Computed tomographic dimensions of the external ear canal and tympanic sinus of healthy ears in rabbits

A comparison between lop and erect ears

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Swedish University of Agricultural Sciences, SLU
Faculty of Veterinary Medicine and Animal Science
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Abstract

This study aimed to evaluate whether there are size differences in the external ear canal and tympanic sinus between groups of healthy domestic rabbits with lop versus erect ear conformation. The hypothesis was that lop-eared rabbits have a narrower external ear canal (I), and a smaller tympanic sinus (II). A retrospective study was conducted using medical records from the University Animal Hospital (2021–2024) of rabbits with at least one healthy ear, that underwent CT imaging of the skull. Measurements of the tympanic bulla (length, width, height) and external ear canal (cross-sectional circumference at four different points) were obtained from multiplanar CT reconstructions. Statistical analysis was performed using independent samples t-tests ($p < 0.05$), with outliers identified by the interquartile range method. Twenty rabbits with lop-ear conformation (Group L) and eighteen with erect-ear conformation (Group E-a) were compared, from a total of 38 rabbits. Ears with lop conformation showed a statistically significant smaller minimal cross-sectional circumference (p= <0.001) and a narrower lumen at the midpoint (p= <0.001) of the cartilaginous external ear canal compared to erect ears. Thus, the first hypothesis was confirmed, lop-eared rabbits indeed had a narrower external ear canal than erect-eared rabbits in this study. This study found no significant difference in the comparison of tympanic bulla size and cross-sectional circumference of the bony external ear canal between the groups. Overall, these findings contribute to the understanding of breed-related anatomical variations that could be a central factor in predisposing some rabbits to otitis media and externa.

Keywords: rabbit, size, measurements, CT imaging, otitis, predispose

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Abbreviations

Abbreviation	Description
BCS	Body condition score
CBCT	Cone beam computed tomography
CT	Computed tomography
HU	Hounsfield units
MHTS	Maximum height of the tympanic sinus
MLTS	Maximum length of the tympanic sinus
MPR	Multiplanar reconstruction
MSCT	Multislice computed tomography
MWTS	Maximum width of the tympanic sinus
ROI	Region of interest
CSC 1	Cross-sectional circumference of the most ventral part of the osseus external meatus
CSC 2	Cross-sectional circumference of the osseus external meatus proximal to the junction with the cartilaginous meatus
CSC 3	Cross-sectional circumference of the cartilaginous meatus at the estimated middle point
CSC 4	Minimal cross-sectional circumference of the cartilaginous meatus

1. Introduction

The domestic rabbit is a popular pet that has been the third most common mammal pet species in Sweden 2012 (SCB 2012), the United Kingdom in 2023 (UK Pet Food 2023), and in the United States 2022 (AVMA 2022), making it essential for small animal practitioners to stay updated on current advancements in rabbit medicine. Recently, ear disease has gained interest in veterinary research (de Matos *et al.* 2015; Richardson *et al.* 2019; Chivers *et al.* 2023), and diagnostic imaging advances have given new opportunities for deeper research into the subject.

In the early 2000's, veterinary literature suggested that lop-eared rabbits are predisposed to ear disease compared to erect-eared rabbits (Capello 2004; Harcourt-Brown 2002a). Since then, several studies have investigated this hypothesis and found an association between lop-ear conformation and otitis media (de Matos *et al.* 2015; Richardson *et al.* 2019), and found more aural pathologies in the lop-eared rabbits (Johnson & Burn 2019). Stenosis of the external ear canal and folding of the pinnae have generally been mentioned as key mechanisms for predisposing lop-eared rabbits to otitis (Capello 2004; Csomos *et al.* 2016; Johnson & Burn 2019; Richardson *et al.* 2019). However, no clear evidence is to be found on the pathogenesis of otitis in lop-ear conformation.

Computed tomography (CT) has been increasingly used in veterinary medicine over the last two decades (Greco *et al.* 2023). It is currently the most accurate diagnostic method and therefore the gold standard for diagnosing otitis media in rabbits (King *et al.* 2012). Recently, a CT grading scale has been produced by Richardson *et al.* (2019) which enables objective definition and documentation of aural CT changes in rabbits. In some canine breeds, specific aural CT measurements have been studied to establish normal variation in mesocephalic and brachycephalic breeds, with specific evaluation of ear canal stenosis in the latter group (Kaimio *et al.* 2020). Similar studies on rabbits have not been conducted to the author's knowledge.

The purpose of this study was to evaluate if there is a conformation difference of the external ear canal and tympanic bulla between healthy ears of domestic rabbits with lop versus erect-ear conformation. It aimed to describe the size of aural structures in both groups using CT-images, and to test the hypothesis that lop-eared rabbits have narrower external ear canal (I) and smaller tympanic bulla (II) than erect-eared rabbits. This work aimed to contribute to identifying breed related anatomical differences that are possible risk factors for otitis media and externa.

2. Background

2.1 Rabbit welfare perspective

Several survey-based studies on rabbit welfare have been conducted over the past two decades, examining both internal and external factors impacting quality of life (Mullan & Main 2006; Rooney *et al.* 2014; Rioja-Lang *et al.* 2019; McMahon & Wigham 2020; Chivers *et al.* 2023; O'Neill *et al.* 2024) and reflecting an increase in status of the pet rabbit. Two recent studies investigated rabbit welfare focusing on potential effects of body conformation; Chivers *et al.* (2023) on the relationship between ear health and quality of life and O'Neill *et al.* (2024) on the association between breed, ear, and skull conformation and disease. This highlights the demand for further investigation into the effects of ear conformation on aural health and quality of life. Ultimately, lop-ear conformation may be an important rabbit welfare issue if proven to be a predisposing factor for ear disease.

2.2 Breed differences: ear conformation

Domestication of rabbits *(Oryctolagus cuniculus)* has given rise to a variety of breeds with different body conformations. The ear pinna may be of various lengths and sizes and can be either erect (Fig. 1) or pendulous i.e. lop ears (Fig. 2) (Vella & Donnelly 2012; Meredith 2014).

Figure 1. Erect-eared rabbit (Sandström n.d.)

Figure 2. Lop-eared rabbit (Smeds n.d.)

Lop-ear conformation is a heritable trait (Castle & Reed 1936) represented in nine currently recognized breeds by the British Rabbit Council (Breed Standards 2021-2025). Surveys indicate that lop-eared breeds make up a large percent of the pet rabbit population, representing 43% (n=72/167) of rabbits in Finland (Mäkitaipale *et al.* 2015) and ranging between 57% (n= 47,824/83,821), 32% (n=2053/6349) and 28% (n=599/2126) in England (O'Neill *et al.* 2024, 2020; McMahon & Wigham 2020).

2.3 Ear anatomy of the rabbit

2.3.1 The external ear

The ear pinnae are for capturing and determining the direction of sound. They also play a role in visual communication among rabbits, and thermoregulation through large arterio-venous shunts (Chitty & Raftery 2013; Donnelly & Vella 2021).

The rabbit external ear canal is vertical (Donnely & Vella 2021). It is supported by three interdigitating auricular cartilages: the *auricular*, *scutiform* and *annular cartilage* (Chitty & Raftery 2013). Fibrous tissue connects these cartilages and allows for mobility (Jekl *et al.* 2015). The auricular cartilage forms the distal part of the external ear canal and the pinna (Fig. 3). Its proximal part, the *tragus*, interlocks with the ring-shaped annular cartilage which subsequently connects to the osseus part of the external ear canal, the *osseus acoustic meatus*. The scutiform cartilage is small and placed dorsally (Popesko *et al.* 1992; Mancinelli & Lennox 2017). Several publications report lop-eared rabbits to have a 3 to 5 mm gap between the tragus and annular cartilage, which is believed to cause folding of the soft ear canal, resulting in pendulous pinnae (Chitty & Raftery 2013; Johnson & Burn 2019; Mancinelli & Lennox 2017; Richardson *et al.* 2019; Varga & Paterson 2021). However, it is seemingly not possible to find the original source of this information.

Measurements of the external ear canal have been obtained by dissection of eight

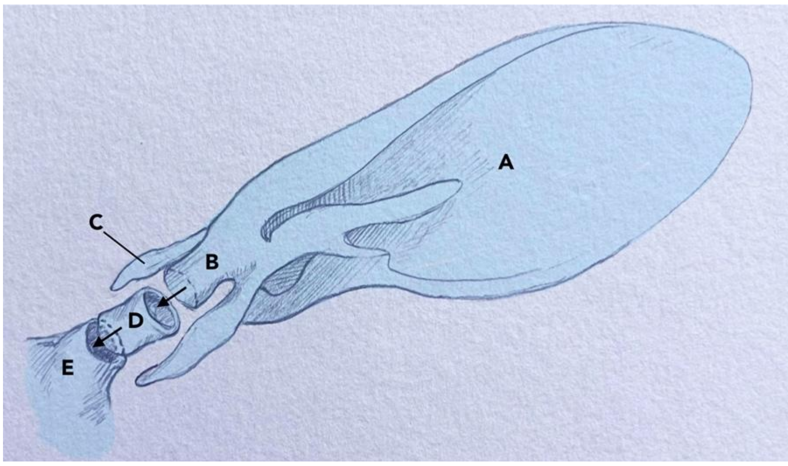


Figure 3. Cartilages of the ear. A, auricular cartilage; B, tragus; C, scutiform cartilage; D, annular cartilage. E; osseus acoustic meatus. Illustration: Bianca Smeds with inspiration from Popesko et al. *1992 and Chow 2011.*

erect-eared rabbits (16 ears) from a study by Guan *et al.* (2018), and by King *et al.* (2007) from four erect-eared rabbits (8 ears), see table 1. The results are most likely not directly applicable to all breeds as size may vary significantly between breeds and both studies used New Zealand white rabbits, which normally weight between 4.08-5.44 kg (BRC 2021). Additionally, the small sample sizes risk sampling bias, variability, and confounding variables that can obscure the results.

