Thin tubes, Thin wires and Earpiece Options: How Much Gain?

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Thin tubes, Thin wires and Earpiece Options: How Much Gain?

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Popularity of Thin Tube/Thin Wire Fittings

- 2011: 44.8% thin wire
  - Thin wire aids exceeded the sale of ITE aids

This growth is felt to be caused by the wide scale availability of smaller BTE hearing aids with less conspicuous ear molds and one or more of the following features:
  - Open fit
  - Thin almost invisible ear tubes & wires
  - Creative form factors making the product look less like a hearing aid

% of BTE aids fit by year

Source: HIA
Consistency of Terminology

- **Thin tube BTEs (RITA)**
  - Acoustical output from a receiver in a BTE case is delivered to the ear canal via a thin tube and a retention device

- **Thin wire BTEs (RIC)**
  - BTEs with a receiver in the ear canal, connected via a wire to the rest of the electronic apparatus in the case

- **Open vs. closed**
  - Open could refer to any fitting that results in the patient’s REOG closely resembling the REUG
  - Open could refer to any fitting that results in a lack of perceived occlusion effect
Terminology: Open vs. closed

• Terminology of open fitting, open canal, open ear may not always apply

• Important to remember that not all thin tube or thin wire fittings are “open”

• Depending on the method for retaining the tube or receiver in the ear, the ear canal may be fully or partially occluded, or unoccluded

<table>
<thead>
<tr>
<th></th>
<th>#13 tubing</th>
<th>RITA</th>
<th>RIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td><img src="image" alt="Standard open-ear" /></td>
<td><img src="image" alt="Thin-tube open-ear" /></td>
<td><img src="image" alt="Thin-wire open-ear" /></td>
</tr>
<tr>
<td>Occluded (there is a wide range from partial to total occlusion)</td>
<td><img src="image" alt="Standard occluded-ear" /></td>
<td><img src="image" alt="Thin-tube occluded-ear" /></td>
<td><img src="image" alt="Thin-wire occluded-ear" /></td>
</tr>
</tbody>
</table>
Are these aids appropriate for everyone?

- Real ear and soundfield aided thresholds obtained for a thin tube “open” fitting.
- Patient had 4 sets of hearing aids fit in the past 5 years; ALL were thin tube or thin wire
- Patient reported significant difficulty hearing in quiet and in noise
In the Trenches Clinical Questions

Question 1: Which receiver location should I choose and why?

In-aid (RITA) vs. in-ear (RIC)

- Are there differences between thin tube and thin wire hearing aids in the maximum achievable amplification for your patient?
- Factors to consider:
  - RITA: Acoustic effects of the tubing
  - RIC: MPO of the receiver
In the Trenches Clinical Questions

Question 2: Which coupling method should I choose and why?

Custom vs. non-custom    Open vs. closed
Hollow vs. Solid

- What are the acoustic effects of different earmold options?
- What are the effects of custom and non-custom earpiece configurations on max stable gain before feedback (MSGBF) and the occlusion effect?
Question #3: How important is real ear verification when fitting thin tube and thin wire hearing aids?

Question #4: How realistic are the manufacturer’s suggested fitting ranges for RIC vs. RITA instruments?
Figure 1. Survey participants expressed their preference for RIC or RITA on 12 criteria.
So, Let’s Start from Scratch...

Research Questions:

• What are the differences in the maximum available gain/output based on receiver location (RIC vs. RITA)?
• What are the effects of custom and non-custom earpiece configurations on maximum stable gain?
• What are the effects of custom and non-custom earpiece configurations on occlusion?
• How accurate is the manufacturer’s prescribed 1st fit algorithm in approximating the NAL-NL1 targets for RIC and RITA aids?
• How realistic are the manufacturer’s suggested fitting ranges for RIC vs. RITA instruments?
ASU/UA study

Thin tubes, Thin wires and Earpiece Options: How Much Gain is achievable?
Acknowledgement of support

Westone Laboratories provided all custom earmolds for the study at no charge.

Oticon provided all study hearing aids on consignment.

