*Iran J Reprod Med Vol. 13. No. 5. pp: 251-262, May 2015*

**Review article**

# The imbalance in expression of angiogenic and anti-angiogenic factors as candidate predictive biomarker in preeclampsia

***Pooneh Nikuei[1] M.D., Kianoosh Malekzadeh[1] Ph.D., Minoo Rajaei[2] M.D., Azim Nejatizadeh[1] M.D., Ph.D., Nasrin Ghasemi[3] M.D., Ph.D.***

1. *Molecular Medicine Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran.*
2. *Fertility and Infertility Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran.*
3. *Research and Clinical Center for Infertility, Shahid Sadoughi University of Medical Sciences, Yazd, Iran.*

**Corresponding Authors:**
Kianoosh Malekzadeh and Minoo Rajaei are co-correspondence authors.

*Kianoosh Malekzadeh*, Molecular Medicine Research Center, Shahid Mohammady Hospital, Hormozgan University of Medical Sciences, Bandar Abbas, Iran.
**Email:** keyanoosh@gmail.com
**Tel:** (+98) 9176108396

*Minoo Rajaei*, Fertility and Infertility Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran.
**Email:** rajaei_minoo@yahoo.com
**Tel:** (+98) 7613332424

Received: 4 October 2014
Accepted: 30 December 2014

**Abstract**

Preeclampsia is an important pregnancy disorder with serious maternal and fetal complications which its etiology has not been completely understood yet. Early diagnosis and management of disease could reduce its potential side effects. The vascular endothelial growth factor (VEGF) family including VEGF-A is the most potent endothelial growth factor which induces angiogenesis and endothelial cell proliferation and has basic role in vasculogenesis. VEGF and its tyrosine kinase receptors (Flt1 and KDR) are major factors for fetal and placental angiogenic development. Finding mechanisms involved in expression of angiogenic factors may lead to new prognostic and therapeutic points in management of preeclampsia. Recent researches, has shown capability of some anti-angiogenic factors as potential candidate to be used as early predictors for preeclampsia. Soluble fms-like tyrosin kinase-1 (sFlt1) is a truncated splice variant of the membrane-bound VEGF receptor Flt1, that is produced by the placenta and it can bind to angiogenic growth factors and neutraliz, their effects. It is also observed that the ratio of sFlt1 to placental growth factor is valuable as prognostic marker. In this review, VEGF family member's role in angiogenesis is evaluated as biomarkers to be used for prediction of preeclampsia.

***Key words:*** *Preeclampsia, Angiogenic proteins, Biomarker, Vascular endothelial growth factor (VEGF-A), Vascular endothelial growth factor receptor-1 (VEGFR-1).*

## Introduction

Preeclampsia (PE) is a life threatening complication of pregnancy which is diagnosed by hypertension and proteinuria after 20 weeks of gestation. PE is a multiple organ syndrome that affects at least 5% of all pregnancies worldwide (1,2). About 75000 mothers and 500000 neonates die every year around the world because of the PE complications (3). It is a major cause of maternal and fetal mortality and morbidity (4). Early diagnosis and treatment of disease can reduce its potential fetal and maternal side effects. Because of unknown pathophysiology, it is referred as the disease of theories (5). Women with PE are more prone to cardiovascular disorders later in their life (6). According to the onset time, the disease is classified to early (before 34 weeks) and late onset (after 34 weeks) (7). There is difference in the origin of PE regarding to onset time. While the cause of early onset PE is most related to inadequate placentation and angiogenesis balance, the late onset PE is associated with long term cardiovascular risk factors like obesity, diabetes and hypertension (8).

PE could also result in HELLP syndrome (hemolysis, elevated liver enzymes, and low platelets) and seizures (eclampsia) (9). Low birth weight, prematurity and death are its fetal complications (10). Placenta removal could

[ Downloaded from ijrm.ir on 2026-11-12 ]

improve the symptoms but it threats neonatal health due to serious complications such as early preterm delivery and prematurity (11). Conditions that increase the risk of PE are chronic hypertension, diabetes mellitus, renal disease, obesity, hypercoagulable states such as antiphospholipid syndrome and factor V Leiden, advanced maternal age and conditions associated with increased placental mass such as multifetal gestations and hydatidiform mole (12). Angiogenic factors imbalance in preeclampsia result in decreased activity of proangiogenic factors in association with high activity and expression of the anti angiogenic factors (13). Among angiogenic factors, vascular endothelial growth factor (VEGF) and its receptors look to play a major role in not only physiological but also pathological angiogenesis like cancer (14).

**Angiogenesis in normal pregnancy and preeclampsia**

Adequate nutrient and substrate supply are necessary for placental and fetal normal intrauterine development. Uterine blood supply disorders are associated with higher risk for preterm delivery, PE and intrauterine growth restriction (15). The placenta is a significant organ for fetal development. Not only fetus exchange of gases, nutrients, and waste products perform through placenta but also it protects fetus from rejection by maternal immune system. During fetal development high levels of angiogenesis and vasculogenesis take place in placenta (16).

A number of causes for placental dysfunction are hypoxia, oxidative stress, reactive oxygen species, catechol-O-methyltransferase deficiency, hemoxygenase deficiency, and immunologic/inflammatory factors that result in imbalance between angiogenic and anti-angiogenic factors (17). Vasculogenesis, angiogenesis and pseudovasculogenesis are three stages of placental vascular network development. Vasculogenesis that takes places in first weeks of gestation is stage in which transformation of a subpopulation mesenchymal precursor cells into hemiangioblastic endothelial precursors take places. New blood vessels formation in the placenta is due to differentiation of these cells (18). Vasculogenesis is followed by angiogenesis, which begins at day 21 of pregnancy. Angiogenesis is formation of new vessels from pre-existing vessels. Soluble angiogenic factors expressed in the trophoblasts of the placenta, maternal decidua and macrophages stimulate capillary formation in the chorionic villi of the placenta. Development of capillary beds of the villi will continue until week 26 of gestation. From 26 weeks of gestation to delivery time villous vascular growth will mainly done by non-branching angiogenesis due to the formation of mature intermediate villi that contain poorly branched capillary loops (19). VEGF is a crucial inducer for branching angiogenesis (20). Pseudovasculogenesis or epithelial-endothelial transformation is a key event during vascular development of placenta. The result of this stage is remodeling of spiral arteries from high resistance and low flow muscular vessels to sac like vessels with low resistance and high flow which leads to the increased blood flow to fetus (19, 21).

Insufficient maternal spiral arterial remodeling, disability of cytotrophoblast cells to obtain endothelial-like phenotype and invasion defect to myometrial spiral arteries result in narrow myometrial segments (22-24). This pathologic process leads to release of series of pro-inflammatory factors from hypoxic placenta and following that damage of maternal circulatory system happens. Therefore PE has two stages, first is poor placentation in early gestation and second stage is maternal system dysfunction (25). There is evidence that show VEGF and transforming growth factor-β1 (TGF-β1) are necessary for endothelial health and normal pregnancy and normal vascular homeostasis (19). Placental ischemia causes higher production of anti-angiogenic proteins like soluble fms-like tyrosin kinase-1 (sFlt1) and soluble endoglin/CD105 (sEng) that have serious effects on cardiovascular system by disrupting normal placental angiogenesis. Release of these placental anti-angiogenic factors into maternal circulation lead to damage of maternal endothelium and clinical manifestations of preeclampsia such as hypertension and PE (12). Genetic explanations are suggested for the overproduction of anti-angiogenic factors in preeclampsia. Understanding mechanisms involved in disrupting angiogenesis in

[ Downloaded from ijrm.ir on 2026-11-12 ]

pregnancy may provide novel preventive and therapeutic points in early management of PE.