Table 1. Measurements of the external ear canal (mean ± standard deviation)

Measurement	Guan *et al.* 2018	King *et al.* 2007
Height of osseous ear canal	5.04 ± 0.34mm	
Transverse diameter of osseous ear canal	5.61 ± 0.20mm	6.5 mm ± 0.6 mm
Length of osseous ear canal	10.50 ± 0.50mm	7.6 ± 0.4mm
Height of cartilaginous ear canal	6.39 ± 0.61mm	
Transverse diameter of cartilaginous ear canal	8.96 ± 0.55mm	
Length of cartilaginous ear canal	19.23 ± 0.82mm	

The skin lining the external ear canal contains hair follicles as well as sebaceous and ceruminous glands. The latter produces a white to yellow colored cerumen (Jekl *et al.* 2015), a common finding in healthy rabbits (Harcourt-Brown 2002a).

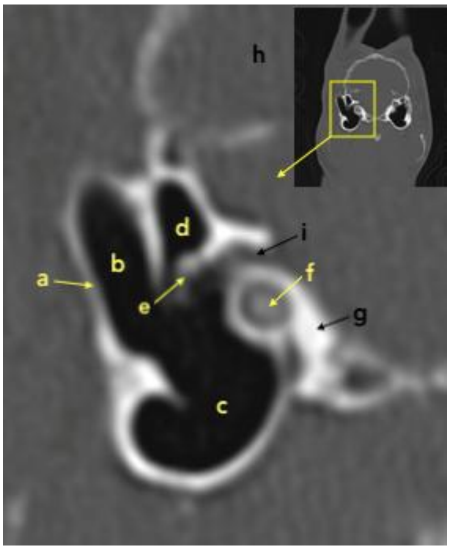
2.3.2 The middle ear

Separating the external ear canal from the middle ear is the tympanic membrane. It is located dorsally to the tympanic bulla (Popesko *et al.* 1992) and attached to the osseus external ear canal proximal to its conjunction with the annual cartilage (Jekl *et al.* 2015). The tympanic membrane has an elliptical shape with the long axis oriented vertically (Chitty & Raftery 2013) and is divided into pars tensa and pars flaccida (Puria *et al.* 2013).

The tympanic bulla is a convex osseus structure forming a cavity with a smooth surface. Due to an internal bone rim at the junction of the acoustic meatus and the tympanic bulla, the bone of the lateral wall is thickest, while the ventral wall is the thinnest (King *et al.* 2007). Compared to dogs and cats, the tympanic bulla is proportionally larger in rabbits (Chitty & Raftery 2013). King *et al.* (2007) documented the dimensions of the tympanic bulla by dissection of four New Zealand white rabbits with no evidence of ear disease. The tympanic bulla had an ellipsoid shape with the mean length of 11,3 ± 0,6 mm, width of 9 ± 0,4 mm, and depth of 9,6 ± 0,8 mm.

The tympanic cavity is air-filled and houses the auditory ossicles: malleus, incus, stapes (Dyce *et al.* 2010). It is divided into the tympanic sinus (further classified in meso- and hypo tympanic recesses) and epitympanic recess (Mancinelli & Lennox 2017; Abd El-Hameed *et al.* 2023). The epitympanic recess is the most dorsal part of the tympanic cavity where the auditory ossicles reside (see Fig 4). The tympanic bulla is separated from the inner ear through the petrous part of the temporal bone that forms the medial wall of the cavity, where the oval and round windows are found (Dyce *et al.* 2010). The malleus, incus and stapes interconnect forming the ossicular chain which connects the tympanic cavity to the oval window and the vestibule. The round window is closed by a thin membrane and leads to the cavity of the cochlea. The tympanic cavity communicates with the nasopharynx through the auditory tube which is important for pressure regulation of the middle ear, and clearance of fluid.

Figure 4. CT image of the right ear of a rabbit, transverse plane. Osseus acoustic meatus (a), external acoustic orifice (b), tympanic sinus (c), epitympanic recess (d), ossicular chain (e), inner ear (f), petrosal part of temporal bone (g), cerebral hemisphere (h); facial canal (i). The figure is created by the author. (Abd El-Hameed et al. *2023; Caelenberg* et al. *2010)*



2.3.3 The inner ear

The inner ear in mammals is a complex structure that comprises of the osseus labyrinth and the membranous labyrinth (Dyce *et al.* 2010). The osseus labyrinth originates from the temporal bone and encloses the membranous labyrinth (Abd El-Hameed *et al.* 2023). It consists of the cochlea, which encompasses the membranous cochlear duct; three semicircular canals, that encompass three membranous semicircular ducts; and the vestibule, which encompasses the utriculus and sacculus. The dorsal wall of the inner ear is the temporal bone of the cranium floor.

2.3.4 Cranial nerves

Close to the tympanic bulla is the facial nerve (cranial nerve VII) which runs in the facial canal (Fig. 4) ventral to the vestibulocochlear nerve (cranial nerve VIII) and close to the inner ear and tympanic bulla (De Lahunta *et al.* 2021). The canal is in the petrosal bone and exits the skull through the stylomastoid foramen caudally to the tympanic bulla (Fig. 5). After exiting the skull, the facial nerve branches out to innervate the pinna, the masseter muscle and the jaw. The major branch of the facial nerve continues in a rostral direction ventrally to the bulla until it reaches the eye where it divides into smaller branches (Popesko *et al.*

1992; Osofsky *et al.* 2007). The facial nerve provides sensory and motor innervation and of the facial muscles, and parasympathetic innervation of the salivary and lacrimal glands (Csomos *et al.* 2016).

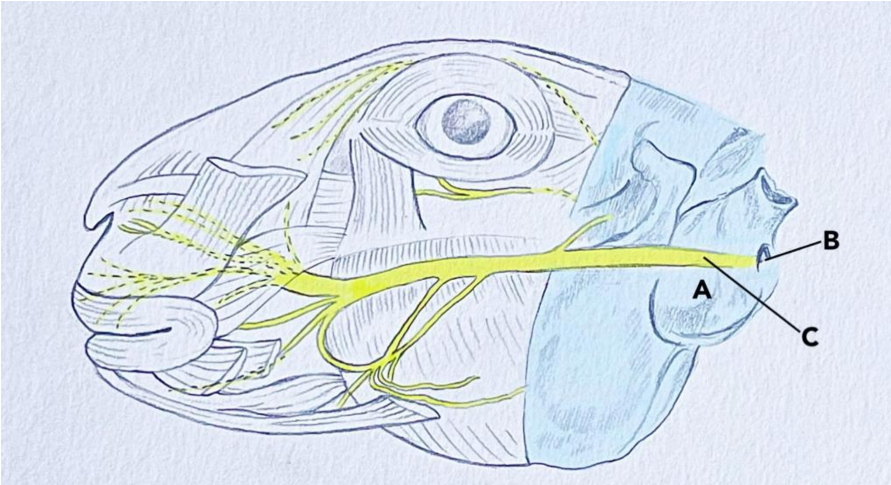


Figure 5. Anatomy of the facial nerve. A, tympanic bulla; B, stylomastoid foramen; C, facial nerve. Illustration by the author with inspiration from Popesko et al. *1992 and Eatwell* et al. *2013.*

The vestibulocochlear nerve runs from the inner ear, passes the petrosal bone and internal acoustic meatus to reach the medulla of the brain (Lorenz *et al.* 2010). Its function is hearing and equilibrium.

2.4 Ear disease in the rabbit

Rabbits with disease of the middle and external ear are commonly presented in veterinary practice (Chitty & Raftery 2013; de Matos *et al.* 2015; Csomos *et al.* 2016; Richardson *et al.* 2019; Monge *et al.* 2023; SKVF 2022; O'Neill *et al.* 2024). Prevalence estimates of ear disease in pet rabbits vary among different studies, ranging from 2,39 % to 28,5% in surveys and retrospective reviews (Chivers *et al.* 2023; O'Neill *et al.* 2024). This large variation could be explained by differences in study design, study populations, inclusion criteria, and methods used. A lack of detection can also contribute to varying prevalences, and recognizing ear disease in rabbits can be challenging as they naturally hide signs of weakness to avoid predation (Barter 2011).

2.4.1 Inflammation of the external ear canal, otitis externa

Otitis externa can result from parasitic (e.g. *Psoroptes cuniculi*) (Lennox & Kelleher 2009), bacterial, or fungal infections (Varga & Paterson 2021). Primary bacterial otitis externa is relatively uncommon in rabbits. It more commonly originates from infection of the middle ear, through a perforated tympanic membrane.

Supporting this, de Matos *et al.* (2015) found otitis externa to have a significant association with otitis media.

Vecere *et al.* (2022) found distinct differences between the aural biome of rabbits with and without otitis externa. Even so, results of a bacterial culture should be interpreted together with cytology to establish that an inflammatory process is present, since the clinically healthy rabbit ear has a large number of commensal bacteria and yeast (Varga & Paterson 2021).

The diameter of the external ear canal has been suggested to be associated with risk of otitis externa in dogs, impaired ventilation and accumulation of secretions likely to be the cause (Eom *et al.* 2000). Some dog breeds may have anatomical changes and narrowing of the external ear canal, for example brachycephalic dogs. A study of 75 brachycephalic dogs, however, did not show a connection between stenosis of the external ear canal and otitis externa (Töpfer *et al.* 2022). There have not been studies to evaluate if stenosis of the external ear canal could be directly linked to otitis externa in rabbits, however it might be a predisposing factor as it has been suggested in dogs (Eom *et al.* 2000).

Clinical manifestations of otitis externa are excessive grooming, ear scratching, head shaking, lethargy, pain, and inappetence. Initially, subclinical disease may occur (Chow 2011; Mancinelli & Lennox 2017), and subtle signs risk being overlooked (Keeble 2023).

