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RESEARCH ARTICLE

HEMATOLOGICAL AND BONE METABOLISM ABNORMALITIES IN CHILDREN AND ADOLESCENTS WITH B-THALASSEMIA MAJOR

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Abstract

β-thalassemia major (TM) is a transfusion-dependent hemoglobinopathy characterized by ineffective erythropoiesis and progressive iron accumulation. Despite improvements in transfusion and chelation regimens, metabolic bone disease remains a common and debilitating complication in young patients. To evaluate hematological indices and biochemical markers of bone metabolism in children and adolescents (≤21 years) with β-thalassemia major attending the Pediatric Department at the National Oncology Center, Aden, during January–December 2022. A cross-sectional analytical study of 40 transfusion-dependent TM patients was performed. Patients underwent complete blood counts and biochemical testing including serum ferritin, 25-OH vitamin D, parathyroid hormone (PTH), calcium and phosphorus. Descriptive statistics and categorical distributions versus reference ranges were analyzed. The cohort demonstrated severe chronic anemia (mean Hb 6.72 ± 1.77 g/dL; mean Hct 21.7 ± 6.1%) with microcytosis (mean MCV 73.5 ± 6.54 fL) and marked anisocytosis (RDW-CV 21.61 ± 7.00%). Median leukocyte count was 10.8 ×10³/µL with 60% of patients exhibiting leukocytosis; mean platelet count was increased (463.47 ± 281.4 ×10³/µL). Iron overload was profound (mean serum ferritin 3718.9 ± 2453.8 ng/mL), with 92.5% of patients above the normal ferritin range and 77.5% classified as high or severe (≥2000 ng/mL). Vitamin D insufficiency/deficiency was highly prevalent (mean 25-OH vitamin D 23.85 ± 9.96 ng/mL; 47.5% deficient, 27.5% insufficient, 25% adequate). Biochemical evidence of disturbed mineral homeostasis included hypocalcemia in 55% of patients, low PTH in 40%, and hyperphosphatemia in 45%. Together, these findings indicate a strong association between iron overload, endocrine dysfunction, and impaired bone mineral metabolism. Children and adolescents with β-thalassemia major in this cohort exhibit severe anemia, overwhelming iron accumulation, high prevalence of vitamin D deficiency, and frequent disturbances in calcium-phosphate-PTH axis—factors that collectively predispose to metabolic bone disease. Early, integrated strategies—including vigilant iron management, routine endocrine assessment, vitamin D optimization, and targeted bone health monitoring—are essential to mitigate long-term skeletal morbidity in this population.

Keywords: β-thalassemia major; Iron overload; Bone metabolism; Vitamin D deficiency; Hypocalcemia; Parathyroid hormone; Pediatric.

1 Introduction

Hemoglobinopathies are among the most common inherited disorders worldwide, resulting from genetic mutations that alter either the structure or synthesis of hemoglobin. Hemoglobin (Hb) is a tetrameric protein composed of two α- and two β-chains, each containing a heme group that binds oxygen reversibly. [1,2] Throughout human development, hemoglobin variants undergo a well-defined transition from embryonic forms to fetal hemoglobin (HbF, α2γ2) and finally to adult hemoglobins, HbA (α2β2) and HbA2 (α2δ2).[3–5] Mutations affecting globin gene expression lead to two major categories of disorders: thalassemia syndromes,

characterized by quantitative defects in globin chain production, and structural hemoglobin variants involving qualitative alterations.[6,7] The first clinical description of thalassemia was made by Thomas Benton Cooley in 1925 in children of Mediterranean origin, establishing the foundation for subsequent research on what became known as β-thalassemia major.[8]Later studies expanded the geographical distribution of the disease to South Asia and the Middle East, and by the mid-twentieth century, the molecular basis of thalassemia had been identified.[9–13] The introduction of regular blood transfusions in the 1960s significantly improved the prognosis and life expectancy of affected individuals.[14]

