Original Article

Association between maternal vitamin E status and alpha-tocopherol levels in the newborn and colostrum

Karla Danielly da Silva Ribeiro*, Mayara Santa Rosa Lima[†], Jeane Franco Pires Medeiros[†], Amanda de Sousa Rebouças*, Raquel Costa Silva Dantas*, Danielle Soares Bezerra[‡], Mônica Maria Osório[§] and Roberto Dimenstein[†]

*Department of Nutrition, Federal University of Rio Grande do Norte, Natal, RN, Brazil, [†]Department of Biochemistry, Federal University of Rio Grande do Norte, Natal, RN, Brazil, [‡]Faculdade de Ciências Médicas do Trairi, Federal University of Rio Grande do Norte, Natal, RN, Brazil, and [§]Department of Nutrition, Federal University of Pernambuco, Recife, PE, Brazil

Abstract

Vitamin E is important because of its antioxidant activity in situations of oxidative stress, especially postnatally. Hence, the objective was to verify whether maternal alpha-tocopherol level is associated with the alpha-tocopherol levels of the newborn and colostrum. This is a cross-sectional study of 58 women and their term newborns from a public hospital. Blood and colostrum were collected to measure alpha-tocopherol levels by high-performance liquid chromatography. Mothers with serum alpha-tocopherol levels $<16.2 \text{ mmol L}^{-1}$ and newborns $<11.6 \text{ mmol L}^{-1}$ were indicative of deficiency or low levels. Mothers were divided into two groups: $<16.2 \text{ mmol L}^{-1}$ and those with levels $\geq 16.2 \text{ mmol L}^{-1}$. The mean (95% confidence interval) serum alpha-tocopherol levels of mothers, umbilical cords and colostrum were 28 (24–32), 6 (5–8) and 39 mmol L^{-1} (32–45), respectively ($P < 0.001$); 19% of the women and 90% of the newborns had low alpha-tocopherol levels. Maternal alpha-tocopherol level was associated with that of the umbilical cord. Newborns from mothers at risk of deficiency had low alpha-tocopherol levels ($P < 0.001$). Colostrum levels of vitamin E were not influenced by maternal serum. Maternal deficiency influenced the vitamin E level of the umbilical cord but does not in the colostrum, evidencing distinct transfer mechanisms via the mammary gland.

Keywords: vitamin E, micronutrients, breast milk, neonate, lactation, nutritional status.

Correspondence: Karla Danielly da Silva Ribeiro, Department of Nutrition, Federal University of Rio Grande do Norte, Natal, RN, Brazil. E-mail: karladaniellysr@yahoo.com.br

Introduction

During delivery and right after birth, fetal tissues are exposed to oxidative damage caused by higher free-radical production because the newborn passes from a low-oxygen environment to a high-oxygen environment (Woods *et al.* 2002). Oxidative damage may also be caused by low antioxidant capacity because newborns have low antioxidant-enzyme complex activity and possibly low levels of non-enzymatic antioxidants, such as vitamins A and E (Negi *et al.* 2012; Turgut *et al.* 2004).

In newborns with vitamin E deficiency, oxidative stress may cause neonatal diseases, such as congenital malformation, retinopathy and respiratory diseases, and affect the central nervous system, increasing mortality

especially in preterm infants (Brion *et al.* 2003; Fares *et al.* 2014a). Maternal levels of tocopherols are higher than those of newborns (Horton *et al.* 2013; Masters *et al.* 2007; Sánchez-Vera *et al.*, 2004), but it is not known whether maternal vitamin E deficiency is a determinant of newborn deficiency and levels in breast milk.

Schulpis *et al.* (2004) found normal levels of alpha-tocopherol in most Albanese mothers they studied ($20 \pm 9 \text{ mmol L}^{-1}$), but 15% of their newborns were vitamin E deficient ($<11.6 \text{ mmol L}^{-1}$), a difference attributed to low maternal socioeconomic level and poor nutritional status.

Exclusive breastfeeding can be a strategy against vitamin E deficiency because the milk excreted until postnatal day 4 (colostrum) is particularly rich in

alpha-tocopherol, supplying infants with their vitamin E requirement, essential for accrue reserves and preventing deficiency (Tijerina-Sáenz *et al.* 2009; Melo *et al.* 2013).

