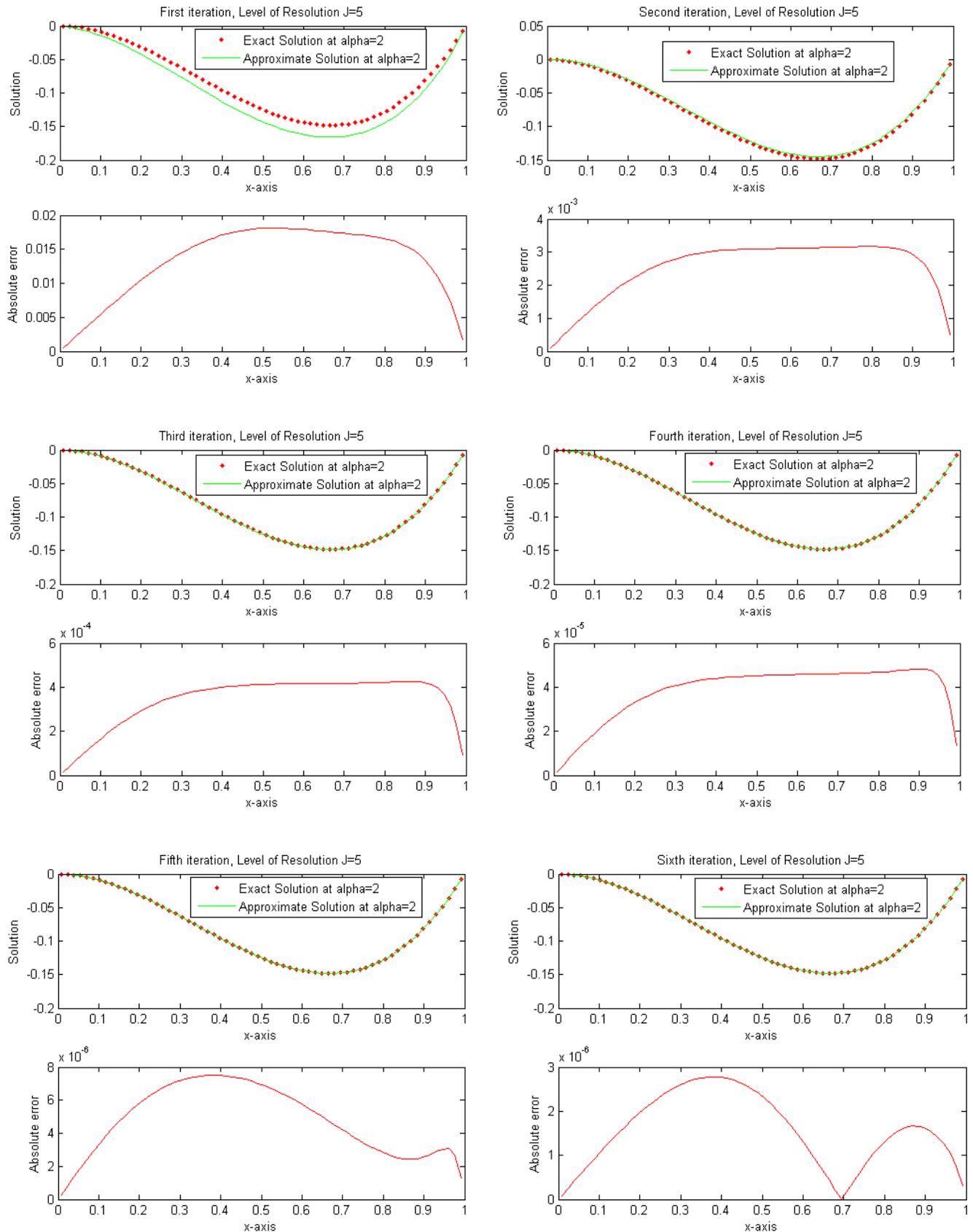
Figure 7. Comparison of exact solution and solutions by Haar wavelet-Picard technique at *J* = 5*,* for different iterations, and α = 2.
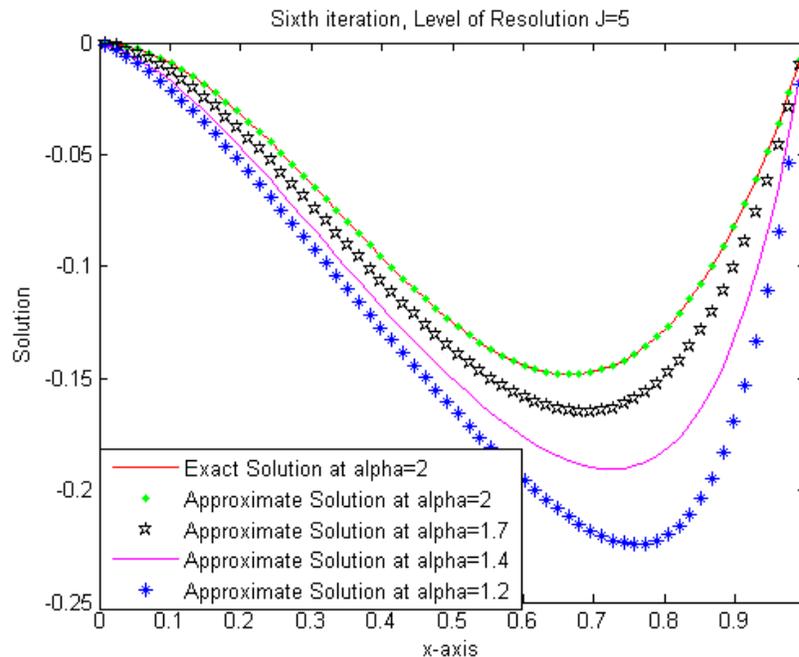
Figure 8. Exact solution at α = 2 and the Haar wavelet-Picard solution at α = 2, α = 1.7, α = 1.4, and α = 1.2.

Conflict of Interests

The author(s) have not declared any conflict of interests.

REFERENCES

Babolian E, Shahsavaran A (2009). Numerical solution of nonlinear Fredholm integral equations of the second kind using Haar wavelets. J. Comput. Appl. Math. 225:87-95. http://dx.doi.org/10.1016/j.cam.2008.07.003

Bellman RE, Kalaba RE (1965). Qusailinearization and Nonlinear Boundary Value Problems. Am. Elsev. Publish. Comp.

Chen CF, Hsiao C H (1997). Haar wavelets method for solving lumped and distributed-parameter systems, IEE proceed. Cont. Theo. Appl. P. 144.

Daubechies I (1990). The wavelet transforms, time-frequency localization and signal analysis. IEEE Transact. Inf. Theo. 36:961-1005. http://dx.doi.org/10.1109/18.57199

Kiymaz O (2010). Variational iteration method for a class of nonlinear differential equations. Int. J. Contemp. Math. Sci. 5:1819-1826.

Mujeeb ur Rehman, Khan RA (2012). A Numerical method for solving boundary value problems for fractional differential equations. Appl. Math. Model. 36:894-907.

Podlubny I (1999). Fractional differential equations. Acad. Press, San Diego.

Siraj-ul-Islam I, Aziz I, Sarler B (2010). The numerical solution of second-order boundary-value problems by collocation method with the Haar wavelets. Math. Comp. Model., 52:1577-1590. http://dx.doi.org/10.1016/j.mcm.2010.06.023

Full Length Research Paper

Recycling sodium dichromate in sodium chlorate crystallization mother liquor by nanofiltration membrane

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In the process of sodium chlorate electrolysis production, chemical precipitation is often used to remove the sulfate radical in the crystallization mother liquor which leads to the dichromate deposit to salt sludge together with sulfate, and finally causes chromium pollution. The nanofiltration membrane and freezing crystallization integrated technology was presented to treat crystallization mother liquor. The research conducted in this work shows that, $Na_2Cr_2O_7$ concentration was lower than 0.05 g/L, Na_2SO_4 concentration was lower than 1 g/L in the nanofiltration permeate and it could be recycled for brine refining stage avoiding the chromium pollution caused by subsequent treatment. The content of $Na_2Cr_2O_7$ in salt sludge was less than 8.5 ppm below the 10 ppm discharge standards. Then, the nanofiltration concentrate was frozen, Na_2SO_4 crystallized and precipitated. The supernatant mainly containing sodium dichromate could recycle to the electrolytic system. This method not only could recycle sodium dichromate, avoiding chrome sludge generated, but also could remove sulfate radicals.

Key words: Sodium chlorate, chrome sludge, nanofiltration, freezing crystallization, sodium dichromate recycling, sodium sulfate.

INTRODUCTION

Sodium chlorate used for preparing chlorine dioxide and a variety of chlorate salts is an important inorganic salt widely used in many areas, such as papermaking bleach, drinking water and wastewater treatment, printing and dyeing, medicine, pesticide, tanning, mineral processing (Bai, 2012). China sodium chlorate production capacity is about 200000 t/a, actual output of about 150000 t/a, equivalent to one or two factories' production capacity of the developed countries (Wang and Si, 2008). Domestic

sodium chlorate production is still in the stage of development, and the scope of application is also constantly expanding, so the potential market is very broad. To save water resources, the crystallization mother liquor is returned to the process of dissolving salt and be recycled in the industrial production of sodium chlorate. However, compared with foreign countries, domestic existing brine purification equipment is relatively deficient, which leads to impurities such as sulfate radical abound,
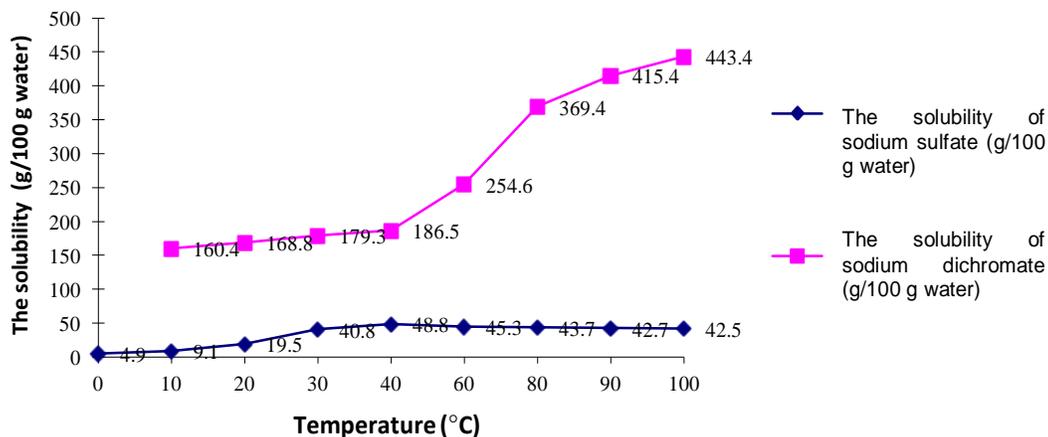
Figure 1. The solubility in the water of sodium dichromate and sodium sulfate.

and this will increase side reaction of the electrolytic process and reduce the current efficiency (Ye, 2008).