The mucosal lining of the external ear canal may show signs of inflammation (Richardson *et al.* 2019) and purulent material may be present. Material may accumulate in the external ear canal. This accumulation may cause medial bulging and possibly rupture of the tympanic membrane. Consequently, there is a secondary risk of material accumulation in the tympanic bulla and otitis media (Mancinelli & Lennox 2017). In lop-eared rabbits, accumulation of material in the external ear canal may lead to lateral pouching at the base of the ear, as the wall of the canal gives way due to the pressure and expands where the tragus and annular cartilages do not interlock (Chitty & Raftery 2013). This condition is called *aural diverticulosis*.

2.4.2 Inflammation of the middle ear, otitis media

Bacterial otitis media can occur following hematogenous spread to the middle ear (Csomos *et al.* 2016), an extension of upper respiratory infection, or as an extension of otitis externa (Meredith & Richardson 2015). Bacterial infections are mainly caused by *Pasteurella multocida, Staphylococcus aureus, Streptococcus, Bordetella bronchiseptica, Pseudomonas aeruginosa, Escherichia coli, and Proteus mirabilis*.

Otitis media secondary to otitis externa, through a ruptured tympanic membrane, is uncommon (Fisher *et al.* 2021). Ascending infection from the upper respiratory tract via the auditory tubes is suggested to cause primary otitis media as studies have reported most of the infections to be caused by *P. multocida* which is a respiratory tract pathogen (de Matos *et al.* 2015; Deeb *et al.* 1990; Kunstýř & Naumann 1985). Older studies have reported an association between otitis media and concurrent upper respiratory tract infections upon necropsy (Smith 1926; Deeb *et al.* 1990), however a more recent study using CT-evaluation did not find the association to be statistically significant (de Matos *et al.* 2015). Ultimately, the findings suggested that additional factors play a role in the pathogenesis, such as immunity, other concurrent diseases, and pathogenicity of the bacteria.

Otitis media often presents in a subclinical form (Chitty & Raftery 2013). The prevalence of subclinical otitis media has been reported in several studies of meat and research rabbits (postmortem), ranging from 11,5% to 32% (Flatt *et al.* 1977; Smith *et al.* 1925; Deeb *et al.* 1990 see de Matos *et al.* 2015). Additionally, the prevalence based on retrospective CT evaluation in a group of rabbits who had no clinical signs of ear disease was 27% (n=18/67) (de Matos *et al.* 2015) and 61% (n=22/36) (Richardson *et al.* 2019).

The morphology of the tympanic bulla, such as variations in size, shape, and wall thickness has been studied in some breeds of dogs (Salgüero *et al.* 2016; Mielke *et al.* 2017). Mielke *et al.* (2017) suggest tympanic bulla malformation to be a part of the brachycephalic phenotypic traits. A study found brachycephalic dogs had smaller tympanic bulla and a greater prevalence of subclinical otitis media (Salgüero *et al.* 2016).

Clinical signs of otitis media in rabbits are often non-specific: gastrointestinal hypomobility, inappetence and weight loss (Chitty & Raftery 2013). These signs may arise from a discomfort associated with chewing, due to the anatomical proximity of the temporomandibular joint to the middle ear. Facial paresis in the form of facial contracture ipsilateral to the affected ear can occur secondary to facial nerve deficits (Fig. 6) (Csomos *et al.* 2016; Fisher *et al.* 2021). Chronic cases of otitis media can lead to deafness **(**Chitty 2014).

Accumulation of fluid or material in the bulla may cause a distended tympanic membrane (Chow *et al.* 2009). This could be observed during otoscopy or video otoscopy. However, the tympanic membrane may be difficult to visualize due to material in the external ear canal or excessive swelling of the canal. Severe otitis media may progress to thickening, lysis, or disruption of the bulla wall and expansion of the tympanic cavity (Chow 2011; Richardson *et al.* 2019). The tympanic bulla can be difficult to evaluate through palpation due to the positioning of the mandible, and even severe bone lysis may therefore be overlooked during physical examination (Chow 2011).

Figure 6. Rabbit with left facial contracture (arrow). Photo: granted by anonymous, used with permission.

Clinical examination should include otoscopy or video otoscopy and diagnostic imaging if indicated since disease otherwise can be difficult to recognize and diagnose unless it is associated with otitis interna or externa (Csomos *et al.* 2016; Fisher *et al.* 2021). Early diagnosis and treatment are important as the infection can spread and cause severe disease and destruction of tissues.

2.4.3 Inflammation of the inner ear, otitis interna

Otitis interna may result from an extension of bacterial otitis media, or by hematogenous spread (Csomos *et al.* 2016). Rabbits with otitis interna typically present with peripheral vestibular syndrome due to labyrinthitis. These signs include head tilt ipsilateral to the lesion, ataxia, circling, and spontaneous nystagmus (Chitty & Raftery 2013; de Matos *et al.* 2015; Fisher *et al.* 2021; Lorenz *et al.* 2010). In severe cases, loss of balance results in falling over and rolling (Fisher *et al.* 2021). If the facial nerve is involved, deficits may cause ipsilateral contracture of the facial muscles (Fig. 6) (Eatwell *et al.* 2013).

The infection can spread to the brain through the vestibulocochlear nerve and result in encephalomyelitis with severe central neurological signs such as seizures (Meredith & Richardson 2015; Harcourt-Brown 2002b).

Due to differences in treatment and prognosis, it is important to make a distinction between peripheral and central vestibular disease (Lorenz *et al.* 2010). This can be challenging as otitis media may precede otitis interna (de Matos *et al.* 2015). It is relatively common for otitis media to be present together with otogenic intra-cranial infections, supporting that some infections tend to expand. This may be due to a certain level of pathogenicity of the bacteria, or perhaps because of prolonged disease.

2.4.4 Lop-ear conformation, predisposing factor to ear disease

Research has indicated that the lop-ear phenotype is a predisposing factor to otitis externa and media. Analysis of a French teaching hospital's clinical records between 2011-2021, found a majority (79%) of the rabbits who went through lateral ear canal resection and bulla osteotomy, or were diagnosed with otitis media by CT examination, were lop-eared (Monge *et al.* 2023). This finding is in line with the results of two retrospective studies that found CT detected changes in the middle ear to be more prevalent in lop-eared rabbits (de Matos *et al.* 2015; Richardson *et al.* 2019). Richardson *et al.* (2019) analyzed 161 CT scans to determine the presence or absence of otitis media. Out of the 36 rabbits that were diagnosed with otitis media, 24 (67%) had lop-ear conformation and the association between lop-ear conformation and otitis media was statistically significant. De Matos *et al.* (2015) similarly found a statistically significant association with lop-ear conformation and otitis media and reported that 21 (70%) out of 30 rabbits diagnosed with otitis media had lop ear conformation.

Although not representable outside the studied population due to non-randomized convenience sample, and risk for bias due to non-blinded collection of data, Johnson & Burn (2019) also found lop-eared rabbits at increased risk of aural pathologies compared to those with erect ears. The study examined 30 rabbits from a rescue population that were equally divided in two groups based on ear conformation, 15 rabbits with lop ears and 15 rabbit with erect ears. The lop-eared rabbits showed higher odds of stenosis of the external ear canal, and pain response during examination, and had higher scores of cerumen and erythema compared to the erect-eared rabbits.

The correlation between otitis externa, otitis media, and lop-ear conformation is suggested to be due to two types of alterations in aural anatomy: a stenotic ear canal (Chow 2011) and folding of the pinnae which causes flexion of the ear canal (Capello 2004; Chitty & Raftery 2013). This information is used by several publications (Chow *et al.* 2011; Eatwell *et al.* 2013; Jekl *et al.* 2015; Csomos *et al.* 2016; Johnson & Burn 2019; Richardson *et al.* 2019; Chivers *et al.* 2023; Monge *et al.* 2023). However, there seems to be some cross referencing and a lack of a clear primary source for information regarding the pathophysiology of otitis in lop-eared rabbits. Chow (2011) refers to Capello (2004), however the pathophysiology is not presented in Capello and there are no clear references for Capello's claims in the Exotic DVM journal. Chitty & Raftery (2013) report that the folding of the pinnae closes the ear canal and subsequently hinders cerumen and secretions from draining properly, resulting in build-up that increases the risk of secondary bacterial or yeast overgrowth and secondary otitis externa. Again, clear references are missing, and the source appears to be Capello (2004) and Chow (2011). It is important to note that lop-eared rabbits are predisposed to both otitis externa and media, however it is relatively uncommon for otitis externa to extend into the middle ear (Varga & Paterson 2021). This raises two possibilities: either there is a specific pathophysiological mechanism in lop-eared rabbits where stenosis and folding of the pinna may facilitate the extension of otitis externa into the tympanic bulla causing secondary otitis media, or the folding and stenosis alone may not fully explain the increased prevalence of otitis media in these animals.

In conclusion, there is conflicting information about how lop-ear conformation predisposes some rabbits to otitis media and externa. Furthermore, there is a notable lack of studies that provide quantitative data and compare normal anatomical differences across groups of rabbits with different ear conformations.

2.5 Computed tomographic imaging of the ear

Computed tomography (CT) has been increasingly used in veterinary medicine (Greco *et al.* 2023) over the last two decades (King *et al.* 2012). This imaging modality uses x-rays to produce multiple cross-sectional images that are combined to generate 3D images (Veraa & Schoemaker 2013).

2.5.1 The basics of CT imaging

A conventional CT unit has a scanning unit which is a doughnut-shaped gantry containing a rotating x-ray tube and detectors, a patient table that can slide through the central hole of the gantry, and a console with a computer for image reconstruction (d'Anjou 2018).

There are several scanning modes. Helical scanning is a mode that uses the continuous movement of the table through the gantry simultaneously with a continuous circular rotation of the x-ray tube (the slip-ring technology) (Saunders & Ohlerth 2011). Instead of creating separate slices, a helical scanner produces a continuous spiral which prevent acquisition gaps and improves scanning speed (Wang & Vannier 1999). There is single slice, dual slice and multislice (MSCT) helical CT, based on maximum number of slices per gantry rotation. It has largely replaced sequential scanning which scans a single slice at a time between increments.