Pathophysiologically, thalassemia is characterized by impaired hemoglobin synthesis, ineffective erythropoiesis, hemolysis, and chronic anemia.[15–17] Iron overload resulting from repeated transfusions remains a major clinical challenge, contributing to oxidative stress and multiorgan dysfunction.[18–21] Accurate diagnosis requires an integrated approach combining clinical evaluation, hematologic indices, hemoglobin electrophoresis, and molecular analysis, often supported by biomarkers such as erythropoietin (EPO) and growth differentiation factor 15 (GDF-15), which are significantly elevated in affected patients.[22–26] Clinically, thalassemia manifests with pallor, jaundice, hepatosplenomegaly, skeletal deformities, and thromboembolic complications, particularly in individuals who have undergone splenectomy.[12, 27–29] The global distribution of thalassemia varies considerably, with the β-thalassemia trait prevalence estimated at 4.4% in Yemen, 64% for thalassemia major in Lebanon, and a 4.48% carrier incidence in Tunisia.[30–33] Such variations are influenced by genetic background and cultural practices, particularly consanguineous marriages.

Among the major complications associated with β-thalassemia major (TM), skeletal abnormalities and bone fractures are of particular significance. Bone deformities and osteoporosis represent key features that arise from marrow expansion, hormonal imbalance, iron toxicity, and suboptimal chelation therapy.[33–40] Bone loss in TM is multifactorial, involving genetic, metabolic, hormonal, and treatment-related factors. Genetic influences account for approximately 70% of bone mineral density (BMD) variance. [41] Variations in the vitamin D receptor (VDR) gene located on chromosome 12q12 alter receptor activity and may predispose TM patients to bone loss.[42–44] Similarly, mutations in the calcitonin receptor gene have been implicated in TM-associated osteoporosis. At the molecular level, the RANKL/RANK/osteoprotegerin (OPG) signaling pathway plays a pivotal role in bone remodeling by regulating osteoclast differentiation and activity.[45] In TM, increased levels of sclerostin and Dickkopf-1, both inhibitors of the Wnt signaling pathway, have been associated with enhanced bone turnover and reduced BMD, particularly in the lumbar spine and distal radius.[46,47]

Iron overload also contributes to bone deterioration by promoting oxidative stress, cortical bone thinning, and impairment of osteoblast function.[46,48] Elevated ferritin levels are correlated with both bone loss and endocrine disturbances. Endocrinopathies such as hypogonadism[49], growth hormone (GH) dysregulation, diabetes, hyperthyroidism, and parathyroid disorders exacerbate bone resorption and further reduce BMD. Although GH therapy initially enhances bone resorption, it subsequently promotes bone formation, with improvements observed within 12 to 18 months of treatment.[50] Hormonal replacement and bisphosphonate therapies have demonstrated benefits in preserving bone mass among thalassemia patients. Conversely, excessive doses of the iron chelator deferoxamine (DFO) have been associated with skeletal abnormalities, including rickets-like lesions, genu valgum, vertebral demineralization, and flattening of vertebral bodies.[51,52,53] Continuous monitoring of growth and skeletal development is therefore essential to identify and prevent irreversible DFO-related complications.

In light of these observations, the present study aims to evaluate bone markers in children and adolescents (≤21 years) with β-thalassemia major attending or admitted to the Pediatric Department at the National Oncology Center in Aden during January–December 2022. This investigation seeks to explore the relationship between hematologic parameters, iron overload, endocrine status, and bone metabolism, thereby contributing to a better understanding of the mechanisms underlying bone fragility and osteoporosis in thalassemia and supporting improved clinical management and preventive strategies.

2 Research Problem

β-thalassemia major is one of the most prevalent hereditary hemoglobin disorders in developing countries and requires lifelong regular blood transfusions. Despite advances in transfusion and iron chelation therapy, **chronic iron overload** remains a major complication, leading to various **endocrine and metabolic disturbances**, including **metabolic bone disease** caused by impaired calcium–phosphate–vitamin D–parathyroid hormone regulation.

