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Effects of Zinc supplementation in Magnesium alloys on hemogram and erythrocyte osmotic fragility

Efectos de la suplementación de zinc en aleaciones de magnesio sobre el hemograma y la fragilidad osmótica de los eritrocitos

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ABSTRACT

Magnesium and zinc are important trace elements that have important roles in metabolism, immune function and blood cell formation. The effects of dietary supplementation with magnesium and zinc on erythrocyte, leukocyte, platelet parameters and erythrocyte osmotic fragility were studied here. Rats were implanted with several magnesium - zinc alloys in the muscle next to the femur. The animals were divided into seven groups and in the 4th and 7th weeks blood samples were collected for hemogram analysis and osmotic fragility test. The groups were: Control, magnesium (4th and 7th week), magnesium + zinc1 (4th and 7th week) and magnesium + zinc3 (4th and 7th week). The mean corpuscular volume and red blood cell distribution frequency values were significantly higher in the magnesium + zinc3 (4th week) group, while the mean corpuscular volume value was lower in the magnesium (7th week) group. A decrease in lymphocyte count and percentage was observed only in the magnesium + zinc1 (4th week) group, whereas the increase was found in the magnesium (7th week) group. Neutrophil count and percentage were significantly increased in magnesium + zinc1 (4th week) whereas decreased in both groups of magnesium + zinc at 7th week. Hemolysis levels at sodium chloride 0.4 % and 0.5 % concentration were no less than 94 and 86 %, respectively, for the magnesium + zinc3 (7th week) group. It seems that the magnesium + zinc mixture may influence erythropoiesis and might produce macrocytosis as well as anisocytosis changes, which could normalize over time by physiological adaptation. The stable increments achieved in the magnesium group also indicate a more constant role for magnesium in homeostasis of blood elements.

Key words: Biocompatibility; fragility; hemogram; magnesium alloy; zinc alloy.

RESUMEN

El magnesio y el zinc son oligoelementos que desempeñan funciones importantes en el metabolismo, la función inmunitaria y la formación de células sanguíneas. Se estudiaron los efectos de la suplementación dietética con magnesio y zinc en los parámetros de eritrocitos, leucocitos, plaquetas y fragilidad osmótica de los eritrocitos. Se implantaron varias aleaciones de magnesio - zinc en ratas en el músculo próximo al fémur. Los animales se dividieron en siete grupos y en la cuarta y séptima semanas se recogieron muestras de sangre para el análisis del hemograma y la prueba de fragilidad osmótica. Los grupos fueron: Control, magnesio (cuarta y séptima semana), magnesio + zinc1 (cuarta y séptima semana) y magnesio + zinc3 (cuarta y séptima semana). Los valores de volumen corpuscular medio y amplitud de distribución eritrocitaria fueron significativamente más altos en el grupo magnesio + zinc3 (semana 4), mientras que el valor de volumen corpuscular medio fue más bajo en el grupo magnesio (semana 7). Se observó una disminución en el recuento y el porcentaje de linfocitos solo en el grupo magnesio + zinc1 (semana 4), mientras que el aumento se encontró en el grupo magnesio (semana 7). El recuento y el porcentaje de neutrófilos aumentaron significativamente en magnesio + zinc1 (semana 4), mientras que, disminuyeron en ambos grupos de magnesio + zinc en la semana 7. Los niveles de hemólisis en una concentración de cloruro de sodio al 0,4 % y 0,5 % no fueron inferiores al 94 y 86 %, respectivamente, para el grupo magnesio + zinc3 (semana 7). Parece que la mezcla magnesio + zinc puede tener un efecto sobre la eritropoyesis y podría producir macrocitosis, así como cambios de anisocitosis, que podrían normalizarse con el tiempo por adaptación fisiológica. Los incrementos estables logrados en el grupo magnesio también indican un papel más constante del magnesio en la homeostasis de los elementos sanguíneos.

Palabras clave: Biocompatibilidad; fragilidad; hemograma; aleación de magnesio; aleación de zinc.