**VEGF**

The VEGF family including VEGF-A, VEGF-B, VEGF-C, VEGF-D, VEGF-E, and placental growth factor (PlGF). VEGF-A is one of the most potent endothelial growth factors. It induces angiogenesis and endothelial cell proliferation and has basic role in vasculogenesis. Splice variants of VEGF-A including 121, 165, 189, and 206 amino acids, each has a specific exon addition. Among these variants the most predominant protein is VEGF 165 (26, 27). VEGF and its tyrosine kinase receptors (VEGFR-1/Flt1 also called fms-like tyrosine kinase-1 and VEGFR-2/KDR/Flk-1) are major factors for fetal and placental angiogenic development. Biological VEGF activity is mediated through interaction with its receptors Flt1 , that is expressed in vascular endothelial cells in placental trophoblast cells in macrophages and in monocytes and VEGFR-2 (KDR1/Flk1), a potent receptor tyrosine kinase that is primarily expressed in vascular endothelial cells especially during vascular development (28, 29).

The kinase activity of VEGFR-1 is relatively weak compared with that of VEGFR-2. VEGF is highly expressed in the early human placenta. Immunohistochemical and in situ hybridization studies showed that villous trophoblast and Hofbauer cells are the main source of this cytokine (30, 31). VEGF promotes nitric oxide and vasodilatory prostacyclins in endothelial cells, and plays its role by decreasing vascular tone and blood pressure (32, 33). Expression of *VEGF* gene is induced by hypoxia as a strong exciter and it enhance VEGF mRNA stability (34, 35). Under in vitro conditions, VEGFA induces cytotrophoblast invasion, which can be blocked by addition of sFlt1 (36). In cancer patients received VEGF inhibitor drugs PE symptoms like hypertension, proteinuria and glomerular damage was observed (37, 38). Also there is evidence indicating that women affected to PE have decreased long-term risk for malignancy (39).

**PlGF**

In VEGF family, PlGF is closely related to VEGF-A and is another pro-angiogenic factor secreted by placenta. PlGF is expressed in syncytiotrophoblast layer of the placenta with direct contact with maternal circulation (40) and have several different isoforms (PlGF-1, -2, -3, and -4) (41). PlGF induce its role in angiogenesis by binding to Flt1 (42), unlike VEGF-A which binds to both Flt1 and KDR, PlGF could not bind to KDR (43, 44). PlGF may raise angiogenesis by replacing VEGF from Flt1 and shift VEGF towards KDR with kinase activity about ten-fold higher than that of Flt1 (25, 45).

PlGF and VEGF could also bind to soluble and splice variant form of Flt1 (sFlt1) and be deterred from acting with their main receptors (16). PlGF concentrations increase during normal pregnancy significantly at 28-32 weeks but Levels of free VEGF decreases with progression of pregnancy (46). Most studies show that the level of free PlGF in maternal blood decreases in PE. This reduction could help in early diagnosis of PE because it occurs few weeks before clinical presentation of disease. In early onset PE, maternal serum PlGF levels in weeks 21-32 of gestation are lower compared with late onset PE, in severe forms compared with mild forms and in association with small-for-gestational age compared with isolated PE (46, 47).

**VEGF and PlGF expression in preeclampsia**

Most of serological studies about circulating angiogenic factors in PE reported decreased circulating levels of free VEGF and PlGF, which has been associated with increased circulating sFlt1, a splice variant of the VEGF receptor Flt1 (46, 48, 49). In study of Levin *et al* observed that women who later affected to PE had lower PlGF levels in weeks 13-16 pregnancy with the highest difference in concurrent with sFlt1 rising (46). Helske *et al* study showed that PlGF concentrations in maternal plasma were lower in preeclamptic patients (50). But Savvidou *et al* reported that PE could not be preceded by alteration in urinary PlGF concentration in first trimester of pregnancy (51).

Cooper *et al* found that levels of VEGF mRNA were significantly lower in the preeclamptic women compared with the control women (52). Polliotti *et al* studied on severe, early onset preeclamptic patients and reported that PlGF and VEGF were significantly lower in patients than in controls (53). Kim *et al* also reported decreased

[ Downloaded from ijrm.ir on 2026-11-12 ]

expressions of VEGF in both level of mRNA and protein in placenta of preeclamptic patients compared with the normotensive controls (54). Andraweera *et al* reported mRNA placental expression of VEGFA and PlGF were reduced in preeclamptic patients compared to normal control pregnancy (55). In contrast, three studies showed the increase in expression of angiogenic factors such as VEGF in preeclampsia (26- 57). This contrast is also observed in microarray studies. In Lee *et al* study with aim of investigating cytokine- and oxidation-related genes or preeclampsia using DNA microarray analysis they found up-regulation of VEGFA mRNA that were confirmed using quantitative real time-polymerase chain reaction (QRT-PCR) (56). But Jarvenpaa *et al* showed down-regulation of VEGF in both early and late onset PE by microarray (58). Ranheim *et al* reported that there were no statistically significant differences in expression of VEGF in mRNA levels between the preeclampsia and the control group for either the decidual or placental tissues (59). Sgambati *et al* reported that in the cases of preeclampsia, the levels of VEGF mRNA were the same as the control group (60).

These findings consider that circulating angiogenic proteins have a crucial role in PE pathogenesis. However, it seems that VEGF and PlGF are two most studied serum markers for PE. According to most studies their free levels decreased in PE accompanied with increase in serum level of sFlt1. In PE excess sFlt1 binds to VEGF and PlGF and antagonizes these proangiogenic molecules resulting in preventing them to interact with their main cell surface receptors Flt1 and KDR and cause endothelial dysfunction. Despite significant role of VEGF-A in PE pathogenesis, it seems that maternal VEGF-A levels have a limited role as PE predictor, unlike PlGF with capability as a biomarker in preceding PE (61).

**Flt1 and sFlt1 status in preeclampsia**

Flt1 is detected in the primitive vascular lumens and angiogenic cell cords (62). *Flt1* gene produces two mRNAs in placenta and vascular endothelial cells, a long form for the full-length receptor Flt1 and a short form for sFlt1 which carries only the ligand binding region (14). Alterations in these two forms are reported in studies related to PE. Most of studies except a few studies showed up-regulation of Flt1 mRNA in preeclampsia (55, 63). For instance, Chung *et al* study showed that Flt1 mRNA and protein both increase in preeclamptic pregnancies (57). Up-regulation of Flt1 was also reported by Nishizawa *et al* in severe preeclamptic pregnancies and unexplained fetal growth restriction (64). Munaut *et al* studies on 30 severe PE women compared to 30 normal pregnancies showed VEGFR-1 mRNA up-regulation and increased its plasma level in severe PE (65). Tripathi *et al* reported elevation of sFlt1 in serum and also up-regulation of Flt1 in placenta (66). Levine *et al* reported that the level of sFlt1 increase in placenta at 5$^{th}$ week before onset of clinical symptoms of PE (46).

Serum levels of sFlt1 observed to be higher in earlier onset PE compared with late onset, in severe PE compared with mild disease and in association with small-for-gestational-age compared with isolated PE (46, 49, 67, 68). In microarray study done by Jarvenpaa *et al* up-regulation of Flt1 was also reported (58).

