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*Article*:

# Microscopic architecture of the upper and lower beak in budgerigar (*Melopsittacus undulates*): A histological perspective

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## Abstract

The oral cavity of birds differs significantly from that of mammals. Unlike mammals, birds lack teeth and instead possess upper and lower beaks. The beak is adapted for various functions, the most important being food handling and preparation. This study aims to describe the histological characteristics of the upper and lower beaks of the budgerigar. Morphological observations were conducted on five adult male budgerigars. Histologically, the beak consists of a central bony support covered by dermal and epidermal layers. The bony support comprises the premaxillary bone in the upper beak and the mandibular bone in the lower beak. The outermost epidermal layer consists of dense, highly keratinized stratified squamous epithelium arranged in multiple layers. Beneath it, the dermis contains dense connective tissue, distinct blood vessels, nerve bundles, melanocytes, and sensory corpuscles. In conclusion, the budgerigar's beak is structurally composed of a bony core covered by dermal and epidermal layers, playing a vital role in food processing.

**Keywords:** Dermis; Epidermis; Morphology; Sensory corpuscles

## Introduction

The budgerigar (*Melopsittacus undulatus*) is a member of the parrot family, Psittacidae. This species is colonial and nomadic, inhabiting the dry grasslands of Australia. While research has primarily focused on domesticated strains, general biological information is well-documented **[1]**. Budgerigars, commonly known as budgies, naturally exhibit green and yellow plumage with black, scalloped markings on their back, nape, and wings. They are among the most popular pet birds worldwide due to their small size and affordability. Budgerigars rank as the third most popular pets globally, following domesticated dogs and cats **[2]**.

Birds are distinguished by the absence of teeth, lips, jaw muscles, and a soft palate **[3]**. Instead, they possess a hard beak adapted for scooping, ripping, and seizing food. The lack of teeth may be advantageous, as food moistening and breakdown occur primarily further along the digestive tract. Rather than mastication, birds rely on repetitive muscle movements in the gizzard, where food is ground and mixed with digestive juices **[4]**. The primary functions of the beak include food and water collection as well as food preparation for swallowing.

The beak plays a crucial role in splitting and hulling seeds, as well as carrying, shredding, and crushing food. Many bird species also use their beaks for defense and protection **[5]**, while hook-shaped beaks, such as those of

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parrots, aid in locomotion **[6]**. The upper beak consists of several parts: the base, dorsum, curved dertrum, and lateral surfaces, which feature sharp edges known as the upper tomium. The lower beak includes the slant, rami, and borders, collectively referred to as the lower tomium. Both the upper and lower beak have pointed edges **[7, 8]**.

The bones of the beak are covered by the rhamphotheca, a thick, modified layer of the integument that is hard and heavily cornified in most birds, consisting of densely packed, keratinized cells **[9, 10]**. Keratin is continuously worn down and replenished through new growth. The location and rate of keratin growth and wear influence the beak's exact shape, allowing for subtle changes based on dietary variations. The tomia, or outer edges of the beak, are somewhat sharp to aid in cutting seed coats **[11]**. Keratin exists in two forms: a weight-bearing (working) horn, found on the tips and tomia of both beaks and extending to the palatine ridge of the rhinotheca, and a covering horn, which coats the outer non-contact surfaces **[6]**. In birds, the beak and claws have a thickened stratum corneum primarily composed of hard keratin. Its hardness varies among species, exceptionally tough in large psittacines and softer in many water birds **[12]**. In budgerigars and other birds, the beak consists of modified skin that sheathes the underlying bones. The epidermis is heavily keratinized, while the dermis is fused with the periosteum **[13]**.

In birds, beak shape is closely linked to diet and feeding methods **[7]**, with beak size playing a crucial role in regulating food intake **[14-16]**. The deep, curved beak is thought to aid in seed consumption **[17]**, while the pointed upper beak helps birds pick up and hold seeds and grains, preventing them from slipping **[18]**. In the parrot family, detailed studies on the morphological features of the upper and lower beak are limited, particularly in budgerigars. Therefore, this study aims to provide a comprehensive histological description of the budgerigar's upper and lower beak.

## Materials and Methods

### Ethics Statement

The study was approved by the Veterinary Medical Research Ethics Committee of the Faculty of Veterinary Medicine, Sohag University, Sohag, Egypt, following OIE standards for the use of animals in research (Approval No. Soh.un.vet/00018 R1).