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INTRODUCTION

The main cellular components of blood are erythrocytes, which make up most of the cell volume in the haematocrit. Their haemoglobin content gives them both their red colour and their oxygen-carrying function. Because of their high surface-to-volume ratio, they are highly deformable without losing their integrity. Although they are fairly resistant to the mechanical stresses of passing through small capillaries, they are susceptible to osmotic changes. This is why the pH and osmotic value of the blood are kept constant within a narrow range. This fragility of erythrocytes has given rise to an important laboratory test. This is the erythrocyte osmotic fragility test, an indicator of membrane stability. This stability is affected by factors such as oxidative stress induced lipid peroxidation, protein carbonylation and loss of spectrin, the main mechanical support network of the erythrocyte cell membrane. At a certain level, erythrocytes lose their resistance to these changes and begin to disintegrate [1].

The hemogram (complete blood count) is a fundamental laboratory test that quantitatively evaluates the cellular components of blood. It provides critical data in clinical and physiological stress conditions [2] as well as in experimental studies [3].

This test measures erythrocyte (red blood cell), leukocyte (white blood cell), and platelet counts, along with some volumetric and proportional parameters related to these cells. It is utilized in the diagnosis of a wide range of conditions including blood disorders, infections, inflammation [2, 4], anemia, poisoning [5, 6], diabetes [7, 8] and immune system disorders [9].

Zinc (Zn) is the most commonly used alloying element in magnesium (Mg) alloys. Zn refines the grain structure of Mg and improves its mechanical properties. Mg-Zn alloys typically contain 1–6 % Zn, a concentration that influences both the strength and corrosion resistance of the alloy [10]. When in contact with body fluids, Mg-Zn alloys gradually degrade. Corrosion resistance increases with Zn content up to a certain level, but excessive Zn may impair solubility. Hydrogen gas release and pH changes during degradation should be carefully monitored [11].

Magnesium-Zinc alloys demonstrate low cytotoxicity in biological environments and cause physiological changes in blood mineral levels and urine profiles [12, 13]. The degradation products Mg^{2+} and Zn^{2+} may support bone tissue regeneration. However, uncontrolled degradation can damage cell membranes and cause hemolysis [14].

Elevated pH and metal ion release during alloy degradation may harm erythrocyte membranes. Zn and Mg ions are believed to disrupt ionic balance in the membrane, increasing erythrocyte susceptibility to hemolysis. The severity of this effect depends on the alloy composition and surface treatments [15].

The release of Mg and Zn ions may also be associated with macrophage activation and cytokine production. Zn's immunomodulatory effect, particularly on T-cell activity, is well documented [16].

Excessive Zn intake has been shown to increase erythrocyte osmotic fragility, leading to microcytic hypochromic anemia. This is thought to result from Zn interfering with copper (Cu) and iron (Fe) absorption, which induces oxidative stress Zn deficiency also increases erythrocyte osmotic fragility due to reduced membrane stability. [17].

Magnesium supplementation has been reported to increase hemoglobin levels and erythrocyte counts, and to positively affect erythropoiesis by supporting erythropoietin (EPO) production [18]. Mg-gluconate has been shown to reduce lipid peroxidation in erythrocyte membranes, thereby decreasing osmotic fragility and enhancing membrane stability [19].

Biodegradable alloys containing Mg and Zn can cause hemolysis and cytotoxicity when in contact with erythrocytes, primarily due to pH changes and corrosion by-products. Surface treatments such as micro-arc oxidation applied to Mg-Zn-Ca alloys have been shown to reduce hemolysis and improve blood compatibility [20, 21].

This study aimed to investigate the effects of Mg and Mg + Zn supplementation on hematological parameters in experimental groups. Although the direct effects of Zn addition to Mg alloys on hemogram and erythrocyte osmotic fragility have not been widely studied, findings from existing literature [11, 22] indicate that both elements play significant roles in hematological parameters and erythrocyte membrane stability. Therefore, more specific research on the biocompatibility and hematological effects of Mg-Zn alloys is needed, as this topic is typically examined within the contexts of biomaterials and implant biocompatibility or mineral supplementation and hematological health.