In **Yemen**, there is a lack of local data regarding the **hematological and biochemical alterations** associated with bone metabolism disorders among children and adolescents with β-thalassemia major. Therefore, it is essential to evaluate these **hematological indices and biochemical markers of bone metabolism** to determine the prevalence and extent of metabolic abnormalities, and to support the development of early monitoring and

management strategies aimed at reducing long-term skeletal complications in this population.

3 Methodology

A cross-sectional analytical study was conducted at the Pediatric Department of the National Oncology Center, Aden, from January to December 2022. The study included 40 children and adolescents (≤21 years) with transfusion-dependent β-thalassemia major who attended regular follow-ups at the center.

Clinical and demographic data were collected from patient records. Laboratory investigations included **complete blood count (CBC)** and biochemical measurements of **serum ferritin, 25-hydroxy vitamin D, parathyroid hormone (PTH), calcium, and phosphorus**. All analyses were performed in the center's laboratory following standard quality control procedures.

Data were analyzed using **SPSS version 25**. Descriptive statistics were presented as **mean ± standard deviation (SD)** for normally distributed quantitative variables, **median** and **range** for non-normally distributed variables, and **frequencies** (%) for categorical variables. Hematological parameters, serum ferritin, vitamin D, parathyroid hormone, calcium, and phosphorus levels were summarized accordingly. Patients were further classified based on ferritin status, vitamin D levels, and biochemical parameters relative to reference ranges.

Ethical approval was obtained from the **Ethics Committee of the National Oncology Center**, and **written informed consent** was obtained from parents or guardians of all participants.

4 Laboratory Aspects of Beta-Thalassemia Major

4.1 *Complete Blood Count (CBC)*

Patients with beta-thalassemia major typically exhibit microcytic hypochromic anemia, with hemoglobin (Hb) levels below 7 g/dL, mean corpuscular volume (MCV) ranging from 50–70 fL, and mean corpuscular hemoglobin (MCH) between 12–20 pg. Beta-thalassemia intermedia presents with Hb values of 7–10 g/dL, MCV of 50–80 fL, and MCH of 16–24 pg. In beta-thalassemia minor, the red cell count is often elevated, with reduced MCV and MCH, while the red cell distribution width (RDW) typically shows mild elevation. This pattern helps differentiate thalassemias from other microcytic hypochromic anemias, such as iron deficiency and sideroblastic anemia, which present with markedly elevated RDW.

Peripheral blood smear in severe beta-thalassemia shows microcytic hypochromic anemia with target cells, teardrop cells, coarse basophilic stippling, anisopoikilocytosis, bizarre red cell morphology, and numerous nucleated red blood cells.[54] Bone marrow examination is generally unnecessary for diagnosis, as the marrow is highly cellular due to erythroid hyperplasia, with a reversed myeloid/erythroid ratio of 3 or 4 to 0.1 or less.

4.2 *Serum Ferritin (SF)*

Serum ferritin correlates with body iron stores and is useful for repeated monitoring due to its relative ease and low cost. Trends in SF are more informative than absolute values: decreasing SF indicates a reduction in iron burden, while increasing SF suggests iron accumulation but may also reflect inflammation or tissue damage. Long-term monitoring of SF is critical in assessing the risk of complications from iron overload in thalassemia major.[55–58]

Studies indicate that maintaining SF below 2,500 µg/L with chelation therapy (e.g., deferoxamine, DFO) over a decade reduces the risk of cardiac disease and mortality. Further benefits may be observed when SF levels are kept below 1,000 µg/L.[55,57] Variations in SF response to chelation can occur due to inflammation, nonlinear relationships between body iron and SF, or high starting iron loads. SF values below 3,000 µg/L primarily reflect macrophage iron stores, while values above 3,000 µg/L increasingly indicate hepatocyte ferritin leakage.[56,59]

4.3 *Parathyroid Hormone (PTH) and Phosphate (P)*

Moderate to severe thalassemia patients require regular transfusions. Overt hypoparathyroidism is uncommon[60]but asymptomatic forms have been reported, with incidences up to 42% in some studies[61] Hypoparathyroidism is primarily associated with iron overload.[62–65]

