European Journal of Nutrition
https://doi.org/10.1007/s00394-022-02916-w

ORIGINAL CONTRIBUTION

Recommendation on an updated standardization of serum magnesium reference ranges

Andrea Rosanoff[1] · Christina West[2] · Ronald J. Elin[3] · Oliver Micke[4] · Shadi Baniasadi[5] · Mario Barbagallo[6] · Emily Campbell[1,7] · Fu-Chou Cheng[8] · Rebecca B. Costello[1] · Claudia Gamboa-Gomez[9] · Fernando Guerrero-Romero[10] · Nana Gletsu-Miller[11] · Bodo von Ehrlich[12] · Stefano Iotti[13] · Ka Kahe[14] · Dae Jung Kim[15] · Klaus Kisters[16,17] · Martin Kolisek[18] · Anton Kraus[19] · Jeanette A. Maier[20] · Magdalena Maj-Zurawska[21] · Lucia Merolle[22] · Mihai Nechifor[23] · Guitti Pourdowlat[24] · Michael Shechter[25,26] · Yiqing Song[27] · Yee Ping Teoh[28] · Rhian M. Touyz[29] · Taylor C. Wallace[1,30,31] · Kuninobu Yokota[32] · Federica Wolf[33,34] · for the MaGNet Global Magnesium Project (MaGNet)

Received: 11 November 2021 / Accepted: 13 May 2022

Abstract

Purpose Serum magnesium is the most frequently used laboratory test for evaluating clinical magnesium status. Hypomagnesemia (low magnesium status), which is associated with many chronic diseases, is diagnosed using the serum magnesium reference range. Currently, no international consensus for a magnesemia normal range exists. Two independent groups designated 0.85 mmol/L (2.07 mg/dL; 1.7 mEq/L) as the low cut-off point defining hypomagnesemia. MaGNet discussions revealed differences in serum magnesium reference ranges used by members' hospitals and laboratories, presenting an urgent need for standardization.

Methods We gathered and compared serum magnesium reference range values from our institutions, hospitals, and colleagues worldwide.

Results Serum magnesium levels designating "hypomagnesemia" differ widely. Of 43 collected values, only 2 met 0.85 mmol/L as the low cut-off point to define hypomagnesemia. The remainder had lower cut-off values, which may underestimate hypomagnesemia diagnosis in hospital, clinical, and research assessments. Current serum magnesium reference ranges stem from "normal" populations, which unknowingly include persons with chronic latent magnesium deficit (CLMD). Serum magnesium levels of patients with CLMD fall within widely used "normal" ranges, but their magnesium status is too low for long-term health. The lower serum magnesium reference (0.85 mmol/L) proposed specifically prevents the inclusion of patients with CLMD.

Conclusions Widely varying serum magnesium reference ranges render our use of this important medical tool imprecise, minimizing impacts of low magnesium status or hypomagnesemia as a marker of disease risk. To appropriately diagnose, increase awareness of, and manage magnesium status, it is critical to standardize lower reference values for serum magnesium at 0.85 mmol/L (2.07 mg/dL; 1.7 mEq/L).

Keywords Serum magnesium · Serum magnesium reference range · Chronic latent magnesium deficit · CLMD · Hypomagnesemia

Abbreviations

CLMD	Chronic latent magnesium deficit
CVD	Cardiovascular disease
MaGNet	Magnesium global network

Introduction

Magnesium is essential for life. Although its homeostasis at the cellular, tissue, and organism levels seems to be well buffered, there is a widely distributed tendency for low magnesium status to be associated with the most common chronic diseases [1]. In the absence of a more selective, reliable, and easily testable biomarker, serum magnesium is the most frequently used laboratory test for evaluating clinical

✉ Andrea Rosanoff
arosanoff@gmail.com

Extended author information available on the last page of the article

magnesium status. Researchers use serum magnesium reference ranges to designate hypo-, normo-, or hypermagnesemic status, whereas hospitals and primary care physicians use serum magnesium values in deciding whether to administer magnesium therapy. Consequently, the lower cutoff for serum magnesium reference value of a hospital or clinical laboratory determines the number of patients diagnosed as "hypomagnesemic."

Hypomagnesemia has several clinical manifestations that vary from asymptomatic to severe. Overt symptoms present at ≤ 0.6 mmol/L [2] (Fig. 1). These clinical manifestations include metabolic issues (hypokalemia and hypocalcemia), neuromuscular-central nervous system symptoms (hyperexcitability, muscle weakness, tremors, seizures, tetany, headaches, and fatigue), cardiovascular abnormalities (tachycardia, arrhythmias such as torsade de pointes, ventricular fibrillation, mitral valve prolapse, cardiac ischemia, myocardial infarct, and hypertension), and endocrine abnormalities (insulin resistance and type 2 diabetes) [2, 3] (Table 1). Reported severe, overt symptoms of hypomagnesemia also include the mimic of acute stroke [4], life-threatening arrhythmias [3], metabolic acidosis [5], and new-onset diabetes following heart transplantation [6]. In intensive-care units, hypomagnesemia is associated with higher mortality, the need for mechanical ventilation, and increased length of stay [7].

