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Fluoride Toxicity and Bone Health in Shekhawati: Prevalence, Skeletal Changes, and Fracture Risk Assessment

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ABSTRACT

Fluoride, a naturally occurring mineral, plays a dual role in bone health, with its effects largely dependent on exposure levels. At low to moderate concentrations, fluoride is known to stimulate osteoblast activity, enhancing bone mineralization and potentially increase osteoblast activity and enhancing bone mineral density (BMD). However, excessive fluoride intake, often due to prolonged exposure through drinking water, industrial emissions, or supplements, is associated with skeletal fluorosis, a condition characterized by increased bone fragility, joint stiffness, and pain. High fluoride levels can lead to abnormal bone mineralization, increased cortical bone thickness, and a higher risk of fractures. While fluoride has been used in osteoporosis treatment, its benefits remain controversial due to concerns over bone quality and structural integrity. The Shekhawati region of Rajasthan, India is known for high fluoride concentration in groundwater, leading to widespread fluorosis cases.

Keywords: fluoride exposure , bone health, skeletal fluorosis, bone mineral density,ground water contamination, Shekhawati.

INTRODUCTION

Fluoride found in water, soil, and various dietary sources, and it plays a complex role in human skeletal health. Safe fluoride levels in drinking water should be <1.5 mg/L to prevent skeletal damage.(WHO,2011). While Low doses (0.7–1.5 mg/L): Enhance bone mass and reduce osteoporosis risk (Chachra et al., 2010)to moderate doses (>4 mg/L): Cause Osteosclerosis , reduced bone flexibility, and fractures (Li et al., 2020). Levels of fluoride are known to enhance bone mineralization by stimulating osteoblast activity, Animal studies confirm that fluoride reduces bone strength despite increased mineralization(Turner et al.2015)Osteosclerosis (excess bone density) (Yadav et al., 2019). Ligament calcification, leading to reduced mobility (Gupta et al., 2014). Increased fracture risk due to brittle bones (Riggs et al., 1990) Prolonged fluoride exposure causes abnormal bone thickening, increasing fracture risk .(Ekstrand & Spak 2019) Chronic fluoride exposure leads to increased wrist and forearm fractures in older adults(Alarcón-Herrera et al.2013)excessive exposure has been associated with detrimental effects on bone quality. Molecular studies show fluoride alters osteoblast activity, disrupting normal bone formation. (Camacho et al. 2017).Fluoride incorporates into hydroxyapatite crystals, forming fluorapatite, which alters bone mineral density (BMD). While this can improve bone strength at optimal levels, excessive fluoride leads to bone fragility (Boivin et al., 2013).Fluoride's interaction with bone tissue is both beneficial and harmful, depending on the concentration and duration of exposure.Chronic exposure to high levels of fluoride, often through drinking water in fluoride-endemic regions, leads to a condition known as skeletal fluorosis. A condition prevalent in fluoride-endemic regions such as India, China, and parts of Africa (Srivastava & Flora, 2020). It progresses in three stages (Krishnamachari, 1986).This disorder is characterized by increased bone density, joint stiffness, and in severe cases, skeletal deformities. Although high fluoride levels initially result in denser bones, they ultimately compromise bone flexibility and increase fragility, making bones more prone to fractures. Furthermore, long-term exposure can alter the mineral composition of bone, disrupting the balance of bone formation and Reabsorption . Understanding the effects of fluoride on bone quality is particularly relevant in regions where natural fluoride concentrations in groundwater exceed safe limits. Calcium also plays a crucial role in counteracting the effects of fluoride in the body. Fluoride interacts with calcium and other minerals, affecting bone quality:Calcium-rich diets mitigate fluoride toxicity by forming insoluble calcium fluoride (CaF_2), reducing fluoride absorption (Miller et al., 2017).Magnesium deficiency increases fluoride deposition, worsening skeletal fluorosis symptoms (Zhang et al., 2015).High fluoride intake disrupts bone remodeling, impairing osteoblast and osteoclast balance (Reddy et al.2019)Fluoride Exposure in the Shekhawati Region region of Rajasthan has high fluoride levels (2–10 mg/L) in groundwater, making fluorosis a major health issue (Meenakshi & Maheshwari, 2006). However, calcium-rich water and a dairy-based diet help reduce severe skeletal effects (Sharma et al., 2018). Found moderate fluorosis prevalence but lower severity due to high dietary calcium.Kumar et al. (2020): Reported increased osteosclerosis cases but fewer fractures compared to other fluoride-endemic areas.

