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# The paleodietary reconstruction of Roopkund skeletons through trace element analysis

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**Abstract**
Palaeodietary reconstruction, a rapidly emerging field of multidisciplinary archaeology, helps to reconstruct prehistoric people's food consumption or subsistence behavior. Trace element analysis plays a vital role in the palaeodietary reconstruction of prehistoric populations. Trace elements such as Strontium (Sr), Zinc (Zn), Barium (Ba), Calcium (Ca), Copper (Cu), Magnesium (Mg), and Iron (Fe) found in the human bone provide valuable indicators for reconstructing dietary behavior of the ancient human population. It has been observed that the concentration of the trace element Zn depleted from herbivore to carnivore, whereas it is reversed in the case of Sr. The present study of the dietary behavior of the Roopkund skeletons shows higher concentrations of strontium than Zn, as reported in the human skeletons of Roopkund. Based on preliminary results, a significant component of vegetal material can be ascertained in the diet of most of the human skeletons reported from the Roopkund region.

**Keywords** Roopkund · Paleodietary reconstruction · Subsistence behavior · Trace elements · Zinc · Strontium

## 1 Introduction

Roopkund, a lake situated at an altitude of 5029 above MSL in the higher Himalayas of the Garhwal region of Uttarakhand on the pilgrimage route of the esteemed Nanda Raj Jaat, is famous for hundreds of scattered human skeletons intact with flesh and hair. The magnificent peaks of Nanda Ghungti and Trishul surround this glacial lake. Notwithstanding its cultural, religious, and spiritual significance, the human skeletons of Roopkund have intrigued anthropologists, archeologists, and scientists alike. These human skeletons first came to light after their discovery by the forest range officer H.K. Madhwal in 1942, and ever since, the place has been visited by several archaeological, historical, anthropological, and scientific expeditions and teams, but these studies have been carried out in isolation with scant respect for an integrated approach. Due to tough, rugged terrain and extremely adverse climatic and hazardous altitudinal conditions, studies on detailed scientific investigations are few and far between. Most integrative approaches are still in their infancy.

The traditional studies based on oral history, myth, and folklore all have different tales to tell about these human skeletons. One of the many myths considers that these skeletons were armed people belonging to General Jaurawar Singh. At the same time, another propagates the view that these belonged to traders, Japanese soldiers, or diseased persons. On the other hand, the general folklore of the region opines the view of collective suicide by the people to attain *mokṣa*. But the most relevant theory or belief is that of a natural calamity that struck the group of people while on a pilgrimage (possibly Nanda Raj Jaat?) and their complete preservation in the extreme climate. Legend has it that due to severe famines prevailing in his kingdom, Jasodhwal, the king of Kannauj, on the advice of the priests, commenced the Nanda Devi Raj Jaat to please the Goddess Nanda. As the queen of the Jasodhawal originally hailed from Chandpurgarhi (a place situated in Chamoli District, the Capital of the famous Garhwal King Ajaypal), it was quite natural that she accompanied the king along with her attendants; this practice did not align with the observed belief wherein females were prohibited for the Nanda Raj Jaat. This angered the deity, and she struck the entourage with a storm that sent them crashing into the lake.

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William S. Sax, anthropologist of Heidelberg University, in his book "Mountain Goddess: Gender and Politics in a Himalayan Pilgrimage," references the lake and the skeletons. The anthropologist also gave his experience of being surrounded by a blizzard and the bone-strewn cirque in whiteout conditions, with several skeletons with intact flesh and hair. In the anthropological analysis, the author shows how goddess Nanda's appeal stems from the fact that her mythology parallels the life courses of the local women. It has shaped the lives of local women and their post-marital journey from their natal home to their in-law's home (Sax, 1991).

Various theories and local folklore have attempted to explain the origin of these skeletons. Legends recount a pilgrimage to the nearby shrine of the goddess Nanda, where a group of pilgrims, including a king and queen, met a tragic end due to their inconsiderate conduct. Other explanations for the presence of the skeletons suggest they may belong to an army, a group of merchants caught in a storm, or victims of an epidemic. The challenging terrain of the site, prone to rockslides and frequented by pilgrims and hikers, has hindered systematic anthropological or archaeological investigations (Biswas, 2021).

In a collaborative effort involving Deccan College, Pune, CSIR Centre for Cellular and Molecular Biology, Hyderabad, and Harvard University, Cambridge, the Roopkund skeleton was subjected to biomolecular analysis, stable isotope dietary reconstruction, and carbon dating. The study identified three distinct groups within the Roopkund skeleton by examining mitochondrial DNA. The largest group exhibited genetic similarities to present-day Indians, while the second group showed genetic resemblances to modern-day Cretans and Greeks. The remaining third group displayed DNA indicative of a Southeast Asian origin. The presence of individuals with Eastern Mediterranean ancestry highlights Lake Roopkund's significance as a local attraction and underscores its ability to attract people from around the globe (Harney et al., 2019).