Fibroblast growth factor-23 (FGF-23), a phosphaturic hormone secreted by osteoblasts and osteocytes, responds to hyperphosphatemia and elevated 1,25-dihydroxyvitamin D (1,25-(OH)2D) levels.[66] FGF-23 reduces phosphate reabsorption in the kidneys and inhibits 1α-hydroxylase, decreasing active vitamin D production. It also suppresses PTH secretion, modulating phosphaturia.[67,68]

Hypoparathyroidism typically manifests during the second decade in transfusion-dependent thalassemia major, with incidence ranging from 1.2% to 19%, affecting males slightly more frequently than females (M/F ratio = 1.35). Neurological and cardiac complications, including tetany, seizures, and cardiac failure, may occur in severe cases.[69]

4.4 *Calcium and Phosphate*

Calcium and phosphate are essential for bone integrity, muscle function, nerve conduction, intracellular signaling, and glandular activity. PTH is the principal regulator of calcium homeostasis.[70] Phosphate balance depends on coordinated interactions between the

intestine, bone, parathyroid gland, and kidneys.[71,72] Thalassemia patients often exhibit lower serum calcium and higher phosphate levels compared to controls.[73,74] with calcium levels correlating inversely with serum ferritin.[75]

4.5 *Calcium and Vitamin D*

Vitamin D deficiency is prevalent among thalassemia patients (85–100%).[76,77] even in sunny regions.[78] Contributing factors include low calcium intake[79] and hypercalciuria[80] Deficiency impairs bone mineralization, muscle function, and cardiac performance, particularly due to left ventricular dysfunction associated with iron overload.[81,82] Supplementation with calcium and vitamin D (2,000 IU/day) is recommended for all patients, with serum vitamin levels monitored every six months.[78,83,84]

5 Laboratory Procedure

Blood samples (5 mL) were collected via venipuncture after applying a tourniquet and disinfecting with 70% alcohol. Three milliliters were placed in blood sample tubes and centrifuged within 30 minutes. Samples were transported in a cooler box at 2–8 °C for 8–72 hours to the laboratory.

Forty patients (both sexes, ≤21 years) receiving multiple transfusions were included. EDTA tubes were used for hematology analysis via automated cell counter (Sysmex XP-300), measuring Hb, Hct, MCH, MCHC, MCV, RBC, WBC, and platelets. Serum samples were analyzed for biochemistry using Cobas c311. Vitamin D and PTH were assessed via electrochemiluminescence immunoassay (ECLIA) using Cobas e411, while phosphate was analyzed using the Roche Cobas Integra 400 Plus at the National Center for Central Public Health Laboratory, Aden.

6 Result

6.1 *Hematological Findings*

Table 1: Descriptive statistics of hematological findings

VARIABLE	MEAN	SD	MEDIAN	MIN	MAX	REFERENCE RANGE
WBC (×10³/µL)*	10.8	40.34	10.85	4.1	148	3.0–10
RBC (MCL)	2.88	0.693	2.76	1.58	4.80	M: 4.5–6.5 F: 3.9–5.6
HB (G/DL)	6.72	1.77	6.50	3.2	10.8	12–16
HCT (%)	21.72	6.09	20.65	11	39.9	36–48
MCV (FL)	73.5	6.54	72.85	58.5	87.6	80–95
MCH (PG)	23.92	2.86	23.60	18.6	30.5	27–34
MCHC (G/DL)	32.44	2.29	32.5	27.6	36.4	20–35
PLATELETS (×10³/µL)	463.47	281.4	379	120	1295	150–400
RDW-CV (%)	21.61	7.00	19.2	13	37.2	11.5–14.5

*Median [Interquartile range].

Patients demonstrated significantly low Hb (6.72 ± 1.77 g/dL) and Hct (21.7 ± 6.1%). MCV averaged 73.5 ± 6.54 fL (range 58.5–87.6 fL). Median leukocyte count was 10.8 × 10³/µL; 24 patients (60%) had WBC >10,000 × 10³/µL. Mean platelet count was 463.47 ± 281.4 × 10³/µL.