MATERIALS AND METHODS

This research was carried out at the Van Yuzuncu Yil University Experimental Research Center, with approval granted by the Sivas Cumhuriyet University Animal Experimentation Local Ethics Committee (Approval Number: 80, Date: 22.08.2025).

Previously in vitro biocompatibility-tested pure Mg and Mg-Zn alloy implants were used [13]. The implants were placed under appropriate conditions into the "gluteus-superficialis" muscle, a mobile muscle located near the femur of the rats Wistar Albino (*Rattus norvegicus*).

The rats were divided into 7 groups: Control group, Mg group (4th and 7th weeks), Mg + Zn 1 group (4th and 7th weeks), and Mg + Zn 3 group (4th and 7th weeks). At the end of the 4th and 7th weeks, under anesthesia (i.p. injection of 70 mg/kg ketamine-HCl and 10 mg/kg xylazine-HCl), blood was collected from the hearts of the rats using sterile syringes and transferred into ethylenediaminetetraacetic acid (EDTA)-containing tubes.

The experimental study was conducted at the Yüzüncü Yıl University Animal Research Center. Erythrocyte parameters assay: Red blood cell (RBC) count, haemoglobin content (HGB), haematocrit (HCT), mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), mean corpuscular haemoglobin concentration (MCHC) and red blood cell distribution frequency (RDWC) were determined in whole blood using the rat mode of a Veterinary blood cell counter (Abocus Junior Vet-5, Austria) [1].

Red blood cell fragility measured: Erythrocyte fragility was measured at 546 nm using a spectrophotometric device (Boeco, S-22 UV/Vis, Germany). Solutions containing different concentrations of NaCl and distilled water between 0.1, 0.4, 0.5 and 0.85 % were prepared. Buffering of the solutions

was ensured by adding sufficient amounts of Na2HPO4 and NaH2PO4. After blood collection in tubes containing Dipotassium EDTA, blood samples were incubated for 24 hours (h) at room temperature. 30 microlitres of blood were added to the dilution tubes. Each tube contains 2 mL of solutions. Mixed blood was incubated for 30 minutes (min) and centrifuged (Hettich, Universal 320R, Germany) for 5 min to 402 G. The supernatant fractions were placed in the spectrophotometer and recorded [1].

Stastical analysis

Data were presented as mean±standard deviation. SPSS version 21 was used for statistical analysis. One Way Annova and tukey test were used for comparison of erythrocyte fragility and blood cells.

RESULTS AND DISCUSSION

Mean Corpuscular Volume values in the Mg Zn 3 4th week group significantly increased, while in the Mg 7th week group, they decreased significantly. The RDWc parameter was significantly higher in the Mg Zn 3 4th week group compared to the control and most other groups. HGB and HCT values were lower in the Mg Zn 3 (4th week) group, but this difference was statistically insignificant (TABLE I).

The increase in MCV values in the MgZn3 (4th week) group (Shown in TABLE I) indicates an enlargement in the average volume of erythrocytes, suggesting macrocytosis. In contrast, a significant decrease in MCV was observed in the Mg (7th week) group, indicating microcytic (small-sized) erythrocytes. This suggests that Zn or Mg may influence cell size regulation.

Furthermore, the significant increase in RDWC (TABLE I) suggests that the erythrocyte population became heterogeneous in size, indicating anisocytosis (erythrocytes of varying sizes). Such changes are typically associated with stress responses in erythropoiesis or vitamin deficiencies.

Zinc plays a role in cell proliferation and DNA synthesis, making it important in the erythropoiesis process. However, high doses of Zn supplementation can interfere with Cu and Fe absorption, leading to hematological disorders [23].

Magnesium is an important cofactor in ribosomal functions and ATP production. Mg deficiency can disrupt the hematopoiesis process [24]. In this study, it is suggested that the combination of Mg Zn alloys imposes additional stress on erythrocytes during the adaptation period.

