The principle objective of this paper is to review some of the disabilities associated with unilateral conductive loss, as well as two methods of predicting patient benefit from middle ear surgery, and preliminary data that validate the methods outlined.

**Unilateral Hearing Loss**
In adults, unilateral hearing loss is commonly associated with difficulty in sound localization, difficulty in hearing and understanding speech. Traditionally, otologists have reported the results of middle ear surgery as the closure of the air-bone gap or the reduction in air conduction thresholds. The closure of the air-bone gap refers to improvement of the air conduction thresholds (involving conductive and sensorineural components) to the level of the bone conduction thresholds (sensorineural component). While these provide a measure of the technical success of the operation, they may not always translate into real life benefit for the patient. This is because listening is a binaural task, while the benefit to the patient is determined by factors such as hearing in the non-operated ear. In this paper, the two most common methods used to estimate patient benefit from middle ear surgery are reviewed; these methods are the Glasgow Benefit Plot and the Belfast Rule of Thumb. Both methods are based on perceived subjective benefit to patients. In fact, little objective data currently exist that measure the benefit to patients undergoing middle ear surgery. In this discussion, a new, more objective method is introduced, with preliminary evidence that supports the validity of the standard current methods.

**Introduction**
Both ear surgeons and patients alike hope for an improvement in hearing and also a functional benefit from middle ear surgery to correct unilateral conductive hearing loss. The potential benefit for any surgical procedure is different depending on specific patient characteristics. In particular, unilateral or grossly asymmetric conductive hearing loss is challenging for ear surgeons. If hearing is much better in one ear, the benefits of improving the hearing in the worse ear are not as clearly defined as they are in bilateral symmetric hearing loss. In the latter case, there is an obvious increase in benefit with any improvement in hearing.

Many patients who present to an ear surgeon with a conductive hearing loss have only one ear impaired. In addition, with bilateral conductive loss, the degree of hearing impairment is often asymmetric. Traditionally, the most common methods used to assess hearing improvements from middle ear surgery have been the post-operative closure of the air-bone gap and improvements in air conduction thresholds. The first method measures the technical success of the operation, while the second method measures the decrease in monaural disability. While this improvement in hearing is a desirable outcome, it does not always translate into real life benefit, since neither of these methods takes into account the role of the contralateral ear in hearing. Furthermore, as with any surgery, there are many technical risks associated with middle ear surgery, which must be balanced against potential benefits. In particular, the risk of damage to the inner ear must be considered.

Other methods have been used to evaluate the effectiveness of middle ear surgery including questionnaires that evaluate a patient’s subjective benefit from surgery. Using questionnaires to evaluate benefit is complicated by the fact that both surgeons and patients want to believe that the operation has succeeded. At the present time only subjective interpretations are available, although more objective measures would be desirable. The two
most common methods found in the otologic literature to evaluate patient benefit from middle ear surgery are the 15/30 dB ‘Belfast Rule of Thumb’ and the Glasgow Benefit Plot.

Belfast Rule of Thumb
Smythe and Patterson developed the Belfast Rule of Thumb based on analysis of the relationship between the patient’s perceived subjective benefit and post-operative audiometric changes. The subjective perception of operative success compared with the degree of symmetry indicated that the least satisfied patients were those whose degree of symmetry differed by more than 15 dB. (The degree of symmetry is the difference in hearing between the ears.) The results showed that patients were likely to report significant benefits if the average air conduction threshold (for 0.5, 1, 2 kHz) was ≤ 30 dB or the interaural difference ≤ 15 dB. The putative reason behind this theory is that because the skull does not greatly attenuate the transfer of sound energy, speech impinging on the poorer hearing ear will be heard mostly by the better ear, unless the difference in air conduction thresholds is 15 dB or less.

However, it can be safely assumed that any patient with bilateral hearing loss of ≥ 70 dB will benefit considerably from any surgery that reduces the air conduction thresholds to less than 40 dB in only one ear.

Glasgow Benefit Plot
The Glasgow Benefit plot (Figure 1) is a graphical method of reporting surgical results. This plot has the advantage of allowing one to visualize both the absolute air thresholds in each ear, and the asymmetry by plotting the pre-operative and post-operative results of the air conduction thresholds in both ears. Patients fall into one of three pre-operative impairment groups (1-3), shown in Figure 1; the post-operative results fall into one of four groups (a-d). Joining the pre-operative and post-operative data points produces a vertical line, with the length representing the improvement in air conduction; the benefit depends on the area of the graph in which the line ends (the final hearing result). Patients who fall into groups ‘a’ and ‘b’ are likely to achieve significant benefits, while those who fall into ‘c’ and ‘d’ are unlikely to achieve significant benefit. For example, a 50 dB improvement in a patient with air conduction thresholds at point A on the graph would not result in a change in the auditory status. In contrast, a smaller improvement of 30 dB in a patient at point B on the graph would change the auditory status and may reflect a significant benefit to the patient.

Discussion
The Belfast Rule of Thumb and the Glasgow Benefit Plot are similar in predicting benefit for patients presenting with unilateral or asymmetric conductive loss. For example, a patient with mixed hearing loss (HL), with an air conduction average of 80 dB HL, bone conduction average of 40 dB HL and a normal contralateral ear would not be indicated for surgery by these methods. This finding makes sense because even if the air-bone gap were to close, the impaired ear would not be significantly involved in the listening process because of the normal contralateral ear. However, a patient presenting with a perforated eardrum, with an air conduction average of 60 dB HL, normal bone conduction thresholds and a normal contralateral ear would be indicated for surgery. In between these two examples, there are many factors to consider such as the degree of asymmetry, the nature of the pathology, the use of hearing aids, inner ear reserve, and patient motivation, before performing middle ear surgery.