In global placental gene expression profile by microarray in severe preeclampsia done by Sitras *et al*, up-regulation of Flt1 was deduced (69). Lee *et al* showed up-regulation of Flt1 by using microarray analysis. Their results were confirmed using quantitative real time-polymerase chain reaction (QRT-PCR) (56). Toft *et al* studied on the transcriptomes of placental tissues from PE and small for gestational age (SGA) pregnancies by whole-genome microarray and quantitative Real time PCR. The authors mentioned increased expression of Flt1 was detected by QRT-PCR in the PE+SGA group but microarray analysis did not reveal any significant differences between groups (70).

Bdolah *et al* reported that the rate of circulating sFlt1 to PlGF was significantly increased in women carrying fetus with trisomy 13 (71). Regarding to the position of *Flt1* gene on chromosome 13 it could be resulted in increased risk of PE in the women carrying fetus with additional copy of chromosome 13. Foyouzi *et al* reported no significant difference in levels of sFlt1 and VEGF in cerebrospinal fluid (CSF) of patients with preeclampsia compared with normotensive controls (72). Meynard *et al* injected exogenous sFlt1 to pregnant rats. Consequently, the symptoms of preeclampsia such as hypertension, proteinuria and glomerular endotheliosis have been observed

[ Downloaded from ijrm.ir on 2026-11-12 ]

(49). This increase in Flt1 expression in PE could derived from dual role of Flt1 in angiogenesis, a negative role in early embryogenesis and a positive role in cancer and other diseases. Its negative role in early embryogenesis maybe resulted from its strong binding and neutralizing of VEGF via the ligand-binding domain (14).

In the other hand, increase in level of circulating sFlt1 is also observed in most studies related to PE (9, 46, 67, 73-79). Levels of sFlt1 rise at 33-36 weeks at pregnancy (46). The concentration of sFlt1 and PIGF had been measured in different studies summarized in table I. As it can be seen the serum levels of sFlt1 are increased in preeclampsia associated with decreased levels of free VEGF and PIGF. Alternative mRNA processing has major role to produce sFlt1 in such a way the transmembrane and cytoplasmic domains are eliminated (80). This molecule can potentially release into maternal circulation, binds and inhibits VEGF and PIGF (81). sFlt1 antagonizes pro-angiogenic proteins such as VEGF and PlGF, which are essential for normal vascular endothelial homeostasis(82).

Levine *et al* found that the sFlt1 concentrations in controls remained constant until 33-36 weeks of gestation but increased in women who later had PE beginning 11 to 9 weeks before the onset of PE. More rapid increase in the sFlt1 levels observed within five weeks before the onset of preeclampsia. In the other hand, the PlGF concentrations began to decrease 11 to 9 weeks before the onset of preeclampsia, with substantial reductions during the 5 weeks before the onset of hypertension or proteinuria (46).

Also sFlt1 circulating levels rise before disease onset and correlates with disease severity and is related with proteinuria and hypertension onset time inversely (36, 83). Levein *et al* had also reported that alterations in the sFlt1 and PlGF levels were more pronounced before the onset of PE in women who had preeclampsia before term (<37 weeks of gestation) than in women who had an onset of preeclampsia at term (37 weeks) (46). Verlohren *et al* reported that in healthy pregnant patients, median serum concentrations of sFlt1 increased continuously from a lowest serum concentration of 1445 pg/mL in 10-14 weeks of gestation to a highest serum concentration of 4400 pg/mL in >37 weeks of gestation. The PIGF serum concentrations in normal pregnancies showed a continuous increase until the middle of the third trimester and then a decrease to the end of pregnancy. Overall PIGF serum concentrations ranged from 25.89-2096 pg/mL. Median PIGF serum concentrations ranged from a minimum of 62.8 pg/mL in 10-14 weeks of gestation to a maximum of 439 pg/mL in 29-33 weeks of gestation (84).

**KDR (FLK or VEGFR-2) and preeclampsia**

In some studies no difference in expression of KDR mRNA between PE and controls was observed (26, 50, 57, 65). However, down-regulation of placental KDR expression mentioned in some studies (55, 63, 85). Also low plasma concentrations of soluble KDR are reported by Chaiworapongsa *et al* in PE and small for gestational age (86). The soluble form of the KDR receptor is hypothesized to be generated due to alternative mRNA splicing or proteolysis cleavage of the membrane-bound receptor and also considered as an anti-angiogenic protein with unknown mechanism of action (61).

**Clinical sensitivity and specificity for sFlt1 / PlGF as candidate prediction biomarker**

It appears that PlGF deficiency and sFlt1 excess may result from placental hypoxia associated with incomplete remodeling of maternal spiral arteries. The incompletely remodeled arteries offer persistently high resistance to uterine artery blood flow, and they may be predisposed to vascular rupture in the placental bed, especially after the onset of hypertension (87).

Numerous studies have consistently demonstrated elevated serum levels of sFlt1 and decreased free PlGF in women with preeclampsia compared with normal pregnancies (Table I). Most studies agreeing that the higher the sFlt1 level, the more predictive for PE especially for early onset of clinical disease. Importantly, this increase in serum sFlt1 levels is detectable up to 5 weeks before the onset of clinical symptoms. Altered concentrations of angiogenic and anti-angiogenic peptides observed not only in the maternal circulation in PE but also in placental

[ Downloaded from ijrm.ir on 2026-11-12 ]

implantation disorders such as IUGR, small-for-gestational-age (SGA) births, fetal death of unexplained etiology, and twin-to-twin transfusion syndrome (26, 46, 49, 88-96).

As discussed in above, reduction in serum level of PlGF in preeclamptic women was observed in different studies (46, 49, 68, 84, 97-104). It seems that decrease of free PlGF is because of elevation of sFlt1 levels, which bind to PlGF and consequently neutralize it. This reduction in serum PlGF is seen 9-11 weeks before the development of hypertension and proteinuria. Considerable reduce observed in the 5 weeks before the onset of disease (46, 98, 100, 105). sFlt1 was found to be generally higher in the pre-eclamptic group in both 2$^{nd}$ and 3$^{rd}$ trimester. Therefore its diagnostic accuracy, sensitivity, specificity were lower than PlGF, endoglin and sFlt1: PlGF ratio. This result is probably due to the late increase of sFlt1 in PE patients (1). It has been reported that sFlt1 levels are not different between preeclamptic patients and controls at 17 weeks of gestation and that this difference becomes significant only a few weeks before the onset of the clinical signs of the disease (115).

The sFlt1/PlGF ratio as an anti-angiogenic activity index shows alterations in both sFlt1 and PlGF and it is a better predictor of PE than either measure alone (83). sFlt1/PlGF ratio was found to be more strongly associated with PE because, as reported in literature, it reflects the balance between sFlt1 and PlGF that is modified in the preeclamptic group (91). However, it is difficult to measure free VEFG due to its low concentration in PE and PlGF levels and sFlt1/PlGF ratio during mid-gestation are better tools for prediction of PE (83). A recent study about clinical validity of sFlt1/PlGF showed because of low sensitivity of test it could not be used as a diagnostic test alone, but it could be one element beside other tests (116).

The calculated sFlt1 /PlGF ratio was summarized in table II. According to study of Verlohren *et al* lowest values were observed in gestational weeks 24-28 with a median sFlt1/PlGF ratio of 3.80. Higher values were detected in the beginning and end of pregnancy, with sFlt1 /PlGF ratio of 22.7 in weeks 10-14 and a sFlt1 /PlGF ratio of 26.2 in pregnancies more than 37weeks (84). In most of studies the sensitivity of more than 75% is demonstrated for prediction value of sFlt1 /PlGF ratio especially for early onset preeclampsia (Table II).

The diagnostic power of the sFlt1 /PlGF ratio appears to be greater in patients with early-onset preeclampsia compared with late onset (117).

