Data availability statement

The data that support the findings of this study are available from the corresponding author, [MC], upon reasonable request.

Key points

- Exostosis is a benign, irreversible growth of bone in the external auditory canal commonly seen in aquatic enthusiasts such as surfers and swimmers.
- Traditional assessment of the severity of exostosis is by visual estimate during otoscopic exam, with four grades; Grade 0 (no identifiable exostosis), Grade 1 (less than 33 percent obstruction), Grade 2 (≥34% to ≤ 66% obstruction) or Grade 3 (> 67% obstruction).
- Gold standard diagnostic assessment of exostosis severity is traditionally via computerized tomography; however, this technique exposes the patient to high dose radiation, is expensive and cannot typically be conducted during appointments.
- We describe a novel analysis of exostosis using National Institute of Health public domain software which allows accurate determination of the severity of exostosis from otoscopic exam images during patient consults.
- ImageJ analyses presents an accurate, highly reliable, time and cost-efficient method of exostosis analysis in clinical practice and research.

Text

Introduction

External auditory exostosis is attributed to hyperostosis of the temporal bone, usually multiple and found bilaterally. The mechanism for development of exostosis is believed to be a resultant of exposure to cold water and cold air (particularly below 19ºC) (1); however, the condition is considered to be idiopathic. Contrary to this widespread belief, we recently documented exostosis in surfers limited to warm water conditions, with water temperatures ranging from 20.6ºC (69.1ºF) in winter to 28.2ºC (82.8ºF) in summer.(2)

Exostosis is typically diagnosed by otoscopic examination with severity reported as Grade 0 (no exostosis identifiable), Grade 1(≤ 33 percent obstruction), Grade 2 (≥ 34% to ≤ 66% obstruction) or Grade 3 (≥ 67% obstruction) (Figure 1).(3)

FIGURE 1. Otoscopic images identifying severity of exostosis.

In Grade 1, exostosis is usually asymptomatic; however, increased severity is associated with symptoms which can include water trapping, recurrent cerumen blockage, otitis externa, otalgia and deterioration of hearing. (7) The treatment currently available for Grade 3 or highly symptomatic exostosis, is surgical removal; however, there are risks associated with this procedure which can include permanent hearing loss, facial nerve injury, tympanic membrane rupture and infection. (4)

Exostosis is the most common benign tumors of the external auditory canal in surfers (and other aquatic enthusiasts) with an estimated 60 to 74 percent reported to have at least Grade 1 in a number of studies (6, 10) and as high as 95 to 100 percent in professional surfers. (5) In our recent study of exostosis prevalence among surfers (5) we encountered difficulty with determining severity in a number of the participants (approximately 20%) where their degree of stenosis was not clearly identifiable as Grade 1, Grade 2 or Grade 3.

Although established clinical best practice for diagnosis of exostosis and its severity is based upon visual estimate of the degree of stenosis during the otoscopic exam, this will be particularly problematic when a clearly defined severity is not evident, or the clinician is determining the progression of the disorder or where the clinician intends to conduct serial otoscopic examinations for research purposes. Serial otoscopies in an attempt to determine the rate of progression of exostosis, which is currently unknown. We therefore sought an uncomplicated, efficient methodology whereby clinicians can accurately determine the severity of the condition (percent of occlusion of external auditory canal by lesions) which is applicable for a patient visit or serial otoscopies over time.

Technical description

In this study we followed (as practical as possible) the AGREE reporting for clinical practice. (6) Initially, we conducted a review of computer aided design and drafting software programs that would provide analyses (diameter for calibration and perimeter for area determination) of irregularly shaped objects. Ideally, the software program would be designed for medical and/ or biological analyses and with an established high validity and reliability.

ImageJ is a freely available (public domain) Java image processing software which was developed by the National Institute of Health (NIH) , it is operational on an online applet, as a downloadable application or any computer using Microsoft, Apple or Linux operating systems that are running with Java version 5.0 or later. The software was specifically designed for biological imaging and supports a multitude of image formats (i.e., TIFF, GIF, JPEG, BMP) which can be stacked to allow serial images to be viewed and/or analyzed simultaneously. Additionally, ImageJ has been previously shown to have an outstanding validity ($r = 0.988$) and reliability (Cronbach's alpha = 0.994) (7) and is utilized in a number of medical fields, including computerized tomography analyses, blood vessel diameter analyses, abdominal and skeletal muscle mass and wound healing. (8).