Additionally, breast milk can protect against oxidative stress and damage to newborns' DNA (Turhan *et al.* 2011; Ledo *et al.* 2009), but it can also increase oxidative stress index to newborns if its vitamin E level is low (Erdem *et al.* 2012). Therefore, it is critical for women to have adequate vitamin E levels in breast milk to protect infants from deficiency and the effects of low antioxidant capacity. The present study assessed whether the serum alpha-tocopherol levels of mothers can be associated with the alpha-tocopherol levels of the newborn and colostrum.

Methods

Subjects

Volunteers and their newborns attending the University Hospital Ana Bezerra, located in the municipality of Santa Cruz – RN, Brazil, from June 2012 to December 2013, participated in the study. This study is part of the graduate project in Biochemistry of the Federal University of Rio Grande do Norte (UFRN) called 'Assessment of the alpha-tocopherol status of the mother-child dyad'. The study was approved by UFRN's Research Ethics Committee under protocol CAAE 07416912.8.0000.5537.

Women aged 18 years or more without diabetes, high blood pressure, neoplasms, gastrointestinal tract diseases, liver diseases, heart diseases, syphilis and/or HIV who delivered a single term infant (≥ 37 weeks of gestation) without malformations were included, providing they did not take vitamin E supplements during pregnancy. These data were collected from the patients' hospital records.

Data collection

Socioeconomic data and childbirth history were collected from the medical record and by structured interview. All samples were placed in light-proof polypropylene tubes. To determine the serum concentrations of alpha-tocopherol, blood was collected at the time of preparation for delivery (under fasting, when collecting samples for Venereal Disease Research Laboratory and HIV tests); 5 mL of blood sample was drawn via brachial venipuncture. The neonates underwent umbilical cord blood extracting, immediately after delivery. After being collected, blood samples were centrifuged (at 4000 rpm 10 min) to separate and extract the serum.

Colostrum was collected after an overnight fast within 48 h of delivery on two consecutive days, and the samples analyses were performed separately, to obtain a mean concentration of alpha-tocopherol. Roughly 500 μ L was collected each day by manually expressing a single breast, at time intervals of at least 2 h between the last breastfeeding and the sample collection.

Milk and blood samples were stored at -20°C until analysis.

Chemical analyses

Alpha-tocopherol was measured by high-performance liquid chromatography (HPLC) using a Shimadzu device (Shimadzu, Kyoto, Japan) and a reverse phase C18 column (LiChroCART 250–4, Merck, Darmstadt, Germany). Alpha-tocopherol from serum and milk was extracted by adaptation of the method proposed by Ortega *et al.* (1998) and described by Lira *et al.* (2013). Ethanol (95%) (Merck, Darmstadt, Germany) was used for protein precipitation and hexane p.a. (Merck, Darmstadt, Germany) for extraction. After evaporation in nitrogen atmosphere, the extract was diluted in 250 μ L of absolute ethanol (Vetec, St. Louis,

Key messages

- Most full-term neonates had low alpha-tocopherol levels, and these values were related to the mother, being lower in the group of women with marginal levels.
- Monitoring of vitamin E deficiency (VED) during pregnancy and childhood must be performed to avoid exposing the possible effects of VED.
- The maternal vitamin E status was not decisive for the alpha-tocopherol concentration in colostrum and indicates that the body manages to maintain adequate levels in breast milk in the first days of life.

MO, USA), and 20 μL was applied to the HPLC. The mobile phase used was methanol 100% in an isocratic system with a flow rate of 1.0 mL min^{-1} and wavelength of 292 nm. Alpha-tocopherol levels in the samples were identified and quantified by comparing their areas under the chromatographic curve with the standard area (Sigma-Aldrich, St. Louis, MO, USA). The standard concentration was confirmed by the specific extinction coefficient of alpha-tocopherol (1%, $1\text{ cm} = 75.8$ to 292 nm) in absolute ethanol (Merck, Darmstadt, Germany) (Nierenberg & Nann 1992). The result of the sensitivity method was 0.03 mmol L^{-1} for alpha-tocopherol; the long-term imprecision (coefficient of variation) was 0.01% at concentrations of 0.29 mmol L^{-1} for standard and 0.05% at 41 mmol L^{-1} for milk samples. Recovery of vitamin added to colostrum and serum was 109% and 103%, respectively.