### Sampling

A total of five healthy adult male budgerigars were used in this study. The birds were obtained from a local pet store in Sohag Governorate, Egypt. They were anesthetized using a xylazine-ketamine combination before being humanely sacrificed. Following complete bleeding, samples from the oropharyngeal roof and floor were collected, rinsed with normal saline, and fixed in 10% neutral buffered formalin for further analysis.

### Morphometrical analysis

Morphometrical analyses were measured using ImageJ software Version 1.54g, including the length and width of the upper and lower beaks. The data were recorded and expressed as mean ± SD.

### Histological investigation

Cross and longitudinal sections were prepared from the oropharyngeal roof and floor for histological analysis. After proper fixation, the bony samples were decalcified using formic acid (Alpha Chemika, India) and 10% formol saline **[19]**. Following decalcification, the specimens were washed under running water for 24 hours and then dehydrated in ascending concentrations of ethanol (Sigma- Aldrich, Germany). The samples were subsequently cleared in methyl benzoate (Oxford- Lab- Chem, India) and embedded in paraffin wax. Sections, 5 µm thick, were cut, mounted on glass slides, and stained with Hematoxylin and Eosin (H&E) (Alpha Chemika, India) for general histological examination **[20]**, as well as Crossmon's trichrome stain for differentiation of connective tissue and muscle fibers **[21]**. All of these stains were performed according to Bancroft's theory and practice of histological techniques **[22]**. Following that, stained sections were examined and photographed using an OPTIKA B-293 microscope (OPTICA S.r.l., Ponteranica, BG, Italy) and an OPTICA C-B10 camera.

## Results

### Morphometrical analysis

In budgerigars, the upper beak is stout, sharply pointed, and strongly curved, overlapping the smaller, blunter lower beak. The tomium is sharp with a smooth edge. The average lengths of the upper and lower beaks are 7.58 mm and 6.57 mm, respectively. The width of the upper and lower beaks measures 0.75 mm and 2.87 mm at the tip, respectively, increasing caudally to 5.75 mm and 5.94 mm at the level of the mouth angle **(Table 1)**.

**Histological investigation**

The upper beak of the budgerigar comprises a bony framework enveloped by dermal and epidermal layers. The centrally located premaxillary bone lies adjacent to the dermis, providing structural support. The epidermis consists of a dense, highly keratinized stratified squamous epithelium with multiple cell layers. The stratum basale, a single layer of columnar cells, interdigitates with the dermis. Above it, the stratum spinosum contains 3–5 layers of cells, while the stratum germinativum consists of multiple epithelial cell layers. The outermost stratum corneum comprises flattened, dead, anucleate cells, forming a thick, durable layer of hard keratin. The dermis, fused with the periosteum, consists of a single layer of irregularly arranged dense connective tissue. It contains distinct bundles of blood vessels, nerve fibers, collagen fibers, sensory corpuscles, and melanocytes **(Figure 1–2)**

***Table 1*** *The dimensions (mm) of the upper and lower beak. Data were presented as mean ± SD.*

| **Upper beak** | **Dimensions (mm)** |
|---|---|
| Length | 7.58 ± 0.24 |
| Width at the level of the tip | 0.75 ± 0,1 |
| Width at the level of the angle of the mouth | 5.75 ± 0.42 |
| **Lower beak** | **Dimensions (mm)** |
| Length | 6.57 ± 0.13 |
| Distance between the tip and lingual apex | 0.51 ± 0.02 |
| Width at the level of the tip | 2.87 ± 0.1 |
| Width at the level of the angle of the mouth | 5.94 ± 0.1 |