To avoid cathodic reduction reaction, it is necessary to add dichromate to electrolysis bath (Lin, 2006). In the existing process, chemical precipitations is often used to remove the sulfate radical in the crystallization mother liquor, which leads to the dichromate deposit to salt sludge together with sulfate, and finally causes chromium pollution (Gupta et al., 2002). Hexavalent chromium ion in dichromate will cause serious pollution to the environment and water source, thus do harm to fishing, forestry, agriculture and human health, and hexavalent chromium ion has a strong carcinogenic effect (Zhitkovich, 2011; Lone et al., 2013). Therefore, it is very urgent to solve the problem of chromium pollution in sodium chlorate production which has important theoretical significance and social value.

A series of processing for chrome sludge, landfill treatment, sludge deoxidation detoxification technology cannot achieve good results. The application of nano-material in containing Cr(VI) nanowastes processing achieves the effective separation of Cr(VI), recycling and nanowastes safe disposal (Liu et al., 2009). However, this method still cannot be applied on an industrial scale production and the processing cost is high.

At present, a variety of methods have been applied for the removal of Cr(VI) from industrial effluents which include chemical reduction-precipitation (Gheju and Balcu, 2011; Golder et al., 2007), adsorption (Cho et al., 2011), ion exchange (Lin and Kiang, 2003), membrane separation (Sankır et al., 2010; Ho and Poddar, 2001), biological reduction (Xu et al., 2009), radiolysis (Djouider, 2012), etc. The focus shifts from chrome sludge to the entire process of sodium chlorate production. So, we put forward the combination separation technology of nanofiltration and freezing crystallization for treating the crystallization mother liquor of sodium chlorate production in order to achieve the recycling utilization of sodium dichromate. It reduces costs, makes the wastewater and

sludge produced in the production of sodium chlorate no longer contain chromium, and reaches safe discharge standards, so as to realize clean production. Furthermore, it achieves the purpose of separation sulfate ion from the system, and improves the efficiency of electrolysis.

MATERIALS AND METHODS

The separation of solutes by nanofiltration membranes results from a complex mechanism including steric hindrance as well as Donnan and dielectric effects (in the case of charged solutes) (Luo and Wan, 2013). It was reported that nanofiltration technology could separate low molecular weight solutes from inorganic salt solutions (Bao et al., 2013; Luo et al., 2009; Hong et al., 2006). Nanofiltration membranes have the advantages of providing a high water flux at low operating pressure and maintaining a high salt and organic matter rejection (Hilal et al., 2005; Moravia et al., 2013). In addition, the nanofiltration process benefits from easy operation, high reliability and relatively low energy consumption as well as high efficiency of pollutant removal, so it has become a very valuable water treatment in the field of separation technology nowadays. Some studies have shown that nanofiltration membrane technology could be successfully used in the treatment of wastewater containing chromium (Wang et al., 2007; Cassano et al., 2007; Campagna et al., 2013). At the same time, membrane separation technology is also applied to the separation of sulfate and chloride ions in the chlor-alkali industry and has achieved a satisfactory result (Xiao et al., 2009).

The solution separated in this process is the crystallization mother liquor of sodium chlorate production. The main anions of the solution are Cl^-, SO_4^{2-} and $Cr_2O_7^{2-}$. The Cl^- is monovalent monatomic anion, and its relative molecular weight is 35.45, while the SO_4^{2-} and $Cr_2O_7^{2-}$ are bivalent polyatomic anions and their relative molecular weight are 96.07 and 216.00, respectively. Compared with Cl^-, SO_4^{2-} and $Cr_2O_7^{2-}$ have a heavier weight, larger size, more number of charges, and the interception of nanofiltration membrane to SO_4^{2-} and $Cr_2O_7^{2-}$ is greater than that of Cl^- (Luo et al., 2009). Therefore, it is logical that choosing appropriate nanofiltration membrane to realize the interception and enrichment of SO_4^{2-} and $Cr_2O_7^{2-}$ and the purification of Cl^-.

As shown in Figure 1, compared with the sodium dichromate, the sodium sulfate has a low solubility in water, and with the decrease
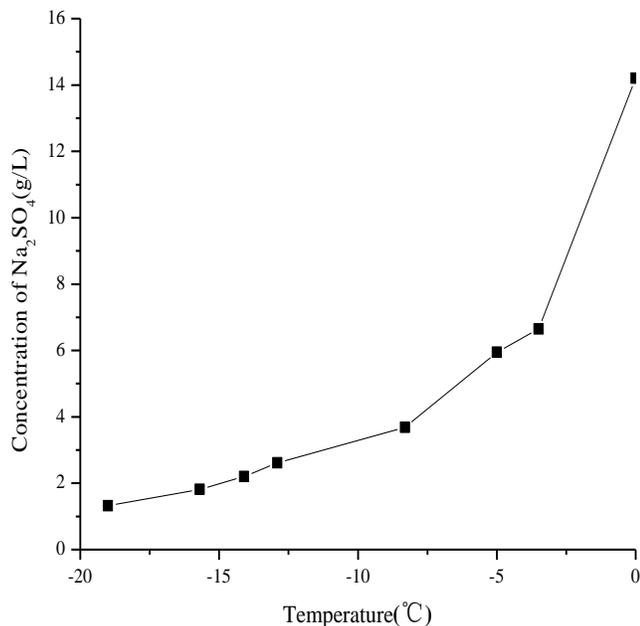
Figure 2. Sodium sulfate concentration changes with temperature during -20~0°C.
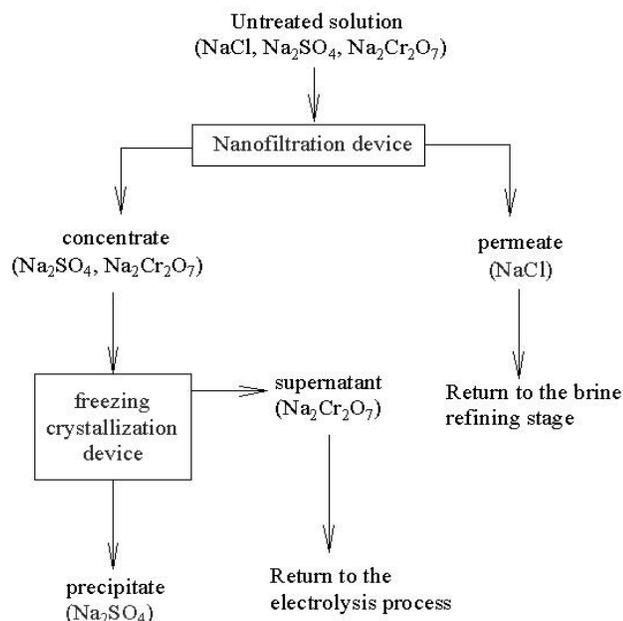
Figure 3. The process flow diagram.

of temperature, it will decline significantly. Especially under the condition of low temperature, the solubility of sodium sulfate is far lower than that of sodium dichromate. Figure 2 shows that in -8~0°C the reducing rate of sodium sulfate solubility is faster, but it becomes smooth below the temperature. Freezing crystallization temperature is controlled below -5°C, Na_2SO_4 concentration in the solution is less than 5 g/L after freezing (Cui, 2012). Combined with the energy saving consideration, the freezing crystallization

temperature is generally determined as -5~-10°C. So, freezing crystallization method is effective by this way, the sodium dichromate can be concentrated under the low temperature, and sodium sulfate crystallize and separate out, realizing the separation of them.

In summary, nanofiltration device can realize the purification of Cl⁻ and the intercept and enrichment of SO_4^{2-} and $Cr_2O_7^{2-}$, and through freezing crystallization, SO_4^{2-} can crystallize and precipitate, while $Cr_2O_7^{2-}$ is recycled. Finally, the recycling of sodium dichromate in production of sodium chlorate will be realized at the same time the sulfate impurity is removed.

The main technological process includes nanofiltration separation and crystallization separation as shown in Figure 3. Experimental equipment mainly comprises raw material tank, pump, pressure gauge, nanofiltration device and freezing crystallization device as shown in Figure 4. Nanofiltration membrane used in the experiment was GE2540, volume type membrane, effective membrane area 2.5 m², salt rejection 98%, and the coat material is glass fiber reinforced plastic. CIC-100 ion chromatography was used for the analysis of negative ion concentration following the standard of HJ/T84-2001 "Water quality-determination of inorganic anions by ion chromatography".

The property parameters of the raw material liquid are shown in Table 1, and experimental operating conditions are shown in Table 2. The main ingredient of penetrating fluid through nanofiltration device was NaCl which can be returned directly to the brine refining stage. Concentrates mainly composed of Na_2SO_4 and $Na_2Cr_2O_7$ which need to be further separated by freezing crystallization. After crystallization by freezing, Na_2SO_4 precipitated from the solution, and $Na_2Cr_2O_7$ presented in the supernatant. The supernatant can be returned to sodium chlorate electrolysis system to inhibit side reactions, protecting the cathode electrode, so as to achieve the recycling of $Na_2Cr_2O_7$.