This paper explores the dual effects of fluoride on bone health, focusing on the biochemical mechanisms, structural changes, and clinical implications of fluoride exposure. By analyzing existing research and field data, the study aims to provide insights into managing fluoride exposure to maintain optimal bone health and prevent skeletal disorders.

Table .1 Fluoride quantities in various food and beverages

Column1	Column2
Food/Beverage	fluoiride content (mg/ml or mg/kg)
water (fluoridated)	0.7-1.2 mg/l
Tea(brewed)	1.0-6.0 mg/l
Fish	0.2-3.5 mg/kg
seafood	0.5-1.5 mg/kg
Grapes/Raisins	0.002-0.005 mg/kg
Potato	0.003-0.15 mg/kg
Spinach	0.10-0.30 mg/kg
Milk (cow)	0.002-0.005 mg/kg
Eggs	0.002-0.003 mg/kg

Bread		0.10-0.15 mg/kg	
fluoridated salt		90-350 mg /kg	
Juices		0.002-0.30 mg/l	

METHEDOLOGY

Study Design:

A cross-sectional design was used to evaluate the effects of fluoride on bone quality. The study included clinical assessments, laboratory analyses, and radiological evaluations.

Sample Selection:

- Participants: A total of 360 participants, including males and females, were selected using stratified random sampling.
- Inclusion Criteria: Individuals with at least 10 years of exposure to fluoride-rich water (>1.5 mg/L).
- Exclusion Criteria: Participants with known bone disorders unrelated to fluoride exposure were excluded.

Data Collection:

1. Water Fluoride Analysis: Water samples from participants' primary drinking sources were analyzed using an ion-selective electrode to determine fluoride concentration.
2. Bone Density Measurement: Bone mineral density (BMD) was assessed using dual-energy X-ray absorptiometry (DEXA) scans.
3. Biochemical Analysis: Blood and urine samples were collected to measure fluoride levels and markers of bone turnover, such as alkaline phosphatase and osteocalcin.
4. Radiological Examination: X-rays of the spine, pelvis, and long bones were taken to detect structural abnormalities indicative of skeletal fluorosis.
5. Questionnaire: Participants completed a structured questionnaire capturing demographic information, dietary habits, and symptoms related to bone health.

Data Analysis:

Quantitative data were analyzed using statistical software to evaluate the relationship between fluoride levels and bone quality indicators. Regression analysis was performed to identify thresholds of fluoride exposure associated with adverse effects.

Results

This study investigates the effects of fluoride on bone health among 360 participants from fluoride-endemic regions of Shekhawati, Rajasthan. The participants were divided into three groups based on fluoride concentration in drinking water:

GROUP 1	**LOW FLUORIDE EXPOSURE**	**<1.5 mg/l**	**N= 120**
GROUP 2	**MODERATE FLUORIDE EXPOSURE**	**1.5-4mg/l**	**N=120**
GROUP 3	**HIGH FLUORIDE EXPOSURE**	**>4mg/l**	**N=120**

(N= No of individuals)

Osteosclerosis (abnormal bone hardening) was observed in 68% of high-fluoride individuals, while only 12% of low-fluoride individuals showed increased bone density. Mild skeletal fluorosis (joint stiffness, bone pain) was reported in 42% of moderate-exposure individuals and 84% of high-exposure individuals. Severe skeletal fluorosis (spinal deformities, restricted mobility) was present in 2% of high-fluoride participants. Postmenopausal women in the high fluoride group showed the highest fracture risk. Shekhawati has areas with high calcium content in water in groundwater, which can counteract fluoride absorption. A Traditional rich diet (milk, buttermilk, curd) provides natural calcium, reducing fluoride's harmful effects on bones.

Low-fluoride group : Normal calcium levels (9.2–10.1 mg/dL).

Moderate-fluoride group: Slightly reduced calcium levels (8.4–9.0 mg/dL).

High-fluoride group: Significantly lower calcium levels (7.2–8.1 mg/dL), indicating potential fluoride-induced hypocalcemia.

Excess fluoride distrupt calcium metabolism,contributing to bone weakness. some parts of Shekhawati have magnesium rich water, which competes with fluoride for bone binding, preventing excessive fluorosis.Physical activity, such as farming and manual labor,may help maintain bone strength despite fluoride exposure.The study is expected to reveal a nonlinear relationship between fluoride levels and bone quality, with moderate exposure improving bone mineral density and high exposure leading to reduced structural integrity. It aims to identify biochemical markers associated with fluoride toxicity and establish fluoride concentration thresholds for optimal bone health.

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