In addition to hypomagnesemia presenting with overt disease states, patients can present with asymptomatic hypomagnesemia or chronic latent magnesium deficit (CLMD) at serum Mg levels well above 0.6 mmol/L (Fig. 1). CLMD has been defined as a subclinical condition that renders individuals more susceptible to disease. CLMD occurs

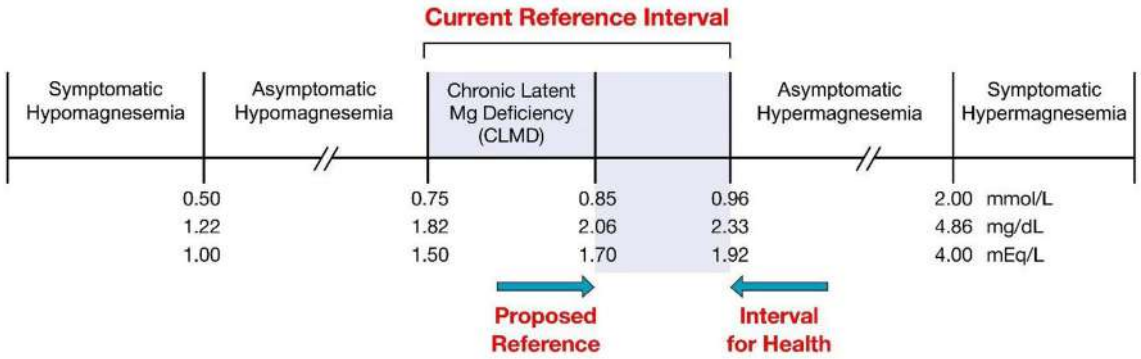

Fig. 1 Total serum magnesium concentration for assessment of magnesium status. *Conversion factor:* for mg/dL to mmol/L, multiply by 0.411; for mmol/L to mg/dL, multiply by 2.43; and for mmol/L to mEq/L, divide by 0.5. Reproduced from Costello and Rosanoff [14], which was adapted from Costello et al. [12]

Table 1 Clinical manifestations of hypomagnesemia. Adapted from Ehrenpreis et al. [2] and Ahmed et al. [3] with permission

System	Clinical manifestation
Neuromuscular/central nervous system	Positive Chvostek's and Trousseau's signs, tremor, fasciculations, tetany, headaches, seizures, fatigue, generalized fatigue, asthenia
	Hyperexcitability, weakness, dysphagia, vertical nystagmus, apathy, delirium, coma
Cardiovascular	Atherosclerotic vascular disease/coronary artery disease
	Arrhythmias (Torsades de pointes, PR prolongation, progressive QRS widening, and diminution of T-waves)
	Hypertension
	Congestive heart failure
	Mitral valve prolapse, tachycardia, cardiac ischemia, myocardial infarct
Endocrine	Altered glucose homeostasis/diabetic complications
	Osteoporosis
	Insulin resistance and type 2 diabetes
Biochemical/other	Hypokalemia
	Hypocalcemia
	Asthma
	Nephrolithiasis

with a small chronic negative magnesium balance, which may be attributed to decreased dietary intake, decreased gastrointestinal absorption, and/or increased renal loss [8]. The most common cause of CLMD worldwide is decreased magnesium dietary intake, since processed food and fast food tend to have low magnesium content [9, 10]. However, illness and drug use must also be taken into account. Over time, this negative magnesium balance causes the serum magnesium concentration to decrease. Since this is a subtle chronic process, some magnesium is depleted in bone to support the circulating serum magnesium pool [11]. Thus, patients with CLMD appear to have "normal" magnesium status, because their serum magnesium value falls within the traditionally normal reference ranges, but these patients are not in sufficient magnesium status for long-term health. The actual magnesium deficiency of the patient is latent—a fallacy of the reference interval as serum magnesium reference intervals have been established with "healthy" individuals, including many who unknowingly have CLMD [11]. This is the basis for updating the lower limit reference interval for the serum magnesium concentration.

Two groups of magnesium researchers, one in the United States [12] and one in Germany [13], have independently agreed on a serum magnesium value of 0.85 mmol/L as the low cut-off point to define hypomagnesemia, since serum magnesium values < 0.85 mmol/L (2.07 mg/dL or 1.7 mEq/L) have been associated with an increased risk of various diseases (e.g., cardiovascular disease [CVD], metabolic), obesity, and aging.

In response to the COVID-19 pandemic, our international group of magnesium researchers (Magnesium Global Network [MaGNet]) began meeting in September 2020 to discuss the research. In these meetings, we discussed the serum magnesium reference ranges used by our institutions' hospitals and laboratory service providers, and we discovered that they were far from uniform. We decided to gather these values to compare them with the suggested evidence-based serum magnesium reference for hypomagnesemia of 0.85 mmol/L [12 13], and we present those findings here.