In the Mg group, a slight increase in RBC, HGB, and HCT values (Shown in TABLE I) was observed between the 4th and 7th weeks. In the MgZn1 and Mg Zn3 groups, the trend of improvement or deterioration over time was unclear, but more stable values were observed in the 7th week.

Lymphocyte count showed a significant decrease in the Mg Zn 1 4th week group, while a significant increase was observed in the Mg group (7th week). In terms of lymphocyte % values, a significant decrease was observed in the Mg Zn 1 group (4th week), while a significant increase was noted in the Mg Zn 1 group (7th week) and Mg Zn 3 group (7th week). A significant increase in neutrophil count was found in the Mg Zn 1 4th week group. In neutrophil % values, a significant increase was observed in the Mg Zn 1 group (4th week), whereas a significant decrease was seen in the Mg Zn 1 group (7th week) and Mg Zn 3 group (7th week) (TABLE II).

TABLE I

Comparison of erythrocyte hematological parameters in control and experimental groups receiving magnesium and magnesium–zinc supplementation at the 4th and 7th weeks

	RBC 10^{12}/L	HGB (g/dL)	HCT (%)	MCV (fl)	MCH (pg)	MCHC (g/dL)	RDWC (%)
Control group	7,48 ^{a} ± 0,13	14,10 ^{a} ± 0,31	41,27 ^{a} ± 0,60	55,40 ^{ab} ± 0,66	18,84 ^{a} ± 0,44	34,16 ^{a} ± 0,81	16,78 ^{ab} ± 0,13
Mg group (4th week)	7,14 ^{a} ± 0,48	13,54 ^{a} ± 0,29	39,45 ^{a} ± 2,94	54,80 ^{ab} ± 1,05	19,52 ^{a} ± 1,34	35,68 ^{a} ± 3,04	15,78 ^{a} ± 0,36
Mg Zn 1 group (4th week)	7,37 ^{a} ± 0,27	14,15 ^{a} ± 0,39	39,15 ^{a} ± 1,73	54,60 ^{ab} ± 0,21	19,61 ^{a} ± 1,18	35,85 ^{a} ± 2,15	17,30 ^{ab} ± 0,26
Mg Zn 3 group (4th week)	6,76 ^{a} ± 0,48	12,67 ^{a} ± 0,59	39,10 ^{a} ± 1,52	60,64 ^{b} ± 3,31	19,21 ^{a} ± 0,80	31,70 ^{a} ± 1,03	18,49 ^{b} ± 0,95
Mg group (7th week)	7,43 ^{a} ± 0,08	14,16 ^{a} ± 0,34	40,03 ^{a} ± 0,62	53,80 ^{a} ± 0,40	19,12 ^{a} ± 0,43	35,46 ^{a} ± 0,83	16,28 ^{a} ± 0,24
Mg Zn 1 group (7th week)	6,90 ^{a} ± 0,46	13,72 ^{a} ± 0,24	39,72 ^{a} ± 2,46	57,83 ^{ab} ± 0,83	20,50 ^{a} ± 1,84	35,40 ^{a} ± 2,71	15,73 ^{a} ± 0,39
Mg Zn 3 group (7th week)	6,92 ^{a} ± 0,87	12,58 ^{a} ± 1,48	37,70 ^{a} ± 4,64	54,83 ^{ab} ± 1,19	18,42 ^{a} ± 0,44	33,65 ^{a} ± 0,71	16,20 ^{a} ± 0,23

RBC: red blood cells; HGB: Hemoglobin; HCT: Hematocrit; MCV: mean corpuscular volume; MCH: mean corpuscular hemoglobin; MCHC: mean corpuscular hemoglobin concentration, RDWC: distribution frequency of red blood cell. The results are the means ± SD for 8 rats in each group. There is a significant difference between groups with different letters. ($P \leq 0.05$)

TABLE II

Comparison of leukocyte parameters in control and experimental groups receiving magnesium and magnesium–zinc supplementation at the 4th and 7th weeks