We are grateful for both contributions, without which we would not have been able to the project. We received no financial support for these efforts.
Oticon hearing aids were used in the study:
- Agil Pro BTE
- Agil Pro Power BTE
- Agil Pro RITE

Real ear measurements were completed with 26 different non-custom and custom ear molds for RITA, RIC, and standard BTE configurations
- Compared 1st fit to NAL-NL1 targets
- Determined maximum stable gain/output available before feedback
- Measured occlusion effect
3 Audiograms: represent the maximum of manufacturer’s suggested fitting range for thin tube open dome, and thin wire S-receiver with plus dome and thin wire P-receiver with power dome
Test Subjects

- 11 subjects (6 ASU, 5 UA)
  - 6 male
  - 5 female
- Age: Average 60.8, Range 32-84
- All subjects had a severe to profound sensorineural hearing loss in the test ear
- Subjects were not paid; but were given the option to keep one of the custom molds
- Study received IRB approval from ASU/UA review boards
Earmold Configurations

<table>
<thead>
<tr>
<th>Thin Tube</th>
<th>Thin Wire S-Receiver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-custom</td>
<td>Non-custom</td>
</tr>
<tr>
<td>• Open dome</td>
<td>• Open dome</td>
</tr>
<tr>
<td>• Tulip (plus) dome</td>
<td>• Tulip (plus)dome</td>
</tr>
<tr>
<td>• Power dome</td>
<td>• Power dome</td>
</tr>
<tr>
<td>Custom Hollow</td>
<td>Custom Hollow</td>
</tr>
<tr>
<td>• 4VH</td>
<td>• 4VH</td>
</tr>
<tr>
<td>• Hollow</td>
<td>• Hollow</td>
</tr>
<tr>
<td>• No vent</td>
<td>• No vent</td>
</tr>
<tr>
<td>• 1mm, 2mm, 3mm vents</td>
<td>• 1mm, 2mm, 3mm vents</td>
</tr>
<tr>
<td>Custom Solid</td>
<td>Custom Solid</td>
</tr>
<tr>
<td>• #85 no vent</td>
<td>• #89 no vent</td>
</tr>
<tr>
<td>• #85 3mm vent</td>
<td>• #89 3mm vent</td>
</tr>
</tbody>
</table>
Earmold Configurations

Thin Wire P-Receiver

- Non-custom
  - Tulip (plus) dome
  - Power dome

- Custom Solid
  - #88 no vent
  - #88 3mm vent

Standard BTE

- Standard Skeleton, acrylic CFA mold
  - No vent
  - 3mm vent
Non-Custom ear domes

- Open dome
- Tulip dome
- Power dome
Custom molds: Hollow Molds—used with thin tube & thin wire S-rec

4VH Lateral view

4VH Medial view

Hollow Lateral view

Hollow Medial view
Custom molds: Solid Molds—tested NV and 3 mm vent conditions

#85 Thin tube

#89 Thin Wire S-rec

#88 Thin Wire P-rec
Hollow vs. Solid molds Kuk et al, 2009

- Demonstrated that for the same vent diameter, the vent effect was greater with the hollow earmold than with the solid earmold
  - Therefore, a smaller vent diameter can be used to achieve the same vent effects as in a solid EM
  - The vent effect associated with a .7mm vent in a hollow mold is similar to that of a 3 mm solid mold

Acoustic mass $= 1500xL/D^2$ where $L$ is the length of the vent in mm and $D$ is the diameter of the vent in mm.
Test Protocol

1\textsuperscript{st} fit REAR/RESR measurements

- Genie software set appropriately for each condition
  - Age: 17-84
  - Long term user
  - Target: General Active NAL-Nl1
  - Adaptation step: 3
  - Directionality: Omni
  - Noise Management, My Voice: OFF

- Acoustics set appropriately for each earmold condition specifying:
  - Earpiece
  - Tubing diameter
  - Dome
  - Venting
  - Hook
Test Protocol

1\textsuperscript{st} fit REAR/RESR measurements

- For each subject, for a given audiogram, earmold configuration, and Oticon aid, the 1\textsuperscript{st} fit starting gain was the same across sites
- Feedback test was run and DFC set to on
- RECD (insert) was measured for each subject to derive the NAL-NL1 targets in the Verifit
- All REAR/RESR measurements were taken with the Verifit set to OPEN and equalization completed prior to each measurement with the aid’s microphone muted
Test Protocol

Max stable gain before feedback: REAR measurements

- FB limits were removed
- Overall gain/output was increased to maximum; verified that the max gain for each subject, audiogram, and earmold configuration was the same across sites
- Feedback test was run and the DFC turned on; if needed the gain was manually decreased overall to reduce feedback.
- Obtained REAR and RESR measurements
- Verifit set to OPEN; equalization completed manually before each measurement
Test Protocol

Occlusion Measurements

- Used Verifit Occlusion test
- Aid/mold in place; microphone muted
- Subject vocalized /i/
- Each measurement taken 3x
- Tester verified consistent dB SPL at the reference microphone ± 1dB between each measurement
Question 1: Which receiver location should I choose and why

In-aid (RITA) vs. in-ear (RIC)

Factors to consider:
- Effects of tubing
- Effects of receiver
Effect of tubing diameter

Remember earmold acoustics???
Thin tube Effects

- The available high frequency output from a hearing aid is compromised by using a thin tube that has less than 1mm internal diameter (.8mm)
  - Tubing resonance moves downward to around 800 Hz
  - Reduction in high frequencies as much as 10-15 dB
- More gain/output required to fit the same degree of hearing loss with a thin tube vs. a regular tube
  - Need a stronger hearing aid and that aid has to work MUCH harder
  - Cannot just swap a regular earhook and tubing for a thin tube without adjusting the gain/output!!!!!