Materials and methods

We collected and evaluated the various serum magnesium reference range values of our institutions, including the laboratory methodology used to obtain those values when available. To expand our indicative database, we also gathered serum magnesium reference range values from colleagues around the world. Institutions were coded by country, and all contributed values were calculated to express commonly used alternate units of serum magnesium—milligrams per deciliter (mg/dL), millimoles per liter (mmol/L), and milliequivalents per liter (mEq/L)—for each reported value. GraphPad Prism version 9 was used to tabulate data and create Fig. 2. The independently suggested evidence-based serum magnesium reference range of 0.85–0.95 mmol/L (2.07–2.3 mg/dL or 1.7–1.9 mEq/L) was added to Figure 2 for comparison.

Results

As shown in Fig. 2 and Table 2, the level of serum magnesium designating a patient as hypomagnesemic differs worldwide. Forty-three values were gathered from institutions in 16 different countries, including China, Germany, India, Iran, Israel, Italy, Japan, Korea, Mexico, Poland, Romania, Slovakia, Switzerland, Taiwan, the United Kingdom, and the United States. Of those 43 values, only 2 (5%) designated a low serum magnesium reference range cut-off value of 0.85 mmol/L. Forty-one values of the 43 institutions (95%) designated their low cutoff for definition of hypomagnesemia below and even well below this suggested standard, from 0.58 mmol/L for IT4 to 0.78 mmol/L for IL1. Most of the collected values (29 of 43; 67%) used colorimetric methodology, with 9 specifying xylidyl blue and 1 indicating calmagite as the colorimetric agent. Of the 43 values, 1 (2%) used atomic absorption spectroscopy and 3 (7%) used enzymatic methodology. Ten values (21%) did not report methodology. Figure 1 summarizes the definition of low and high magnesemia as proposed by previous works on magnesium reference range [14] and highlights how CLMD is currently included in the normal serum magnesium range (see Discussion).

Discussion

Such different serum magnesium reference range values render our current use of this medical tool imprecise, causing many hypomagnesemic patients to be deemed normomagnesemic and potentially minimizing the effects of low magnesium status in research.

When different cut-off values for hypomagnesemia are used, substantially different results can ensue. For instance, in one study at a Warsaw hospital, when a lower cut-off reference value of 0.65 mmol/L was used, 7% of 20,483 patients were deemed hypomagnesemic [15]. With the lower cut-off reference value of 0.75 mmol/L, 25% of this same patient cohort showed hypomagnesemia. Finally, with a lower cut-off reference value of 0.85 mmol/L, 60% were diagnosed as hypomagnesemic [15].