	WBC (10^9 /L)	LYM (10^9 /L)	MON (10^9 /L)	NEU (10^9 /L)	LY (%)	MO (%)	NE (%)
Control group	5,75 ± 0,52	4,36 ^{ab} ± 0,44	0,37 ^{a} ± 0,10	1,01 ^{a} ± 0,07	75,66 ^{bc} ± 1,58	6,50 ^{a} ± 1,44	17,82 ^{ab} ± 0,53
Mg group (4th week)	5,83 ^{a} ± 0,86	4,22 ^{ab} ± 0,60	0,27 ^{a} ± 0,14	1,36 ^{ab} ± 0,18	72,36 ^{b} ± 1,59	3,66 ^{a} ± 1,29	23,96 ^{b} ± 2,04
Mg Zn 1 group (4th week)	5,70 ^{a} ± 0,84	3,44 ^{a} ± 0,49	0,37 ^{a} ± 0,08	1,99 ^{a} ± 0,29	59,47 ^{a} ± 0,70	6,61 ^{a} ± 0,94	34,23 ^{c} ± 0,38
Mg Zn 3 group (4th week)	7,02 ^{a} ± 0,58	5,28 ^{ab} ± 0,55	0,30 ^{a} ± 0,06	1,43 ^{ab} ± 0,14	74,97 ^{bc} ± 3,29	4,07 ^{a} ± 0,70	21,37 ^{ab} ± 3,29
Mg group (7th week)	8,73 ^{a} ± 1,08	6,64 ^{b} ± 1,28	0,27 ^{a} ± 0,09	1,19 ^{a} ± 0,07	78,92 ^{bc} ± 3,27	3,66 ^{a} ± 0,93	17,44 ^{ab} ± 2,74
Mg Zn 1 group (7th week)	6,27 ^{a} ± 0,33	5,25 ^{ab} ± 0,30	0,16 ^{a} ± 0,01	0,85 ^{a} ± 0,07	83,64 ^{c} ± 1,12	2,66 ^{a} ± 0,15	13,72 ^{a} ± 1,05
Mg Zn 3 group (7th week)	6,74 ^{a} ± 0,64	5,56 ^{ab} ± 0,56	0,18 ^{a} ± 0,01	1,00 ^{a} ± 0,08	82,16 ^{c} ± 0,86	2,70 ^{a} ± 0,15	15,14 ^{a} ± 0,82

WBC: White blood cells; LYM: lymphocyte counts; MON: monocyte counts; NEU: neutrophil counts; LY %: lymphocyte percentage; MO %: monocyte percentage; NE %: neutrophil percentage The results are the means ± SD for 8 rats in each group. There is a significant difference between groups with different letters. ($P \leq 0.05$)

An increase in neutrophil percentage in the Mg Zn 1 (4th week) (TABLE II) group suggests a possible acute inflammatory response. Zn supplementation reduced neutrophil percentages in the following weeks (7th week), indicating a potential immune regulation effect. Meanwhile, in the Mg (7th week) group, and in the Mg Zn 3 (7th week) and Mg Zn 1 (7th week) groups, the increase in lymphocyte percentage (82-83 %) (Shown in TABLE 2) suggests modulation and adaptation in the immune system. The highest total leukocyte count in the Mg (7th week) group indicates ongoing immune system activation.

Leukocyte counts are important parameters in determining immune status [9]. Zn affects adaptive immunity by enhancing T cell differentiation and Th1 responses [16]. Mg supports neutrophil functions and chemotaxis [25]. This may explain the increase in neutrophil count in the Mg-supplemented groups.

No significant differences were observed in parameters such as platelet (PLT), mean corpuscular volume (MPV), and platelet distribution width (PDWC) across all groups. However, platelet count in the Mg Zn 3 (4th week) group was relatively lower (TABLE III). This should be monitored carefully.

While Zn deficiency can cause thrombocytopenia, excessive Zn intake may affect platelet function via Cu antagonism [26]. No significant differences were found in PLT, MPV, and PDWC values, but platelet count was relatively lower in the Mg Zn 3 (4th week) group (TABLE III). This may suggest mild bone marrow suppression.