## 2 Review of literature

The Roopkund skeletons got attention among anthropologists, archaeologists, and scientists, but extensive research work is still in its infancy. However, some osteological analysis, palaeodietary reconstruction, and bimolecular analysis have been done on these human skeletons (Farshwan, 2013; Farshwan & Singh, 2015; Harney et al., 2019; Pant, 2018). Some researchers have conducted elemental and isotopic analyses for palaeodietary reconstruction (Farshwan, 2013; Farshwan & Singh, 2015). Based on the Isotopic analysis, it has been said that these people belong to an omnivore group with rich C plants in their diet (Farshwan, 2013), on the other hand, other studies show that the considered population preferred both $C_3$ and $C_4$ plant food in their diet (one group consumed $C_3$ rich plants however the other had $C_3$ and $C_4$ mixed plants in their diet) (Harney et al., 2019). Studies on the skeletons from Roopkund have been carried out at the osteological and bimolecular levels (DNA determination) (Harney et al., 2019; Pant, 2018). The DNA studies of these skeletons show that they belong to three genetically different groups. Based on bimolecular studies, researchers conclude that these skeletons belong to South Asia, West-Eurasian, and East-Asia people (Harney et al., 2019).

### 2.1 Trace elements

Trace elements, though occurring in amounts of less than 0.01% of the human body mass, play an important role in the nutrition of human beings (Schroeder, 1973). The analysis of trace elements such as Strontium (Sr), Barium (Ba), Zinc (Zn), Potassium (K), Magnesium (Mg), Manganese (Mn), Copper (Cu), Iron (Fe) could play an important role in paleonutritional or paleodiet reconstructions. Experimental studies establish that the concentration of trace elements reflects a particular diet (Lambert & Weydert-Homeyer, 1993). On this basis it has been found that peanuts, meat, and alfalfa (generally high in fiber) lead to low levels of bone calcium (Ca); meat, casein, or fish (generally high in protein and low in fibers) lead to low strontium (Sr), whereas alfalfa leads to very high strontium (Sr) and potassium (K) (high in fiber and low in protein), meat and (especially) fish lead to low barium (Ba), however, wheat, casein, and peanuts lead to high zinc (Zn) (Lambert & Weydert-Homeyer, 1993). From the testimony from these signatures, researchers have distinguished plant eaters from meat eaters (Brown, 1973). Approximately 98% of the standards or reference human body (70 kg) is composed of oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorus in descending order of total percentage. However, lesser concentrations of potassium (K), sulfur (S), chlorine (Cl), sodium (Na), magnesium (Mg), and iron (Fe) are found in the human skeletons. Many researchers have used trace element analyses to understand the dietary behavior of ancient populations (Bisel, 1988; Schoeninger, 1982). Trace elements are analyzed as a specific palaeodietary indicator; barium (Ba) and strontium (Sr) have been considered strong vegetable intake indicators (Comar et al., 1957; Lambert & Weydert-Homeyer, 1993; Lambert et al., 1984; Parker & Toots, 1980) while copper (Cu) and zinc (Zn) are discriminators of meat consumption (Underwood, 1977; Klepinger, 1984; Buikstra et al., 1989, pp.155–210; Lambert & Weydert-Homeyer, 1993).

## 3 Material and methods

The samples were collected from the high-altitude glacial lake of Roopkund (Fig. 1). The researcher mainly collected long bones (i.e. femur, humerus, and tibia fibula). All the extraneous material was removed from bone samples. The bone samples were collected *in-toto* from the field, so breaking the bone to expose the modular cavity was essential. The exposed surface was then abraded with an abrasion sheet to remove the contamination. The clean samples were broken into small pieces and placed in small vials, first rinsed with de-ionized water and subsequently in an ultrasonic bath for thirty minutes. After sonification, the samples' small vials were covered with 1N acetic acid, allowed to settle at room temperature, and kept overnight. This method was used to remove the post-deposit carbonate contamination. The acid-washed bones were rinsed with de-ionized water and dried in an oven overnight at 80 to 90 °C. These dried samples were used to make ash, which was then dissolved in concentrated $HNO_3$ and heated to 100–120 °C for 1 hour to achieve complete dissolution. It was then diluted to 100 ml with the help of de-ionized water. Finally, the samples were introduced into AAS for trace element analysis (Juyal & Nautiyal, 2005).


**Fig. 1** Roopkund Lake (**a**) and (**b**) map show the Roopkund location (**c**). Image of Roopkund Lake (**d**). Image of scattered skeletons. (Courtesy by photo Wikipedia, Google map & theatlantic.com)

**Table 1** Trace elements analysis of Roopkund human skeleton

| Roopkund Bone sample | Zn | Sr | Mg | Cu |
|---|---|---|---|---|
| RS-1 | 194 | 89 | 780 | 6 |
| RS-2 | 152 | 350 | 1455 | 1.8 |
| RS-3 | 144 | 267 | 1766 | 0.5 |
| RS-4 | 150 | 197 | 56 | 0.1 |
| RS-5 | 155 | 231 | 67 | 4.1 |
| RS-6 | 158 | 77 | 74 | 2.2 |
| RS-7 | 159 | 158 | 81 | 1.4 |
| RS-8 | 168 | 159 | 50 | 0.6 |
| RS-9 | 157 | 231 | 1767 | 2.6 |
| RS-10 | 145 | 297 | 62 | 4 |
| RS-11 | 163 | 384 | 53 | 1.4 |
| RS-12 | 171 | 435 | 70 | 5.4 |
| RS-13 | 201 | 241 | 85 | 1.2 |
| RS-14 | 125 | 607 | 75 | 2.4 |
| RS-15 | 198 | 315 | 86 | 6.7 |