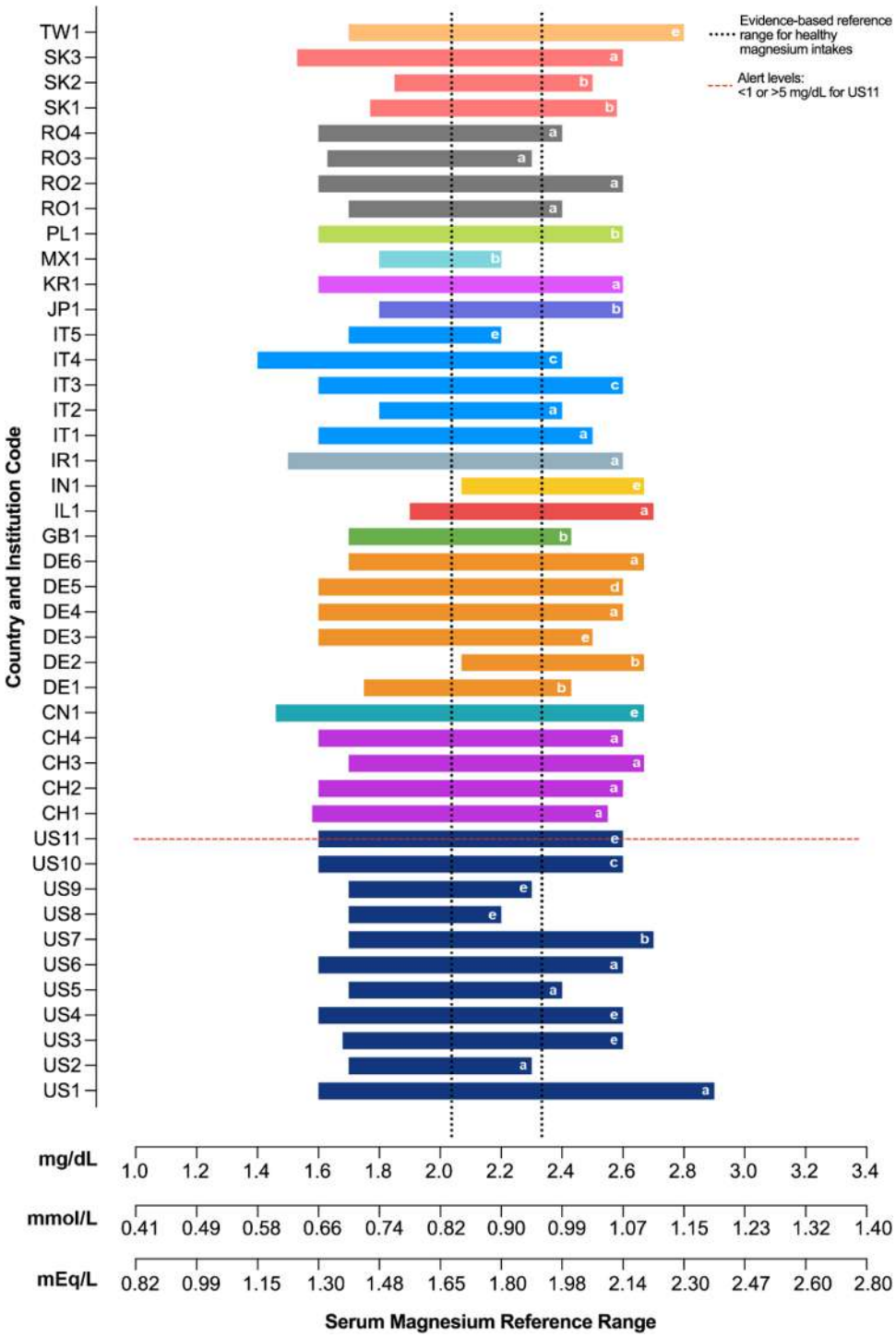

Fig. 2 Serum magnesium reference ranges from several institutions and laboratory service providers, gathered by magnesium researchers for the MaGNet Global Magnesium Project. Assessment methods are indicated with lowercase letters as follows: colorimetric (**a**), colorimetric/xylidyl blue (**b**), enzymatic assay (**c**), atomic absorption spectroscopy (**d**), and not reported (**e**). Colorimetric, photometric, and spectrophometric designations of methodology are all classified under colorimetry. See Table 2 for full details

Clearly, the serum magnesium reference range used by a hospital, clinical, or research laboratory is crucial in the designation of low magnesium status. The present observational study's wide spectrum of serum reference interval values used in hospital and clinical laboratories around the world documents an urgent need for a consensus reference interval for serum magnesium concentration, specifically on the lower cut-off limit, since low magnesium status is currently a common condition worldwide [16]. The evidence-based lower cut-off value of 0.85 mmol/L (2.07 mg/dL or 1.7 mEq/L) proposed by the US and German research groups [12, 13] specifically prevents the inclusion of individuals with CLMD [12], who usually fall into the lower half of the reference interval of < 0.85 mmol/L (see Fig. 1).

Table 2 Working table of serum magnesium reference ranges for various hospitals and institutions

Institution code	Country	Institution	Serum magnesium reference range[a]			Method[b]	Researcher
			mg/dL	mmol/L	mEq/L		
CH1	Switzerland	Kantonsspital Aarau	1.58–2.55	**0.65–1.05**	1.3–2.1	Photometric	Anton Kraus
CH2	Switzerland	University Hospital, Zurich	1.6–2.6	**0.66–1.07** (age dependent)	1.3–2.1	Photometric	Anton Kraus
CH3	Switzerland	Analytica Medizinische Lab, Zurich	1.7–2.67	**0.7–1.10**	1.4–2.2	Photometric	Anton Kraus
CH4	Switzerland	Laboratory of Dr. Risch	1.6–2.6	**0.66–1.07** (age dependent)	1.3–2.1	Photometric	Anton Kraus
CN1	China	Zhanghou Affiliated Hospital of Fujian Medical University, Zhangzhou	1.46–2.67	**0.6–1.1**	1.2–2.2	NR	Andrea Rosanoff [18]
DE1	Germany	Dr. Schottdorf Augsburg Laboratory	1.75–2.43	**0.75–1.0**	1.5–2.0	Photometric, colorimetric, xylidyl blue	Bodo von Ehrlich
DE2	Germany	Medical Office	2.07–2.67	**0.85–1.1**	1.7–2.2	Photometric, colorimetric, xylidyl blue	Bodo von Ehrlich
DE3	Germany	St. Elisabeth Hospitals Herne	**1.6–2.5**	0.66–1.03	1.3–2.06	NR	Klaus Kisters
DE4	Germany	Laboratory Enders, Stuttgart (https://www.labor-enders.de/analysenverzeichnis)	1.6–2.6	**0.66–1.07**	1.3–2.1	Colorimetric	Anton Kraus
DE5	Germany	Laboratory Amedes Hosding, Hamburg (https://www.amedes-group.com)	**1.6–2.6**	0.66–1.07	1.3–2.1	Atomic absorption spectroscopy	Anton Kraus
DE6	Germany	Franziskus Hospital Bielefeld	1.7–2.67	**0.7–1.1**	1.4–2.2	Photometric	Oliver Micke
GB1	UK	UK Hospitals – National Health Service	**1.7–2.43**	0.7–1.00	1.4–2.0	Colorimetric, xylidyl blue	Rhian Touyz and Yee Pang Teoh
IL1	Israel	Chaim Sheba Medical Center	**1.9–2.7**	0.78–1.1	1.6–2.2	Photometric color test	Michael Shechter
IN1	India	Nirogyam Pathology Laboratory	2.07–2.67	**0.85–1.1**	1.7–2.2	NR	Oliver Micke
IR1	Iran	National Research Institute of Tuberculosis and Lung Diseases, Iran	**1.5–2.6**	0.62–1.07	1.2–2.1	Colorimetric	Guitti Pourdowlat and Shadi Baniasadi
IT1	Italy	University Hospital of Palermo, Italy	**1.6–2.5**	0.66–1.03	1.3–2.06	Colorimetric	Mario Barbagallo
IT2	Italy	Policlinico Gemelli, Rome	**1.8–2.4**	0.74–0.99	1.48–2.0	Colorimetric	Federica Wolf
IT3	Italy	Campus Biomedico, Rome	**1.6–2.6**	0.66–1.07	1.3–2.1	Enzymatic assay	Federica Wolf