While hemolysis rates were low in the control group at 0.4 and 0.5 NaCl concentrations (34 % and 11 %), these rates were quite high in the Mg Zn 3 (7th week) group at 94 % and 86 %, respectively (TABLE IV).

TABLE III

Comparison of platelet parameters in control and experimental groups receiving magnesium and magnesium–zinc supplementation at the 4th and 7th weeks

	PLT (10^9 /L)	PCT (%)	MPV (fl)	PDWC (%)
Control group	677,00 a ± 9,24	0,46 a ± 0,00	6,80 a ± 0,07	34,62 a ± 0,40
Mg group (4th week)	633,60 a ± 35,98	0,44 a ± 0,03	6,90 a ± 0,08	34,72 a ± 0,20
Mg Zn 1 group (4th week)	673,16 a ± 38,79	0,47 a ± 0,03	7,08 a ± 0,27	34,50 a ± 0,93
Mg Zn 3 group (4th week)	572,53 a ± 39,83	0,40 a ± 0,02	7,04 a ± 0,14	34,96 a ± 0,47
Mg group (7th week)	621,40 a ± 80,62	0,44 a ± 0,06	7,25 a ± 0,16	33,67 a ± 0,87
Mg Zn 1 group (7th week)	631,33 a ± 52,49	0,45 a ± 0,04	7,23 a ± 0,08	34,78 a ± 0,53
Mg Zn 3 group (7th week)	641,33 a ± 125,02	0,45 a ± 0,09	6,98 a ± 0,09	34,25 a ± 0,25

PLT: platelet count; PCT: plateletcrit; MPV: mean corpuscular volume; PDWC: platelet distribution width. The results are the means ± SD for 8 rats in each group. There is a significant difference between groups with different letters. ($P \leq 0.05$)

TABLE IV

Comparison of erythrocyte osmotic fragility at different sodium chloride concentrations in control and experimental groups receiving magnesium and magnesium–zinc supplementation

	0.1 (%)	0.4 (%)	0.5 (%)	0.9 (%)
CONTROL	100	34^{b}	11b	0
Mg (4th week)	100	65^{ab}	48^{ab}	0
Mg Zn 1 (4th week)	100	79^{a}	42^{ab}	0
Mg Zn 3 (7th week)	100	77^{a}	74^{a}	0
Mg (7th week)	100	79^{a}	74^{a}	0
Mg Zn 1 (7th week)	100	87^{a}	85^{a}	0
Mg Zn 3 (7th week)	100	94^{a}	86^{a}	0

n = 6 for each groups. Results were presented as mean percent hemolysis at different concentrations of sodium chloride (NaCl). There is a significant difference between groups with different letters. (P ≤ 0.05)

Zinc can reduce membrane stability by interacting with protein structures in the cell membrane [27]. Mg, on the other hand, is known to decrease membrane permeability; however, in this study, high-dose combinations appeared to have the opposite effect [28].

The osmotic fragility test is used to evaluate erythrocyte membrane integrity. In the Mg Zn 3 (7th week) group, hemolysis rates at 0.4 % and 0.5 % NaCl concentrations reached 94 % and 86 %, respectively (Shown in TABLE IV). This indicates that erythrocyte membrane structure was weakened, making the cells more susceptible to osmotic stress. However, at the 0.9 % NaCl concentration, all groups-maintained erythrocyte membrane integrity.

CONCLUSION

Magnesium and Mg + Zn supplementation creates differences in hematological parameters. The macrocytosis and increased RDWC observed in the Mg + Zn 3 group should be carefully evaluated as biological effects. However, in the 7th week, this group appears to have returned to more stable values, indicating that the body may have adapted to these changes. Long-term studies could clarify the persistence and biological significance of these effects.

Conflict of interest

The authors have no conflict of interests to declare concerning the authorship or publication of this article.