Stephan *et al* suggested the combination of uterine artery Doppler (UAD) with measurement of sFlt1 / PlGF ratio can predict early-onset preeclampsia with 83% sensitivity and 95% specificity (110). Lim *et al* deduced that more reliable prediction using the combined ratio of (sFlt1 +sEng)/ (PlGF+ TGF-β1) could expand the clinical window for prevention of PE (109).

**Methodology**

In order to collect papers on preeclampsia and angiogenic and anti-angiogenic factors, a comprehensive literature review was conducted in PubMed, Medline, Science Direct, Cochrane, and Google Scholar. We used the following keywords to retrieve related publications: "Pre-eclampsia" OR "Preeclamsia" OR "PE" AND "Aniogenesis" OR "Antiangiogenesis" OR "Anti-angiogenesis" OR "Angiogenic factors " OR "VEGF" OR "PIGF" OR "VEGF receptor" OR "VEGF-R" OR "Flt1 " OR " sFlt1 " OR "soluble fms-like tyrosin kinase-1" OR "KDR" OR "FLK" OR "VEGFR-2". The keywords were search in all fields in a paper.

For instance in PubMed the following search strategy was used: "Preecalmpsia" [All Fields] AND "Angiogenic factors "[All Fields] OR "angiogenesis" [All fields] OR "sFlt1 1" [All Fields]). Totally 415 papers were found, 118 papers were selected on preeclampsia that 29 papers contained measurement of angiogenic and anti-angiogenic factors level in blood of women with preeclampsia in different weeks of pregnancy.

[ Downloaded from ijrm.ir on 2026-11-12 ]

**Table I.** The serum levels of sFlt1 and PlGF in women with preeclampsia demonstrated in main studies

| Study by | Weeks of sampling | sFlt1 (pg/ml) | | Fold of increase | PIGF (pg/ml) | | Fold of decrease |
|---|---|---|---|---|---|---|---|
| | | Preeclampsia | Normal | | Preeclampsia | Normal | |
| Erez et al (106) | 6-15 (PE>37) | 1488 | 1788 | 0.8 | 26.2 | 35.4 | 1.3 |
| Erez et al (106) | 6-15 (PE<37) | 1308 | 1788 | 0.7 | 20.3 | 35.4 | 1.7 |
| Kusanovic et al (107) | 12 | 1426 | 1726 | 0.8 | 24 | 34 | 1.4 |
| Levine et al (46) | 13-16 | - | - | - | 90 | 134 | 1.5 |
| ThadhanI et al (108) | 1st trimester | 1048 | 973 | 1.0 | 23 | 63 | 2.7 |
| Kim et al (104) | 16-18 | 3861 | 3353 | 1.1 | 86 | 146 | 1.7 |
| Lim et al (109) | 14-21 | 4945 | 2788 | 1.7 | 100 | 175 | 1.7 |
| Kusanovic et al (107) | 22 | 1637 | 1612 | 1.0 | 214 | 330 | 1.5 |
| Stepan et al (110) | 21-22 | 1927 | 452 | 4.2 | 119 | 184 | 1.5 |
| Cripsi et al (111) | 24 | 1257 | 526 | 2.4 | 92 | 426 | 4.6 |
| Erez et al (106) | 20-25 (PE>37) | 1532 | 1799.5 | 0.8 | 273.4 | 345 | 1.3 |
| Erez et al (106) | 20-25 (PE<37) | 1946 | 1799.5 | 1.0 | 126.3 | 345 | 2.7 |
| Chaiworapongsa et al (67) | 26-41 | 5063 | 1375 | 3.6 | - | - | - |
| Sunderji et al (112) | 20-36 | 91514 | 2416 | 37.8 | 12 | 447 | 37.2 |
| De Vivo et al (113) | 2nd trimester | 20330 | 7169 | 2.8 | 200 | 961 | 4.8 |
| Ohkuchi et al (114) | 32 | 10471 | 3019 | 3.5 | 53 | 549 | 10.4 |
| Polliotti et al (53) | <34 | - | - | - | 61.3 | 122.4 | 2.0 |
| Tsatsaris et al (97) | 30-38 | 2690 | 120 | 22.4 | 67 | 586 | 8.7 |
| Shibata et al (68) | 34-35 | 5221 | 1857 | 2.8 | 86 | 228 | 2.6 |
| De Vivo et al (113) | 3rd trimester | 44870 | 12560 | 3.6 | 91 | 852 | 9.4 |
| Verlohren et al (84) | Onset of clinical disease | 12981 | 2641 | 4.9 | 76 | 342 | 4.5 |
| Levine et al (46) | Onset of clinical disease | 4382 | 1643 | 2.7 | - | - | - |

sFlt1: soluble fms-like tyrosin kinase-1 PlGF: placental growth factor

**Table II.** The sensitivity and specificity of sFlt1 /PlGF ratio test for prediction of PE mentioned in key studies

| Study by | PE type | Cut off | Sensitivity | Specificity |
|---|---|---|---|---|
| Kim et al (104) | | 1.40 | 80.4 | 78.0 |
| Stepan et al (110) | PE + IUGR | 3.15 | 63 | 50 |
| | Early onset PE | 4.67 | 71 | 76 |
| Verlohren et al (84) | Early onset PE | 85 | 89 | 97 |
| | Late onset PE | 85 | 74 | 89 |
| De Vivo et al (113) | | 38.5 | 88.5 | 88.5 |
| Ohkuchi et al (114) | Early onset PE | 45 | 100 | 95 |
| Sunderji et al (112) | | 137 | 96 | 97 |
| Diab et al (118) | Early onset PE | 7.77 | 100 | 90 |

sFlt1: soluble fms-like tyrosin kinase-1 PlGF: placental growth factor
PE: Preeclampsia IUGR: intrauterine growth retardation

## Conclusion

PE is a pathologic complication of pregnancy that is closely related to placental dysfunction. In this disorder shallow invasion of cytotrophoblasts due to abnormal placentation will result in release of harmful pro-inflammatory molecules from placenta and end to maternal systemic dysfunction. Preeclampsia can be a potentially life threatening condition especially in developing countries and also it has been implicated in an increased risk of cardiovascular disease in later life (6). Genetic factors may role in

[ Downloaded from ijrm.ir on 2026-11-12 ]

pathogenesis of preeclampsia but exact mechanisms are not known yet. Different studies demonstrate the ability of cytokine analysis to differentiate preeclampsia from normal pregnancies. Studying about *Flt1* gene regulation and its splicing may help for better understanding of preeclampsia pathogenesis and lead to prevention and treatment of the disease. It seems that the increased expression of Flt1 could disturb VEGF-mediated function on trophoblast and endothelial cells in preeclampsia (14).

Binding of free VEGF and PlGF with sFlt1 cause inhibition of interacting these angiogenic molecules with their main receptors. In PE, additional production of Flt1 and sFlt1 which cause endothelial dysfunction and anti-angiogenic state are likely related to placental hypoxia. Most of the circulating VEGF and PlGF are bound to sFlt1 which is produced higher than normal pregnancies and inhibits VEGF induced vasodilation effects. Inconsistence in studies about VEGF signaling in PE could be due to factors such as differences in geographic location of the studied population, different sample size and sampling methods, mode of delivery, and different technique methods. Large studies in different ethnicity in base of VEGF signaling may lead to find predictive marker as well as safe treatment for PE. Early prediction of PE could have great benefits for prenatal care and early treatment, so attention has been turned toward finding definite non-invasive test. Among biomarkers under investigation, angiogenic biomarkers like sFlt1, PlGF and sFlt1 to PlGF ratio are at the most advanced stage.