Vitamin E deficiency or low alpha-tocopherol levels were defined as serum alpha-tocopherol levels $<16.2\text{ mmol L}^{-1}$ in women (Sauberlich *et al.* 1974) and $<11.6\text{ mmol L}^{-1}$ in newborns (Galinier *et al.* 2005).

Statistical analysis

The statistical analyses were performed by the software IBM SPSS statistic version 21.0 for Windows (SPSS Inc., Chicago, IL, USA). The alpha-tocopherol data are expressed as means (95% confidence intervals). The Kolmogorov–Smirnov test verified whether the data had normal distribution. The Wilcoxon test compared the alpha-tocopherol levels of maternal serum and umbilical cord. Spearman's ρ correlation assessed whether the relationships between maternal alpha-tocopherol status and alpha-tocopherol levels in umbilical cord and colostrum were linear. To assess the association between maternal alpha-tocopherol status and the alpha-tocopherol levels of newborns and colostrum, the sample size should be 58 for a two-tailed significance level of 95%, power of 0.8 and average effect of 0.35 (software G*POWER, version 3.1.9.2, University Dusseldorf, Germany) (Faul *et al.* 2007). The sample was then divided according to maternal serum alpha-tocopherol level (<16.2 and $\geq 16.2\text{ mmol L}^{-1}$). The Mann–Whitney test measured the difference between the groups. The significance level was set at 5% ($P < 0.05$).

Results

Among 102 women recruited before delivery who attended the selection criteria study, 44 were excluded for records because of lack of milk or blood data, and 58 were included in the final analyses.

Table 1 shows the characteristics of the study women. The participants had low socioeconomic level, 29 (50%) were overweight or obese at the end of gestation, 47 (81%) had household income per member below one minimum salary, 50 (86%)

Table 1. Characteristics of the parturient women ($n = 58$) and their newborns.

Characteristics	Maternal serum $<16.2\text{ mmol L}^{-1}$		Maternal serum $\geq 16.2\text{ mmol L}^{-1}$	
	% (n)	Mean (standard deviation)	% (n)	Mean (standard deviation)
Age (years)	–	25 (6)	–	24 (6)
BMI gestational (kg m^{-2})	–	29 (5)	–	28 (4)
Maternal nutritional status*				
Low weight	36 (4)		21 (10)	
Normal weight	0 (0)		32 (15)	
Excess weight/ obesity	64 (7)		47 (22)	
Family income (BMW) [†]				
<1	82 (9)		81 (38)	
1–2	18 (2)		11 (5)	
2–5	0 (0)		8 (4)	
Education				
Not studied	0 (0)		0 (0)	
Not educated [‡]	0 (0)		2 (1)	
Pre-school	0 (0)		21 (10)	
Primary school	55 (6)		30 (14)	
Secondary	18 (2)		23 (11)	
school incomplete				
Secondary	27 (3)		17 (8)	
school				
High school	0 (0)		7 (3)	
Type of delivery				
Caesarean	18 (2)		13 (6)	
Vaginal	82 (9)		87 (41)	
Birthweight (g)		3425 (504)		3255 (396)
Birth height (cm)		50 (2)		49 (2)

n, number; BMI, body mass index; BMW, minimum Brazilian wage.

*BMI/gestational week (Atalah *et al.* 1997).[†]One minimum Brazilian wage = \$US 306.[‡]Just write and read partly.

had vaginal delivery and 33 (57%) had low education level (elementary school or less).

Table 2 shows the mean alpha-tocopherol levels. Vitamin E in maternal serum was five times higher than that in the umbilical cord ($P < 0.001$), and 19% of the women and 90% of the newborns presented low alpha-tocopherol levels. Moreover, maternal alpha-tocopherol level was positively correlated to umbilical cord alpha-tocopherol level ($\rho = 0.380$, $P = 0.003$) but not with colostrum alpha-tocopherol level.

Newborns born to women at risk of vitamin E deficiency ($<16.2 \text{ mmol L}^{-1}$) had lower alpha-tocopherol levels than those born to women without the said risk ($\geq 16.2 \text{ mmol L}^{-1}$) ($P < 0.001$). The mean alpha-tocopherol levels of colostrum were 44 (19–68) and 38 (31–44) mmol L^{-1} in groups <16.2 and $\geq 16.2 \text{ mmol L}^{-1}$, respectively ($P > 0.05$) (Fig. 1).