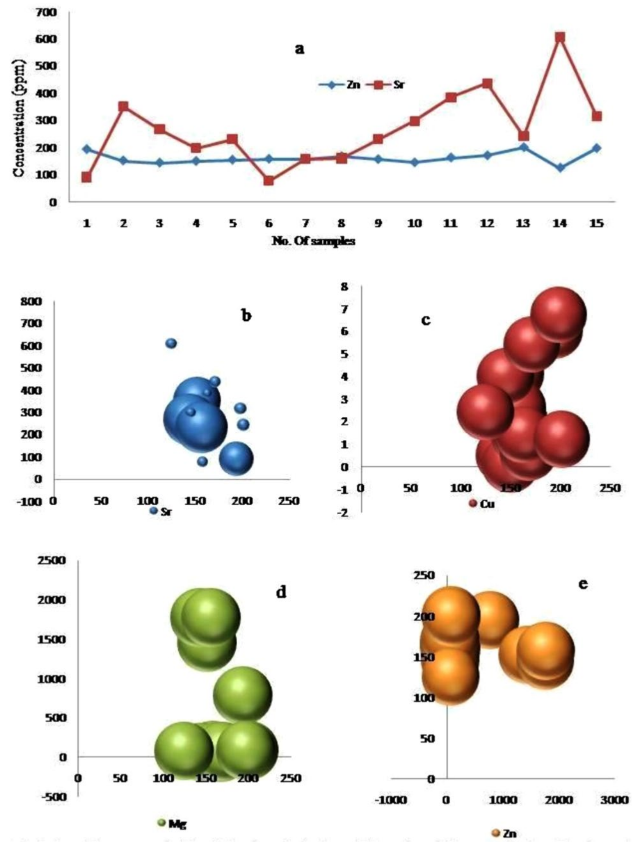


**Fig. 2** Trace elements analysis of Roopkund Skeletons **a** Zn & Sr values differences in Roopkund Samples **b** Strontium concentration in Roopkund sample **c** Copper concentration in Roopkund sample **d** Magnesium concentration in Roopkund sample **e** Zinc concentration in Roopkund sample

## 4 Results

The trace elements analysis of Roopkund samples is presented in Table 1 and Fig. 2. The concentration of zinc varies from 125 to 201 ppm, with the average being 163 ppm, whereas the variation in concentration of strontium (Sr) was estimated to be from 77 to 435 ppm ppm with a mean value of 269 ppm. Magnesium (Mg) and Copper (Cu) concentrations were found to vary between 53 and 1767 ppm and 0.6 to 6.7 ppm, respectively, with the average values being 575 and 2.84 ppm respectively. In comparison to other samples, a significant depletion in the values of Mg for the RS-2, RS-3, and RS-9 is observed. The graphical representation of the variation in the concentrations of Zinc and Strontium in the different samples is also presented Fig. 2a. Figures 2b–e graphically depict the variation in the concentration of Strontium, Copper, Magnesium and Zinc respectively. The range of variation in the concentration of Zn in the different samples depicts a fair degree of stability as compared to the variability of Sr, Mg, and Cu.

## 5 Discussion and conclusion

The present study, though preliminary due to constraints of sample size, aims to reconstruct the dietary behavior of the Roopkund skeletons. The samples of human skeletons were collected from the ridge of the Roopkund–Jauragali route (Fig. 1). The trace element results are presented in Table 1 and Fig. 2. Studies have found that trace elements can be used for reconstructing ancient diets (Bisel, 1988; Schoeninger, 1982). Trace element Strontium (Sr) has a higher concentration in herbivores than carnivores (Schoeninger, 1982; Sillen, 1988), however, Zn concentration is the reverse of Sr (Borgognini Tarli et al., 1988). The high concentration value of strontium shows that people largely consumed vegetable intake in their diet (Elias, 1980). As strontium is more concentrated in plant food than animal flesh, therefore a high value of strontium is found in herbivores (Juyal, 2011). Herbivores have lower Sr/Ca ratios than plants, and this decreases the food chain (Burton & Price, 1990). The present study has found that most skeletons have higher strontium concentrations. However, the Zn concentration is comparatively lower than Sr. The Sr/Ca ratios are also relatively low in the human skeletons of Roopkund. Based on the trace element results, most Roopkund humans consumed more vegetable food than flesh in their diet. Detailed investigations of carbon and nitrogen isotope analysis and larger sample analyses are required for a threadbare conclusion.

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## Declarations

**Conflict of interest** The authors have not disclosed any competing interests.

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