Speech-in-noise tests have also been used to assess the effects of unilateral conductive loss. Audiological tests using speech stimuli to assess hearing ability in patients is advantageous because speech is the most important and widely used auditory stimulus in everyday listening situations.

Using a speech-in-noise test, Feurstein found that simulated conductive unilateral hearing loss reduced ease of listening when background noise was present. In addition, he found that word recognition in background noise was decreased significantly with a simulated unilateral conductive hearing loss. This effect was more pronounced when the speech originated from the side of the hearing loss.

Figure 1. The Glasgow Benefit Plot. The pre-operative area is divided into three parts: (1) unilateral hearing loss, (2) bilateral asymmetric hearing loss, (3) bilateral symmetric hearing loss. The post-operative area is divided into four parts: (a) normal hearing, (b) normal unilateral hearing, (c) bilateral impaired hearing with better operated ear, (d) symmetrically impaired hearing. Refer to the text for explanation of ‘A’ and ‘B’. (Adapted from reference 10).

Figure 2. Word Recognition Score (%) versus Air Conduction Thresholds (dB HL) at 50, 30 and 20 dB HL, 10 dB and 5 dB SN ratio for increasing unilateral conductive loss. The standard error is represented in the error bars.
Nia and Bance (unpublished data) used a speech-in-noise test to assess the effect of asymmetric conductive hearing loss on speech recognition in background noise. Figure 2 shows the results of these experiments. Word recognition score on the Y-axis represents how well subjects recognized speech in background noise. The X-axis represents the air conduction thresholds, where higher thresholds represent increasing unilateral conductive hearing loss in the same set of subjects, simulated by two earplugs. The word recognition score is highest when the presentation level is 50 dB and the signal-to-noise (S/N) ratio is 10 dB, and decreases thereafter if either the presentation level or the S/N ratio is decreased. The word recognition score also decreases significantly with increasing unilateral conductive loss. These results reveal that there is a disability associated with unilateral conductive hearing loss in the presence of background noise. The effect is much more marked for low volume sounds (the word recognition score is lowest at the presentation level of 20 dB) and for sounds with competing background noise (the word recognition score is lower at 5 dB S/N ratios than at 10 dB S/N ratio at any particular presentation level). It appears that increasing presentation level can overcome this disability (note the improvement in word recognition score at 50 dB). Thus, the disability of a unilateral conductive loss depends on both the S/N ratio and the presentation level. In addition, the absolute value for the slope from 25 dB to 4 dB is 1.9 times higher than the slope from 43 dB to 25 dB. This means that the disability associated with monaural hearing does not increase in a linear fashion with increasing unilateral conductive loss.

These results are consistent with the Belfast Rule of Thumb and the Glasgow Benefit Plot. For simplification, one might assume that increased word recognition in background noise is equivalent to increased benefit to the patient. A preliminary study by Nia and Bance found that for every decibel decrease in unilateral conductive hearing loss, the benefits in speech recognition were 1.9 times higher when the unilateral conductive loss was decreased from 25 to 4 dB, than when it was decreased from 43 to 25 dB. Given this finding and our assumption, the same amount of improvement in the air conduction thresholds is likely to be of higher benefit to the patient at lower levels of asymmetry than at higher levels of asymmetry. For example, a 15 dB improvement in hearing for a patient with a small unilateral conductive loss (average air conduction thresholds of 25 dB) will result in 1.9-fold greater benefit than a 15 dB improvement in a patient whose average air conduction thresholds are at 43 dB. This analysis is supportive of the Belfast Rule of Thumb and the Glasgow Benefit Plot.

Currently, the Belfast Rule of Thumb and the Glasgow Benefit Plot are the most common methods used to estimate patient benefit from middle ear surgery to correct unilateral and asymmetric conductive hearing loss. In fact, other methods of estimating patient benefit were not found in an extensive literature search. Both of these methods stress the importance of the final hearing level in the better hearing ear, and the degree of asymmetry as the major determinants of patient benefit. Both of these studies were conducted using patients' subjective interpretations. The rules indicate that the patient has significant benefit only if surgery results in air conduction thresholds of ≤ 30 dB in the impaired ear or the level of hearing is within 15 dB of the contralateral ear. These methods of estimating patient benefit are consistent with our understanding of sound energy attenuation through the skull from one ear to the other.

Furthermore, a study by Toner and Smythe found that patients' estimate of benefit was significantly correlated with both the Belfast Rule of Thumb and the Glasgow Benefit Plot. The latest study using speech-in-noise testing also indicates that the improvement in word recognition score is less at higher levels of conductive loss or higher levels of asymmetry. These results further validate the Glasgow benefit plot and 15/30 rule of thumb in the population of patients used for that study. More research is required to more objectively quantify the potential benefit of middle ear surgery. However, at the current time, the Belfast Rule of Thumb and the Glasgow Benefit Plot seem to be the best methods for predicting patient benefit from middle ear surgery to correct unilateral and asymmetric conductive hearing loss.

References