These angiogenic factors correlate with disease severity, could be detected several weeks before clinical presentation of the disease and have predictive value for diagnosis of severe-early onset PE but have a limited capacity in prediction of late onset PE and could not be used alone for intervention, but in combination with other angiogenic factors like soluble endoglin, Doppler sonography and other clinical and biochemical biomarkers they are more useful for predicting severe early onset PE.

## Conflict of interest

None of the authors have any conflict of interest.

## References


1. Zhu XM, Han T, Sargent IL, Yin GW, Yao YQ. Differential expression profile of microRNAs in human placentas from preeclamptic pregnancies vs normal pregnancies. *Am J Obstet Gynecol* 2009; 200: 661.
2. Wang W, Feng L, Zhang H, Hachy S, Satohisa S, Laurent LC, et al. Preeclampsia up-regulates angiogenesis-associated microRNA (ie., miR-17,-20a, and-20b) that target ephrin-B2 and EPHB4 in human placenta. *J Clin Endocrinol Metab* 2012; 97: 1051-1059.
3. Choudhury M, Friedman JE. Epigenetics and microRNAs in preeclampsia. *Clin Exp Hypertens* 2012; 34: 334-341.
4. Duley L. The global impact of pre-eclampsia and eclampsia. *Semin Perinatol* 2009;33:130-137.
5. Nejatizadeh A, Stobdan T, Malhotra N, Pasha MQ. The genetic aspects of pre-eclampsia: achievements and limitations. *Biochem Genet* 2008; 46: 451-479.
6. Buurma A, Turner R, Driessen J, Mooyaart A, choones J, Bruijn J, *et al.* Genetic variants in pre-eclampsia: a meta-analysis. *Hum Reprod Update* 2013; 19: 289-303.
7. Miko E, Meggyes M, Bogar B, Schmitz N, Barakonyi A, Varnagy A, et al. Involvement of Galectin-9/TIM-3 Pathway in the Systemic Inflammatory Response in Early-Onset Preeclampsia. *Plos One* 2013; 8: e71811.
8. Kleinrouweler C, Wiegerinck M, Ris-Stalpers C, Bossuyt P, van der Post J, Von Dadelszen P, et al. Accuracy of circulating placental growth factor, vascular endothelial growth factor, soluble fms-like tyrosine kinase 1 and soluble endoglin in the prediction of pre-eclampsia: a systematic review and meta-analysis. *BJOG* 2012; 119: 778-787.
9. Lam C, Lim K-H, Karumanchi SA. Circulating Angiogenic Factors in the Pathogenesis and Prediction of Preeclampsia. *Hypertension* 2005; 46: 1077-1085.
10. Mutter WP, Karumanchi SA. Molecular mechanisms of preeclampsia. *Microvasc Res* 2008; 75: 1-8.
11. Karimi S, Azinfar A, Rajaei M, Azizi KM. Evaluation the frequency of factor v leiden mutation in pregnant women with preeclampsia syndrome in an iranian population. *Iran J Reprod Med* 2012; 10: 59-66.
12. Wang A, Rana S, Karumanchi SA. Preeclampsia: the role of angiogenic factors in its pathogenesis. *Physiology* 2009; 24: 147-158.
13. Escudero CA, Roberts JM, Myatt L, Feoktistov I. Impaired adenosine-mediated angiogenesis in preeclampsia: potential implications for fetal programming. *Cardiovasc Smooth Muscle Pharmacol* 2014; 5: 134.
14. Shibuya M. Involvement of Flt1 (VEGF receptor-1) in cancer and preeclampsia. *Proc Japan Acadm Series B, Physic Biol Sci* 2010; 87: 167-178.
15. Zygmunt M, Herr F, Münstedt K, Lang U, Liang OD. Angiogenesis and vasculogenesis in pregnancy. *Eur J Obstet Gynecol Reprod Biol* 2003; 110: S10-S8.
16. Cerdeira AS, Karumanchi SA. Angiogenic factors in preeclampsia and related disorders. *Cold Spring Harbor Perspect Med* 2012; 2: Pii: a006585.
17. Harapan H, Andalas M, Mudhakir D, Pedroza NC, Laddha SV, Anand JR. Micro RNA: New aspect in


[ Downloaded from ijrm.ir on 2026-11-12 ]