Pitch is the ratio of the table movement through the gantry over the detector collimation in the context of multislice helical CT.

Cone beam CT (CBCT) uses a cone shaped x-ray beam instead of a collimated fan beam of a MSCT (d'Anjou 2018). This exposes the patient to a lower radiation dose, however produced more scattered radiation, lower contrast resolution and reduced image quality than the MSCT. Yet, the CBCT is valuable for assessing small parts of the head and has a lower cost of equipment and installation and Riggs *et al.* (2016) found CBCT to be superior to MSCT for assessing dentition and maxillofacial structures, as thinner slices make for better spatial resolution of bone structures. Studies describing and comparing the normal anatomic features of the ear on MSCT and CBCT were not found.

The raw data from a CT study is reconstructed using an equation that produces a linear attenuation coefficient (μ) which then is transformed into Hounsfield Units (HU) to create the greyscale (d'Anjou 2018). The HU of water is 0 and air is -1000 (Cuong *et al.* 2018). The typical scanners can create a greater range of greyscale than electronic screens and the human eye can detect, which is why window width (image contrast), and level (HU at the center of the image) can be adjusted around the median HU range of the tissue that is being assessed in the region of interest (ROI) (d'Anjou 2018).

The CT image is viewed on a monitor in greyscale, displayed as a matrix of pixels. Each image is a slice with preset thickness, and the volume unit (*voxel*) are the small cubical components that compose a slice (d'Anjou 2018). Each pixel on the monitor represents a voxel. The electron density of the medium is what mainly affects the tissue attenuation that is measured by the detectors and in turn the HU and shade of grey of each voxel. Higher intensity of the tissue attenuation equals a brighter pixel, while lower intensity equals a darker pixel. Since the structures within the voxel can have several different tissue attenuation values, the mean attenuation value gives the HU value which is used for the pixel.

Advanced software programs make the image reconstruction possible, and combined with reduced slice thickness, enable high resolution multiplanar reconstruction (MPR) (Saunders & Ohlerth 2011). MPR allows scans to be viewed from all planes and the shape of a structure can be evaluated along the x-, y-, and z-axes.

Minimum intensity projection (MinIP) is a mode for viewing reconstructed data that enhances visualization and detection of the structures with a low attenuation value in a reconstructed image slab created by voxels from multiple slices (Ghonge & Chowdhury 2018). It is generated with an algorithm that displays the minimal voxel value of the voxels in the image slab and displays it in the image as a pixel.

2.5.2 A diagnostic tool

The use of computed tomography has expanded over the past two decades (Greco *et al.* 2023) and it is currently widely used in veterinary medicine (Saunders & Ohlerth 2011). Before the use of CT, radiography has been the most common and available modality for assessing otitis media in rabbits (King *et al.* 2012). Ultrasonography can be used to identify presence of material or fluids in the tympanic bulla, and the ultrasonographic anatomy of the tympanic bulla has been documented in King *et al.* (2007).

Computed tomography is currently the most accurate diagnostic method and therefore the gold standard for diagnosing otitis media in rabbits (King *et al.* 2012). It is an effective diagnostic tool for imaging of areas where ultrasonography and radiography are insufficient, and especially for mineralized structures and air-filled structures (Veraa & Schoemaker 2013).

A study compared the accuracy, sensitivity, specificity and predictive values of radiography, ultrasonography, and computed tomography to identify material or fluids in the tympanic bulla of rabbits (King *et al.* 2012). A single computed tomography slice acquired from a helical scanner had perfect (100%) scores and agreement between two observers' interpretation.

2.5.3 Patient set-up

Sternal recumbency is preferred for head CT. It is important for the patient to remain still during the procedure to avoid movement artefacts and for patient safety. To immobilize the patient, chemical restraint such as sedation or general anesthesia, or physical restraint should be used (Saunders & Ohlerth 2011). The latter is preferred for rabbits due to the risks of general anesthesia, especially for the debilitated patient (Richardson *et al.* 2019). Placing the rabbit in a small plexiglass chamber or wrapping it with blankets in a "bunny burrito" are safe options (Liu *et al.* 2025). Light and environmental sounds can be reduced, and rolled towels can be placed in the plexiglass chamber to minimize movements (Richardson *et al.* 2019).

2.5.4 Features of the diseased ear

The normal CT anatomical features of the head in healthy rabbits have mostly been described with a focus on dentition (Zotti *et al.* 2009; De Rycke *et al.* 2012).

Recently, Richardson *et al.* (2019) developed CT grading scales for assessing material in the external ear canal and otitis media. These grading scales had a high level of agreement between users thus enabling effective categorization and documentation of aural CT changes in rabbits.

The normal external ear canal has an air-filled lumen (Richardson *et al.* 2019). Its size, and presence of material within it can be evaluated on physical examination. Additionally, aural diverticulosis and deviation or obliteration of the tympanum should be assessed. During CT examination the pinnae should preferably rest on the rabbit's back and the use of an intravenous contrast agent is recommended to provide clarity, as material in the in the external ear canal and folding of the pinna may cause misinterpretation.

The normal tympanic bulla is air-filled, and the bony wall is smooth and well defined on CT images (Saunders & Ohlerth 2011). CT abnormalities in the diseased middle ear of rabbits include increased attenuation in the tympanic cavity, thickening or bone lysis of the tympanic bulla wall, or expansion and changes to the shape of the bulla (de Matos *et al.* 2015; Richardson *et al.* 2019). De Matos *et al.* (2015) found these changes to be similar to those described in cats and dogs.

2.5.5 Breed differences

Aural CT anatomy has been studied in some canine breeds to establish normal variation in mesocephalic and brachycephalic breeds, as there is breed differences in the anatomy (Defalque *et al.* 2005; Salgüero *et al.* 2016; Mielke *et al.* 2017). A study by Kaimo *et al.* (2020) described breed specific quantitative CT characteristics of healthy and diseased ears in the American cocker spaniel, a breed with high risk for otitis externa. Specific evaluation of ear canal stenosis, and volume and thickness of the tympanic bulla were made, and the results were compared with mesocephalic dogs. Similar studies in rabbits have not been conducted to the author's knowledge.

3. Material and methods

A retrospective analytical study was conducted. Medical records of the University Animal Hospital of the Swedish University of Agricultural Sciences (SLU) between 2021 – 2024 was searched for rabbits that underwent computed tomography (CT) of the skull. Some cases underwent CT at SLU, others were referrals for radiographic interpretation from a private veterinary clinic (Fågel & Smådjurskliniken).

3.1 Case selection

The case selection was based on the inclusion criteria: rabbits of all ages, sex, weight with no diagnosis or history of ear disease in one or both ears. Ear conformation (lop/erect), breed, and weight of the rabbit was registered for each case. All collected data was anonymized with a code to ensure participants privacy and comply with SLU's ethical standards. Rabbits with lop conformation were assigned Group L, and erect conformation Group E. One ear per rabbit was selected through stratified randomized sampling, evenly divided between right and left ears. Nine rabbits in group L only had one healthy ear and were therefore not randomly selected.

Forty-two rabbits met the inclusion criteria, 20 lop-eared rabbits (Group L) and 22 erect-eared rabbits (Group E). Outliers in weight value were identified using the interquartile range (IQR) method. First, the first ($Q_{1)}$ and third quartile (Q_3) of the dataset was calculated. The difference between the Q_3 and Q_1 then defined the IQR (IQR= Q_3-Q_1). The cases that had a weight value outside the range of IQR×1,5 below Q1 or above Q_3 was classified as outliers and excluded from statistical analysis. With Q_1 (1.6 kg) and Q_2 (2.3 kg) the interquartile range was 0.7 kg and the smallest respectively largest value allowed was 0.55 kg and 3.35 kg. Four rabbits from Group E exceeded the largest value and were excluded, leaving n=18 after the adjustment. Group L remained the same size (n=20). Group E was renamed "Group E-a" after excluding outliers.

3.2 Computed Tomography imaging

A helical multislice 64-slice CT (Somatom Definition AS, Siemens, Germany) was used at SLU, and a cone beam CT (Vimago3030, Imaginalis, Italy) was used at Fågel & Smådjurskliniken. A standard head protocol was used for the patients at SLU, with scan settings of a pitch of 0.35, tube potential of 120 kVp, reference tube current of 50 mA, slice thickness of 1 mm, focal spot of 1.2 mm, convolution kernel H70h. For the cone beam CT, a full body protocol was used, with scan settings of a tube potential of 80 kVp, reference tube current of 45 mA, slice thickness of 0.35 mm. Thirteen rabbits (34%) had been scanned with a cone beam CT, 35% (n=7/20) from group L, and 33% (n=6/18) from group E-a. The rest of the cases had been scanned with helical CT.

3.3 Image analysis

All measurements were performed by the veterinary student with the guidance of the supervisor, a European specialist in veterinary radiology (A. Gombert) using a blinded method. The preparation included a demonstration session with the supervisor, independent practice on a sample of 14 rabbits, and feedback on a subset of these animals. These measurements were not used in the study. Following this, the student conducted all the measurements independently, each structure being measured once. The CT studies were viewed using commercially available software (Horos^{TM} version 3.6.6), default window level (700) and window width (4000) and MinIP to ensure detection of minimal attenuation values of the tympanic sinus. All measurements were performed from multiplanar reconstructions of the CT images to adjust for variations in position of structures of interest and orientation of the rabbit. The vertical axis in dorsal reconstructions was aligned parallel to the nasal septum and the horizontal axis perpendicular to this line. The horizontal axis of the sagittal reconstructions was aligned parallel to the line of the occlusal plane and hard palate, with the cross on the center point of the tympanic bulla, the vertical axis perpendicular to this line. See figure 7.