RESULTS

The experiment was repeated six times and the experimental dates were shown in Table 2. The $Na_2Cr_2O_7$ concentrations were all lower than 0.05 g/L, Na_2SO_4 concentrations were lower than 1 g/L in the nanofiltration permeate, and the permeate could be recycled for the brine refining stage. The content of $Na_2Cr_2O_7$ in salt sludge was less than 8.5 ppm.

DISCUSSION

The experimental results show that, the permeance of sodium chloride and concentration of sodium sulfate and sodium dichromate could be effectively achieved by using nanofiltration. The raw material liquid contains NaCl, Na_2SO_4 and $Na_2Cr_2O_7$, membrane to the interception of SO_4^{2-} and $Cr_2O_7^{2-}$ is prior to Cl⁻. If the concentration of Na_2SO_4 and $Na_2Cr_2O_7$ increases, membrane for interception of Cl⁻ rate reduces. In order to maintain neutral through the membrane of sodium ions will also increase. When the multivalent ions concentration reaches certain value, the retention rate of monovalent ions even can appear negative, namely the Cl⁻ concentration in permeate is greater than that of the feed.

In the six groups of repeated experiments, $Na_2Cr_2O_7$ concentrations were all lower than 0.05 g/L, Na_2SO_4
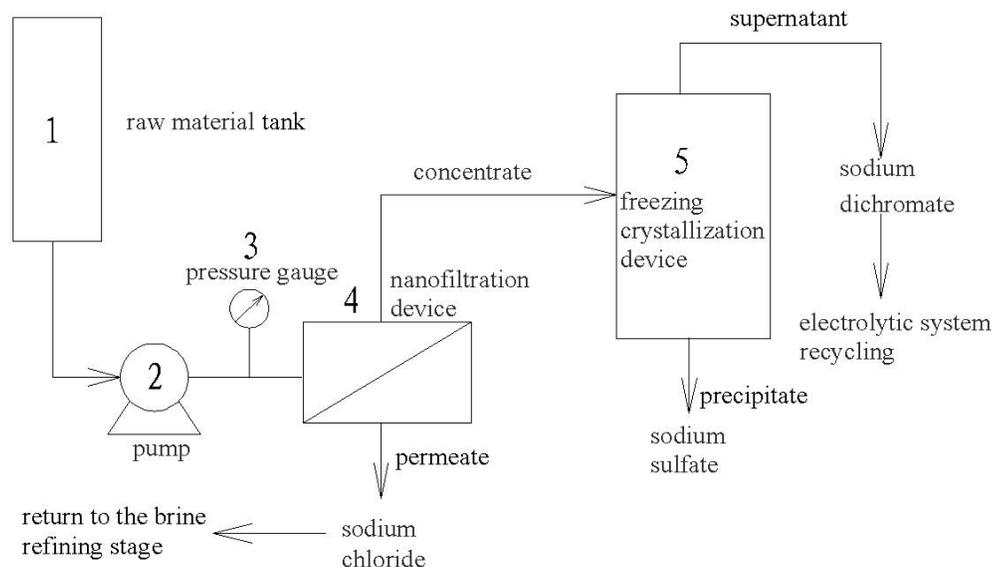
Figure 4. The process flow diagram for the sodium dichromate recycling and sulfate radical removal in the crystallization mother liquor.

Table 1. The property parameters of the raw material liquid.

Concentration (g/L)			Volume (L)	pH
NaCl	Na_2SO_4	$Na_2Cr_2O_7$	40	8.59 - 9.5
113	29	3.35		

Table 2. The experimental operating conditions.

NF inlet pressure (MPa)	NF flow rate (L/min)	Freezing crystallization temperature (°C)	The temperature of raw material solution (°C)
0.5 to 1.5	20	-5 ~ -10	25

concentrations were lower than 1 g/L in the nanofiltration penetrating fluid, and the penetrating fluid could be recycled for the brine refining stage. The content of $Na_2Cr_2O_7$ in salt sludge was less than 8.5 ppm, lower than the United States environmental protection agency of hexavalent chromium content in the sludge discharge standard 10 ppm. Then, the nanofiltration concentrate was frozen, Na_2SO_4 crystallization precipitation, and supernatant could recycle to the electrolytic system. This method not only could recover sodium dichromate but also remove sulfate radicals.

Conclusions

The nanofiltration permeate could be recycled to the brine refining stage, $Na_2Cr_2O_7$ concentration was lower than 0.05 g/L to avoid the subsequent processing of chromium pollution. The $Na_2Cr_2O_7$ content in salt sludge was less than 8.5 ppm below the United States environmental protection agency on the discharge standard of hexavalent chromium content in sludge 10 ppm. Na_2SO_4 concentration in permeate was lower than 1 g/L, which could meet the production requirements. The nanofiltration concentrate was frozen, Na_2SO_4 crystallized and precipitated, and the supernatant was recycled to the electrolytic system, which not only could recover sodium dichromate but also remove sulfate radicals.

This process effectively realized sodium dichromate recycling in the production of sodium chlorate, at the same time also removed sulfate radicals, and solved the dichromate pollution in salt sludge from the original precipitation process.

Conflict of Interests

The author(s) have not declared any conflict of interests.

REFERENCES

Bai YF (2012). Sodium chlorate: Effective agent of pulp bleaching and water treatment. China Salt Ind. 12:55-58.

Bao ZJ, Zheng H, Yang YP (2013). Study on reuse of nanofiltration membranes for application in the treatment of synthetical electroplating wastewater. J. Zhejiang Univ. Sc. 3:314-318.

Campagna M, Çakmakcı M, Büşra Yaman F, Özkaya B (2013). Molecular weight distribution of a full-scale landfill leachate treatment by membrane bioreactor and nanofiltration membrane. Waste manag. 33:866-870. http://dx.doi.org/10.1016/j.wasman.2012.12.010; PMid:23290269

Cassano A, Pietra LD, Drioli E, (2007). Integrated membrane process for the recovery of chromium salts from tannery effluents. Ind. Eng. Chem. Res. 46:6825-6830. http://dx.doi.org/10.1021/ie070144n

Cho DW, Chon CM, Kim Y, Jeon BH, Schwartz FW, Lee ES, Song H (2011). Adsorption of nitrate and Cr(VI) by cationic polymer-modified granular activated carbon. Chem. Eng. J. 175:298-305. http://dx.doi.org/10.1016/j.cej.2011.09.108

Cui YH (2012). Studies on desulfuration from the sodium sulfate-containing brine. Jiangsu Salt Sci. Technol. 4:1-3.

Djouider F (2012). Radiolytic formation of non-toxic Cr(III) from toxic Cr(VI) in formate containing aqueous solutions: A system for water treatment. J. Hazard. Mater. 223:104-109. http://dx.doi.org/10.1016/j.jhazmat.2012.04.059; PMid:22595544

Gheju M, Balcu I (2011). Removal of chromium from Cr(VI) polluted wastewaters by reduction with scrap iron and subsequent precipitation of resulted cations. J. Hazard. Mater. 196:131-138. http://dx.doi.org/10.1016/j.jhazmat.2011.09.002; PMid:21955659

Golder AK, Chanda AK, Samanta AN, Ray S (2007). Removal of Cr(VI) from aqueous solution: electrocoagulation vs chemical coagulation. Sep. Sci. Technol. 42:2177-2193. http://dx.doi.org/10.1080/01496390701446464

Gupta B, Deep A, Tandon SN (2002). Recovery of chromium and nickel from industrial waste. Ind. Eng. Chem. Res. 41:2948-2952. http://dx.doi.org/10.1021/ie010934b

Hilal N, Al-Zoubi H, Mohammad AW, Darwish NA (2005). Nanofiltration of highly concentrated salt solutions up to seawater salinity. Desalination 184:315-326. http://dx.doi.org/10.1016/j.desal.2005.02.062

Ho WS, Poddar TK (2001). New membrane technology for removal and recovery of chromium from waste waters. Environ. Prog. 20:44-52. http://dx.doi.org/10.1002/ep.670200115

Hong SU, Miller MD, Bruening ML (2006). Removal of dyes, sugar, and amino acid from NaCl solutions using multilayer polyelectrolyte nanofiltration membranes. Ind. Eng. Chem. Res. 45:6284-6288. http://dx.doi.org/10.1021/ie060239+

Lin FJ (2006). A review on the production and development of chlorates. Chlor-Alkali Ind. 08:26-27.

Lin SH, Kiang CD (2003). Chromic acid recovery from waste acid solution by an ion exchange process: equilibrium and column ion exchange modeling. Chem. Eng. J. 92:193-199. http://dx.doi.org/10.1016/S1385-8947(02)00140-7

Liu WZ, Xu XJ, Wang YJ, He Z, Zhou N, Huang F, Lin Z (2009). Treatment of Cr(VI)-containing nano wastes via the growth of nanomaterial. Chinese Sci. Bull. 54:3645-3650.

Lone AH, Lal EP, Thakur S, Ganie SA, Saleem M (2013). Accumulation of heavy metals on soil and vegetable crops grown on sewage and tube well water irrigation. Sci. Res. Essays 8:2187-2193.