Same aid with same gain measured with regular tone hook and #13 tubing versus thin tubing (Closed dome) in 2cc coupler
Standard Tube vs. Thin Tube*

*significant differences
Effect of receiver (Size matters)

RIC vs. RITA
Output from 3 BTEs (Kuk et al, 2008)

MPO = 108 dB SPL  MPO = 124 dB SPL  MPO = 135 dB SPL

58 dB SPL

85 dB SPL
<table>
<thead>
<tr>
<th>Receiver Size</th>
<th>Peak OSPL90</th>
<th>HFA OSPL90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>108 dB SPL</td>
<td>104 dB SPL</td>
</tr>
<tr>
<td>Medium</td>
<td>115 dB SPL</td>
<td>110 dB SPL</td>
</tr>
<tr>
<td>Power</td>
<td>124 dB SPL</td>
<td>119 dB SPL</td>
</tr>
</tbody>
</table>
Max RESR vs. target

Max Gain RESR with Solid Unvented Earmolds

- Standard Mold
- Thin Tube
- Thin Wire P
- Thin Wire S
- Tube Target
- Wire S Target
- Wire P Target
Size Matters: Thin Wire S vs. Thin Wire P*

*significant differences
Thin tube WINS!

Thin Tube vs. Thin Wire S*

*significant differences
Need a POWER receiver to trump Thin Tube

Thin Wire P vs. Thin Tube*

*significant differences
Thin Wire P vs. Standard Tube*

*significant differences

**RESR**

**REAR**
Question 2: Which coupling method should I choose and why?

Custom vs. non-custom
Open vs. closed
So how important is the earmold?
CUSTOM VS. NON-CUSTOM OPEN MOLDS
Thin Tube “Open”: Custom vs. Non-Custom*

*significant differences
Thin Wire “Open”:
Custom vs. Non-Custom*

*significant differences
More Occluded Hollow vs. solid molds
what is the effect?

Hollow Medial View

Hollow Lateral View

Hollow Medial View

Solid Mold
Thin Tube “Closed”:
Custom vs. Non-Custom*

*significant differences
Thin Wire “Closed”

Custom vs. Non-Custom*

*significant differences
What is the effect of venting?

Thin tube Hollow vs. Solid molds*

*significant differences with exception of 2mm vs. 3mm
What is the effect of venting?

Thin wire Hollow vs. Solid molds

Average REAR at Max Stable Gain,
Thin Wire Hollow Molds vs Solid Molds

*significant differences with exception of
2mm vs. 3mm
4 VH vs. Hollow 3mm vent

4VH medial and lateral

Hollow medial and lateral
4VH vs. hollow 3mm vent (Thin Tube* vs. Thin Wire S)

Average REAR at Max Stable Gain, "Thin," More Open Conditions

*significant differences for thin tube only
Effect of Earpiece Type on MSGBF

How much gain can you get in the 1-3kHz region with different earpieces?
MSGBF REAR, Ave. 1-3 kHz: Non-Custom, Open Conditions

Average REAR, 1-3kHz.
MSGBF REAR, Ave. 1-3 kHz: 4VH Added

Average REAR, 1-3kHz.
Average REAR, 1-3kHz.

MSGBF REAR, Ave. 1-3 kHz:
Thin Wire S Hollow Molds Added
MSGBF REAR, Ave. 1-3 kHz: Thin Tube Hollow Molds Added

Average REAR, 1-3kHz.
MSGBF REAR, Ave. 1-3 kHz:  
Thin Wire S Sold Molds Added

Average REAR, 1-3 kHz.
MSGBF REAR, Ave. 1-3 kHz:
Thin Tube Sold Molds Added
MSGBF REAR, Ave. 1-3 kHz:
Thin Tube and Thin Wire S Power Domes Added
MSGBF REAR, Ave. 1-3 kHz:
Thin Wire P Molds Added
MSGBF REAR, Ave. 1-3 kHz: Standard Molds Added