6.2 *Serum Ferritin and Bone Markers*

Table 2: Characteristics of Thalassemia Major Patients Including Serum Ferritin and Bone Markers

VARIABLE	MEAN	SD	MEDIAN	MIN	MAX	REFERENCE RANGE
SERUM FERRITIN (NG/ML)	3718.9	2453.8	3020.5	220.2	9975	20–400
25-OH VITAMIN D (NG/ML)	23.85	9.96	23.03	7.75	53.82	>30
PTH (PG/ML)	23.15	13.74	22.3	1.2	59.77	15–65
SERUM CALCIUM (MG/DL)	8.455	1.01	8.45	5.0	10.3	8.6–10.3
SERUM PHOSPHORUS (MG/DL)	4.53	1.53	4.4	2.1	10.9	2.5–4.5

Ferritin levels were markedly elevated (~9× normal), while vitamin D, PTH, and calcium were below normal ranges. Phosphate levels exceeded normal values.

Table 3: Clinical Classification of Ferritin Status Among Patients

CATEGORY	NO. OF PATIENTS	PERCENTAGE (%)
<2000 NG/ML (MODERATE)	9	22.5
2000–4000 NG/ML (HIGH)	15	37.5
>4000 NG/ML (SEVERE)	16	40.0

Most patients exhibited either high (37.5%) or severe (40%) serum ferritin levels, with only 22.5% having moderate levels.

Table 4: Distribution of Patients by Vitamin D Levels

MEDIAN VITAMIN D LEVELS	CATEGORY	NO. OF PATIENTS (N=40)	PERCENTAGE (%)
≥30 NG/ML	ADEQUATE VITAMIN D	10	25%
20–30 NG/ML	INSUFFICIENT	11	27.5%
<20 NG/ML	VITAMIN D DEFICIENCY	19	47.5%

Table 4 demonstrates that nearly half of the patients (47.5%) exhibited vitamin D deficiency, while 27.5% had insufficient levels. Only 25% of patients achieved adequate vitamin D levels despite regular supplementation.

Table 5: Distribution of Biochemical Results According to Normal Reference Ranges

BIOCHEMICAL PARAMETER (REFERENCE RANGE)	CATEGORY	NO. OF PATIENTS	%
SERUM FERRITIN (20–400 µG/L)	NORMAL	3	7.5%
	ABNORMAL (HIGH)	37	92.5%
SERUM CALCIUM (8.6–10.3 MG/DL)	NORMAL	18	45%
	ABNORMAL (LOW)	22	55%
PARATHYROID HORMONE (15–65 PG/ML)	NORMAL	24	60%
	ABNORMAL (LOW)	16	40%
SERUM PHOSPHORUS (2.5–4.5 MG/DL)	NORMAL	22	55%
	ABNORMAL (HIGH)	18	45%
VITAMIN D	NORMAL	10	25%
	INSUFFICIENT	11	27.5%
	DEFICIENT	19	47.5%

Biochemical profiling revealed marked abnormalities: elevated serum ferritin in 92.5% of cases indicating severe iron overload; hypocalcemia in 55%; low PTH in 40%; hyperphosphatemia in 45%; and high prevalence of vitamin D deficiency (47.5%) with only 25% within normal range.

7 Discussion

7.1 *Hematological Findings*

Patients demonstrated significantly low pre-transfusion hemoglobin (Hb 6.7 ± 1.77 g/dL) and hematocrit (Hct 21.7 ± 6.0%), consistent with reports from India (Hb 6.8 ± 1.08 g/dL)[85], Bangladesh (Hb 7.2 ± 1.5 g/dL)[86] ,and Pakistan (Hb 7.4 ± 1.9 g/dL).[87] Higher pre-transfusion Hb levels were reported in Egypt (8.2 ± 0.27 g/dL)[88] , Palestine (8.0 ± 1.0 g/dL).[89] and Turkey (9.2 ± 0.7 g/dL)[90] . Low Hb is primarily attributed to ineffective erythropoiesis due to β-globin chain imbalance, hemolysis, and red blood cell destruction, with additional contribution from splenomegaly.[12,91]