Discussion

Vitamin E deficiency in the mother–child dyad has not been studied much (Dror & Allen 2011). Our results show that 19% of the women were at risk of vitamin E deficiency, different from the 0% found in Greece (Schulpis *et al.* 2004) and Peru (Horton *et al.* 2013), and of the 2% found in Poland (Masters *et al.* 2007). Because vitamin E is fat soluble and its absorption depends on lipid metabolism, low serum levels may reflect a variety of factors, such as low levels of circulating lipids, low vitamin E intake ($<15 \text{ mg day}^{-1}$), low body

Table 2. Alpha-tocopherol levels in maternal serum, umbilical cord and colostrum, and prevalence of vitamin E deficiency in women and newborns ($n = 58$).

	Alpha-tocopherol mmol L^{-1} mean (CI)	% Low alpha-tocopherol levels (women $<16.2 \text{ mmol L}^{-1}$ and neonates $<7 \mu\text{mol L}^{-1}$)
Maternal serum	28 (24–32)*	19
Umbilical cord serum	6 (5–8) [†]	90
Colostrum	39 (32–45)	–

CI, 95% confidence interval. *[†]Difference significant between maternal serum and umbilical cord $P < 0.001$, Wilcoxon test.

Fig. 1. Alpha-tocopherol levels in colostrum and umbilical cord serum by maternal serum alpha-tocopherol level (<16.2 and $\geq 16.2 \text{ mmol L}^{-1}$). Mean (standard deviation). ^{a,b}Significant difference according to the Mann–Whitney test ($P < 0.001$).

reserves or high levels of oxidative stress (Food and Nutrition Board 2000; Traber 2007).

Ninety per cent of the newborns had low levels of alpha-tocopherol in the umbilical cord but that prevalence is higher than that of low-weight preterm newborns. Studies in Tunisia and Thailand found prevalences of low alpha-tocopherol levels in term newborns of 56% (Fares *et al.* 2014b) and 77% (Kositamongkol *et al.* 2011), respectively. Other studies have measured the level of alpha-tocopherol in the umbilical cord, but very few assessed deficiency. Baydas *et al.* (2002) found $\sim 12 \text{ mmol L}^{-1}$, and Saker *et al.* (2008) found values between 5 and 12 mmol L^{-1} , according to birthweight. This fact may explain the non-classification of term newborns as a group at risk of vitamin E deficiency, or they did not consider the measurement of vitamin levels in cord blood as a better parameter to evaluate the deficiency.

This high proportion of children with low levels of alpha-tocopherol is concerning because low levels make them vulnerable to the negative effects of oxidative stress after birth and to changes caused by this deficiency, which may range from retinopathy to increased mortality (Fares *et al.* 2014a). Therefore, it is important to investigate and understand the determinants of vitamin E levels at birth.

Umbilical cord serum can also be used for measuring the transfer of micronutrients from the placenta to the fetus. The alpha-tocopherol level in umbilical cord was 20% of that in maternal serum and associated with the latter, that is, the newborn's alpha-tocopherol level

decreases with the mother's alpha-tocopherol level. This relationship was found in both study groups (<16.2 and $\geq 16.2 \text{ mmol L}^{-1}$). Newborns born to mothers with marginal levels of alpha-tocopherol at the end of pregnancy also had lower alpha-tocopherol levels than the other group ($P < 0.001$, Fig. 1), suggesting that maternal vitamin E status during pregnancy protects against low vitamin E levels at birth.

The exact mechanism of placental vitamin E transfer remains unknown. Placental transfer during pregnancy is low because only 10% of the nutrient is passively transferred to the fetus, mostly in the active *RRR-D*-alpha-tocopherol form (Shenker *et al.* 1998).

On the other hand, there is evidence that the low vitamin E level in umbilical cord compared with maternal vitamin E level is due to fetal hepatic metabolism of vitamin E. A high ratio of the vitamin E metabolite alpha-carboxyethyl-hydroxychroman to alpha-tocopherol was found in umbilical cord, correlating to that in the mother (Didenco *et al.* 2011). Other mechanisms may also contribute to the low level of alpha-tocopherol in newborns, such as reduced fetal expression of the alpha-tocopherol transport protein (α -tocopherol transfer protein) and/or scarcity of circulating lipids in the fetus and newborn (triglycerides, phospholipids and total cholesterol) due to the placental barrier, lowering the amount of circulating lipoproteins essential for vitamin E transport (Debier 2007).