pathobiology of preeclampsia? *Egypt J Med Hum Genet* 2012; 13: 127-131.
18. Bdolah Y, Sukhatme VP, Karumanchi SA. Angiogenic imbalance in the pathophysiology of preeclampsia: newer insights. *Semin Nephrol* 2004; 24:548-556.
19. Agarwal I, Karumanchi SA. Preeclampsia and the anti-angiogenic state. Pregnancy Hypertension: *An Int J Women's Cardiovasc Health* 2011; 1: 17-21.
20. Carmeliet P, De Smet F, Loges S, Mazzone M. Branching morphogenesis and antiangiogenesis candidates: tip cells lead the way. *Nature Rev Clin Oncol* 2009; 6: 315-326.
21. Fu G, Brkić J, Hayder H, Peng C. MicroRNAs in Human Placental Development and Pregnancy Complications. *Int J Mol Sci* 2013; 14: 5519-5544.
22. Zhou Y, Damsky CH, Fisher SJ. Preeclampsia is associated with failure of human cytotrophoblasts to mimic a vascular adhesion phenotype. One cause of defective endovascular invasion in this syndrome? *J Clin Invest* 1997; 99: 2152.
23. Naicker T, Khedun SM, Moodley J, Pijnenborg R. Quantitative analysis of trophoblast invasion in preeclampsia. *Acta Obstet Gynecol Scand* 2003; 82: 722-729.
24. Kadyrov M, Kingdom JC, Huppertz B. Divergent trophoblast invasion and apoptosis in placental bed spiral arteries from pregnancies complicated by maternal anemia and early-onset preeclampsia/intrauterine growth restriction. *Am J Obstet Gynecol* 2006; 194: 557-563.
25. Furuya M, Kurasawa K, Nagahama K, Kawachi K, Nozawa A, Takahashi T, *et al.* Disrupted balance of angiogenic and antiangiogenic signalings in preeclampsia. *J Pregnancy* 2011; 2011: 123717.
26. Tsatsaris V, Goffin F, Munaut C, Brichant J-F, Pignon M-R, Noel A, et al. Overexpression of the soluble vascular endothelial growth factor receptor in preeclamptic patients: pathophysiological consequences. *J Clin Endocrinol Metabo* 2003; 88: 5555-5563.
27. Ferrara N, Gerber HP. The role of vascular endothelial growth factor in angiogenesis. *Acta Haematol* 2001; 106: 148-156.
28. Thomas CP, Andrews JI, Liu KZ. Intronic polyadenylation signal sequences and alternate splicing generate human soluble Flt1 variants and regulate the abundance of soluble Flt1 in the placenta. *FASEB J* 2007; 21: 3885-3895.
29. Kim JY, Whang JH, Zhou W, Shin J, Noh SM, Song IS, et al. The expression of VEGF receptor genes is concurrently influenced by epigenetic gene silencing of the genes and VEGF activation. *Epigenetics* 2009; 4: 313-321.
30. Geva E, Ginzinger DG, Zaloudek CJ, Moore DH, Byrne A, Jaffe RB. Human placental vascular development: vasculogenic and angiogenic (branching and nonbranching) transformation is regulated by vascular endothelial growth factor-A, angiopoietin-1, and angiopoietin-2. *J Clin Endocrinol Metab* 2002; 87: 4213-4224.
31. Demir R, Kayisli U, Seval Y, Celik-Ozenci C, Korgun E, Demir-Weusten A, et al. Sequential expression of VEGF and its receptors in human placental villi during very early pregnancy: differences between placental vasculogenesis and angiogenesis. *Placenta* 2004; 25: 560-572.
32. Morbidelli L, Chang C-H, Douglas JG, Granger HJ, Ledda F, Ziche M. Nitric oxide mediates mitogenic effect of VEGF on coronary venular endothelium. *Am J Physiol Heart Circul Physiol* 1996; 270: 411-415.
33. He H, Venema VJ, Gu X, Venema RC, Marrero MB, Caldwell RB. Vascular endothelial growth factor signals endothelial cell production of nitric oxide and prostacyclin through flk-1/KDR activation of c-Src. *J Biol Chem* 1999; 274: 25130-25135.
34. Taylor C, Stevens H, Anthony F, Wheeler T. Influence of hypoxia on vascular endothelial growth factor and chorionic gonadotrophin production in the trophoblast-derived cell lines: JEG, JAr and BeWo. *Placenta* 1997; 18: 451-458.
35. Kingdom J, Kaufmann P. Oxygen and placental villous development: origins of fetal hypoxia. *Placenta* 1997; 18: 613-621.
36. Cerdeira AS, Karumanchi SA. Angiogenic factors in preeclampsia and related disorders. *Cold Spring Harbor Perspect Med* 2012; 2: pii: a006585.
37. Zhou CC, Ahmad S, Mi T, Xia L, Abbasi S, Hewett PW, et al. Angiotensin II induces soluble fms-Like tyrosine kinase-1 release via calcineurin signaling pathway in pregnancy. *Circul Res* 2007; 100: 88-95.
38. Patel TV, Morgan JA, Demetri GD, George S, Maki RG, Quigley M, et al. A preeclampsia-like syndrome characterized by reversible hypertension and proteinuria induced by the multitargeted kinase inhibitors sunitinib and sorafenib. *J National Cancer Institute* 2008; 100: 282-284.
39. Vatten L, Romundstad P, Trichopoulos D, Skjaerven R. Pre-eclampsia in pregnancy and subsequent risk for breast cancer. *Br J Cancer* 2002; 87: 971-973.
40. Kuroda M, Oka T, Oka Y, Yamochi T, Ohtsubo K, Mori S, et al. Colocalization of vascular endothelial growth factor (vascular permeability factor) and insulin in pancreatic islet cells. *J Clin Endocrinol Metab* 1995; 80: 3196-3200.
41. Torry DS, Mukherjea D, Arroyo J, Torry RJ. Expression and function of placenta growth factor: implications for abnormal placentation. *J Soc Gynecol Invest* 2003; 10: 178-188.
42. Carmeliet P, Moons L, Luttun A, Vincenti V, Compernolle V, De Mol M, et al. Synergism between vascular endothelial growth factor and placental growth factor contributes to angiogenesis and plasma extravasation in pathological conditions. *Nature Med* 2001; 7: 575-583.
43. Park JE, Chen HH, Winer J, Houck KA, Ferrara N. Placenta growth factor. Potentiation of vascular endothelial growth factor bioactivity, in vitro and in vivo, and high affinity binding to Flt1 but not to Flk-1/KDR. *J Bioll Chem* 1994; 269: 25646-25654.
44. Sawano A, Takahashi T, Yamaguchi S, Aonuma M, Shibuya M. Flt1 but not KDR/Flk-1 tyrosine kinase is a receptor for placenta growth factor, which is related to vascular endothelial growth factor. *Cell Growth Differ* 1996; 7: 213-221.
45. Shibuya M, Claesson-Welsh L. Signal transduction by VEGF receptors in regulation of angiogenesis and lymphangiogenesis. *Exp Cell Res* 2006; 312: 549-560.
46. Levine RJ, Maynard SE, Qian C, Lim K-H, England LJ, Yu KF, et al. Circulating angiogenic factors and the risk of preeclampsia. *New Engl J Med* 2004; 350: 672-683.

[ Downloaded from ijrm.ir on 2026-11-12 ]