Luo JQ, Wan YH (2013). Effects of pH and salt on nanofiltration-a critical review. J. Membr. Sci. 438:18-28. http://dx.doi.org/10.1016/j.memsci.2013.03.029

Luo JQ, Wei SP, Su Y, Chen XR, Wan YH (2009). Desalination and recovery of iminodiacetic acid (IDA) from its sodium chloride mixtures by nanofiltration. J. Membr. Sci. 342:35-41. http://dx.doi.org/10.1016/j.memsci.2009.06.019

Moravia WG, Amaral M, Lange LC (2013). Evaluation of landfill leachate treatment by advanced oxidative process by Fenton's reagent combined with membrane separation system. Waste Manag. 33:89-101. http://dx.doi.org/10.1016/j.wasman.2012.08.009; PMid:23058598

Sankır M, Bozkır S, Aran B (2010). Preparation and performance analysis of novel nanocomposite copolymer membranes for Cr(VI) removal from aqueous solutions. Desalination 251:131-136. http://dx.doi.org/10.1016/j.desal.2009.09.134

Wang KY, Chung TS, Rajagopalan R (2007). Novel Polybenzimidazole (PBI) nanofiltration membranes for the separation of sulfate and chromate from high alkalinity brine to facilitate the Chlor-Alkali process. Ind. Eng. Chem. Res. 46:1572-1577. http://dx.doi.org/10.1021/ie061435j

Wang SM, Si HF (2008). Introduction to the technology and application of sodium chlorate. Mod. Sci. 18:55-56.

Xiao F, Wei JQ, Wei MD, Wang ML (2009). Industrial application of nanofiltration membrane in denitrification process. Tianjin Chem. Ind. 23:34-36.

Xu WH, Liu YG, Zeng GM, Li X, Peng QQ (2009). Sulfate-reducing bacteria and research progress of Cr (VI) reduction by sulfate-reducing bacteria. Microbiology 36:1040-1045.

Ye YY (2008). On domestic and international sodium chlorate manufacturing and equipment technology. Inorg. Chem. Ind. 40:1-3.

Zhitkovich A (2011). Chromium in drinking water: sources, metabolism, and cancer risks. Chem. Res. Toxicol. 24:1617-1629. http://dx.doi.org/10.1021/tx200251t; PMid:21766833 PMCid:PMC3196244

Scientific Research and Essays

Full Length Research Paper

The effects of humic acid application upon the phosphorus uptake of the tomato plant (*Lycopersicum esculentum L.*)

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Humic acid can transform mineral nutrients into available forms for the plants. High lime content, low organic matter content, high pH, low moisture content and insufficient profile characteristics all higher plant phosphorus uptakes and consequently regress plant growth and development. The present research was conducted to investigate the effects of humic acid treatments (H.A.) (0, 60, 120 mg/kg) on phosphorus use efficiency (PUE) (0, 50, 100 mg/kg P) of grape and pole tomato (*Lycopersicum esculentum L.*) varieties. Pot experiments were carried out in a glasshouse in randomized block design with three replications. As basic fertilization, 250 mg/kg N and 200 mg/kg K was applied to the pots. Plants were harvested when they had their 5th raceme. Dry matter yields, N, P and K contents were analyzed. Dry matter yields increased with humic acid and phosphorus treatments. Phosphorus contents also increased with increasing phosphorus doses. While humic acid and phosphorus treatments affected the potassium contents, Ca contents increased through only the humic acid application.

Key words: Humic acid, phosphorus use efficiency, tomato plant.

INTRODUCTION

Phosphorus is a macro-element that plays an important role upon the development of higher plants. Phosphorus has several functions in plants. It is a component of key molecules such as nucleic acids, phospholipids and ATP, and, consequently, plants cannot grow without a reliable supply of this nutrient (Daniel et al., 1998). P is also involved in controlling key enzyme reactions and in regulation of metabolic pathways (Theodorou and Plaxton, 1993).

Lime dissolves in neutral or acidic soils, but does not readily dissolve in alkaline soils and instead serves as a sink for surface-adsorbed calcium phosphate precipitation (Hopkins and Ellsworth, 2005). Moreover, high pH decreases the availability of phosphorus administered as low organic matter chemical fertilizer. Phosphorus is an efficient mineral upon the root development of the plant and poor root development is observed in case of insufficient supply of phosphorus.

Significant yield losses are also experienced in plants which are not nourished with sufficient phosphorus, and the quality of crop is affected negatively, as well. Efficiency and beneficialness of phosphorus fertilizers can increase the solubility of phosphorus in soil solution.

Chemical formula of the soil organic matter is not specific due to its dynamic structure (Khaled and Fawy, 2011). Soil organic matter mainly includes humic and fulvic acid (Andriesse, 1988). Humic substances are deterioration-resistant heterogeneous natural resources that have high molecular weight and varying in colors from yellow to black (Akıncı, 2011). Humic substances in interaction with phosphorus in the soil can decrease the phosphorus fixation and increase the phosphorus uptake of plants (Hua et al., 2008).

Cation exchange capacity and soil productivity are increased through administering humic acid into soils and having positive impacts on mineral matter uptake of plant (Stevenson, 1994). Humic acid serves as a buffer at a broad pH interval and several micro-elements can be taken by the plants since the soil is neutralized (Yılmaz, 2007). The studies carried out on humic acids have revealed the necessity of using these substances in vegetative production. Commercial humic-fulvic acid treatments improve the phosphorus fertilizer use efficiencies (Delgado et al., 2002). Besides increasing the plant growth of squash, humic acid application also increased fruit yield and quality (Hafez, 2004). Humic acid treatments increased the total yield of watermelon hybrids (Salman et al., 2005). Together with increased root dry matter yields and plant heights, humic acid also increased the N. P, K, Ca, Cu, Mn, Zn and Fe uptake of maize plants (Eyheraguibel et al., 2008).

The present study was conducted to investigate the effects of humic acid applications upon phosphorus uptake of tomato plant in soils with high lime content under greenhouse conditions.

MATERIALS AND METHODS

This study was carried out in a greenhouse over experimental fields Gaziosmanpasa University in the year 2011. A pot experiment was conducted in completely randomized block design with three replications. Pots were filled with four kg of calcareous soil.Bandita and Bestona tomato varieties (*Lycopersicum esculentum L.*) were grown in pots. Each pot had a single plant.

Commercial liquid humic substance (TKI Humas; total organic matter 5%, total humic and fulvic acid 12% and potassium oxide 2%) was administered at 0.60, 120 mg/kg doses as the humic substance of the experiments. Phosphorus fertilizer was administered at 0, 50, 100 and 150 mg/kg P doses as phosphoric acid (H_3PO_4). As basic fertilization, 250 mg/kg N as ammonium nitrate and 200 mg/kg K as potassium nitrate were administered to the pots. For plant development, other nutrients were administered to each pot equally as they needed. When the leaves of the plants reached up to 5th raceme, they were harvested, dried to a constant weight at 68°C and their dry weights were determined.

The leaves of plant were combusted according to dry combustion method (Kacar and Inal, 2008). Plant N content was analyzed according to distillation method (Bremner, 1965) and P, K, Ca, Mg,

and S contents were analyzed using ICP-AES (Perkinelmer 2100DV). In the experimental soil, texture (Gee and Bouder, 1986), soil $CaCO_3$ (Chapman and Pratt, 1961), soil pH (McLean, 1986), exchangeable potassium (Richards, 1954) and available P (Olsen et al., 1954), organic matter (Jackson, 1956) and available Fe, Zn, Cu and Mn contents in DTPA were determined (Lindsay and Norwell, 1978). Experimental soil has a clay-loam texture and has clay, silt and sand contents respectively of 31%, 33% and 36%. Lime content was 18.90%, pH (soil:H_2O = 1:2.5) was 8.15, organic matter content was 1.20%, available P content was 1.45 kg/da, CEC = 36.90 me/100 g and exchangeable K content was 200 mg/kg. DTPA soluble Fe, Cu, Zn, and Mn contents were 2.05, 1.02, 0.11 and 3.65 µg/g, respectively.

Variance analysis of the obtained data was performed using the MSTAT-C statistical software and the differences between the means were determined by Duncan's multiple range test (Düzgüneş et al., 1978).

RESULTS

Dry matter yields and P contents

The effects of different doses of humic acid and phosphorus treatments on dry matter yields of Bandita and Bestona tomato species and variance analysis results are presented in Tables 1 and 2. Humic acid treatments had significant impacts *(p<0.05)* on dry matter yields of Bandita and Bestona tomato species. Through the humic substance treatments, dry matter yield of Bandita tomato species increased from 25.8 g pot[-1] to 34.3 g pot[-1]. Compared to control treatment, humic substance treatments also significantly increased the dry matter yields of Bestona tomato species (from 18.3 to 26.3 g pot[-1]).

Phosphorus treatments also resulted in significant increases in dry matter yields of tomato species (p<0.01). The highest dry matter yield of Bandita and Bestona tomato species in 150 ppm P application was respectively observed as 49.5 g pot[-1] and 43.6 g pot[-1]. The effects of humic substance x phosphorus interaction on dry matter yields of tomato species were also found to be significant (p < 0.01).

The effects of humic acid treatments on phosphorus contents of tomato species were not found to be significant (Tables 1 and 2). In both tomato species, foliar P contents did not significantly change with humic acid treatments. However, phosphorus doses had significant (p<0.01) impacts on P contents of the leaves (Tables 1 and 2) and increasing P contents were observed with increasing phosphorus doses. The highest P content in Bandita tomato species was 1.69% in 100 mg/kg P and 120 mg/kg H.A treatment and the highest P content in Bestona tomato species was 1.65% in 150 ppm P and 60 mg/kg H.A treatment. Exploited phosphorus amounts showed parallelism with phosphorus contents of the plant for both tomato species (Tables 1 and 2).

N, K, Ca, S, and Mg contents of tomato plants

Humic substance and phosphorus treatments did not

Table 1. The effects of humic acid and phosphorus treatments on dry matter yield and macro nutrient contents of Bandita tomato species.