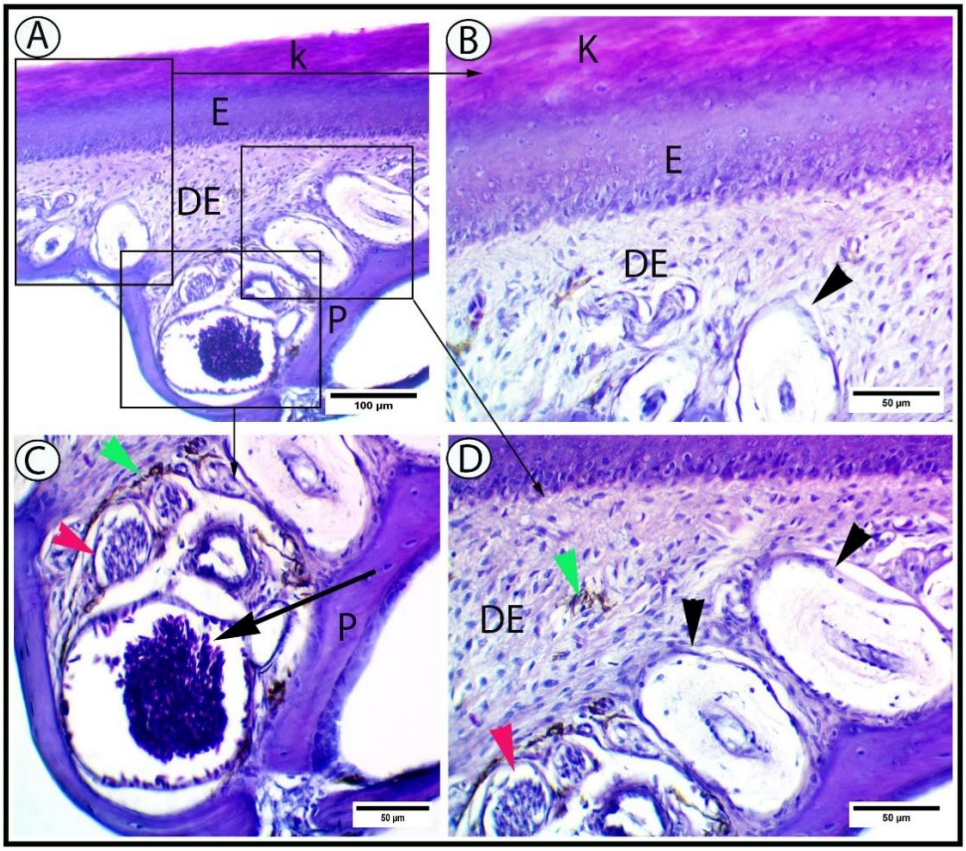


***Figure 1*** *(A-D) Photomicrographs of longitudinal section of the upper beak showing keratinized layer (K), epidermis (E), dermis (DE), sensory corpuscles (black arrowhead), melanocyte (green arrowhead), nerve endings (red arrowhead), and premaxillary bone (P) and bone marrow (black*

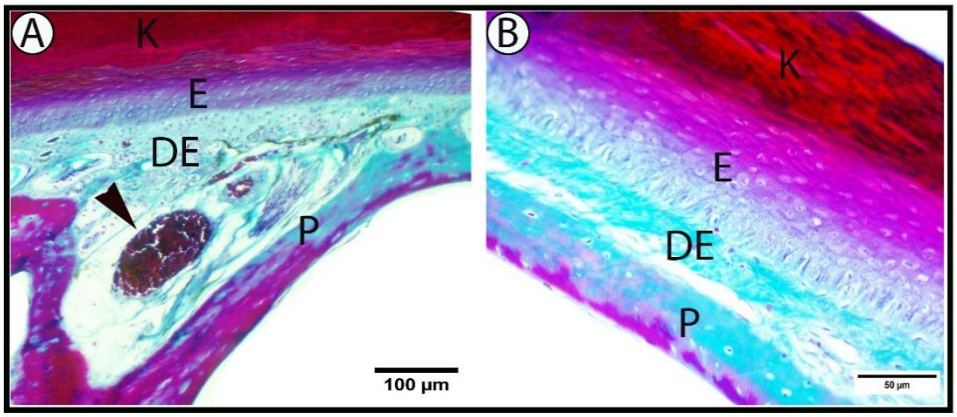


***Figure 2*** *(A & B) Photomicrographs of longitudinal section of the upper beak showing keratinized layer (K), epidermis (E), dermis (DE) premaxillary bone (P), and blood vessels (black arrowhead). Crossmon's trichrome stain.*