Table 2 (continued)

Institution code	Country	Institution	Serum magnesium reference range[a]			Method[b]	Researcher
			mg/dL	mmol/L	mEq/L		
IT4	Italy	Clinical Pathology Laboratory at Sacco Hospital	**1.4–2.4**	0.58–0.99	1.15–2.0	Enzymatic assay (isocitrate dehydrogenase)	Jeanette Maier
IT5	Italy	Used UCSF (USA) ref range for study at Reggio Emilia Hospital	**1.7–2.2**	0.70–0.905[c]	1.4–1.8	NR	Stefano Iotti and Lucia Merolle
JP1	Japan	Jikei University, Japan	**1.8–2.6**	0.74–1.07	1.48–2.14	Colorimetric, xylidyl blue	Ka Kahe and Kuninobu Yokota
KR1	Korea	Ajou University School of Medicine, South Korea	**1.6–2.6**	0.66–1.07	1.3–2.1	Colorimetric	Ka Kahe and Dae Jung Kim
MX1	Mexico		**1.8–2.2**	0.74–0.905	1.48–1.8	Colorimetric, xylidyl blue	Claudia Gamboa
PL1	Poland	Diagnostic Medical Laboratory "Synevo"	**1.60–2.60** (age dependent)	0.66–1.07	1.3–2.1	Colorimetric, xylidyl blue; fasting	Jeanette Maier and Magdalena Maj-Zurawska
RO1	Romania	Fundeni Clinical Hospital Bucuresti	**1.7–2.4** (adult patients)	0.70–0.99	1.40–1.98	Spectrophometric	Mihai Nechifor
RO2	Romania	Iasi Recovery Clinical Hospital	**1.6–2.6** (> 12 y)	0.66–1.07	1.36–2.14	Spectrophometric	Mihai Nechifor
		BIOCLINICA	**1.6–2.6** (> 14 y)				
		St. Spiridon County Clinical Hospital Iasi	**1.6–2.6** (no age specified)			Colorimetric	
RO3	Romania	Timis Country Emergency Clinical Hospital, Timisoara	**1.6–2.3** (no age specified)	0.66–0.95	1.36–1.90	Spectrophometric	Mihai Nechifor
RO4	Romania	Synevo network of private labs	**1.6–2.4** (> 20 y)	0.66–0.99	1.36–1.98	Colorimetric	Mihai Nechifor
SK1	Slovakia	ICB, University Hospital Martin, Slovakia	1.77–2.58	**0.73–1.06** (adult male)	1.46–2.1	Colorimetric, xylidyl blue	Martin Kolisek
SK2	Slovakia	ICB, University Hospital, Martin, Slovakia	1.87–2.5	**0.77–1.03** (adult female)	1.5–2.06	Colorimetric, xylidyl blue	Martin Kolisek
SK3	Slovakia	Alpha Medical, Unilabs Group, Slovakia	1.53–2.6	**0.63–1.07**	1.26–2.14	Colorimetric	Martin Kolisek
TW1	Taiwan	Taichung Veterans General Hospital, Taichung, Taiwan	**1.7–2.8**	0.70–1.15	1.4–2.3	NR	Fu-Chou Cheng
US1	USA	Indiana University Hospital Pathology Laboratory	**1.6–2.9**	0.66–1.19	1.3–2.4	Colorimetric	Nana Gletsu-Miller and Taylor Wallace
US2	USA	University of Louisville, Louisville, KY	**1.7–2.3**	0.70–0.95	1.4–1.9	Colorimetric, calmagite	Ron Elin
US3	USA	Dartmouth	1.68–2.60	**0.69–1.07**	1.4–2.1	NR	Emily Campbell

Table 2 (continued)