H.A ppm		Bandita phosphorus treatment (mg/kg)				Average
		0	50	100	150	
	0	14.3	29.4	23.3	31.1	25.8
Dry matter yield (gr/pot)	60	19.4	28.1	38.2	49.5	36.1
	120	28.3	35.8	43.2	44.1	34.3
	0	0.36	0.85	1.09	1.21	0.87
P (%)	60	0.48	1.10	1.26	1.23	1.01
	120	0.39	1.25	1.69	1.47	1.20
	0	51.4	250.1	254.1	375.1	232.3
Total P, mg/pot	60	93.1	306.3	475.1	607.6	370.1
	120	110.3	457.6	733.9	648.2	487.1
	0	3.00	2.91	3.19	2.83	2.98
N (%)	60	3.17	3.20	3.16	2.87	3.07
	120	2.75	3.33	3.26	3.06	3.10
	0	2.60	3.60	3.72	3.28	3.30
K (%)	60	3.66	4.32	4.36	3.54	3.97
	120	3.46	3.91	4.20	3.99	3.89
	0	1.72	1.51	1.42	1.85	1.62
Ca (%)	60	1.96	2.30	2.24	2.14	2.16
	120	2.48	2.06	2.43	2.12	2.27
	0	0.20	0.13	0.14	0.13	0.15
S (%)	60	0.12	0.21	0.13	0.21	0.17
	120	0.21	0.20	0.24	0.17	0.20
	0	0.90	0.80	0.61	0.85	0.79
Mg (%)	60	0.79	0.95	0.80	0.86	0.85
	120	0.92	0.87	0.91	0.83	0.88

Dry matter yield: H.A.:*, P.A.:**, HA x PA:*; P content: H.A.: N.I.,P.A.:**, HA x P.A:N.I.; Total P: H.A.:*, P.A.:**, HA x PA:*; K content: H.A.:**, P.A.:**, H.A x P.A.: ** Ca content: H.A.:**, P.A.:N.I, HA x P.A.:N.I.; NI: Not Important; * $P<0,05$ and **$P<0,01$, $P<0,001$ possibility are important.

have significant effects on nitrogen contents of tomato species (Tables 1 and 2). On the other hand, H.A. and treatments had significant impacts on K contents of tomato plants at 1% level (Tables 1 and 2). Considering the averages, potassium content of Bendita tomato species increased from 3.30% to 3.97% through the humic acid treatments. In Bestona species, potassium content increased from 3.59 to 3.98% with the humic acid treatments. Similarly, it was also noticed that K contents of both species increased with phosphorus applications. According to research results, it was seen that as a result of the increase at vegetative development the plant produced at low phosphorus, the plant benefited more from the administered potassium.

While the humic acid treatments had significant ($p<0.01$) effects on calcium contents of the plants, phosphorus treatments did not result in any significant impacts on calcium contents. Ca content of Bandita tomato species was observed as 1.62% in H 0 mg/kg treatment, 2.16% in H 60 mg/kg and 2.27% in H 120 mg/kg treatment. Ca contents of Bestona tomato species were, respectively observed as 2.08, 2.31, and 2.11%.

Table 2. The effects of humic acid and phosphorus treatments on dry matter yield and macro nutrient contents of Bestona tomato species.

H.A ppm		Bestona phosphorus treatments (mg/kg)				Average
		0	50	100	150	
	0	11.8	16.3	20.1	24.9	18.3
Dry matter yield (gr/pot)	60	13.2	19.2	19.4	33.0	21.2
	120	16.6	17.9	27.0	43.6	26.3
	0	0.36	1.22	1.23	1.64	1.11
P (%)	60	0.32	1.30	1.65	1.51	1.19
	120	0.36	1.13	1.41	1.30	1.05
	0	42.8	198.2	333.2	408.3	245.8
Total P (mg/pot)	60	42.8	253.6	327.2	500.5	281.1
	120	59.7	202.2	283.4	566.8	227.2
	0	3.11	2.88	2.98	3.25	3.05
N (%)	60	2.94	2.87	3.10	3.28	3.05
	120	3.02	3.52	3.27	3.12	3.23
	0	3.33	4.02	3.54	3.49	3.59
K (%)	60	3.67	3.92	3.98	3.42	3.75
	120	3.86	4.08	4.14	3.86	3.98
	0	2.23	2.39	1.81	1.90	2.08
Ca (%)	60	2.97	2.10	2.16	2.01	2.31
	120	2.25	1.92	2.09	2.18	2.11
	0	0.22	0.19	0.23	0.16	0.20
S (%)	60	0.23	0.23	0.24	0.27	0.24
	120	0.26	0.21	0.21	0.23	0.23
	0	0.76	0.78	0.81	0.84	0.79
Mg (%)	60	0.76	0.88	0.90	0.89	0.86
	120	0.88	0.88	0.87	0.91	0.88

Dry matter yield: H.A.:*, P.A.:**, HA x PA:*; P content: H.A.: N.I.,P.A.:**, HA x P.A:N.I.; Total P: H.A.:*, P.A.:**, HA x PA:*; K content: H.A.:**, P.A.:**, H.A x P.A.: ** Ca content: H.A.:**, P.A.:N.I, HA x P.A.:N.I.; NI: Not Important; * $P<0,05$ and **$P<0,01$, $P<0,001$ possibility are important.

Finally, humic acid and phosphorus treatments did not have any significant effects on sulfur and magnesium contents of tomato plants.

DISCUSSION

Compared to the control treatment, humic acid treatments resulted in significant increases in dry matter yields of tomato plants. Previous studies also reported significant positive impacts of humic substance treatments on dry matter yields of different plants (Hafez, 2004; Salman et al., 2005; Eyheraguibel et al., 2008).

Functional groups of humic molecules form complexes with metals through various means (Livens, 1991). These functional groups provide percolation of cations in soils and serve as natural chelate in soils. Stable complexes of humic substances with metal ions are related to these functional groups. Humic substances have high cation exchange capacity, thus metals in soils can form chelates with humic acids. Humic substances may hold the existing and externally applied soil minerals and consequently enrich plant growth and development. The increases in dry matter yields of the present study may also be related to these functions of humic substances. Increasing foliar phosphorus concentrations were

observed in this study with increasing phosphorus doses. Plant phosphorus uptake from the soil is directly related to dry matter yields of the plants. Exploited amount of phosphorus was higher in Bestona than Bandita tomato species. Effects of humic acid were more distinctive in this case.

Conclusions

The present results revealed that tomato dry matter yields significantly increased with humic substance treatments and such results comply with the findings of the previous studies (Hafez, 2004; Türkmen et al., 2004; Akıncı, 2011). P treatments also significantly increased P contents of the leaves and dry matter yields of the plants at 1% level. High pH, high lime and low organic matter content of experimental soil might have restricted the phosphorus uptake and the effects of these characteristics could clearly be inferred from the results of the study.

K and Ca contents of the plants also increased through the humic acid treatments, but significant effects were not observed on other minerals. These findings comply with the results of previous studies (Eyheraguibel et al., 2008; Mohamed, 2012). It was concluded in this study that the organic sedimentary compounds such as humic acids administered to the rhizosphere part of the plant roots after plantation increased the nutrient uptakes of the plants. Moreover, phosphorus treatments also enriched root development and growth.

Conflict of Interests

The author(s) have not declared any conflict of interests.

REFERENCES

Akıncı Ş (2011).Humic acids, plant growth and nutrient uptake.Journal of Marmara University Institute of Natural and Applied Sciences. 23(1):46-56 (in Turkish).

Andriesse JP (1988). Nature and management of tropical peat soils. FAO Soils Bulletin No. 59, 165, United Nations, Rome. PMid:3141155

Bremner JM (1965). Methods of soil analysis. Part II. chemical and microbiological properties. Ed. A.C.A. Black Amer. Soc. of Agron. Inc. Pub. Agron. Series No: 9 Madison USA.

Chapman HD, Pratt PF (1961). Method of analysis for soils and water.University of California, Div. Agric. Sci., USA.

Daniel P S, Robert JR, Ayling SM (1998). Phosphorus uptake by plants: from soil to cell. Plant Physiol. 116:447-453. http://dx.doi.org/10.1104/pp.116.2.447

Delgado A, Madrid A, Kassem S, Andreu L, Del Carmen CM (2002). Phosphorus fertilizer recovery from calcareous soils amended with humic and fulvic acids. Plant Soil. 245:277-286. http://dx.doi.org/10.1023/A:1020445710584

Düzgüneş O, Kesici T, Kavuncu O, Gürbüz F (1987). Experimental Design (Statistical Methods II). Ankara University Agricultural Facultu Press, Publication No: 1021 (in Turkish).

Eyheraguibel B, Silvestre J, Morard P (2008). Effects of humic substances derived from organic waste enhancement on the growth

and mineral nutrition of maize. Bioresour. Technol. 99:4206-4212. http://dx.doi.org/10.1016/j.biortech.2007.08.082; PMid:17962015

Gee GW, Bouder JW (1986). Particle size analysis.In A. Clute (edit.)Methods of Soil Analysis. Amer. Soc. Agric. No. 9:825-844, Madison, WI.

Hafez MM (2004). Effect of some sources of nitrogen fertilizer and concentration of humic acid on the productivity of squash plant. Egypt. J. Appl. Sci. 19:293-309.

Hopkins B, Ellsworth J (2005). Phosphorus availability with alkaline/calcareous soil.Western Nutrient Management Conference. 6:88-93, Salt Lake City, UT

Hua QX, Li JY, Zhou JM, Wang HY, Du CW, Chen XQ (2008). Enhancement of phosphorus solubility by humic substances in ferrosols. Pedosphere.18:533-538. http://dx.doi.org/10.1016/S1002-0160(08)60044-2

Jackson ML (1956). Soil analysis. Adv. Course. Fourth Print. Dept. of Soil Sci. Univ. of Wisconsin, Madison.WI.

Kacar B, Inal A (2008).Bitkianalizleri. Nobel Yay., ISBN 978-605-395-036-3.

Khaled H, Fawy HA (2011). Effect of different levels of humic acids on the nutrient content, plant growth, and soil properties under conditions of salinity. Soil Water Res. 6(1):21-29.