Herbst corpuscles, enclosed by a capsule, are observed in the dermal layer in two distinct types, classified based on corpuscle size, the shape of the central axon, and the arrangement of sensory cells. The larger type is characterized by an elongated central axon, symmetrically arranged sensory cells along the axon, and an inner space containing collagen fibers. In contrast, the smaller Herbst corpuscle features a small, oval-shaped central axon, sensory cells, and a free inner space **(Figure 3).**

The lower beak of the budgerigar is composed of the centrally located mandibular bone, which lies close to the dermal layer. The outermost layer is highly keratinized, characterized by a thick, hard keratin layer. The epidermis, similar to that of the upper beak, consists of multiple layers of stratified squamous epithelium. The dermis is fused with the mandibular bone and is composed of dense connective tissue containing distinct bundles of blood vessels, nerve fibers, collagen fibers, and melanocytes **(Figure. 4).**

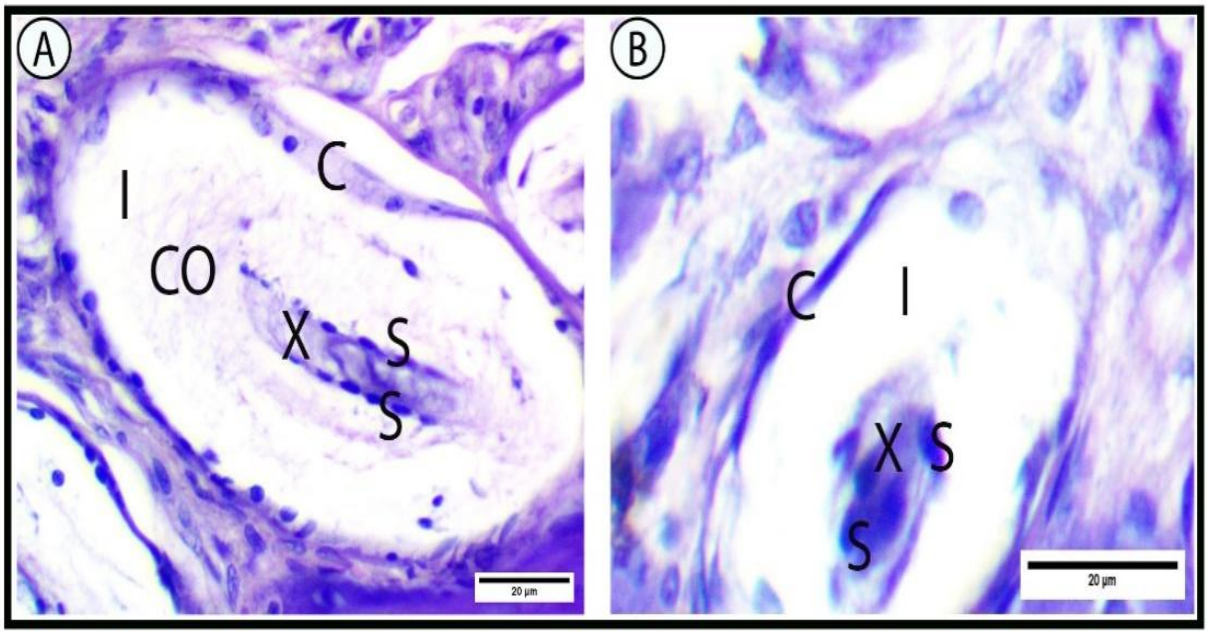


***Figure 3*** *Photomicrographs of the sensory corpuscles in the upper beak showing the detailed structure of the two different Herbst corpuscles in the dermal layer. (A) Large Herbst corpuscle characterized by the central elongated axon (X), sensory cells (S) are arranged symmetrically along the axon, and inner space (I) that contains collagen fibers (CO). (B) Small Herbst corpuscle characterized by a central small oval axon (X), sensory cells (S), and free inner space (I). Herbst corpuscles are surrounded by a capsule (C). H&E stain.*