47. Madazli R, Kuseyrioglu B, Uzun H, Uludag S, Ocak V. Prediction of preeclampsia with maternal mid-trimester placental growth factor, activin A, fibronectin and uterine artery Doppler velocimetry. *Int J Gynecol Obstet* 2005; 89: 251-257.
48. Muy-Rivera M, Vadachkoria S, Woelk G, Qiu C, Mahomed K, Williams M. Maternal plasma VEGF, sVEGF-R1, and PIGF concentrations in preeclamptic and normotensive pregnant Zimbabwean women. *Physiol Res* 2005; 54: 611.
49. Maynard SE, Min J-Y, Merchan J, Lim K-H, Li J, Mondal S, et al. Excess placental soluble fms-like tyrosine kinase 1 (sFlt1) may contribute to endothelial dysfunction, hypertension, and proteinuria in preeclampsia. *J Clin Invest* 2003; 111: 649-658.
50. Helske S, Vuorela P, Carpén O, Hornig C, Weich H, Halmesmäki E. Expression of vascular endothelial growth factor receptors 1, 2 and 3 in placentas from normal and complicated pregnancies. *Mol Hum Reprod* 2001; 7: 205-210.
51. Savvidou M, Akolekar R, Zaragoza E, Poon L, Nicolaides K. First trimester urinary placental growth factor and development of pre-eclampsia. *BJOG* 2009; 116: 643-647.
52. Cooper JC, Sharkey AM, Charnock-Jones DS, Palmer CR, Smith SK. VEGF mRNA levels in placentae from pregnancies complicated by pre-eclampsia. *BJOG* 1996; 103: 1191-1196.
53. Polliotti BM, Fry AG, Saller Jr DN, Mooney RA, Cox C, Miller RK. Second-trimester maternal serum placental growth factor and vascular endothelial growth factor for predicting severe, early-onset preeclampsia. *Obstet Gynecol* 2003; 101: 1266-1274.
54. Kim SC, Park MJ, Joo BS, Joo JK, Suh DS, Lee KS. Decreased expressions of vascular endothelial growth factor and visfatin in the placental bed of pregnancies complicated by preeclampsia. *J Obstet Gynaecol Res* 2012; 38: 665-673.
55. Andraweera PH, Dekker GA, Laurence JA, Roberts CT. Placental expression of VEGF family mRNA in adverse pregnancy outcomes. *Placenta* 2012; 33: 467-472.
56. Lee GSR, Joe YS, Kim SJ, Shin JC. Cytokine-related genes and oxidation-related genes detected in preeclamptic placentas. *Arch Gynecol Obstet* 2010; 282: 363-369.
57. Chung J-Y, Song Y, Wang Y, Magness RR, Zheng J. Differential expression of vascular endothelial growth factor (VEGF), endocrine gland derived-VEGF, and VEGF receptors in human placentas from normal and preeclamptic pregnancies. *J Clin Endocrinol Metab* 2004; 89: 2484-2490.
58. Jarvenpaa J, Vuoristo JT, Savolainen E-R, Ukkola O, Vaskivuo T, Ryynanen M. Altered expression of angiogenesis-related placental genes in pre-eclampsia associated with intrauterine growth restriction. *Gynecol Endocrinol* 2007; 23: 351-355.
59. Ranheim T, Staff AC, Henriksen T. VEGF mRNA is unaltered in decidual and placental tissues in preeclampsia at delivery. *Acta Obstet Gynecol Scand* 2001; 80: 93-98.
60. Sgambati E, Marini M, Zappoli Thyrion GD, Parretti E, Mello G, Orlando C, *et al.* VEGF expression in the placenta from pregnancies complicated by hypertensive disorders. *BJOG* 2004; 111: 564-570.
61. Andraweera PH, Dekker GA, Roberts CT. The vascular endothelial growth factor family in adverse pregnancy outcomes. *Hum Reprod Update* 2012; 18: 436-457.
62. Demir R. Expression of VEGF receptors VEFGR-1 and VEGFR-2, angiopoietin receptors Tie-1 and Tie-2 in chorionic villi tree during early pregnancy. *Folia Histochem Cytobiol* 2009; 47: 435-445.
63. Marini M, Vichi D, Toscano A, Thyrion GZ, Parretti E, Mello G, *et al.* Expression of vascular endothelial growth factor receptor types 1, 2 and 3 in placenta from pregnancies complicated by hypertensive disorders. *Reprod Fertil Dev* 2007; 19: 641-651.
64. Nishizawa H, Ota S, Suzuki M, Kato T, Sekiya T, Kurahashi H, *et al.* Comparative gene expression profiling of placentas from patients with severe pre-eclampsia and unexplained fetal growth restriction. *Reprod Biol Endocrinol* 2011; 9: 107.
65. Munaut C, Lorquet S, Pequeux C, Coulon C, Le Goarant J, Chantraine F, et al. Differential expression of Vegfr-2 and its soluble form in preeclampsia. *Plos One* 2012; 7: e33475.
66. Tripathi R, Rath G, Jain A, Salhan S. Soluble and membranous vascular endothelial growth factor receptor-1 in pregnancies complicated by pre-eclampsia. *Ann Anat* 2008; 190: 477-489.
67. Chaiworapongsa T, Romero R, Espinoza J, Bujold E, Mee Kim Y, Gonçalves LF, *et al.* Evidence supporting a role for blockade of the vascular endothelial growth factor system in the pathophysiology of preeclampsia: Young Investigator Award. *Am J Obstet Gynecol* 2004; 190: 1541-1547.
68. Shibata E, Rajakumar A, Powers RW, Larkin RW, Gilmour C, Bodnar LM, *et al.* Soluble fms-like tyrosine kinase 1 is increased in preeclampsia but not in normotensive pregnancies with small-for-gestational-age neonates: relationship to circulating placental growth factor. *J Clin Endocrinol Metab* 2005; 90: 4895-4903.
69. Sitras V, Paulssen R, Grønaas H, Leirvik J, Hanssen T, Vartun A, *et al.* Differential placental gene expression in severe preeclampsia. *Placenta* 2009; 30: 424-433.
70. Toft JH, Toft JH, Lian IA, Tarca AL, Erez O, Espinoza J, et al. Whole-genome microarray and targeted analysis of angiogenesis-regulating gene expression (ENG, FLT1, VEGF, PlGF) in placentas from pre-eclamptic and small-for-gestational-age pregnancies. *J Matern Fetal Neonat Med* 2008; 21: 267-273.
71. Bdolah Y, Palomaki GE, Yaron Y, Bdolah-Abram T, Goldman M, Levine RJ, *et al.* Circulating angiogenic proteins in trisomy 13. *Am J Obstet Gynecol* 2006; 194: 239-245.
72. Foyouzi N, Norwitz E, Tsen L, Buhimschi C, Buhimschi I. Placental growth factor in the cerebrospinal fluid of women with preeclampsia. *Int J Gynecol Obstet* 2006; 92: 32-37.
73. Stepan H, Faber R, Dornhöfer N, Huppertz B, Robitzki A, Walther T. New insights into the biology of preeclampsia. *Biol Reprod* 2006; 74: 772-776.
74. Redman CW, Sargent IL. Latest advances in understanding preeclampsia. *Science* 2005; 308: 1592-1594.
75. Krysiak O, Bretschneider A, Zhong E, Webb J, Hopp H, Verlohren S, *et al.* Soluble vascular endothelial growth factor receptor-1 (sFlt1 ) mediates downregulation of FLT1 and prevents activated

[ Downloaded from ijrm.ir on 2026-11-12 ]