All otoscopic examinations were completed with a digital otoscope (Digital MacroViewTM, halogen HPX fiber-optic otoscope, Welch Allyn®, Skaneateles Falls, NY, USA) attached to a laptop computer. This otoscope provided live images displayed on a high-resolution computer monitor. The images were saved digitally in JPEG file format to be visually analyzed for presence and severity of exostosis. We then repeated the analysis using ImageJ for percentage occlusion of the external auditory ear canal.

Results and analysis

The analysis initiated with the assumption that rounding to a 10th of a millimeter^2 was sufficient for the purpose of estimating exostosis percent ((exostosis area mm2/auditory canal area mm2)*100).

The next step was to determine if an area of an object captured in an image could be accurately assessed with ImageJ. As such, an image of a micrometer (Vernier callipers, dual graduation dial, model SCMT26118, factory accuracy of 0.025mm) set to 10.0 mm was placed in the field of view of the digital otoscope and an image was captured (Figure 1). The image was then imported into ImageJ and used for software linear calibration of pixels to mm. Following this process, images of US coins of a quarter and a dime were captured. The images were collected at the same position in the field of view (depth) as that of the micrometer image. The coins were placed on a flat surface such that the images were collected at a 90-degree angle to the coin surface. The images of the coins were then imported into ImageJ for analysis. Silhouettes using freehand selections were then sketched around the perimeter of each of the coins and the captured area within the perimeters of the coin silhouettes was then calculated by the ImageJ software. The known diameter of a US dime and quarter are 17.91 mm and 24.26 mm, respectively. As such the known areas of a US dime and quarter are: 251.9 mm^2 and 462.2 mm^2. The ImageJ assessed areas of the US dime and quarter were: 252.3 mm^2 and 477.9 mm^2. The difference in areas between the known and assessed values of the US dime and quarter were: 0.15% and 3.4% respectively. Given the small acceptable deviations between the known and ImageJ measured areas of the US coins we proceeded to the next phase of the analysis.

Figure 2. Otoscopic calibration using Vernier callipers and a metal ruler.

An image from our recent study which exhibited borderline Grade 1 to Grade 2 exostoses (Figure 2) was selected for analysis and imported into ImageJ. Clinicians could not meet consensus upon the severity, split between Grade 1 (n=6) and Grade 2 (n=4) (Figure 3). A silhouette was then sketched around the perimeter of the auditory canal and the exostoses. The areas contained within the perimeters of the silhouettes were then calculated with ImageJ. Exostosis percent was then calculated ((exostosis area mm^2/auditory canal area mm^2)*100). Analyses (test, re-test) of the otoscopic image to establish severity of exostosis was completed in two minutes and resulted in an exostosis percentage of 38.1%, with a repeat measurement at 37.6%. These two measurements confirmed a Grade 2 severity of exostosis for this particular patient.

An independent clinician measured one image ten times (total area and exostosis area), the coefficient of variation (CoV) was 0.22% for the total area and 0.64% for the exostosis area. The same clinician then repeated duplicate measurements of five images (with varying severities of exostosis) using the methods described above. The technical error of measurement (TEM) was 0.37 and relative TEM was 0.83%. The coefficient of reliability ($R=1-TEM^2/SD^2$) was R=0.999. A bivariate correlation with Pearson correlation coefficient (two-tailed) of the total area and exostosis area was found to be significant ($p<0.01$, $r=0.999$) and a near perfect positive relationship between repeated measurements. The aforementioned statistics: CoV, TEM%, R, and r suggest the analysis procedures provide highly consistent results.

Figure 3. Example otoscopic image of a surfer's left ear with ImageJ analyses indicating Grade 2 severity of exostosis.

Discussion

In this paper, we present a novel, time and cost-efficient method of analysis for clinicians to accurately determine the severity of exostosis via otoscopic exam digital images. Given exostosis are three dimensional in nature, high resolution computerized tomography is considered the gold standard(9) for quantification. However, this technique requires referral for specialized imaging, predisposes the patient to high dose radiation and cannot be completed within the same appointment.

Magnification error may be considered a potential limitation in our recommended analysis; however, the procedure assesses relative areas (external auditory canal and exostosis) as opposed to quantifying absolute 3D measurements of the exostosis. In the event a clinician is going to use this technique for serial measurements, the expectation is the exostosis will enlarge and change shape. Given exostosis severity is determined by percentage occlusion of the external auditory canal as viewed during otoscopic examination, our proposed analysis is appropriate for best practice. Our novel methodology has wide clinical use in accurately assessing the severity of exostosis in day-to-day practice and in research settings.

Competing interests

All authors declare that none of the authors have any disclosures to share, nor any conflict of interest.