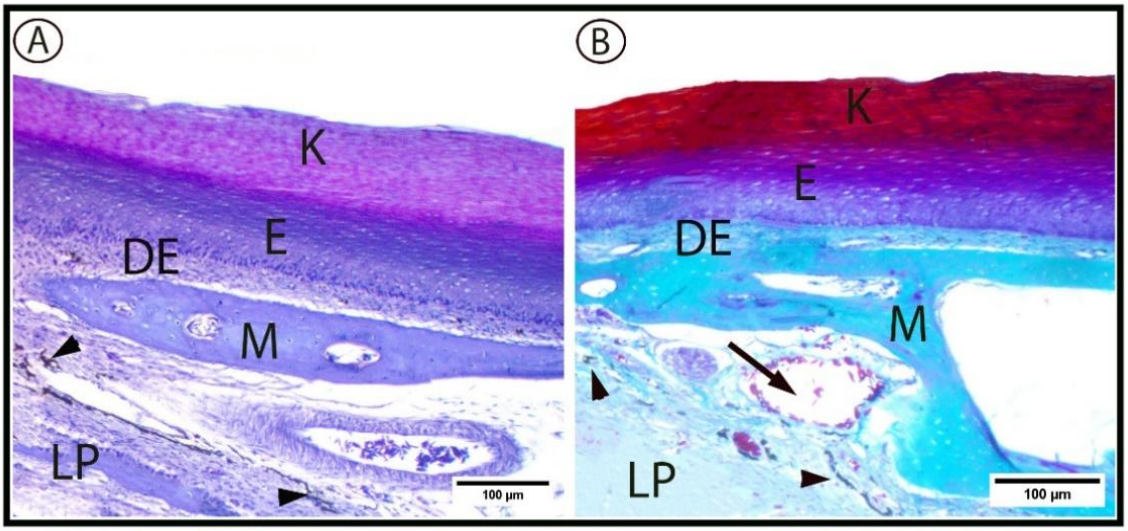


***Figure 4*** *(A & B) Photomicrographs of longitudinal section of the lower beak showing keratinized layer (K), epidermis (E), dermis (DE), mandibular bone (M), bone marrow (arrow), and melanocyte (arrowheads) that present in the lamina propria (LP). (A) H&E stain and (B) Crossmon's trichrome stain.*

## Discussion

The shape and function of a bird's beak vary across species. In budgerigars, the upper beak is stout, sharply tipped, and strongly curved, overlapping a small, blunt lower beak. The tomium is sharp with a smooth edge. In contrast, the peahen has nearly equal-sized upper and lower beaks with a short, thick, triangular shape **[23]**. The emu's beak is also triangular but significantly broader **[23]**. In flamingos, the upper beak is convex and curved, while the lower beak is concave **[23]**. Meanwhile, in the Eurasian hobby, the beak is thin, sharp, and pointed rostrally **[24]**.

In domestic birds, such as guinea fowl, pigeons, turkeys, and quails, the beak has a triangular shape with a pointed apex, and the upper beak extends beyond the lower beak in a hooked form **[25-29]**. Chickens have shorter, narrower beaks adapted for pecking and cracking small, dry seeds **[30]**. Ducks, geese, and ostriches possess spoon-shaped beaks **[14, 15]**. In ostriches, the edges of both the upper and lower beaks are soft **[15]**. In ducks and geese, the beak is entirely covered by a smooth, yellow, waxy skin called "ceroma" **[14]**. In partridges, the beak is curved, flat, hard, and ends in a sharp tip **[31]**.

In budgerigars, the mean length of the upper and lower beak is 7.58 ± 0.24 mm and 6.57 ± 0.13 mm, respectively. Beak length varies significantly among bird species. In pigeons, the upper beak length in adults is 24.27 ± 1.29 mm, while the lower beak measures 23.74 ± 0.45 mm **[28, 32]**. In turkeys, the upper and lower beak lengths are 1.73 ± 0.04 cm and 1.23 ± 0.02 cm, respectively **[25]**. In domestic fowl, the upper beak length is 3.61 ± 0.08 cm, while the lower beak measures 3.34 ± 0.04 cm **[16]**. In ostriches, the upper beak length is 6.3 ± 0.4 cm, and that of the lower beak is 2.5 ± 0.3 cm **[15]**. For ducks, the upper beak length varies with age, measuring 19.32 mm at one day old, 31.53 mm at 15 days old, and 65.52 mm at 60 days old **[33]**. In partridges, the beak length averages 4.90 cm in females and 4.80 cm in males **[31]**.

The structural histological analysis of the current study reveals that the budgerigar's upper beak comprises dermal and epidermal layers covering the premaxillary bone, which provides skeletal support and contains bone marrow within its spaces. Similar findings have been observed in the turkey **[25]**, Black-capped chickadee **[34]**, fowl **[35]**, Java sparrow **[36]**, and duck **[33]**.