Institution code	Country	Institution	Serum magnesium reference range[a]			Method[b]	Researcher
			mg/dL	mmol/L	mEq/L		
US4	USA	Medical University of South Carolina	**1.6–2.6**	0.66–1.07	1.3–2.1	NR	Emily Campbell
US5	USA	Clinical laboratories, Hawaii	**1.7–2.4**	0.70–0.99	1.4–1.98	Colorimetric	Andrea Rosanoff
US6	USA	Diagnostic laboratories, Hawaii	**1.6–2.6**	0.66–1.07	1.3–2.1	Colorimetric	Andrea Rosanoff
US7	USA	Clinical Laboratory, Indiana University School of Medicine Diabetes Center Translation Core	**1.70–2.70**	0.70–1.1	1.4–2.2	Colorimetric (xylidyl blue)	Yiqing Song
US8	USA	UCSF (https://www.ucsfhealth.org/medical-tests/magnesium-blood-test)	**1.7–2.2**[c]	0.70–0.905[c]	1.4–1.8[c]	NR	Stefano Iotti
US9	USA	Mayo Clinical Laboratories (age > 17 y)	**1.7–2.3** (age dependent)	0.70–0.95	1.4–1.9	NR	Stefano Iotti
US10	USA	National Institutes of Health Clinical Center	**1.6–2.6**	0.66–1.07	1.3–2.1	Enzymatic, assayed on Abbott Architect. Alert levels: < 1.0 or > 5.0 mg/dL	Rebecca Costello
US11	USA	Columbia University Presbyterian Hospital, New York	**1.6–2.6**	0.66–1.07	1.3–2.1	NR	Ka KaHe

These data were gathered by MaGNet for the Global Magnesium Project, 2020–2021

NR, not reported; UCSF, University of California, San Francisco

[a]Bolded values are those provided by the researchers. Nonbolded values are the respective conversions (*conversion factor:* for mg/dL to mmol/L, multiply by

0.4114; for mmol/L to mg/dL, multiply by 2.43; and for mmol/L to mEq/L, divide by 0.5)

[b]In Fig. 2, colorimetric, photometric, and spectrophometric designations of methodology are all classified under colorimetry

[c]The published UCSF serum magnesium reference range reports 1.7–2.2 mg/dL (shown in bold here) converting to 0.85–1.1 mmol/L on their webpage. However, the correct conversion for 1.7–2.2 mg/dL is 0.70–0.905 mmol/L, not 0.85–1.1 mmol/L; possibly their reported value of 1.7–2.2 is mEq/L (rather than mg/dL), which converts to 0.85–1.1 mmol/L

Despite the central role of magnesium in maintaining proper immune, vascular, and pulmonary function, emerging evidence indicates that magnesemia is seldom assessed in patients [17]. Additionally, an evidence-based standard for the upper range of serum magnesium to differentiate between a "safe" and "hypermagnesemic" value is yet to be determined.

Conclusion

The 43 serum magnesium reference range values we collected from 16 countries varied widely, and all but 2 (DE2 and IN1) had a hypomagnesemic cut-off point well below that of the recommended 0.85 mmol/L (2.07 mg/dL or 1.7 mEq/L). Thus, the hypomagnesemic reference values in this informal collection indicate that physicians and researchers are vastly underestimating hypomagnesemia in their patients and institutions, interpreting as "normal" serum magnesium values that fall well below that recently

proposed to be safe for good health. It is critically important to appropriately identify, diagnose, and manage low magnesium status, which is often overlooked and may play a role in susceptibility to increasingly common chronic diseases (e.g., CVD, diabetes, and chronic obstructive pulmonary disease), among other conditions.

A consensus serum magnesium to define hypomagnesemia is suggested to be 0.85 mmol/L (2.07 mg/dL or 1.7 mEq/L). An evidence-based, standardized serum magnesium reference range for hypermagnesemia still needs to be determined. MaGNet researchers should continue gathering and monitoring new evidence to further update recommendations for guidelines that define the correct serum magnesium reference range to maintain health.

Disclosures

Christina West received financial support from CMER for her role in this work. She provides editorial consulting services to authors, nonprofit organizations, and publishers, but has no conflicts of interest that influenced or are relevant to this work. Anton Kraus is an employee of Verla-Pharm Arzneimittel.

Author contributions A.R.: conceptualization; data curation; formal analysis; investigation; methodology; project administration; resources; supervision; validation; visualization; roles/writing—original draft; writing—review and editing. C.W.: data curation; visualization; software; writing—review and editing. R.J.E., O.M., S.B., M.B., E.C., F.-C.C., R.B.C., C.G., F.G.-R., N.G.-M., B.v.E., S.I., K.K.H., D.J.K., K.K., M.K., A.K., J.A.M., M.M.-Z., L.M., M.N., G.P., M.S., Y.S., Y.P.T., R.M.T., T.C.W., K.Y., and F.W.: conceptualization; data curation; formal analysis; investigation; methodology; validation; visualization; writing—review and editing.