neutrophils from women with preeclampsia from additional migration by VEGF. *Circul Res* 2005; 97: 1253-1261.
76. Karumanchi S, Epstein F. Placental ischemia and soluble fms-like tyrosine kinase 1: cause or consequence of preeclampsia? *Kidney Int* 2007; 71: 959-961.
77. Romero R, Nien JK, Espinoza J, Todem D, Fu W, Chung H, et al. A longitudinal study of angiogenic (placental growth factor) and anti-angiogenic (soluble endoglin and soluble vascular endothelial growth factor receptor-1) factors in normal pregnancy and patients destined to develop preeclampsia and deliver a small for gestational age neonate. *J Matern Fetal Neonat Med* 2008; 21: 9-23.
78. Haggerty CL, Seifert ME, Tang G, Olsen J, Bass DC, Ananth Karumanchi S, et al. Second trimester anti-angiogenic proteins and preeclampsia. *Pregnancy Hypertens* 2012; 2: 158-163.
79. Staff AC, Braekke K, Harsem NK, Lyberg T, Holthe MR. Circulating concentrations of sFlt1 (soluble fms-like tyrosine kinase 1) in fetal and maternal serum during pre-eclampsia. *Eur J Obstet Gynecol Reprod Biol* 2005; 122: 33-39.
80. Huckle WR, Roche RI. Post-transcriptional control of expression of sFlt-1, an endogenous inhibitor of vascular endothelial growth factor. *J Cell Biochem* 2004; 93: 120-132.
81. Nevo O, Lee DK, Caniggia I. Attenuation of VEGFR-2 Expression by sFlt1 and Low Oxygen in Human Placenta. *Plos One* 2013; 8: e81176.
82. Kendall RL, Thomas KA. Inhibition of vascular endothelial cell growth factor activity by an endogenously encoded soluble receptor. *Proc Nat Acad Sci* 1993; 90: 10705-10709.
83. Kar M. Role of Biomarkers in Early Detection of Preeclampsia. *J Clin Diagn Res* 2014; 8: BE01-BE04.
84. Verlohren S, Galindo A, Schlembach D, Zeisler H, Herraiz I, Moertl MG, et al. An automated method for the determination of the sFlt1 /PIGF ratio in the assessment of preeclampsia. *Am J Obstet Gynecol* 2010; 202: 161.
85. Groten T, Gebhard N, Kreienberg R, Schleussner E, Reister F, Huppertz B. Differential expression of VE-cadherin and VEGFR-2 in placental syncytiotrophoblast during preeclampsia- New perspectives to explain the pathophysiology. *Placenta* 2010; 31: 339-343.
86. Chaiworapongsa T, Romero R, Gotsch F, Espinoza J, Nien JK, Goncalves L, et al. Low maternal concentrations of soluble vascular endothelial growth factor receptor-2 in preeclampsia and small for gestational age. *J Matern Fetal Neonat Med* 2008; 21: 41-52.
87. Dommisse J, Tiltman A. Placental bed biopsies in placental abruption. *BJOG* 1992; 99: 651-654.
88. Venkatesha S, Toporsian M, Lam C, Hanai J-i, Mammoto T, Kim YM, et al. Soluble endoglin contributes to the pathogenesis of preeclampsia. *Nature Med* 2006; 12: 642-649.
89. Spencer K, Cowans NJ, Nicolaides KH. Low levels of maternal serum PAPP-A in the first trimester and the risk of pre-eclampsia. *Prenat Diagn* 2008; 28: 7-10.
90. Marik PE. Hypertensive disorders of pregnancy. *Postgrad Med* 2009; 121: 69-76.
91. Levine RJ, Lam C, Qian C, Yu KF, Maynard SE, Sachs BP, *et al.* Soluble endoglin and other circulating antiangiogenic factors in preeclampsia. *New Engl J Med* 2006; 355: 992-1005.
92. Jauniaux E, Poston L, Burton GJ. Placental-related diseases of pregnancy: involvement of oxidative stress and implications in human evolution. *Hum Reprod Update* 2006; 12: 747-755.
93. Hung T-H, Skepper JN, Charnock-Jones DS, Burton GJ. Hypoxia-Reoxygenation A Potent Inducer of Apoptotic Changes in the Human Placenta and Possible Etiological Factor in Preeclampsia. *Circul Res* 2002; 90: 1274-1281.
94. Demir R, Seval Y, Huppertz B. Vasculogenesis and angiogenesis in the early human placenta. *Acta Histochem* 2007; 109: 257-265.
95. Chafetz I, Kuhnreich I, Sammar M, Tal Y, Gibor Y, Meiri H, et al. First-trimester placental protein 13 screening for preeclampsia and intrauterine growth restriction. *Am J Obstet Gynecol* 2007; 197: 35.
96. Barton JR, Sibai BM. *Prediction and prevention of recurrent preeclampsia*. *Obstet Gynecol* 2008; 112: 359-372.
97. Tsatsaris V, Goffin F, Munaut C, Brichant J-F, Pignon M-R, Noel A, *et al.* Overexpression of the soluble vascular endothelial growth factor receptor in preeclamptic patients: pathophysiological consequences. *J Clin Endocrinol Metab* 2003; 88: 5555-5563.
98. Torry DS, Wang H-S, Wang T-H, Caudle MR, Torry RJ. Preeclampsia is associated with reduced serum levels of placenta growth factor. *Am J Obstet Gynecol* 1998; 179: 1539-1544.
99. Tjoa ML, van Vugt JM, Mulders MA, Schutgens RB, Oudejans C, van Wijk IJ. Plasma placenta growth factor levels in midtrimester pregnancies. *Obstet Gynecol* 2001; 98: 600-607.
100. Taylor RN, Grimwood J, Taylor RS, McMaster MT, Fisher SJ, North RA. Longitudinal serum concentrations of placental growth factor: evidence for abnormal placental angiogenesis in pathologic pregnancies. *American journal of obstetrics and gynecology*. 2003;188:177-182.
101. Reuvekamp A, Velsing-Aarts FV, Poulina IE, Capello JJ, Duits AJ. Selective deficit of angiogenic growth factors characterises pregnancies complicated by pre-eclampsia. *BJOG* 1999; 106: 1019-1022.
102. Livingston JC, Haddad B, Gorski LA, Neblett P, Ahokas RA, Ramseya R, et al. Placenta growth factor is not an early marker for the development of severe preeclampsia. *Am J Obstet Gynecol* 2001; 184: 1218-1220.
103. Livingston JC, Chin R, Haddad B, McKinney ET, Ahokas R, Sibai BM. Reductions of vascular endothelial growth factor and placental growth factor concentrations in severe preeclampsia. *Am J Obstet Gynecol* 2000; 183: 1554-1557.
104. Kim S-Y, Ryu H-M, Yang J-H, Kim M-Y, Han J-Y, Kim J-O, et al. Increased sFlt1 to PlGF ratio in women who subsequently develop preeclampsia. *J Korean Med Sci* 2007; 22: 873-877.
105. Levine RJ, Thadhani R, Qian C, Lam C, Lim K-H, Kai FY, et al. Urinary placental growth factor and risk of preeclampsia. *JAMA* 2005; 293: 77-85.

[ Downloaded from ijrm.ir on 2026-11-12 ]

106. Erez O, Romero R, Espinoza J, Fu W, Todem D, Kusanovic JP, et al. The change in concentrations of angiogenic and anti-angiogenic factors in maternal plasma between the first and second trimesters in risk assessment for the subsequent development of preeclampsia and small-for-gestational age. *J Matern Fetal Neonat Med* 2008; 21: 279-287.
107. Kusanovic JP, Romero R, Chaiworapongsa T, Erez O, Mittal P, Vaisbuch E, et al. A prospective cohort study of the value of maternal plasma concentrations of angiogenic and anti-angiogenic factors in early pregnancy and midtrimester in the identification of patients destined to develop preeclampsia. *J Matern Fetal Neonat Med* 2009; 22: 1021-1038.
108. Thadhani R, Mutter WP, Wolf M, Levine RJ, Taylor RN, Sukhatme VP, et al. First trimester placental growth factor and soluble fms-like tyrosine kinase 1 and risk for preeclampsia. *J Clin Endocrinol Metab* 2004; 89: 770-775.
109. Lim JH, Kim SY, Park SY, Yang JH, Kim MY, Ryu HM. Effective prediction of preeclampsia by a combined ratio of angiogenesis-related factors. *Obstet Gynecol* 2008; 111: 1403-1409.
110. Stepan H, Unversucht A, Wessel N, Faber R. Predictive value of maternal angiogenic factors in second trimester pregnancies with abnormal uterine perfusion. *Hypertension* 2007; 49: 818-824.
111. Crispi F, Llurba E, Dominguez C, Martín-Gallán P, Cabero L, Gratacos E. Predictive value of angiogenic factors and uterine artery Doppler for early-versus late-onset pre-eclampsia and intrauterine growth restriction. *Ultrasound Obstet Gynecol* 2008; 31: 303-309.
112. Sunderji S, Gaziano E, Wothe D, Rogers LC, Sibai B, Karumanchi SA, et al. Automated assays for sVEGF R1 and PlGF as an aid in the diagnosis of preterm preeclampsia: a prospective clinical study. *Am J Obstet Gynecol* 2010; 202: 40.
113. De Vivo A, Baviera G, Giordano D, Todarello G, Corrado F, D'anna R. Endoglin, PlGF and sFlt-1 as markers for predicting pre-eclampsia. *Acta Obstet Gynecol Scand* 2008; 87: 837-842.
114. Ohkuchi A, Hirashima C, Suzuki H, Takahashi K, Yoshida M, Matsubara S, et al. Evaluation of a new and automated electrochemiluminescence immunoassay for plasma sFlt1 and PlGF levels in women with preeclampsia. *Hypertens Res* 2010; 33: 422-427.
115. Unal ER, Robinson CJ, Johnson DD, Chang EY. Second-trimester angiogenic factors as biomarkers for future-onset preeclampsia. *Am J Obstet Gynecol* 2007; 197: 211.
116. Lehnen H, Mosblech N, Reineke T, Puchooa A, Menke-Möllers I, Zechner U, et al. Prenatal clinical assessment of sFlt1 (soluble fms-like tyrosine kinase-1)/PlGF (placental growth factor) ratio as a diagnostic tool for preeclampsia, pregnancy-induced hypertension, and proteinuria. *Geburtshilfe Frauenheilkund* 2013; 73: 440.
117. Lapaire O, Shennan A, Stepan H. The preeclampsia biomarkers soluble fms-like tyrosine kinase-1 and placental growth factor: current knowledge, clinical implications and future application. *Eur J Obstet Gynecol Reprod Biol* 2010; 151: 122-129.
118. Diab AE, El-Behery MM, Ebrahiem MA, Shehata AE. Angiogenic factors for the prediction of pre-eclampsia in women with abnormal midtrimester uterine artery Doppler velocimetry. *Int J Gynecol Obstet* 2008; 102: 146-151.

[ Downloaded from ijrm.ir on 2026-11-12 ]