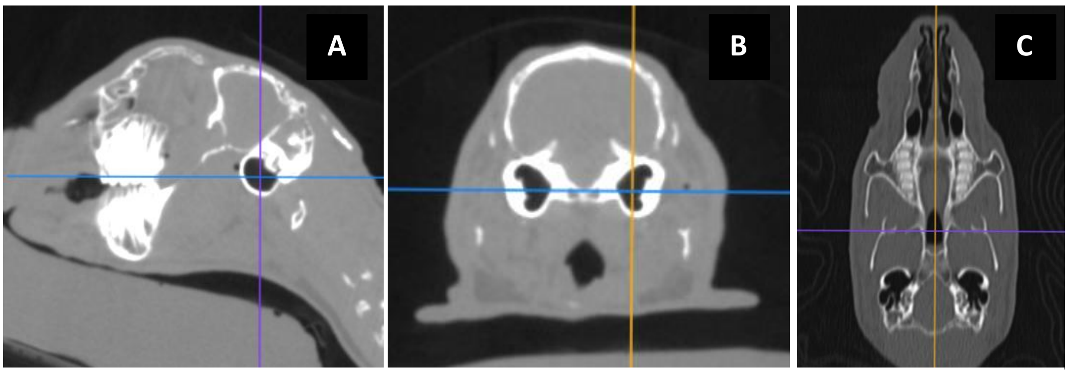


Figure 7. Alignment of the vertical and horizontal axis on the A, sagittal plane (yellow line); B, transversal (purple line); C, dorsal (blue line); plane.

For each case, following parameters were recorded from the CT images: maximum width (mm) of the tympanic sinus (MWTS); maximum length (mm) of the tympanic sinus (MLTS); and maximum height (mm) of the tympanic sinus (MHTS); cross-sectional circumference (mm) of the external bony meatus at the most ventral point (CSC1); cross-sectional circumference (mm) of the external bony meatus at the junction with the cartilaginous external ear canal (CSC2); cross-sectional circumference (mm) of the cartilaginous external ear canal at the estimated middle point (CSC3); and cross-sectional circumference (mm) at the narrowest point of the cartilaginous external ear canal (CSC4). The measurements of the tympanic sinus (MWTS, MLTS, MHTS) were made with a slice thickness to fit the whole area of interest (Fig. 8). The greatest diameter was determined. The MLTS was measured from the sagittal plane (Fig 8A), the MHTS from the transversal plane (Fig 8B), and the MWTS from the dorsal plane (Fig 8C).

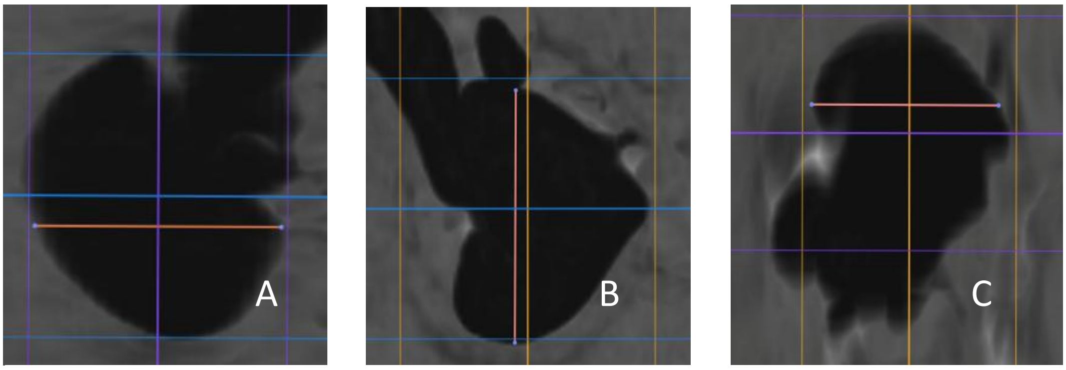


Figure 8. CT view (MinIP) of the tympanic bulla with a wide slice thickness. A, sagittal plane; B, transversal plane; C, dorsal plane. The orange line represents the measurement taken by the student. The yellow lines represent the sagittal plane, the purple lines the transversal plane, and the blue lines the dorsal plane.

The measurements of the external ear canal were made with multiplanar reconstruction (MPR) with 0.5 mm slice thickness, and the axis was placed so that the evaluated part of ear canal was viewed from its center point in all planes (Fig. 9).

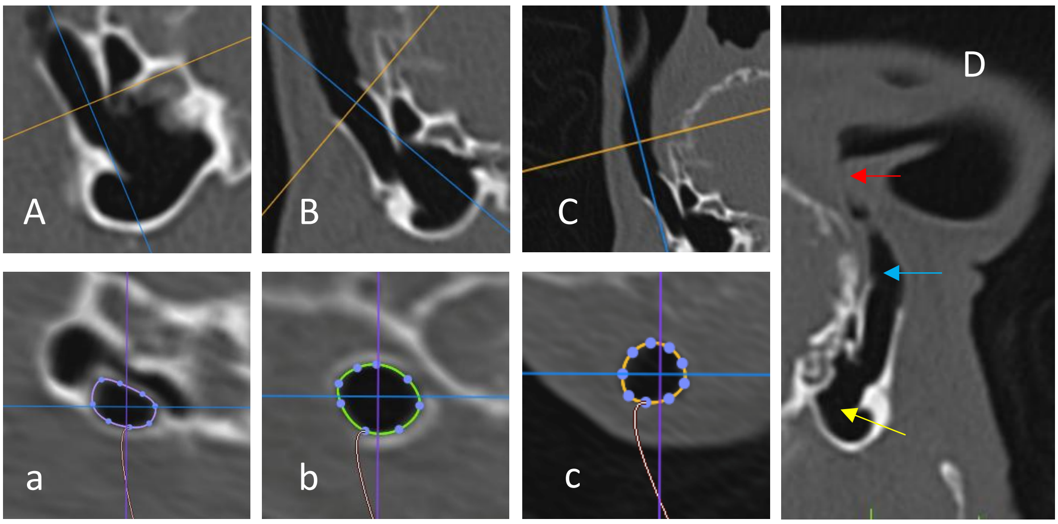


Figure 9. A, showing the level of the measurement at the ventral point of the bony meatus transversal plane; a, cross-sectional circumference of A (purple tracing). B, showing the level of the measurement at the distal point of the bony acoustic meatus transversal plane; b, cross-sectional circumference of B (green tracing). C, showing the estimated middle of the cartilaginous external ear canal; c, cross-sectional circumference of C (orange tracing). D, lop-eared rabbit, view of an external ear canal with distal narrowing where the cross-sectional circumference of the estimated narrowest point was measured (red arrow), external ear canal (blue arrow), tympanic sinus (yellow arrow).

3.4 Statistical analysis

The results for each parameter were recorded in a Microsoft® Excel sheet separately for group L (lop ears) and group E (erect ears). Group L and E-a were compared using a two-sided, independent samples t-test with unequal variances in Excel. The mean, standard deviation, and p-value for each parameter (MLTS, MWTS, MHTS, CSC1, CSC2, CSC3, CSC4) as well as for the weight was reported. A significance level of $p < 0.05$ was considered statistically significant for comparison of group means.

4. Results

4.1 Before adjusting for outliers

4.1.1 Weight distribution between groups

Weight of the rabbits is presented in figure 10. The median of lop-eared rabbits, Group L (2.1 kg) and erect-eared rabbits, Group E (1.95 kg), were not far apart. The range however was notably wider in Group E (4.8 kg) than Group L (1.4 kg) visualized in the figure below. This led to an adjustment for outliers being made, which is presented under heading 4.2.

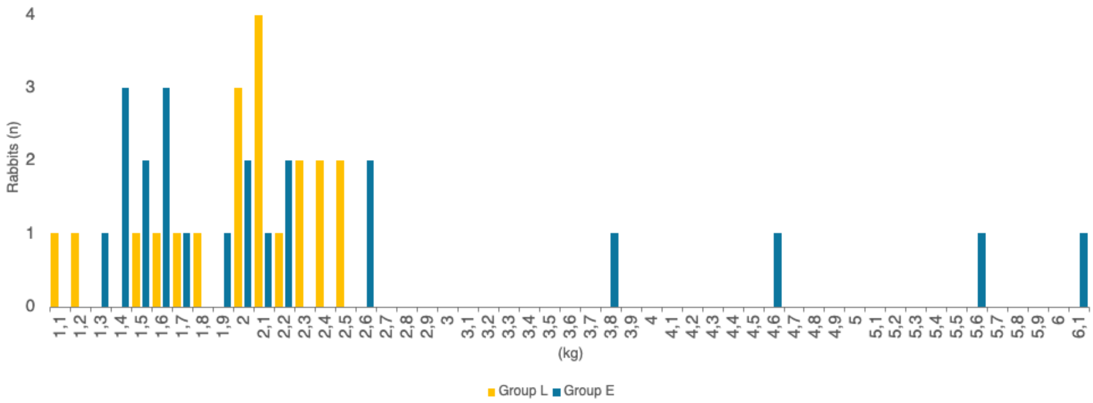


Figure 10. Weight distribution. Group L (n=20), Group E (n=22).

4.2 After adjusting for outliers

4.2.1 Weight distribution between groups

After adjusting for outliers group E (erect-eared rabbits) decreased from 22 to 18 rabbits. This new group was named E-a. The range in the group with erect-ears was lowered from 1.3 – 6.1kg (group E) to 1.3 – 2.6 kg (group E-a) (fig 11). The median of Group E-a was lowered from 1.95 to 1.6 kg. Mean weights were 2 ±0.4 kg (group L) and 1.8 ± 0.4 kg (group E-a). No statistically significant difference (p=0.17) between the mean weight of the groups was found.