Funding This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Fiorentini D, Cappadone C, Farruggia G, Prata C (2021) Magnesium: biochemistry, nutrition, detection, and social impact of diseases linked to its deficiency. Nutrients 13(4):1136. https://doi.org/10.3390/nu13041136
2. Ehrenpreis ED, Jarrouj G, Meader R, Wagner C, Ellis M (2022) A comprehensive review of hypomagnesemia. Dis Mon 68(2):101285. https://doi.org/10.1016/j.disamonth.2021.101285
3. Ahmed F, Mohammed A (2019) Magnesium: the forgotten electrolyte—a review on hypomagnesemia. Med Sci (Basel). https://doi.org/10.3390/medsci7040056
4. Rico M, Martinez-Rodriguez L, Larrosa-Campo D, Calleja S (2016) Dilemma in the emergency setting: hypomagnesemia mimicking acute stroke. Int Med Case Rep J 9:145–148. https://doi.org/10.2147/imcrj.S101011
5. Fulop T, Agarwal M, Keri KC (2020) Hypomagnesemia clinical presentation. https://emedicine.medscape.com/article/2038394-clinical. Accessed 13 April 2022
6. Peled Y, Ram E, Lavee J, Tenenbaum A, Fisman EZ, Freimark D, Klempfner R, Sternik L, Shechter M (2019) Hypomagnesemia is associated with new-onset diabetes mellitus following heart transplantation. Cardiovasc Diabetol 18(1):132. https://doi.org/10.1186/s12933-019-0939-5
7. Upala S, Jaruvongvanich V, Wijarnpreecha K, Sanguankeo A (2016) Hypomagnesemia and mortality in patients admitted to intensive care unit: a systematic review and meta-analysis. QJM 109(7):453–459. https://doi.org/10.1093/qjmed/hcw048
8. Reddy ST, Soman SS, Yee J (2018) Magnesium balance and measurement. Adv Chronic Kidney Dis 25(3):224–229. https://doi.org/10.1053/j.ackd.2018.03.002
9. Sawicki CM, Jacques PF, Lichtenstein AH, Rogers GT, Ma J, Saltzman E, McKeown NM (2021) Whole- and Refined-grain consumption and longitudinal changes in cardiometabolic risk factors in the Framingham Offspring Cohort. J Nutr 151(9):2790–2799. https://doi.org/10.1093/jn/nxab177
10. Rosanoff A (2013) Changing crop magnesium concentrations: impact on human health. Plant Soil 368(1):139–153. https://doi.org/10.1007/s11104-012-1471-5
11. Elin RJ (2010) Assessment of magnesium status for diagnosis and therapy. Magnes Res 23(4):S194-198. https://doi.org/10.1684/mrh.2010.0213
12. Costello RB, Elin RJ, Rosanoff A, Wallace TC, Guerrero-Romero F, Hruby A, Lutsey PL, Nielsen FH, Rodriguez-Moran M, Song Y et al (2016) Perspective: the case for an evidence-based reference interval for serum magnesium: the time has come. Adv Nutr 7(6):977–993. https://doi.org/10.3945/an.116.012765
13. Micke O, Vormann J, Kraus A, Kisters K (2021) Serum magnesium: time for a standardized and evidence-based reference range. Magnes Res 34:84–89. https://doi.org/10.1684/mrh.2021.0486
14. Costello RB, Rosanoff A (2020) Magnesium. In: Marriott BP, Birt DF, Stalling VA, Yates AA (eds) Present knowledge in nutrition, 11th edn. Academic Press, San Diego, pp 349–373
15. Malinowska J, Małecka M, Ciepiela O (2020) Variations in magnesium concentration are associated with increased mortality: study in an unselected population of hospitalized patients. Nutrients 12(6):1836. https://doi.org/10.3390/nu12061836
16. Rosanoff A (2021) US adult magnesium requirements need updating: impacts of rising body weights and data-derived variance. Adv Nutr 12(2):298–304. https://doi.org/10.1093/advances/nmaa140
17. Trapani V, Rosanoff A, Baniasadi S, Barbagallo M, Castiglioni S, Guerrero-Romero F, Iotti S, Mazur A, Micke O, Pourdowlat G et al (2021) The relevance of magnesium homeostasis in COVID-19. Eur J Nutr 61:625–636. https://doi.org/10.1007/s00394-021-02704-y
18. Yang W, Wang E, Chen W, Chen C, Chen S (2021) Continuous observation of serum total magnesium level in patients undergoing hemodialysis. Blood Purif 50(2):196–204. https://doi.org/10.1159/000509788

Authors and Affiliations

Andrea Rosanoff[1] · Christina West[2] · Ronald J. Elin[3] · Oliver Micke[4] · Shadi Baniasadi[5] · Mario Barbagallo[6] · Emily Campbell[1,7] · Fu-Chou Cheng[8] · Rebecca B. Costello[1] · Claudia Gamboa-Gomez[9] · Fernando Guerrero-Romero[10] · Nana Gletsu-Miller[11] · Bodo von Ehrlich[12] · Stefano Iotti[13] · Ka Kahe[14] · Dae Jung Kim[15] · Klaus Kisters[16,17] · Martin Kolisek[18] · Anton Kraus[19] · Jeanette A. Maier[20] · Magdalena Maj-Zurawska[21] · Lucia Merolle[22] · Mihai Nechifor[23] · Guitti Pourdowlat[24] · Michael Shechter[25,26] · Yiqing Song[27] · Yee Ping Teoh[28] · Rhian M. Touyz[29] · Taylor C. Wallace[1,30,31] · Kuninobu Yokota[32] · Federica Wolf[33,34] · for the MaGNet Global Magnesium Project (MaGNet)