McLean EO (1986). Soil pH and lime requirement. In: Lerne, A. (ed.), Methods of Soil Analysis. ASA., SSSA, Madison, WI.

Lindsay WL, Norwell WA (1978). Development of a DTPA soil test for zinc, iron, manganese and copper.Soil.Sci. Soc. Am. J. 42:421-428. http://dx.doi.org/10.2136/sssaj1978.03615995004200030009x

Livens FR (1991). Chemical reactions of metals with humic material.Environmental Pollution. 70:183. http://dx.doi.org/10.1016/0269-7491(91)90009-L

Mohamed WH (2012). Effects of humic acid and calcium forms on dry weight and nutrient uptake of maize plant under saline condition. Aust. J. Basic App. Sci. 6(8):597-604.

Olsen SR, Cole CV, Watanable FS, Dean LA (1954).Estimation of available P in soils by extraction with sodium bicarbonate. U.S.D. Agric. No: 939, Washington D.C.

Richards LA (1954). Diagnosis and improvement of saline and alkaline soils. U.S. Soil Dept., Agr. Handbook No: 60.

Salman SR, Abou-Hussein SD, Abdel-Mawgoud AMR, El-Nemr MA (2005). Fruit yield and quality of watermelon as affected by hybrids and humic acid application. J. App. Sci. Res. 1(1):51-58.

Stevenson FJ (1994). Humus chemistry: Genesis, composition, reactions, 2nd edition, John Wiley and Sons, Inc, New York.

Theodorou ME, Plaxton WC (1993). Metabolic adaptations of plant respiration to nutritional phosphate deprivation. Plant Physiol. 101:339-344. PMid:12231689 PMCid:PMC160576

Türkmen O, Dursun A, Turan M, Erdinc C (2004). Calcium and humic acid affect seed germination, growth and nutrient content of tomato (Lycopersicon esculentum L.) seedlings under saline soil conditions. Acta Hort. Scandinavica B. 54:168-174.

Yılmaz C (2007). Humic and fulvic acid. J. Hasad Plant Prod. 260:74 (in Turkish).

Full Length Research Paper

A mechanical approach of overload protection mechanism for a heavy truck wheel force transducer

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The wheel force transducer (WFT), which measures the force or torque applied to the wheel, is an important instrument in vehicle testing field and has been extremely promoted by researchers. Since the high cost and technical secret of the commercial products may slow down the development of WFT to some extent, Southeast University has devoted to the WFT research with some prototypes. Essentially, the WFT is a multi-axis force sensor (MFS) in which an elastic-body will deform under the applied forces. However, when applying a MFS into vehicle wheel and making it to be a WFT, it may be subjected to forces/moments which exceed the measuring range under the over rated load, especially on a heavy truck WFT under loads of X or Z direction. Plastic deformation and damage may occur on the elastic-body of WFT. This paper presents a mechanical approach of the overload protection mechanism which can prevent the overload damage and guarantee the sensor performance. An intermediate flange, which is elaborately designed using Computer Aided Engineering (CAE) tools, is installed between wheel hub and the elastic body to meet the overload protection. Experiment and prototyping test are conducted on the hydraulic platform. Results show that the proposed overload protection mechanism performs well. In particular, the applied loads over ±120 kN and ±30 kNm are prevented from damage for the heavy truck WFT.

Key words: Wheel force transducer, overload protection mechanism, vehicle wheels/typres, heavy duty trucks.

INTRODUCTION

When the vehicle is moving on the road, three-axial forces of longitudinal force F_x, lateral force F_y, vertical force F_z, and three-axis torques of heeling moment M_x, twist torque M_y, and aligning torque M_z, are applied to the wheel. The interaction between the vehicle and ground is represented by the forces, and therefore, sensing the wheel forces/torques is quite significant in vehicle testing field (Kadhim et al., 2011; Kuchler and Schrupp, 2001;

Pavkovic et al., 2009; Pytka et al., 2011). To detect these forces, the famous multi-axis wheel force transducer (WFT) (Weiblen et al., 1999), which offers the capability of acquiring load data at the spindle of a vehicle, has been promoted extremely by researchers and engineers with great interests (Hong and Strumpfer, 2011; Zhang et al., 2011).

Due to the superior qualities of well static and dynamic

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Figure 1. The WFTs developed at SEU (The heavy truck WFT consists the overload protection mechanisim in this paper).

performance, on-board testing techniques and flexible, fast and easy installation on different vehicles, the WFTs are made to be necessities of automobile manufactures for vehicles performances verification and product quality improvements. Some world-famous companies including MTS Corp., Michigan Scientific Corp. and Kistler Corp. have already made their products available in market (Lin et al., 2014). The issue is that these WFTs are much expensive and, for business reasons, detailed technical information is not publicly available. It not only impedes the popularization of WFT application but also slows down its further development. Southeast University (SEU, China) has devoted over ten years to developing the instrument. Some prototypes (Figure 1) and published papers are available (Lin et al., 2013, 2014; Wang et al., 2011, 2014).

Generally, as an on-board instrument for wheel forces measurement, the WFT consists of a multi-axis force sensor (MFS) (Song et al., 2007) in which an elastic-body will deform under the applied forces. Measurement of the elastic deformations by appropriate transducers yields electrical signals from which the force components can be derived. However, when applying a common MFS into the vehicle wheel and make it to be a WFT, it may be subjected to forces/moments which exceed the measuring range under the over rated load, plastic deformations and damage may occur on the elastic-body. From the perspective of reliability, since vehicle loads can vary greatly from 100 kg for a motorcycle to more than 10000 kg for a truck, the sensor must bear the whole vehicle weight and have a large measuring range. It implies that performance of force sensitivity, strength and stiffness should be satisfied simultaneously. Moreover, the damage and failure will be much more prone to occur on the WFT of a heavy truck under dynamic loads at X and Z direction. Nevertheless, increasing the force sensitivity always changes the structural dimension so

that optimization design and dimensional synthesis need to be processed. It may result in the loss of structural strength and stiffness due to cutting material or using exotic materials. Nowadays, the sensor material covers from normal structure steel to the Aluminum or Titanium alloy which can be learned in some products. Weiblen et al. (1999) has evaluated several different designs of the WFT and the material selection including Titanium alloy versus Carbon fiber composite are compared in detail for two WFT systems. Using the exotic material may not only increase the costs but also increase the processing complexity including quenching, tempering and fatigue tests. If considering road conditions such as rough sandstone, tidal flats and drifting terrain, the reliability and practicability will be more complicated in design.

For the reasons presented above, the problem needs to be tackled with practical considerations. In a broad sense of engineering research, an overload protection mechanism can be made to guarantee the sensor performance and prevent the overload damage. No more exotic material is required and it maintains the merit of economy, practicability and reliability. This paper presents such an overload protection mechanism that a mechanical approach is performed on a heavy truck WFT to meet the requirement. Principle and methodology, design optimization and experimental tests are investigated for the overload protection mechanism of WFT.

PRINCIPLE AND METHODOLOGY

Sensor principle and problem

Essentially, the WFT is a multi-axis force sensor in which an elastic body (Figure 2b) is used to deform under the applied loads and then the wheel force/moment signals are converted by virtue of strain gauges, piezoelectric sensor or other sensing units which are
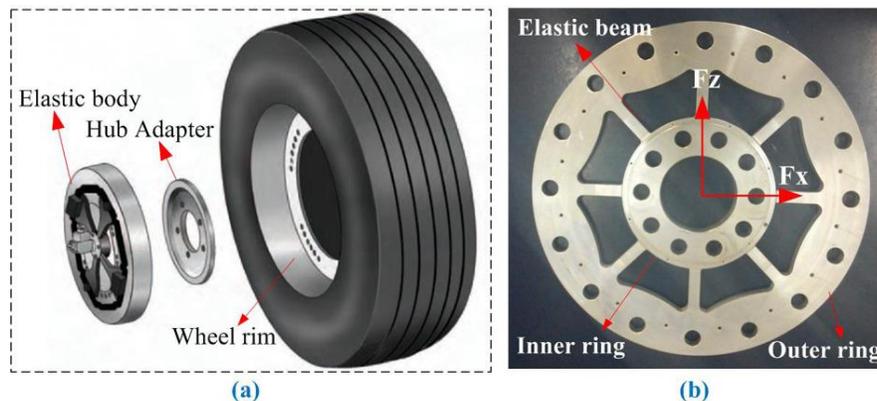
Figure 2. (a) The assembly diagram of WFT; (b) A typical elastic body of WFT developed at SEU.
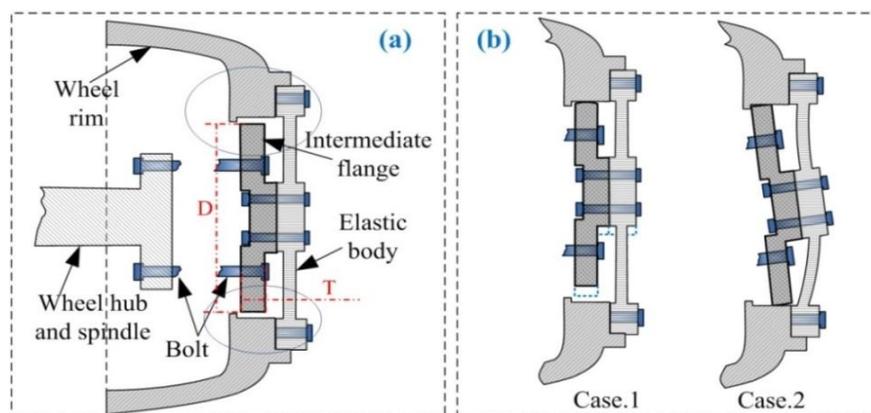
Figure 3. (a) Overload protection mechanism and (b) the intermediate flange deformation.

attached on the sensor body. The most common ways for wheel force detection may be strain gauge measurement technique because of technical accessibility and general applicability (Weiblen et al., 1999). The strain gauge arrangement, Wheatstone bridge and signal amplification and processing circuit are used to convert the force signal into strain, and then into digital voltage outputs. As a mathematical description, the vectors between applied load $\boldsymbol{F}$ (F_x, F_y, F_z, M_x, M_y, M_z) and output signal $\boldsymbol{S}$ (S_{Fx}, S_{Fy}, S_{Fz}, S_{Mx}, S_{My}, S_{Mz}) is related by $\boldsymbol{S}=C\cdot\boldsymbol{F}$. C is the compliance matrix which can be obtained either analytically in structural analysis or experimentally in actual calibration.