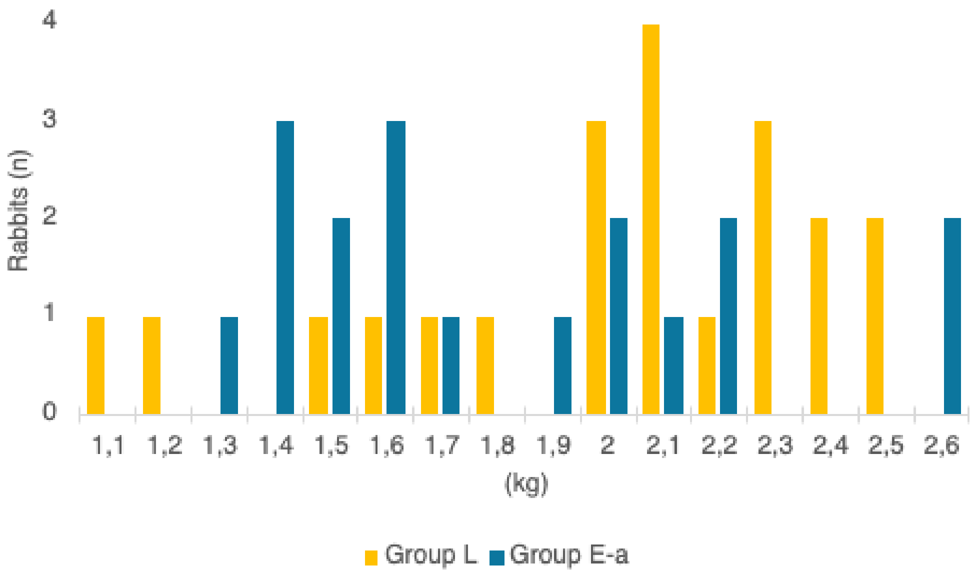


Figure 11. Weight distribution of group L (n=20) and group E-a (n=18) after outliers were excluded from group E.

4.2.2 Breed distribution

The breed distributions in groups L (lop ears) and E-a (erect ears with outliers excluded) are presented in figure 12-13. There was a greater variety of breeds in group E-a than group L. The Dwarf lop breed was heavily overrepresented (70%) in Group L. There was a greater percentage of rabbits with unknown breed in Group E-a (28%) compared to Group L (15%).

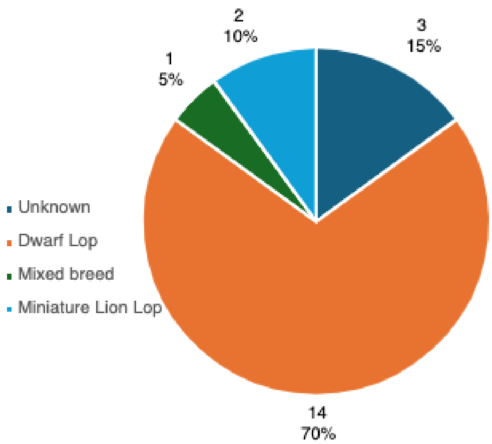


Figure 12. Distribution of breeds in group L (n=20)

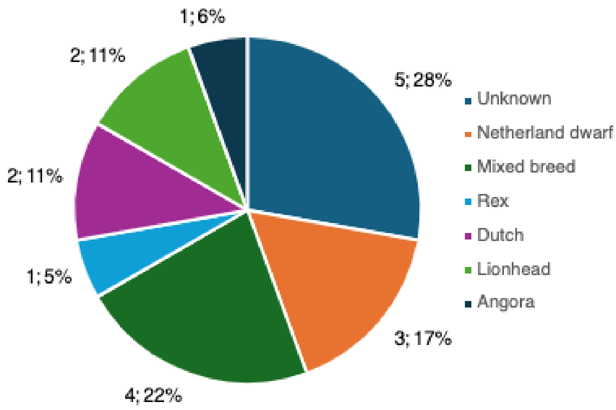


Figure 13. Distribution of breeds in group E-a (n=18)

4.2.3 Measurements of the tympanic sinus

Measurements of tympanic sinus are described below (Fig. 14). No evident differences between the groups were seen.

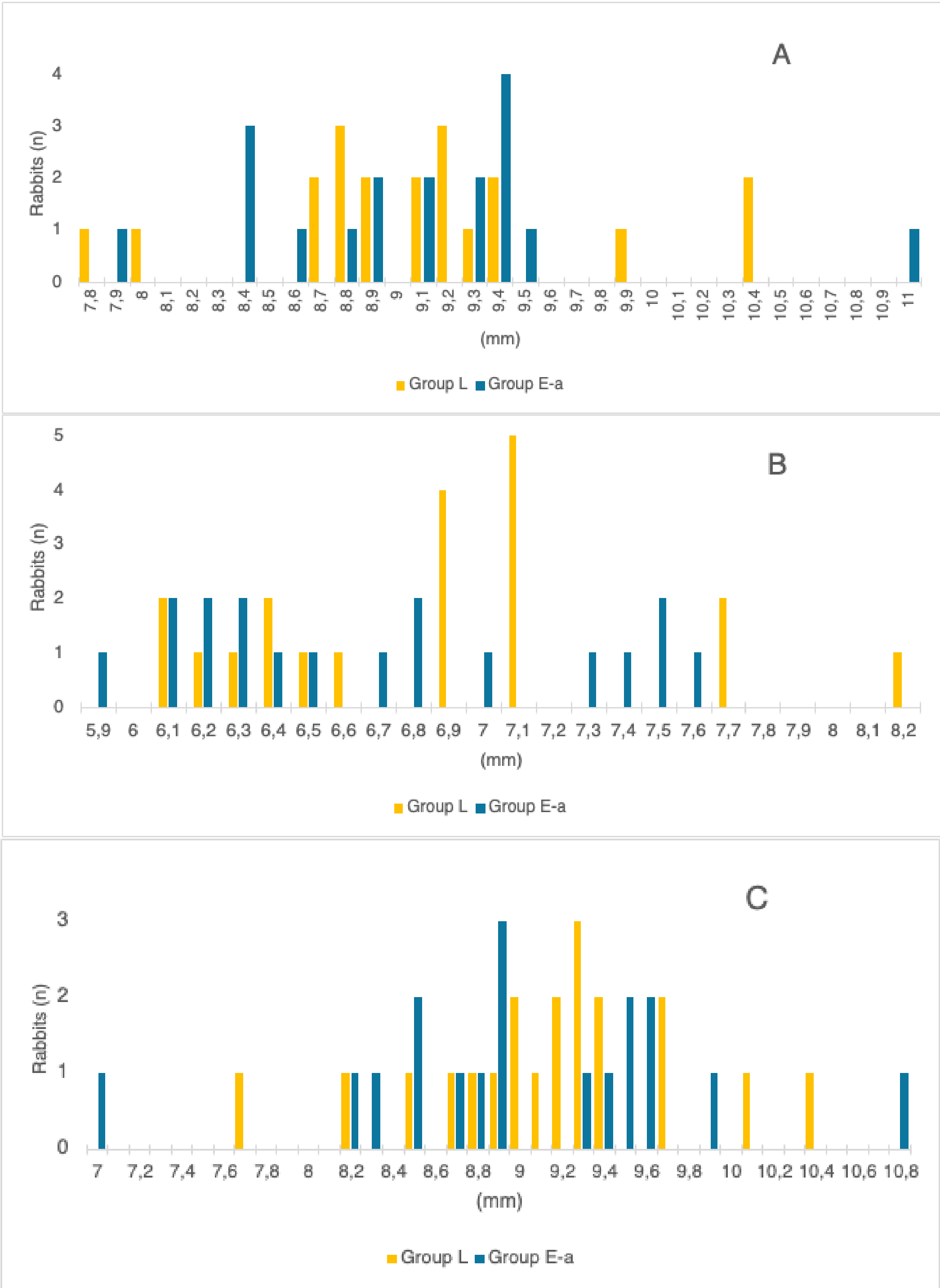


Figure 14. Results for A) max length of the tympanic sinus (MLTS); B) max width of the tympanic sinus (MWTS); C) max height of the tympanic sinus (MHTS) of group L (lop-eared rabbits) (n=20) and E-a (erect-eared rabbits) (n=18).

4.2.4 Measurements of the external ear canal

The cross-sectional circumference of the external ear canal was measured at four levels and is presented in figure 15 – 17. Group L represents the lop-eared rabbits (n=20), and group E-a the erect-eared rabbits (n=18) in these figures. No evident differences between the groups were seen in the cross-sectional circumference of the most ventral part of the osseus external meatus (CSC 1) and the osseus external meatus proximal to the junction with the cartilaginous meatus (CSC 2).

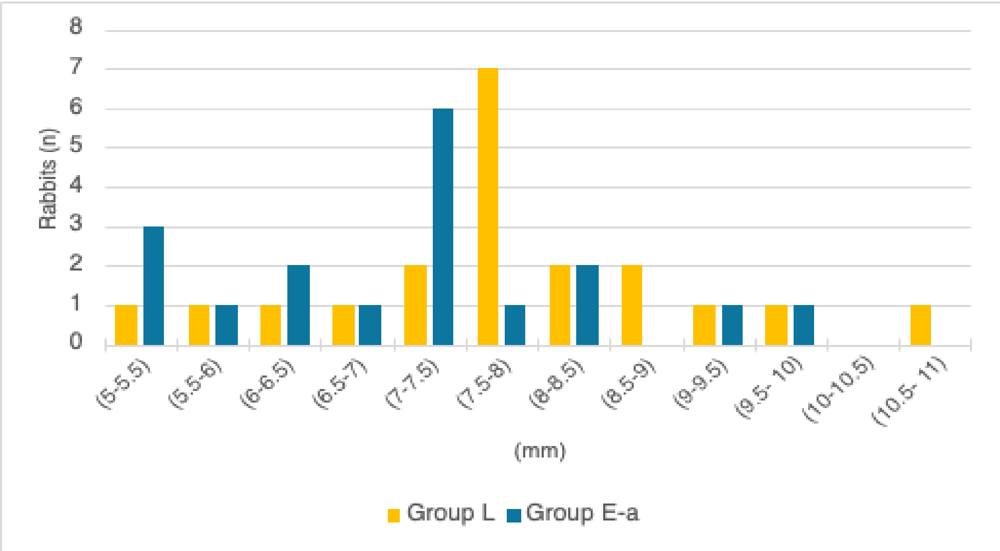


Figure 15. Histogram of the CSC 1.