Christina West
christina.west@comcast.net

Ronald J. Elin
ronald.elin@louisville.edu

Oliver Micke
strahlenklinik@web.de

Shadi Baniasadi
sbaniasadi@yahoo.com

Mario Barbagallo
mario.barbagallo@unipa.it

Emily Campbell
Emily.Y.Campbell@hitchcock.org

Fu-Chou Cheng
vc1035@gmail.com

Rebecca B. Costello
rbcostello@earthlink.net

Claudia Gamboa-Gomez
clau140382@hotmail.com

Fernando Guerrero-Romero
guerrero.romero@gmail.com

Nana Gletsu-Miller
ngletsum@iu.edu

Bodo von Ehrlich
aioloskalo@t-online.de

Stefano Iotti
stefano.iotti@unibo.it

Ka Kahe
kk3399@cumc.columbia.edu

Dae Jung Kim
djkim@ajou.ac.kr

Klaus Kisters
klaus.kisters@elisabethgruppe.de

Martin Kolisek
martin.kolisek@uniba.sk

Anton Kraus
info@magnesium-ges.de

Jeanette A. Maier
jeanette.maier@unimi.it

Magdalena Maj-Zurawska
mmajzur@chem.uw.edu.pl

Lucia Merolle
Lucia.Merolle@ausl.re.it

Mihai Nechifor
mihainechif@yahoo.com

Guitti Pourdowlat
pourdowlat_g@yahoo.com

Michael Shechter
Michael.Shechter@sheba.health.gov.il;
shechtes@netvision.net.il

Yiqing Song
yiqsong@iu.edu

Yee Ping Teoh
YeePing.Teoh@wales.nhs.uk

Rhian M. Touyz
Rhian.Touyz@mcgill.ca

Taylor C. Wallace
taylor.wallace@me.com

Kuninobu Yokota
yokota@jikei.ac.jp

Federica Wolf
federica.wolf@unicatt.it

[1] CMER Center for Magnesium Education and Research, 13-1255 Malama Street, Pahoa, HI 96778, USA

[2] White House, TN, USA

[3] Department of Pathology and Laboratory Medicine, University of Louisville, Louisville, KY, USA

[4] Department of Radiotherapy and Radiation Oncology, Franziskus Hospital, Kiskerstraße 26, 33615 Bielefeld, Germany

[5] Tracheal Diseases Research Centre, National Research Institute of Tuberculosis and Lung Diseases, Shahid Beheshti University of Medical Sciences, Tehran, Iran

[6] Geriatric Unit, Department of Medicine, University of Palermo, Palermo, Italy

[7] Geisel School of Medicine, Dartmouth Medical College, Hanover, NH, USA

[8] Department of Medical Research, Taichung Veterans General Hospital, Taichung, Taiwan, People's Republic of China

[9] Biomedical Research Unit of Mexican Social Security Institute, Durango, Mexico

[10] Research Group on Diabetes and Chronic Illnesses, Durango, Mexico

[11] Indiana University School of Public Health, Bloomington, IN, USA

[12] Internal Medicine Private Practice, Kempten, Germany

[13] Department of Pharmacy and Biotechnology (FaBit), National Institute of Biostructures and Biosystems, Università di Bologna, Bologna, Italy

[14] Departments of Obstetrics and Gynecology and Epidemiology, Columbia University Irving Medical Center, New York, NY, USA

[15] Ajou University Hospital, Suwon-si, Korea

[16] St. Anna Hospital, Medizinische Klinik I, Herne, Germany

[17] Academy of Micronutrient Medicine, Essen, Germany

[18] Biomedical Center in Martin, Jessenius Medical Faculty in Martin, Comenius University, Mala Hora 4D, Martin 03601, Slovakia

[19] German Society for Magnesium Research E.V, Postfach 1256, 82327 Tutzing, Germany

[20] Department of Biomedical and Clinical Sciences L. Sacco, Università Di Milano, Milan, Italy

[21] Faculty of Chemistry, Biological and Chemical Research Centre, University of Warsaw, Warsaw, Poland

[22] Transfusion Medicine Unit, AUSL-IRCCS Di Reggio Emilia, Reggio Emilia, Italy

[23] Department of Pharmacology, Grigore T. Popa University of Medicine and Pharmacy, Iasi, Romania

[24] Chronic Respiratory Diseases Research Centre, National Research Institute of Tuberculosis and Lung Diseases, Shahid Beheshti University of Medical Sciences, Tehran, Iran

[25] Clinical Research Unit, Leviev Cardiothoracic and Vascular Center, Chaim Sheba Medical Center, Tel Hashomer, Israel

[26] Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel

[27] Department of Epidemiology, Fairbanks School of Public Health, Indiana University Richard M, Indianapolis, IN, USA

[28] Department of Clinical Biochemistry, Wrexham Maelor Hospital, Wales, UK

[29] Research Institute of the McGill University Health Centre, Montreal, QC, Canada

[30] Department of Nutrition and Food Studies, George Mason University, Fairfax, VA, USA

[31] Think Healthy Group, Washington, DC, USA

[32] Jikei University School of Medicine, Tokyo, Japan

[33] Department of Translational Medicine and Surgery, Fondazione Policlinico Gemelli Scientific Institute for Research, Hospitalization and Healthcare (IRCCS), Università Cattolica del Sacro Cuore, Rome, Italy

[34] Unicamillus International Medical University, Rome, Italy