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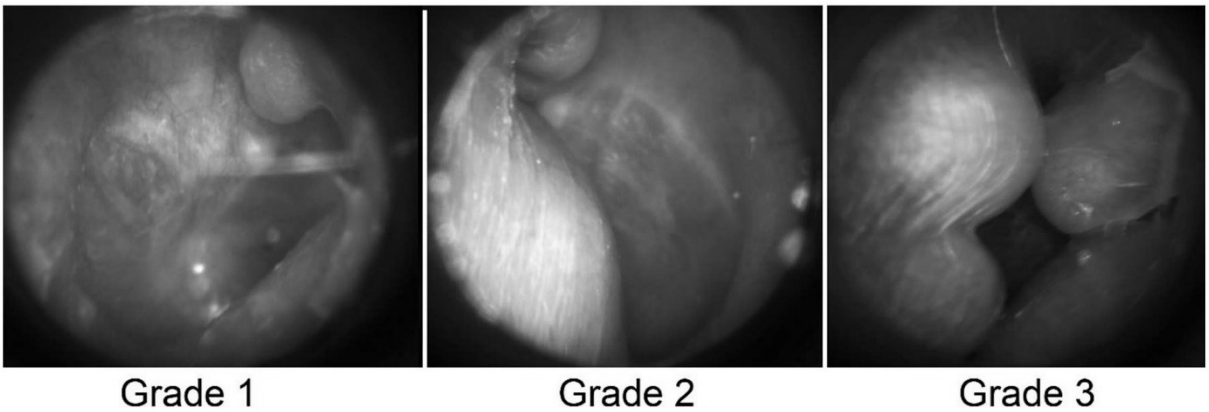

Figure 1.