Breastfeeding is a strategy to increase newborn vitamin E reserves. Kositomongkol *et al.* (2011) found that low intake of breast milk by low birthweight infants was one of the factors associated with the maintenance of vitamin E deficiency after birth. In addition to the short-term and long-term benefits of breast milk for the child's growth and development, from preventing infections to establishing a healthy diet during early childhood, breast milk can increase the antioxidant defences (Ledo *et al.* 2009), and colostrum is particularly high in vitamin E (Lima *et al.* 2014).

Although the study participants are socially vulnerable due to their low income and education levels (Table 1), their colostrum (39 mmol L^{-1}) contained more vitamin E than those of Turkish (31 mmol L^{-1}) (Orhon *et al.* 2009) women but were similar to those of Brazilian women studied elsewhere (Garcia *et al.* 2010). Colostrum compo

sition does not seem to be affected by dietary and socioeconomic factors (Lima *et al.* 2014), suggesting that the mammary gland uses many mechanisms to capture alpha-tocopherol, giving breast milk its characteristic nutritional profile.

Maternal serum alpha-tocopherol level was not associated with that of colostrum (Table 2). This absence of correlation indicates that even in situations of deficiency, the body manages to maintain adequate levels in breast milk, ensuring the supply of vitamin E to the infant. This finding suggests that the transfer of tocopherol to breast milk occurs through controlled mechanisms, not passively like placental transfer. These high vitamin E levels even in the colostrum of women with low serum vitamin E levels show a possible mobilization of alpha-tocopherol in extrahepatic tissues by the mammary gland, as proposed by Debier (2007).

Vitamin E reserves in body fat apparently help to maintain its circulating levels even when intake is inadequate (El-Sohemy *et al.* 2001), and deficiency does not deplete adipose tissue reserves, contrary to hepatic reserves (Uchida *et al.* 2012). Because roughly 90% of the vitamin E is located in the adipose tissue (Traber 2014), the mammary gland probably uses this source to maintain the breast milk level of alpha-tocopherol even when the mothers are deficient. Another evidence of the maintenance of high vitamin E levels in colostrum is the expressive capturing capacity of mammary tissue due to high lipoprotein lipase activity during lactation, promoting absorption of circulating vitamin E in detriment of its storage in adipose tissues (Martínez *et al.*, 2002).

It is necessary to study whether this non-correlation between maternal serum and breast milk vitamin E levels continues during the entire breastfeeding period because the breast level of vitamin E starts to decrease 4 days after delivery (Lima *et al.* 2014).

This study found an association between maternal serum and newborn alpha-tocopherol levels, evidencing low levels of vitamin E in newborns. Newborns born to mothers with marginal levels of vitamin E had lower vitamin E levels than those born to mothers with normal levels of vitamin E, but maternal levels of vitamin E did not affect colostrum levels of the said nutrient. These findings indicate the need of investigating vitamin E deficiency in preterm and term newborns of low

socioeconomic status, its persistency during lactation and its determinants because vitamin E deficiency can increase newborn morbidity and mortality, making nutritional interventions critical in the first days of life.

Acknowledgements

To University Hospital Ana Bezerra and Federal University of Rio Grande do Norte.

Source of funding

All phases of this study were supported by Post-graduate of Biochemistry – Federal University of Rio Grande do Norte.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Contributions

KDR, MLRD and JFM designed the research; DBS, MMO, AR and RCD conducted the research; ML, JFM, AR and RCD analysed the data and KDR and RD wrote the paper. KDR had primary responsibility for the final content. All authors read and approved the final manuscript.