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BIBLIOGRAFIC REFERENCES

[1] Comba B, Oto G, Arihan O, Comba A, Uyar H. RBC. How long-term intake of sodium fluoride (NaF) in different doses and 7,12-dimethylbenz(a)anthracene (DMBA) affect the erythrocyte parameters in rats? J. Anim. Plant Sci. [Internet]. 2019 [cited 20 Jan 2026]; 29(1):75–81. Available in: https://goo.su/HnQVIY

[2] Comba B, Oto G, Mis L, Özdemir H, Comba A. Effects of borax on inflammation, haematological parameters, and total oxidant-antioxidant status in rats applied 3-methylcholanthrene. Kafkas Univ Vet Fak Derg. [Internet]. 2016; 22(4):539–544. doi: https://doi.org/q82h

[3] Çelik R, Mert H, Comba B, Mert N. Effects of cinnamaldehyde on glucose-6-phosphate dehydrogenase activity, some biochemical and hematological parameters in diabetic rats. Biomarkers. [Internet]. 2022; 27(3):270–277. doi: https://doi.org/q83

[4] Comba A, Oto G, Comba B, Özdemir H, Keskin S, Akveran GA. Effects of boric acid on proinflammation cytokines, total oxidative antioxidative status, and hematological parameters in rats applied benzo(a)pyrene. Fresenius Environ. Bull. [Internet]. 2020 [cited 20 Jan 2026]; 29(5):3599–3605. Available in: https://goo.su/jRi6f

[5] Yıldırım S, Oto G, Comba B, Ekin S, Çınar DA. An investigation of the protective effects of resveratrol on some biochemical parameters and histopathological findings in experimentally-induced chronic fluorosis in rats. Fluoride. [Internet]. 2017 [cited 20 Jan 2026]; 50(3):365–373. Available in: https://goo.su/sqIlWdC

[6] Yıldırım S, Ekin S, Huyut Z, Oto G, Comba A, Uyar H, Sengul E, Çınar DA. Effect of chronic exposure to sodium fluoride and 7,12-dimethylbenz(a)anthracene on some blood parameters and hepatic, renal, and cardiac histopathology in rats. Fluoride. [Internet]. 2018 [cited 20 Jan 2026]; 51(3):278-290. Available in: https://goo.su/MHme

[7] Taş A, Karasu A, Comba B, Aksu DS, Düz E, Tanritanir P. Effects of sildenafil citrate on the hematological parameters in the early phase of wound healing in diabetic rats. Asian J. Anim. Vet. Adv. [Internet]. 2011; 6(3):290–296. doi: https://doi.org/cd2xtw

[8] Comba B, Mis L, Comba A, Çınar A, Taş A. The effects of sildenafil citrate on some haematological parameters and mineral matters in wound healing of rats created experimental diabetes. Atatürk Univ. J. Vet. Sci. [Internet]. 2014; 9(3):180–186. doi: https://doi.org/q83f

[9] Vadi M, Comba B. Effect of resveratrol on total oxidative-antioxidative status and DNA damage in rats induced by methotrexate. J. Cumhuriyet Univ. Health. Sci. Inst. [Internet]. 2022; 7(2):84–91. doi: https://doi.org/q83g

[10] Gu XN, Zheng YF. A review on magnesium alloys as biodegradable materials. Front. Mater. Sci. China. [Internet]. 2010; 4:111–115. doi: https://doi.org/bbw8bm

[11] Li H, Zheng Y, Qin L. Progress of biodegradable metals. Prog. Nat. Sci. Mater. Int. [Internet]. 2014; 24(5):414–422. doi: https://doi.org/f6sfjd

[12] Comba A, Cicek B, Comba B, Sancak T, Arslan-Akveran G, Sun Y, Elen L, Torkamanian-Afshar M. Investigation of in-vitro biocompatibility and in-vivo biodegradability of AM series Mg alloys. Mater. Technol. [Internet]. 2022; 37(13):2819–2831. doi: https://doi.org/g88zs4

[13] Comba B, Cicek B, Comba A, Sancak T, Akveran GA, Koc E, Sun Y, Torkamanian Afshar M. Experimental study of in-vitro bioanalysis and in-vivo living tissue biocompatibility of Mg–Zn alloys. J. Mater. Res. [Internet]. 2023; 38(8):2203–2212. doi: https://doi.org/q83h