The mean RBC count was 2.88 ± 0.69 × 10^3/µL, comparable to India (2.76 ± 0.53 × 10^3/µL)[85] and Bangladesh (2.80 ± 0.63 × 10^3/µL)[92] Microcytosis and hypochromia were prevalent, with mean MCV 73.5 ± 6.54 fL, similar to reports from Saudi Arabia (70.4 ± 2.68 fL)[93] ,Bangladesh (70 ± 9.5 fL)[92] ,and India (78.29 ± 6.79 fL).[85]

White blood cell (WBC) count median was 10.85 × 10^3/µL [range 7.0–32.85], with 60% exceeding the upper normal limit, reflecting immunological hyperactivity and possible nucleated RBC miscounting.[94–97] Platelet count averaged 463.47 ± 281.4 × 10^3/µL, with 42.5% exceeding the normal upper range, consistent with reports from Gaza[89] ,Egypt[98] , and Aden, Yemen[95] .Thrombocytosis may result from elevated erythropoietin-induced megakaryopoiesis and contributes to a hypercoagulable state.[99–101]

RDW-CV was markedly elevated, indicative of anisopoikilocytosis, independent of transfusion status, aligning with studies in Turkey and other populations.[102–104]

7.2 *Biochemical and Endocrine Findings*

Serum ferritin levels were elevated in 77.5% of patients (mean 3718.98 ± 2453.82 ng/mL), consistent with severe iron overload.[85,105–107] Transfusion with chelation therapy prolongs survival but predisposes to systemic complications, including skeletal deformities and endocrine dysfunctions.[108–110]

Hypoparathyroidism was observed in 40% of children, mirroring findings from Pakistan (40%).[75,111] Low PTH, serum calcium (mean 8.4 ± 1.0 mg/dL), and high phosphorus (mean 4.5 ± 1.5 mg/dL) levels indicate disruption of calcium-phosphorus homeostasis, influenced by iron overload, chelation therapy, and hepatic dysfunction.[75,109,110,119–128,112–118]Vitamin D deficiency was prevalent (47.5%), with insufficient levels in 27.5%, consistent with studies worldwide reporting rates from 44.3% to 98% in thalassemia patients.[87, 129–133] Contributing factors include malabsorption, inadequate intake, hepatic dysfunction, iron deposition in skin, and hypoparathyroidism. [42,60,128,134–138]

In the PTH-calcium axis, normal compensatory PTH elevation in response to vitamin D deficiency was blunted in our cohort, likely due to iron-induced parathyroid damage. This is supported by 40% of patients exhibiting hypoparathyroidism, a finding consistent with previous studies[111,123,139–142] Serial PTH measurements are recommended to monitor early parathyroid impairment.

8 Conclusion

Children and adolescents with β-thalassemia major exhibit a complex interplay of hematologic, metabolic, and endocrine abnormalities that predispose them to long-term skeletal complications. Beyond the characteristic anemia and iron overload, compensatory hematopoiesis, elevated platelet counts, and dysregulated mineral metabolism contribute to impaired bone health. The high prevalence of vitamin D deficiency, hypocalcemia, and low parathyroid hormone levels underscores the critical role of endocrine and nutritional factors in the development of metabolic bone disease. Iron-induced oxidative stress further exacerbates skeletal fragility by affecting osteoblast function and promoting bone resorption. These findings highlight the multifactorial etiology of osteoporosis in thalassemia

major and emphasize the necessity for early, integrated management strategies. Comprehensive care should include optimized transfusion protocols, vigilant iron chelation, routine endocrine assessment, correction of vitamin D and calcium deficiencies, and regular bone health monitoring. Implementing such multidisciplinary approaches can mitigate long-term morbidity, preserve skeletal integrity, and enhance the quality of life for patients living with this chronic and debilitating condition.