References

- Atalah E., Castillo C., Castro R. & Aldea A. (1997) Propuesta de um nuevo estandar de evaluación nutricional em embarazadas. *Revista Médica de Chile* **123**, 1429–1436.
- Baydas G., Karatas F., Gursu M.F., Bozkurt H.A., Ilhan N., Yasar A. et al. (2002) Antioxidant vitamin levels in term and preterm infants and their relation to maternal vitamin status. *Archives of Medical Research* **33**, 276–280.
- Brion L.P., Bell E.F. & Raghuvier T.S. (2003) Vitamin E supplementation for prevention of morbidity and mortality in preterm infants. *Cochrane Database of Systematic Reviews* **4**, CD003665, 2–5.
- Debiec C. (2007) Vitamin E during pre- and postnatal periods. *Vitamins and Hormones* **76**, 357–373.
- Didenco S., Gillingham M.B., Go M.D., Leonard S.W., Traber M.G. & Mcevoy C.T. (2011) Increased vitamin E intake is associated with higher alpha-tocopherol concentration in the maternal circulation but higher alpha-carboxyethyl hydroxychroman concentration in the fetal circulation. *American Journal of Clinical Nutrition* **93**, 368–373.
- Dror D.K. & Allen L.H. (2011) Vitamin E deficiency in developing countries. *Food and Nutrition Bulletin* **32** (2), 124–147.
- El-Sohehy A., Baylin A., Ascherio A., Kabagambe E., Spiegelman D. & Campos H. (2001) Population-based study of alpha- and gamma-tocopherol in plasma and adipose tissue as biomarkers of intake in Costa Rican adults. *American Journal of Clinical Nutrition* **74**, 356–363.
- Erdem M., Harma M., Harma I.M., Arikan I. & Barut A. (2012) Comparative study of oxidative stress in maternal blood with that of cord blood and maternal milk. *Archives of Gynecology and Obstetrics* **285** (2), 371–375.
- Fares S., Feki M., Khouaja-Mokrani C., Sethom M.M., Jebnoun S. & Kaabachi N. (2014a) Nutritional practice effectiveness to achieve adequate plasma vitamin A, E and D during the early postnatal life in Tunisian very low birth weight infants. *Journal of Maternal-Fetal and Neonatal Medicine* **10**, 1–5.
- Fares S., Sethom M.M., Khouaja-Mokrani C., Jabnoun S., Feki M. & Kaabachi N. (2014b) Vitamin A, E, and D deficiencies in Tunisian very low birth weight neonates: prevalence and risk factors. *Pediatrics and Neonatology* **55**, 196–201.
- Faul F., Erdfelder E., Lang A.G. & Buchner A. (2007) G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods* **39**, 175–191.
- Food and Nutrition Board (2000) *Institute of Medicine. Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids*. National Academy Press: Washington.
- Galinier A., Périquet B., Lambert W., Garcia J., Assouline C., Rolland M. et al. (2005) Reference range for micronutrients and nutritional marker proteins in cord blood of neonates appropriated for gestational ages. *Early Human Development* **81**, 583–593.
- Garcia L., Ribeiro K., Araújo K., Pires J., Azevedo G. & Dimenstein R. (2010) Alpha-tocopherol concentration in the colostrum of nursing women supplemented with retinyl palmitate and alpha-tocopherol. *Journal of Human Nutrition and Dietetics* **23**, 529–534.
- Horton K.D., Adetona O., Aguilar-Villalobos M., Cassidy B. E., Pfeiffer C.M., Schleicher R.L. et al. (2013) Changes in the concentrations of biochemical indicators of diet and nutritional status of pregnant women across pregnancy trimesters in Trujillo, Peru, 2004–2005. *Nutrition Journal* **12**, 80–90.
- Kositamongkol S., Suthutvoravut U., Chongviriyaphan N., Feungpean B. & Nuntarumit P. (2011) Vitamin A and E status in very low birth weight infants. *Journal of Perinatology* **31**, 471–476.