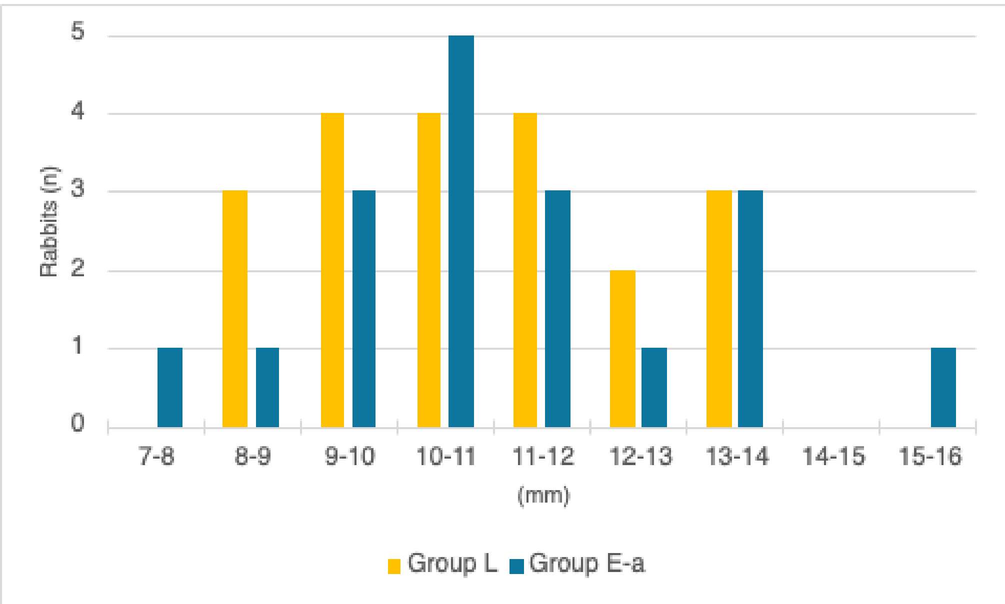


Figure 16. Histogram of the CSC 2.

A clear difference was seen in between group L and E-a in the cross-sectional circumference of the cartilaginous meatus at the estimated middle point (CSC 3) (Fig. 17), and in the minimal cross-sectional circumference of the cartilaginous meatus (CSC 4) (Fig. 18).

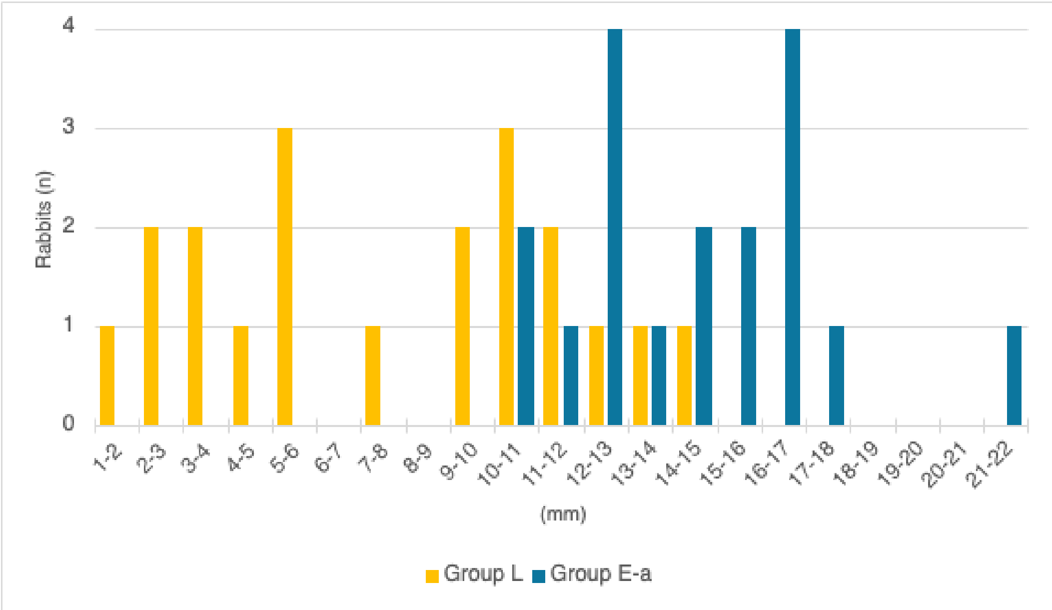


Figure 17. Histogram of the CSC 3.

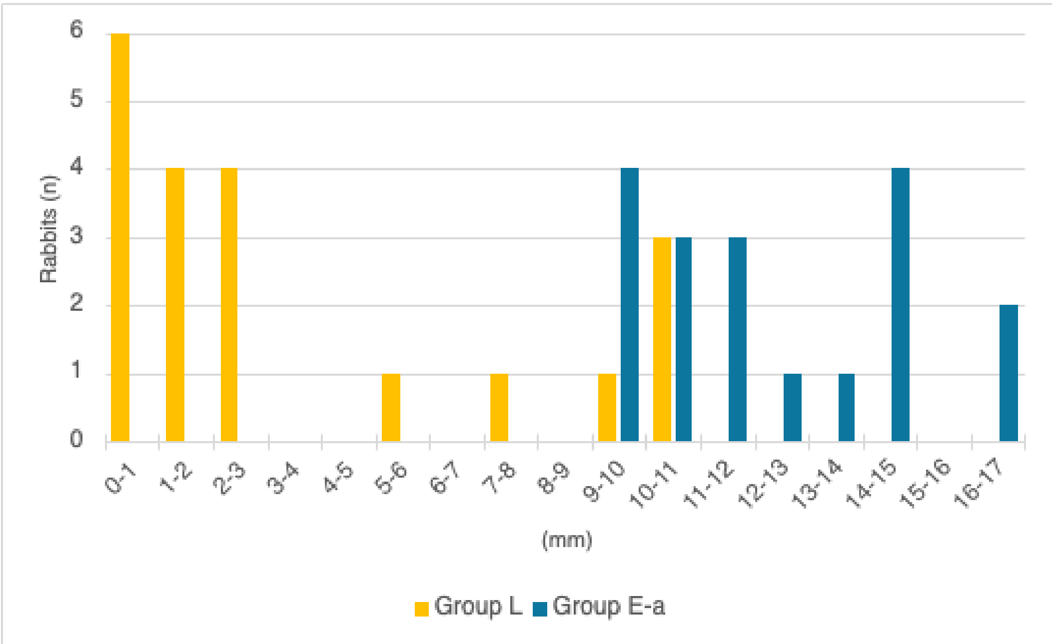


Figure 18. Histogram of the CSC 4.

4.2.5 Overview of all parameters

An overview of the mean value, standard deviation, range, and p-value for each parameter is presented below in table 3. For each parameter, independent t-test for comparison of the mean between the groups was conducted as described in material and methods.

A significant difference between the means of the groups was found in the cross-sectional circumference at the estimated middle point (CSC 3) and minimal cross-sectional circumference of the cartilaginous meatus (CSC 4). There was no statistically significant difference between the means between the groups for the remaining parameters (MLTS, MWTS, MHTS, CSC 1, CSC 2), and for these parameters, the groups were combined, and the mean was calculated (Table 4).

Table 3. Results of the measurements. Presented mean ± standard deviation (range). The table also shows the p-value for the comparison of the mean between the two groups. Group L (n=20) and Group E-a (n=18).

Measurement	Group L	Group E-a	P-value (t-test)
MLTS[1]	9.1 ± 0.6 mm (7.8 – 10.4)	9.1 ± 0.7 mm (7.9 – 11)	0.88
MWTS[2]	6.9 ± 0.6 mm (6.1 – 8.2)	6.7 ± 0.6 mm (5.9 – 7.6)	0.37
MHTS[3]	9.1 ± 0.6 mm (7.7–10.4)	9.0 ± 0.8 mm (7.0 – 10.8)	0.58
CSC 1[4]	7.8 ± 1.4 mm (5.3 – 11)	7.0 ± 1.3 mm (5.0 – 9.7)	0.07
CSC 2[5]	10.7 ± 1.6 mm (8.2 – 13.3)	11.1 ± 2.0 mm (7.7 – 15.6)	0.54
CSC 3[6]	7.7 ± 4.0 mm (1.7 – 14.3)	14.5 ± 2.8 mm (10.1 – 21)	**$1.2 \times e^{-6}$**
CSC 4[7]	3.5 ± 4.0 mm (0 – 10.9)	12.2 ± 2.4 mm (9.1 – 16.6)	**$1.2 \times e^{-9}$**

[1] mean length of the tympanic sinus, [2] mean width of the tympanic sinus, [3] mean height of the tympanic sinus, [4] cross-sectional circumference the most ventral part of the osseus external meatus, [5] cross-sectional circumference of the osseus meatus proximal to the junction with the cartilaginous meatus, [6] cross-sectional circumference of the cartilaginous meatus at the estimated middle point, [7] cross-sectional circumference of the minimal cross-sectional circumference of the cartilaginous meatus

Table 4. Results of both groups combined (n= 38) presented as mean value ± standard deviation (range).

Measurement	All cases
MLTS[1]	9.0 ± 0.6 mm (7.8 – 11)
MWTS[2]	6.8 ± 0.5 mm (5.9 – 8.2)
MHTS[3]	9.1 ± 0.7 mm (7 – 10.8)
CSC 1[4]	7.5 ± 1.4 mm (5 – 11)
CSC 2[5]	11.0 ± 1.8 mm (7.7 – 15.6)

[1] mean length of the tympanic sinus, [2] mean width of the tympanic sinus, [3] mean height of the tympanic sinus, [4] cross-sectional circumference the most ventral part of the osseus external meatus, [5] cross-sectional circumference of the osseus meatus proximal to the junction with the cartilaginous meatus

5. Discussion

This study aimed to present measurements and evaluate if there are size differences in the tympanic sinus and lumen of the external ear canal between healthy ears with lop versus erect conformation. CT measurements of each individual ear were made at four points of the external ear canal, and the length, width, and height of the tympanic sinus was obtained. The group means for each parameter were compared using independent t-test to investigate differences.