According to this basic principle, the sensor body must be installed between the wheel rim and wheel spindle when a multi-axis force sensor (MFS) is made to be a wheel force transducer (WFT). It takes the place of wheel spoke and can be used to sense the forces/moments as a typical installation which is shown in Figure 2a, the elastic body of WFT has such the two-ring structure that an outer ring is connected to wheel rim and an inner ring is connected to the wheel hub. A hub adapter can be used for force transmission between wheel spindle and the elastic body. Apparently, the elastic body is the crucial part of WFT and the damage and failure caused by large vehicle overload at X and Z direction must be avoided.

Overload protection mechanism

Generally, a modified rim and transducer assembly are assembled to the vehicle spindle when using a WFT. Since there is enough space between the wheel hub and wheel rim in a truck wheel, we build the overload protection mechanism by replacing the simple hub adapter with a tailored-designed intermediate flange in the area. As shown in Figure 3, the elastic body connects to the wheel spindle via an intermediate flange. By designing the flange with a proper size, an overload protection mechanism can be built. Two useful cases are illustrated as follows:

Case 1: Overloading force at X or Z direction. If the loading force including the vehicle mass or dynamic load at X or Z direction is too large, the deformation displacement on elastic-body will make the intermediate flange contact with the rim, and then the deflection of elastic-body will be limited to approximately that amount.

Case 2: Overloading moment at X or Z direction. If the overloading moment M_x or M_z is applied, the deformation displacement on elastic-body also makes the flange contact with the rim and it limits the deflection of elastic-body as well. This may occur in such case that the vehicle centre-of-gravity shifts when steering abruptly.
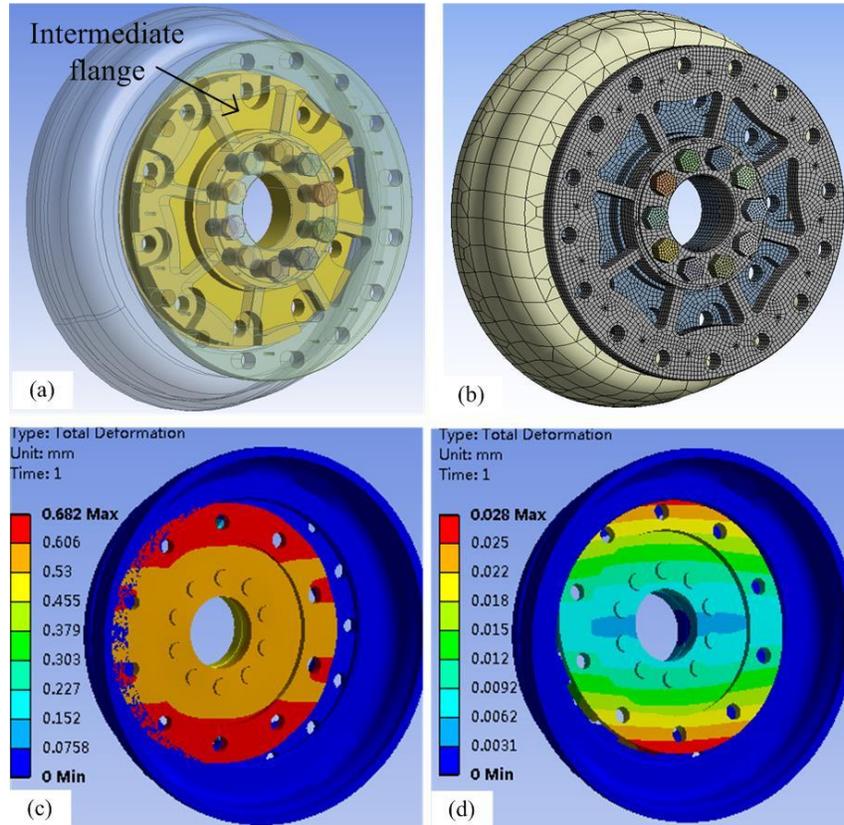
Figure 4. The overload protection using the intermediate flange: (a) the assembly diagram of the intermediate flange; (b) mesh generation (c) the deformation of the intermediate flange under applied force F_x or F_z (d) the deformation of the intermediate flange under applied moment M_x or M_z.

Owning to this mechanism, the boundary dimensions and tolerances of the flange must have the minimum values while the elastic body may have large force sensitivity. Although the monolithic structure of elastic-body makes the sensitivity increase easily, the damage and failure may be prone to occur under loads at X and Z direction. The dimensions of the intermediate flange, which is the key point of the overload protection mechanism, will be designed elaborately and the process may involve practical challenges. Generally, an effort of optimizing the design to meet these often conflicting goals rapidly, and to apply it into the specific vehicle wheels, can be made by using analytical design computer aided design (CAD) and performance prediction tools Computer Aided Engineering (CAE). For the whole mechatronics assembly, the need for physical prototyping is often required to confirm the design and test the mechanism as well.

**Design and optimization using finite element method (FEM)**

Mechanical design of overload protection

Using the ANSYS workbench, the design and optimization procedure is implemented on the overload protection mechanism (Figure 4). Also the parameters and conditions can be determined. For the purpose of improving the sensor sensitivity of the heavy truck WFT, the elastic body which has the material elastic limit of 980 MPa is designed with a safety factor about 1.5. It is much less

than the normal safety factor of allowable stress in engineering mechanics (Gross et al., 2011) where it is larger than 2.0. The sensor has a high sensitivity under the rated loads about 160 kN force and 30 kN.m moment. Considering the two deformation cases, design variables can be identified with the diameter (D) and the thickness (T) of the flange (Figure 3). Since the deformation mainly occurs on the elastic body and the wheel rim is fixed, the aim is to calculate the intermediate flange displacement which can be obtained using Finite Element Method (FEM) analysis under the rated loads. Figure 4 shows the design procedure and optimization result. For better understanding, the connection between wheel rim and the outer ring of elastic body is removed in the Figure. As a result, an outer diameter 385 mm, a thickness 34 mm and a proper gap 0.7 mm can be obtained by Finite Element Method (FEM) simulation. In fact, this design also provides compact assembly to retain the sensor performance, and the non-linearity of response could be reduced to some extent.

Overall design and mechatronics assembly

According to the settled overload protection mechanism of the truck WFT, the overall design including mechanical assembly and electrical system is performed and will be used to test the overload protection. As shown in Figure 5, the intermediate flange and modified rim with its welding flange form the mechanical assembly of the overload protection. The wheel rim is re-formed so that it
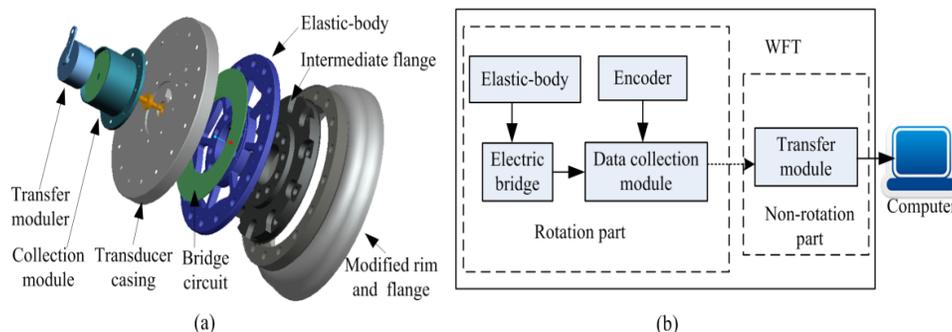
Figure 5. (a) Mechanical assembly of the WFT and (b) the electrical flowchart of WFT system.
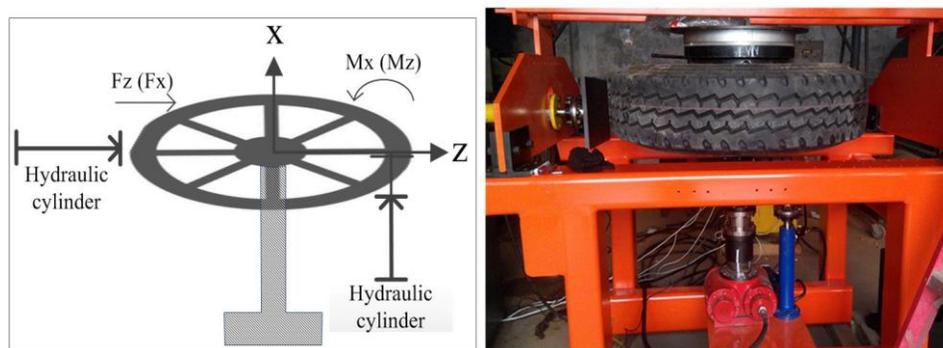
Figure 6. (a) The diagram and (b) physical graph of the overload testing platform.

connects to the outer ring of elastic-body by virtue of its welding flange via bolts. The inner ring of elastic-body connects to the designed intermediate flange and the intermediate flange connects to the wheel hub via bolts as well. This mechanical assembly will support the overload protection mechanism well.

Detailed information of the WFT system can refer to Lin et al. (2014), the overall WFT system consists of transfer module, collection module, transducer casing, elastic-body, intermediate flange, modified rim with its welding flange and some other accessories. The elastic body senses the multi-axis wheel force/moment which can be transfered by the bridge circuit. The collection module, in which an encoder is also placed to detect the rotation angle, is bounded to the transducer casing, and it will rotate with the rolling wheel. The transfer module connects to the collection module by a pair of bearings and does not rotate with the rolling wheel. As a result, the wheel force signals and rotation angle signals will be sampled by the collection module, and then the data is sent to the transfer module by wireless means. The transfer module also receives the data via wireless and transmits it to the upper computer by network bus.