- Ledo A.A., Asensi M.A., Sastre J., Escrig R., Brugada M., Aguar M. *et al.* (2009) Human milk enhances antioxidant defenses against hydroxyl radical aggression in preterm infants. *American Journal of Clinical Nutrition* **89** (1), 210–215.
- Lima M.S., Dimenstein R. & Ribeiro K.D. (2014) Vitamin E concentration in human milk and associated factors: a literature review. *Journal of Pediatric* **90**, 440–448.
- Lira L.Q., Lima M.S.R., Medeiros J.M.S., Silva I.F. & Dimenstein R. (2013) Correlation of vitamin A nutritional status on alpha-tocopherol in the colostrum of lactating. *Maternal & Child Nutrition* **9**, 31–40.
- Martínez S., Barbas C. & Herrera E. (2002) Uptake of α -tocopherol by the mammary gland but not by white adipose tissue is dependent on lipoprotein lipase activity around parturition and during lactation in the rat. *Metabolism* **51** (11), 1444–1451.
- Masters E.T., Jedrychowski W., Schleicher R.L., Tsai W.Y., Tu Y.H., Camann D. *et al.* (2007) Relation between prenatal lipid-soluble micronutrient status, environmental pollutant exposure, and birth outcomes. *American Journal of Clinical Nutrition* **86**, 1139–1145.
- Melo L.R.M., Clemente H.A. & Dimenstein R. (2013) Concentration of alpha-tocopherol in human colostrum and infant formulas and the compliance with the newborn nutritional requirement. *Revista do Instituto Adolfo Lutz* **72** (3), 212–217.
- Negi R., Pande D., Kumar A., Khanna R.S. & Khanna H.D. (2012) Evaluation of biomarkers of oxidative stress and antioxidant capacity in the cord blood of preterm low birth weight neonates. *Journal of Maternal-Fetal and Neonatal Medicine* **25** (8), 1338–1341.
- Nierenberg D.W. & Nann S.L. (1992) A method for determining concentrations of retinol, tocopherol, and five carotenoids in human plasma and tissue samples. *American Journal of Clinical Nutrition* **56**, 417–426.
- Orhon F.S., Ulukol B., Kahya D., Cengiz B., Başkan S. & Tezcan S. (2009) The influence of maternal smoking on maternal and newborn oxidant and antioxidant status. *European Journal of Pediatrics* **168**, 975–981.
- Ortega R.M., López-Sobaler A.M., Martínez R.M., Andrés P. & Quintas M.E. (1998) Influence of smoking on vitamin E status during the third trimester of pregnancy and on breast-milk tocopherol concentrations in Spanish women. *American Journal of Clinical Nutrition* **68**, 662–667.
- Saker M., Mokhtari N.S., Merzouk A.S., Merzouk H., Belarbi B. & Narce M. (2008) Oxidant and antioxidant status in mothers and their newborns according to birthweight. *European Journal of Obstetrics, Gynecology, and Reproductive Biology* **141**, 95–99.
- Sánchez-Vera I., Boneta B., Viana M. & Sanz C. (2004) Relationship between alpha-tocopherol content in the different lipoprotein fractions in term pregnant women and in umbilical cord blood. *Annals of Nutrition and Metabolism* **48**, 146–150.
- Sauberlich H.E., Dowdy R.P. & Skala J.H. (1974) *Laboratory Tests for the Assessment of Nutritional Status*. CRC Press: Cleveland.
- Schulpis K.H., Michalakakou K., Gavrilis S., Karikas G.A., Lazaropoulos C., Vlachos G. *et al.* (2004) Maternal-neonatal retinol and α -tocopherol serum concentration in Greek and Albanians. *Acta Paediatrica* **93**, 1075–1080.
- Shenker S., Yang Y., Perez A., Acuff R., Papas A.M., Henderson G. *et al.* (1998) Antioxidant transport by the human placenta. *Clinical Nutrition* **17**, 159–167.
- Tijerina-Sáenz A., Innis S.M. & Kitts D.D. (2009) Antioxidant capacity of human milk and its association with vitamins A and E and fatty acid composition. *Acta Paediatrica* **98** (11), 1793–1798.
- Traber M.G. (2007) Vitamin E regulatory mechanisms. *Annual Review of Nutrition* **27**, 347–362.
- Traber M.G. (2014) Vitamin E. In: *Modern Nutrition in Health and Disease* (eds A.C. Ross *et al.*), 11th edn. Lippincott Williams & Wilkins: Philadelphia.
- Turgut M., Bas O., Çekmen A.M., Karatas F., Kurt A. & Aygün A.D. (2004) Oxidant and antioxidant levels in preterm newborns with idiopathic hyperbilirubinaemia. *Journal of Paediatrics and Child Health* **40**, 633–637.
- Turhan A.H., Atici A. & Muşlu N. (2011) Antioxidant capacity of breast milk of mothers who delivered prematurely is higher than that of mothers who delivered at term. *International Journal for Vitamin and Nutrition Research* **81** (6), 368–371.
- Uchida T., Abe C., Nomura S., Ichikawa T. & Ikeda S. (2012) Tissue distribution of α - and γ -tocotrienol and γ -tocopherol in rats and interference with their accumulation by α -tocopherol. *Lipids* **47**, 129–139.
- Woods J.R., Cavanaugh J.L., Norkus E.P., Plessinger M.A. & Miller R.K. (2002) The effect of labor on maternal and fetal vitamins C and E. *American Journal of Obstetrics and Gynecology* **187**, 1179–1183.