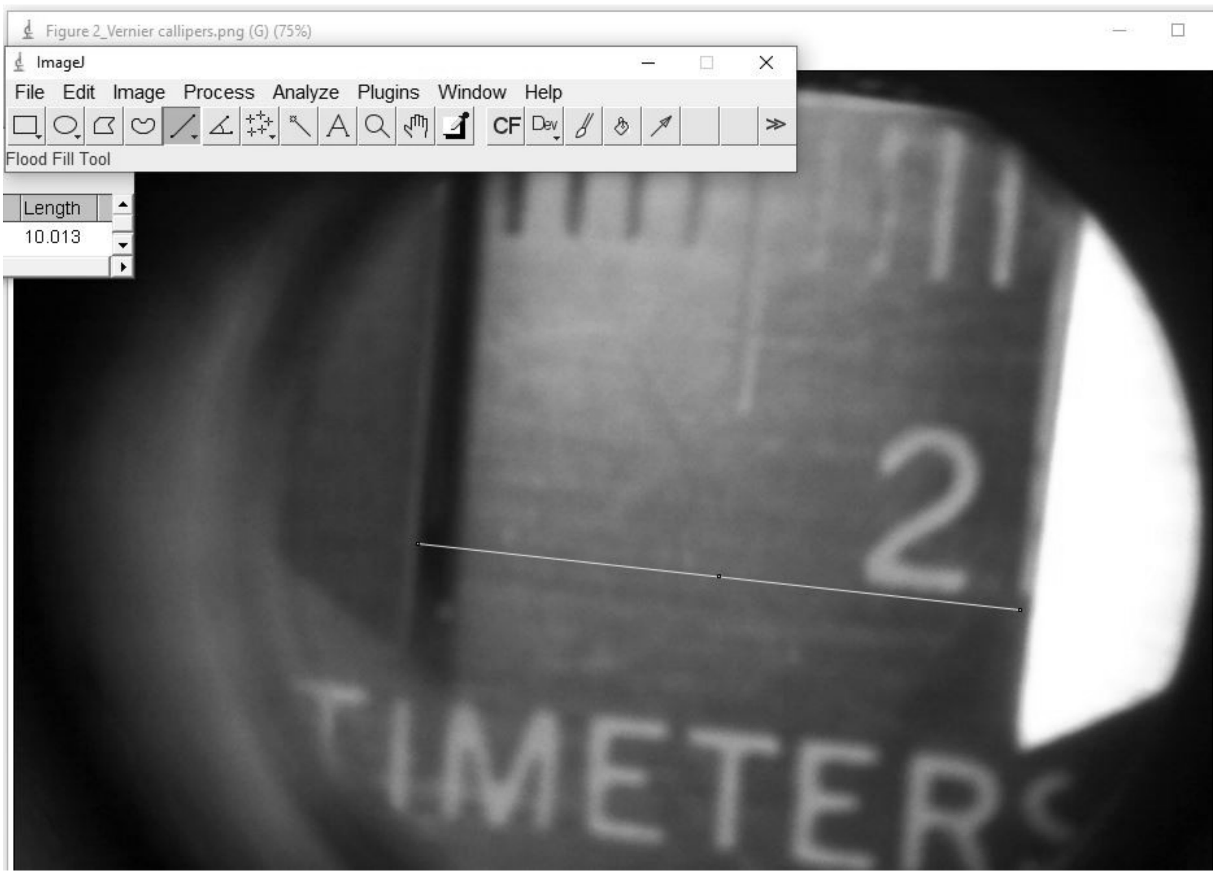

Figure 2.

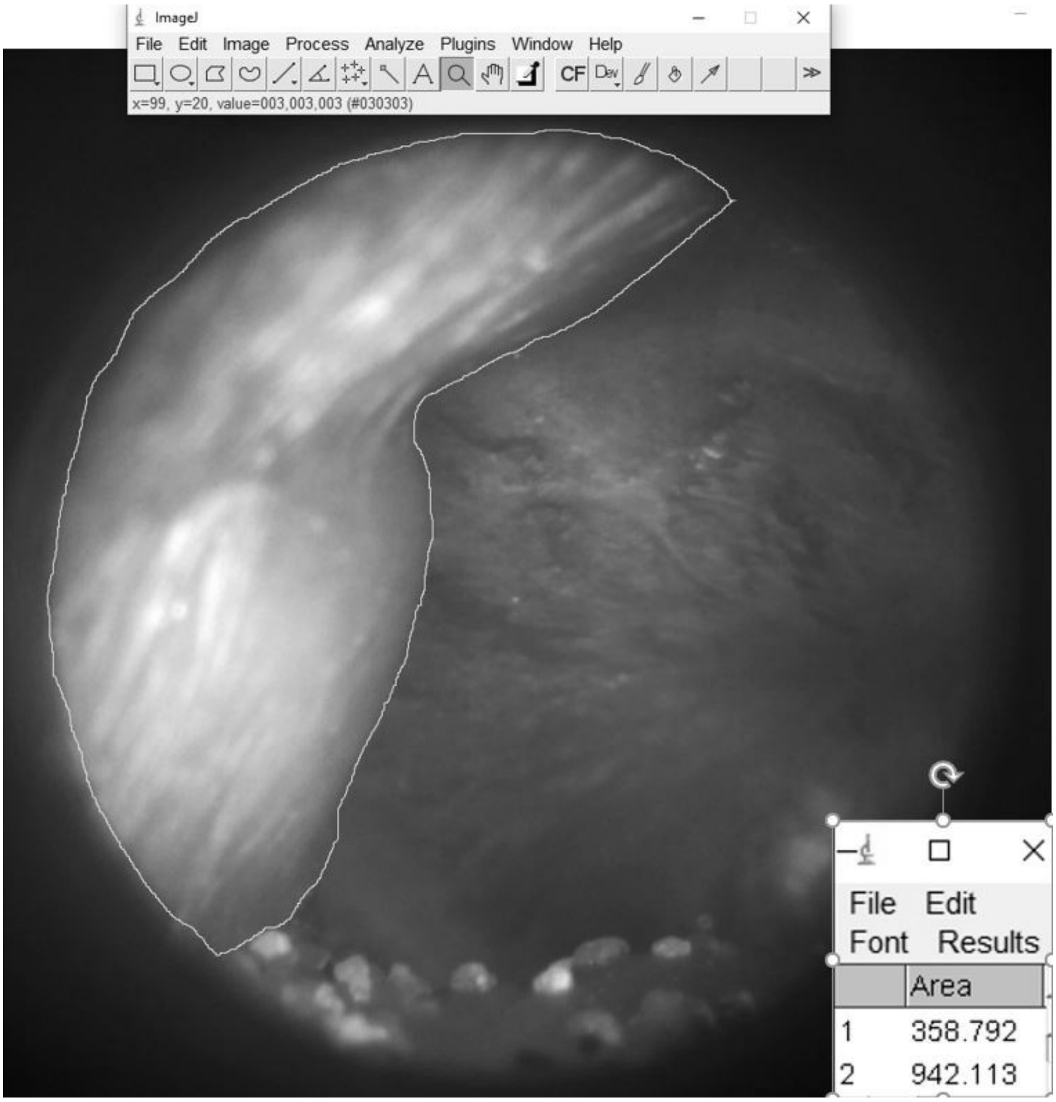
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Figure 3.