The epidermis of the budgerigar is heavily keratinized, consisting of stratified squamous epithelium with multiple cell layers, which aligns with previous findings in the species **[14]**. Similar observations have been reported in the turkey **[25]**, fowl **[35]**, Black-capped chickadee **[34]**, Java sparrow [36], and duck **[33]**. However, the epidermis of the Black-capped chickadee and Java sparrow varies in thickness **[34, 36]**, with the former exhibiting a thickened epidermal tip. In ducks, the epidermis of the upper beak in one-day-old individuals is notably thicker along the lateral edges compared to other regions **[33]**.

The dermis of the budgerigar is composed of dense connective tissue containing distinct bundles of blood vessels, nerve fibers, collagen fibers, and sensory

corpuscles, similar to findings in the turkey and duck **[25, 33]**. In fowl, the dermis is an extremely thin, highly vascular layer situated between two hard substances, with epithelial integrity relying on an intact vascular dermis **[6, 35]**. In the Java sparrow, the dermis consists of a single layer of dense irregular connective tissue housing blood vessels, mechanoreceptors, and nerves **[36]**. In the Black-capped chickadee, the dermal thickness varies **[34]**.

The bony support of the budgerigar's beak consists of the premaxillary bone in the upper beak and the mandibular bone in the lower beak, both positioned close to the dermal layer, consistent with previous findings in the species **[13]**. Similarly, in the Java sparrow **[36]** and turkey **[25]**, the premaxillary bone is centrally located within the upper beak. In the Black-capped chickadee, the premaxillary bone in the upper beak and the mandibular bone in the lower beak extend throughout most of the rhamphotheca, enveloped by dermal and epidermal layers of varying thickness. At the beak's tip, these bones are replaced by broad dermal layers and a thickened epidermis **[34]**.

In ducks, the tip of the beak contains a connective core that extends into the epithelium, forming deep pits known as bill-tip organs. These structures are rich in sensory receptors, including Herbst, Grandry, and Ruffini corpuscles. The Ruffini corpuscles are located in the dermal tissue of the duck beak, extending from the submucosa to the lamina propria. Herbst corpuscles consist of symmetrically aligned sensory cells running along the central axon of the inner bulb, with concentric lamellar layers of fibroblasts and collagen fibers in the interior space. These corpuscles are encased in a capsule and found within the dermal tissue. Grandry corpuscles are located in the lamina propria of the oral mucosa and the dermal tissue of the beak skin **[37]**.

In the quail beak, the overall structure is similar to that of the duck beak, except the tip lacks a bill-tip organ. The oral mucosa at the tip of the beak is rich in Merkel corpuscles, with sub-epithelial Merkel cells organized along the lamina propria. Most Herbst corpuscles are found in the mucosa of the quail beak, differing from those in ducks by having fine collagen lamellae and possibly two axons. Ruffini corpuscles are more prevalent in the quail beak **[37]**.

## Conclusion

The upper and lower beak of the budgerigar consist of a bony framework covered by two layers: the dermis and epidermis. The epidermis features a thick, hard, keratinized layer, while the dermis contains melanocytes and two distinct types of Herbst corpuscles. This study provides a valuable reference for future research on avian beak structure and function.

In this study, two distinct types of Herbst corpuscles were identified within the dermal layer. The larger type is characterized by a central elongated axon, symmetrically arranged sensory cells, and an inner space containing collagen fibers. The smaller type features a central small oval axon, sensory cells, and a free inner space. Both types are encapsulated. Similar findings have been reported in ducks **[37]**. In turkeys, the dermis contains numerous nerve bundles and sensory corpuscles, with the larger corpuscles appearing as spherical structures composed of a central axon surrounded by Schwann cell nuclei and a concentric network of collagen fibers. However, these corpuscles are absent near the tip of the bone **[25]**. In Japanese quail, Herbst corpuscles also exist in two types, large and small, and are located near the epidermal cones, either superficially or deep within the dermis **[38]**.

## Conflict of interest

The authors declare that they have no conflict of interest.

## Author’s contributions:

The work was equally distributed between the authors. All authors have read and approved the final version of the manuscript.

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