EXPERIMENTAL RESULTS AND DISCUSSION

Experiment and prototyping test

To test the performance of the overload protection mechanism, a specially-made hydraulic controller platform (Figure 6) which is used for calibration can be also used for overload testing. The only difference between the calibration and overload test is that the applied loads in calibration increases to the rated loads of 120 kN or 30 kNm moment but the applied loads for overload test will not stop at the rated loads. To simulate real conditions, the whole truck wheel is bolted on the platform, and the proper tire pressure is inflated with a general value of 9 atmospheres. An analog-digital (AD) converter is used in the collection module to output the circuits signals of the applied force (Lin et al., 2014). Each load is stepwise applied individually and the AD output signals of the four channels can be recorded. The loading and unloading process will be repeated three times with an output of averaging values.

Verification and discussion

Figure 7 shows the WFT response curves under the applied loads. When each load increases in the measurement range individually, the AD output signal of the main channel shows linearity but the rest of that are close to the initial value 3000. Since the vehicle motions on road are complicated, the combined actions may occur. As the built test platform cannot support both compression and tension simultaneously in one uniaxial
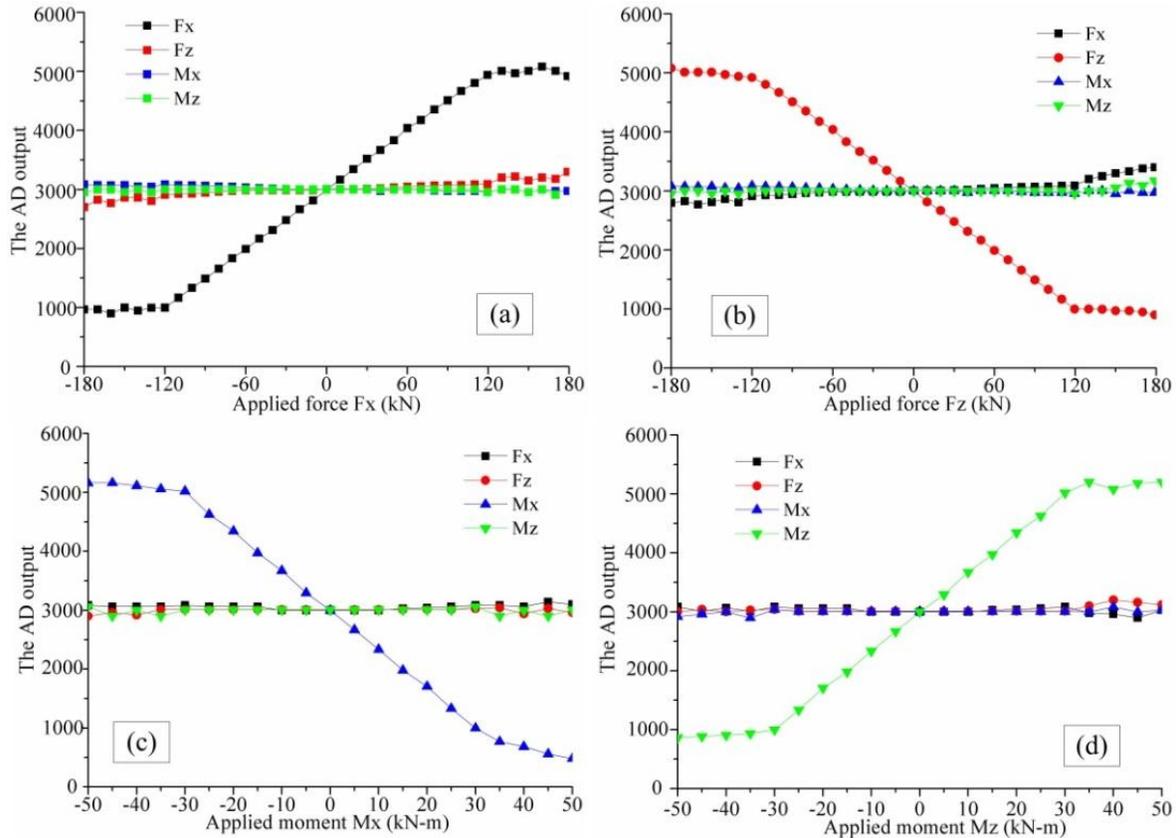
Figure 7. The WFT output curves under each applied load individually.

hydraulic cylinder, two behaviours which combine F_x with M_x and combine F_z with M_z, are tested, respectively. Due to the measuring range difference and unit discrepancy between applied overload force and overload moment, each individual load are depicted separately in Figure 7 for better understanding. Result indicates that the coupling interferences between the multi-dimensions are quite little, and therefore the strain gauge locations are well assigned. However, when the applied loads increase over the rated loads of 120 kN force and 30 kNm moment, the overload protection mechanism starts to take effect. The strain and deformation of the elastic body will be kept and therefore the AD output of the main channel does not increase any more. If considering the safety factor of elastic strength limit of the sensor body, the overloads at ranges of (-180 kN, 180 kN) and (-45 kNm, 45 kNm) are successfully prevented. Since the rest of AD outputs are slightly increasing, it is foreseeable and understandable that the overload protection mechanism makes the intermediate flange contact with the wheel rim and the applied load will be continuously increasing, while the nonlinearity of elastic body deformation may result in the increasing coupling errors. In summary, the overload protection mechanism indeed prevents the overload damage at X and Z direction for the heavy truck

WFT and the sensor sensitivity is guaranteed as well. Figure 1 also depicts the WFT with the overload protection which is assembled into a heavy dump truck. Owning to the overload protection, the sensor shows an excellent performance.

CONCLUSIONS AND SUGGESTIONS

In the present work, a mechanical approach of overload protection mechanism for wheel force transducer is introduced and applied to a heavy truck so that the overload at X and Z direction can be avoided. Not only the overload damage is prevented by using a tailor-designed intermediate flange which is installed between wheel hub and the elastic body, but also the WFT sensor performance is guaranteed under the rated measurement range. By using a hydraulic calibration platform, experimental test is conducted and results show that the proposed overload protection mechanism performed well. The linear relations between applied load and WFT output is kept well under the measurement range of (-120 kN, 120 kN) and (30 kNm, 30 kNm). Meanwhile, the overloads of ±180 kN and ±50 kNm applied on the WFT are prevented from damage that the AD output keeps

unchanged. It confirmed that the overload protection mechanism is well designed and established for the heavy truck WFT.

Conflict of interest

The author(s) declare that there is no conflict of interest.

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REFERENCES

Gross D, Hauger W, Schröder J, Wall WA, Bonet J (2011). Engineering Mechanics 2-Mechanics of Materials. Springer.

Hong HJ, Strumpfer SD (2011). Virtual road load data acquisition for twist axle rear suspension. SAE Technical Paper, 2011-01-0026. http://dx.doi.org/10.4271/2011-01-0026

Kadhim NA, Bdullah SA, Ariffin AK (2011). Effect of the fatigue data editing technique associated with finite element analysis on the component fatigue design period. Mater. Des. 32:1020-1030. http://dx.doi.org/10.1016/j.matdes.2010.07.029

Kuchler M, Schrupp R (2001). Multiaxial motorcycle wheel load transducer (in German). VDI Berichte. 1616:249-275.

Lin GY, Pang H, Zhang WG, Wang D, Feng LH (2014). A self-decoupled three-axis force sensor for measuring the wheel force. Proc. IMechE, Part D: J. Automobile Eng. 228:319-334. http://dx.doi.org/10.1177/0954407013508278

Lin GY, Zhang WG, Yang F, Pang H, Wang D (2013). An initial value calibration method for the wheel force transducer based on memetic optimization framework. Math. Probl. Eng. 2013:275060. http://dx.doi.org/10.1155/2013/275060

Pavkovic D, Deur J, Hrovat D, Burgio G (2009). A switching traction control strategy based on tire force feedback. In: IEEE conference on control applications and intelligent control, Saint Petersburg, Russia, 8–10 July 2009, pp. 588-593. New York: IEEE. http://dx.doi.org/10.1109/CCA.2009.5281121

Pytka JA, Tarkowski P, Fijałkowski S, Budzyński P, Dąbrowski J, Kupicz W, Pytka P (2011). An instrumented vehicle for offroad dynamics testing. J. Terramechanics. 48:384-395. http://dx.doi.org/10.1016/j.jterra.2011.06.003

Song AG, Wu J, Qin G (2007). A novel self-decoupled four degree of freedom wrist force/torque sensor. Measurement 40:883-891. http://dx.doi.org/10.1016/j.measurement.2006.11.018

Wang D, Lin GY, Zhang WG, Zhao N, Pang H (2014). The new method of initial calibration with the wheel force transducer. Sensor Review. 34(1): 98-109. http://dx.doi.org/10.1108/SR-12-2012-734

Wang Y, Zhang WG, Wang H (2011). Application of wavelet method with nonlinear threshold control in vehicle wheel force signal denoising. In Proceedings of the 4th International Conference on Intelligent Computation Technology and Automation (ICICTA '11), pp. 957-960, Shenzhen, China, March. http://dx.doi.org/10.1109/ICICTA.2011.525

Weiblen W, Kockelmann H, Burkard H (1999). Evaluation of different designs of wheel force transducers (part II). SAE Technical Paper, 1999-01-1037. http://dx.doi.org/doi:10.4271/1999-01-1037

Zhang LB, Liu HL, Zhang HT, Xu YZ (2011). Component load predication from wheel force transducer measurements. SAE Technical Paper, 2011-01-0737.http://dx.doi.org/10.4271/2011-01-0737

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