5.1 The external ear canal

This study found that ears with lop conformation (Group L) had a statistically significant smaller mean cross-sectional circumference of the ear canal at the midpoint of the cartilaginous portion (CSC3). This finding supports that lop ear conformation is associated with a narrower cartilaginous external ear canal, which is in line with the suggested ear canal stenosis by some publications (Capello 2004; Chow 2011; Chitty & Raftery 2013; Johnson & Burn 2019). These publications have not described this morphological difference in lop-eared rabbits in greater detail, nor was it the aim of this study. Further investigation into the morphology and extent of the stenosis of the cartilaginous ear canal in lop eared rabbits is needed.

A statistically significant difference in the minimal cross-sectional circumference of the cartilaginous ear canal (CSC4) between Group L (lop-eared) and Group E-a (erect-eared) was also found. Group L showed a smaller value, further supporting the presence of a narrower external ear canal in lop-eared rabbits. Previous publications have indicated that the folding of the pinna causes flexion and narrowing of the external ear canal at that point (Capello 2004; Chitty and Raftery 2013). The identification of the narrowest point was beyond the scope of the present study; however, it was observed that all measurements of 0 mm in CSC4 of lop-eared rabbits were in proximity to the region of the pinna's fold. The clinical relevance of stenosis related to pinna folding in lop-eared rabbits has not been explored in research. The variation in ear placement during CT examinations is a limitation for evaluating the minimal cross-sectional circumference (CSC4) in this study. Some ears were positioned in the natural position (folded or upright), while others were notably wrapped and tucked into position on the dorsum or the head. If all ears had been positioned in their natural, unaltered position, the results may theoretically have shown a larger proportion of lop-eared rabbits with complete collapse of the external ear canal lumen at the point of flexion. Conversely, if all ears had been resting on the rabbit’s dorsum, there may have been less variation in the measurements of the lumen. Further studies evaluating the effect of ear positioning on the cross-sectional diameter of the ear canal could be investigated, as the positioning of the ears during CT-examination may be of importance to rabbits with a clinical question of ear disease. Further research into the extent of collapse of the cartilaginous external ear canal that is associated with the folding of the pinna could improve our understanding of the narrowing of the lumen in lop-eared rabbits. Additionally, other factors, such as a less rigid ear cartilage, may influence the degree of this collapse.

5.2 The tympanic sinus

The hypothesis that ears with lop conformation have a smaller tympanic sinus was not supported by the findings of this study. The mean value for the parameters of the tympanic sinus measured in this study were very similar between lop and erect ears. The total length and height of the tympanic sinus were almost identical, while the width was smaller than the other dimensions in both lop and erect-eared rabbits. These findings suggest that the tympanic bulla is ellipsoid with the width representing the shortest axis. However, previously described measurements in King *et al.* (2007) suggest a different morphology, with the length representing the longest axis, while the width and depth (i.e. height) were smaller. This morphological variation could possibly be breed-related, similar to what is observed in dogs, where certain breeds exhibit distinct differences in bulla morphology (Salgüero *et al.* 2016; Mielke *et al.* 2017). King *et al.* (2007) specifically examined New Zealand White rabbits, whose bulla length and width differed significantly from this present study which included a diverse mix of breeds. Additionally, King *et al.* (2007) had a significantly smaller sample size (eight ears in four rabbits) compared to the 38 rabbits in the present study. The small sample size affects the statistical power negatively of the acquired measurements. The method of measuring may also contribute to differing results, as the present study used intraluminal measurement of CT images, while King *et al.* (2007) used calipers upon dissection, which would result in larger value if measured extraluminally.

It was not possible to draw conclusions regarding breed-specific size differences of the tympanic sinus in the present study, as the parameters were not compared between different breeds. Other important factors to the morphology of the tympanic bulla, such as wall thickness, bulla shape, and bulla volume, were not evaluated in the present study. Including these factors in future research could provide insight into the pathophysiology and predisposing factors for otitis media in lop-eared rabbits.

5.3 Limitations of the study

The generalizability of the results to the general population of pet rabbits may be partly limited as the studied population was limited to rabbits weighing between 1.1 to 2.8 kg. Group L (lop ears) had a slightly higher mean weight (2.0 kg) than Group E-a (erect ears; 1.8 kg), however there was no statistically significant difference between the mean weight of both groups. If there is a strong correlation between weight and ear size, weight difference may have introduced a bias, potentially affecting the results. The observed differences between the groups might have been more pronounced if the rabbits in the two groups had been size matched. The body condition score or a ratio of the measurement to a body structure to account for size differences was not included in the analysis due to insufficient data in the medical records and resources. However, implementing these methods would likely have increased the internal validity of the study by providing a more accurate representation of the rabbits' body size.

It is unclear whether the representation of breeds included in this study accurately reflects the population of pet rabbits in Sweden due to a lack of statistical data on the general population. Group L predominantly consisted of Dwarf Lops, while Group E-a contained a larger proportion of mixed-breed and unknown-breed rabbits. It is possible that this study did not include a greater number of breeds with lop ear conformation due to Dwarf lops being more common, or theoretically, being predisposed to pathologies that tend to be evaluated with CT, such as dental disease. Therefore, it is possible that the results of this study may not be applicable to all lop-eared breeds.

Several limitations should be considered when interpreting the results of this study. First, the sample size for each group was relatively small, which may limit the statistical power and generalizability of the findings to the broader population. Second, the study involved CT scans obtained from different CT machines (cone beam and helical CT), which could introduce variability in image quality and measurement accuracy, potentially affecting the consistency of the data. Third, all measurements were performed by a single individual, which introduces the potential for measurement bias. Although efforts were made to standardize the method of measurement, this approach eliminates the ability to assess inter-rater reliability and increases the risk of subjective errors or inconsistencies in measurement techniques. Additionally, the study did not use advanced statistical models to control for multiple confounding factors, such as age, breed, and body condition score, which may have influenced the observed results. These factors could have introduced bias and limited the ability to draw definitive conclusions regarding the relationships between ear conformation and size differences of the ear canal and tympanic sinus.

5.4 Conclusion and future opportunities

This study provides insight into the anatomical differences between lop-eared and erect-eared domestic rabbits, particularly of the external ear canal and tympanic sinus. The results confirm the hypothesis that lop-eared rabbits have a narrower external ear canal in the cartilaginous portion and supports previous hypotheses suggesting a predisposition for ear canal stenosis in this group. No significant differences were found in the bony external ear canal or the size of the tympanic sinus between the two groups. The hypothesis that lop-eared rabbits have a smaller tympanic sinus was not supported by the data, as no significant size differences were found between the groups.

Although the study has provided valuable insights, further research is needed to explore the full clinical relevance of ear canal stenosis in lop-eared rabbits, particularly the significance of the pinna folding. Future studies could use statistical modelling and investigate the morphological differences of the tympanic bulla across various breeds and address potential confounders such as body condition score, body size, breed, and age. Despite the limitations, including the relatively small sample size, variation in CT machine types, and potential measurement bias, this present study contributes to a better understanding of the ear morphology of lop-eared rabbits compared to erect-eared rabbits.

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Popular science summary

Recent studies on rabbit welfare have highlighted a growing interest in how physical traits, such as ear conformation, affect their quality of life. Particularly lop-eared rabbits, which make up a significant portion of pet rabbits, have been shown to be more prone to ear diseases - specifically outer and middle ear infections. These conditions are believed to stem from anatomical changes in their ears, such as narrow ear canals and folding ear flaps, which can hinder proper drainage and increase the risk for disease. However, while the link between lop ear conformation and disease of the outer and middle ear is widely acknowledged, there are still uncertainties on the mechanism involved. There is a lack of detailed studies comparing the anatomy of rabbits with different ear conformation. Further research is needed to better understand how lop-ear conformation affects ear health, so that pet owners and veterinarians more effectively can prevent and treat these conditions.

In this study, a retrospective analysis was conducted to compare sizes of the ear structures in lop-eared and erect-eared rabbits using computed tomography (CT). The medical records of rabbits that had been referred for specialist image interpretation or underwent CT scans at the University Animal Hospital of SLU between 2021 and 2024 were reviewed. Ears from rabbits of all ages, sexes, weights, with no history of ear disease were included. The rabbits were divided into two groups based on their ear conformation: lop-eared rabbits (Group L) and erect-eared rabbits (Group E-a). One healthy ear per rabbit was assessed, and measurements of the tympanic bulla (middle ear) and external ear canal (outer ear) were taken at specific points from the CT images. The measurements included the length, width, and height of the tympanic bulla, as well as the cross-sectional circumference of the external ear canal (outer ear) at 4 different levels. Data analysis was performed using Microsoft® Excel. Outliers in weight were identified and excluded from the analysis, and an independent t-test was used to compare the groups. Statistical significance was set at a p-value of less than 0.05. This approach aimed to provide an accurate comparison of the ear anatomy in the two groups, focusing on potential differences in ear canal and bulla size.

The results showed that lop-eared rabbits have a narrower soft part of the external ear canal compared to erect-eared rabbits, supporting previous hypotheses suggesting it in this group. The hypothesis that lop-eared rabbits have a smaller tympanic bulla was not supported by this study, as no significant size differences were found between the groups.

While this study provides valuable insights into anatomical differences in ear structure between rabbit breeds, further research is needed to better understand the clinical significance of a narrower ear canal in lop-eared rabbits and folding of the ear flap. Future studies should look at the differences in the outer and middle ear across different breeds and consider factors like body size, breed, and age, with the use of more advanced statistic models. Despite limitations such as a small sample size, differences in CT machines, and possible measurement errors, this study contributes to better understanding the ear anatomy of lop and erect-eared rabbits.

In conclusion, these findings emphasize the importance of monitoring the ear health of lop-eared rabbits, as their unique ear anatomy may require special attention to prevent and manage ear diseases effectively.

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