[14] Witte F, Hort N, Vogt C, Cohen S, Kainer KU, Willumeit R, Feyerabend F. Degradable biomaterials based on magnesium corrosion. Curr. Opin. Solid State Mater. Sci. [Internet]. 2008; 12(5–6):63–72. doi: https://doi.org/bgfqcw

[15] Zheng YF, Gu XN, Witte F. Biodegradable metals. Mater Sci. Eng. R. Rep. [Internet]. 2014; 77:1–34. doi: https://doi.org/f5xmzx

[16] Haase H, Rink L. The immune system and the impact of zinc during aging. Immun. Ageing. [Internet]. 2009; 6:9. doi: https://doi.org/cf7xzz

[17] Hachisuka E, Kido T, Suka M, Yanagisawa H. Ingestion of excess zinc augments the osmotic fragility of red blood cells via an increase in oxidative stress. Biomed. Res. Trace Elem. [Internet]. 2020; 31(3):117–125. doi: https://doi.org/q83j

[18] Lima FS, Fock RA. A review of the action of magnesium on several processes involved in the modulation of hematopoiesis. Int. J. Mol. Sci. [Internet]. 2020; 21(19):7084. doi: https://doi.org/grxwbz

[19] Rojas D, Abad C, Piñero S, Medina Y, Chiarello DI, Proverbio F, Marín R. Effect of Mg-gluconate on the osmotic fragility of red blood cells, lipid peroxidation, and Ca^{2+}-ATPase (PMCA) activity of placental homogenates and red blood cell ghosts from salt-loaded pregnant rats. Front. Physiol. [Internet]. 2022; 13:794572. doi: https://doi.org/q83k

[20] Zhen Z, Liu X, Huang T, Xi T, Zheng Y. Hemolysis and cytotoxicity mechanisms of biodegradable magnesium and its alloys. Mater. Sci. Eng. C. [Internet]. 2015; 46:202–206. doi: https://doi.org/f6w3ps

[21] Cao Y, Qiu H, Wang D, Bi ZG. Improved blood compatibility of Mg-1.0Zn-1.0Ca alloy by micro-arc oxidation. J. Biomed. Mater. Res. A. [Internet]. 2011; 99A(2):166–172. doi: https://doi.org/b589sh

[22] Wang C, Yang HT, Li X, Zheng YF. *In vitro* evaluation of the feasibility of commercial Zn alloys as biodegradable metals. J. Mater. Sci. Technol. [Internet]. 2016; 32(9):909–918. doi: https://doi.org/gtpwb3

[23] Prasad AS. Discovery of human zinc deficiency: Its impact on human health and disease. Adv. Nutr. [Internet]. 2013; 4(2):176–190. doi: https://doi.org/f4tgmg

[24] Elin RJ. Magnesium: The fifth but forgotten electrolyte. Am. J. Clin. Pathol. [Internet]. 20101994; 102(5):616-622. doi: https://doi.org/gf6w74

[25] Watanabe K, Hagen KL, Ramakrishnan V, Andersen BR. Kinetics of CD11b expression on neutrophils isolated from subjects with healthy gingivae and patients with advanced periodontitis. J. Periodontal Res. [Internet]. 1993; 28(2):137–144. doi: https://doi.org/djk3jf

[26] O'Dell BL. Role of zinc in plasma membrane function. J. Nutr. [Internet]. 2000; 130(5):1432S–1436S. doi: https://doi.org/q83z

[27] Kambe T, Taylor KM, Fu D. Zinc transporters and their functional integration in mammalian cells. J. Biol. Chem. [Internet]. 2021; 296:100320. doi: https://doi.org/gn9zms

[28] Swaminathan R. Magnesium metabolism and its disorders. Clin. Biochem. Rev. [Internet]. 2003 [cited 22 Jan 2026]; 24(2):47–66. Available in: https://goo.su/QUHeq5