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مقالة بحثية

الاختلالات الدموية واضطرابات استقلاب العظام لدى الأطفال والمراهقين المصابين بالثلاسيميا بيتا الكبرى

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المُلخّص

تُعدّ بيتا ثلاسيميا الكبرى (TM) من أمراض اضطراب تصنيع الهيموغلوبين المعتمدة على نقل الدم، وتتميز بانخفاض فعالية تكوّن كريات الدم الحمراء وتراكم الحديد بشكل تدريجي. وعلى الرغم من التطورات في نظم نقل الدم والعلاج بالاستخلاب، ما تزال أمراض العظام الأيضية من المضاعفات الشائعة والمُنهِكة لدى المرضى صغار السن. تقييم المؤشرات الدموية والعلامات الكيميائية الحيوية لتمثيل العظام لدى الأطفال والمراهقين (≥21 سنة) المصابين ببيتا ثلاسيميا الكبرى الذين يتابعون في قسم الأطفال بالمركز الوطني للأورام – عدن، خلال الفترة من يناير إلى ديسمبر 2022. أُجريت دراسة تحليلية مقطعية على 40 مريضًا يعتمدون على نقل الدم بشكل دوري. خضع المرضى لفحوصات شاملة تضمنت تعداد الدم الكامل، وقياس مستويات الفيريتين، وفيتامين D (25-OH)، وهرمون جار الدرقية (PTH)، والكالسيوم، والفوسفور في المصل. تم تحليل الإحصاءات الوصفية وتوزيعات المتغيرات مقارنة بالقيم المرجعية. أظهرت العينة فقر دم مزمن شديد (متوسط Hb 6.72 ± 1.77 جم/دل؛ متوسط Hct% 21.7 ± 6.1) مع صِغَر حجم كريات الدم الحمراء (MCV 73.5 ± 6.54 فمتوليتر) وتفاوت كبير في حجمها (RDW-CV% 21.61 ± 7.00). بلغ متوسط عدد الكريات البيضاء 10^3 × 10.8/ميكرولتر، حيث لوحظت الكريات البيضاء المرتفعة في 60% من المرضى، كما كان عدد الصفائح الدموية مرتفعًا (463.47 ± 281.4 × 10^3/ميكرولتر). سُجِّلت زيادة مفرطة في الحديد (متوسط الفيريتين 2453.8 ± 3718.9 نانوغرام/مل)، مع تجاوز 92.5% من المرضى للقيم الطبيعية، و77.5% مصنَّفين ضمن الفئة العالية أو الشديدة (≥2000 نانوغرام/مل). كانت نقص أو قصور فيتامين D شائعة بدرجة كبيرة (متوسط 9.96 ± 23.85 نانوغرام/مل؛ 47.5% مصابون بنقص، 27.5% بقصور، و25% ضمن المستوى الكافي). كشفت التحاليل الكيميائية الحيوية عن اضطراب في توازن المعادن تمثل في انخفاض الكالسيوم لدى 55% من المرضى، وانخفاض هرمون جار الدرقية لدى 40%، وارتفاع الفوسفور لدى 45%. تشير هذه النتائج مجتمعة إلى وجود علاقة قوية بين فرط تراكم الحديد، والخلل الغُدِّي، واضطراب استقلاب معادن العظام. يُظهر الأطفال والمراهقون المصابون ببيتا ثلاسيميا الكبرى في هذه الدراسة فقر دم شديدًا، وتراكُمًا مفرطًا للحديد، وانتشارًا واسعًا لنقص فيتامين D، واضطرابات متكررة في محور الكالسيوم–الفوسفور–PTH، وهي عوامل تُهيّئ لحدوث أمراض العظام الأيضية. لذلك، تُعدّ الاستراتيجيات المبكرة والمتكاملة — التي تشمل ضبط الحديد بدقة، والتقييم الدوري للغدد الصماء، وتحسين حالة فيتامين D، والمتابعة المنتظمة لصحة العظام — ضرورية للحد من المضاعفات الهيكلية طويلة الأمد في هذه الفئة من المرضى.

الكلمات المفتاحية: بيتا ثلاسيميا كبرى؛ تراكم الحديد؛ استقلاب العظام؛ نقص فيتامين D؛ نقص الكالسيوم؛ هرمون جار الدرقية؛ الأطفال.

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