Average REAR, 1-3kHz.
Effect of Earpiece Type on the Occlusion Effect

Do custom molds give more occlusion compared to non-custom molds?
Measured Occlusion:
Open Conditions
Measured Occlusion:
Tulip Domes Added

OE
Measured Occlusion:
4VHs Added

OE

Probe mic - reference mic (dB)
# Measured Occlusion: Hollow Molds Added

<table>
<thead>
<tr>
<th>Probe Mic - Reference Mic (dB)</th>
<th>OE</th>
</tr>
</thead>
<tbody>
<tr>
<td>StandRec Open</td>
<td></td>
</tr>
<tr>
<td>TubeHollow 2 mm</td>
<td></td>
</tr>
<tr>
<td>Stand Rec Tulip</td>
<td></td>
</tr>
<tr>
<td>Tube Hollow 3 mm</td>
<td></td>
</tr>
<tr>
<td>Stand Rec 4VH</td>
<td></td>
</tr>
<tr>
<td>Power Rec Tulip</td>
<td></td>
</tr>
<tr>
<td>Tube 4VH</td>
<td></td>
</tr>
<tr>
<td>Stand Rec Hollow 3 mm</td>
<td></td>
</tr>
<tr>
<td>Tube Open</td>
<td></td>
</tr>
<tr>
<td>Tube Tulip</td>
<td></td>
</tr>
<tr>
<td>Stand Rec Hollow 2 mm</td>
<td></td>
</tr>
<tr>
<td>Tube Hollow 1 mm</td>
<td></td>
</tr>
<tr>
<td>Stand Rec Hollow 1 mm</td>
<td></td>
</tr>
<tr>
<td>Stand Rec Solid 3 mm</td>
<td></td>
</tr>
<tr>
<td>Tube Solid 3 mm</td>
<td></td>
</tr>
<tr>
<td>Power Rec Solid 3 mm</td>
<td></td>
</tr>
<tr>
<td>Tube Power Dome</td>
<td></td>
</tr>
<tr>
<td>Stand Rec Hollow 0 mm</td>
<td></td>
</tr>
<tr>
<td>Standard 3 mm</td>
<td></td>
</tr>
</tbody>
</table>

The chart illustrates the measured occlusion for various probe and reference microphone configurations, showing the difference in decibels (dB) between the two. Each configuration is represented by a different symbol, with the y-axis indicating the occlusion effect (OE) in dB.
Measured Occlusion:
Solid Molds Added

OE

Probe mic - reference mic (dB)

-10.0
-5.0
0.0
5.0
10.0
15.0
20.0

StandRec Open
TubeHollow 2 mm
Stand Rec Tulip
Tube Hollow 3 mm
Stand Rec 4VH
Power Rec Tulip
Tube 4VH
Stand Rec Hollow 3 mm
Tube Open
Tube Tulip
Stand Rec Hollow 2 mm
Tube Hollow 1 mm
Stand Rec Hollow 1 mm
Stand Rec Solid 3 mm
Tube Solid 3 mm
Power Rec Solid 3 mm
Tube Power Dome
Stand Rec Hollow 0 mm
Power Rec Solid 0 mm
Tube Power Dome
Standard 3 mm
Standard 0 mm
Measured Occlusion:
Power Domes Added

OE

Probe mic - reference mic (dB)

StandRec Open
TubeHollow 2 mm
Stand Rec Tulip
Tube Hollow 3 mm
Stand Rec 4VH
Power Rec Tulip
Tube 4VH
Stand Rec Hollow 3 mm
Stand Rec Hollow 2 mm
Tube Hollow 1 mm
Stand Rec Hollow 1 mm
Stand Rec Solid 3 mm
Tube Solid 3 mm
Power Rec Solid 3 mm
Tube Power Dome
Stand Rec Hollow 0 mm
Stand Rec Solid 0 mm
Standard 3 mm
Tube Solid 0 mm
Tube Hollow 0 mm
Power Rec Solid 0 mm
Tube Power Dome
Stand Rec Hollow 0 mm
Standard 0 mm
Measured Occlusion:
Standard Molds Added

OE
Thin Wire S — **MSGBF** and **OE**

**Derived REIG and Measured Occlusion**

- **Solid NV**
- **Hollow NV**
- **Power Dome**
- **Solid 3mm**
- **Hollow 1mm**
- **Hollow 2mm**
- **Hollow 3mm**

**Legend:**
- **REIG 1-3 kHz**
- **Measured Occlusion**
Thin Tube—MSGBF and OE

Derived REIG and Measured Occlusion

![Bar chart showing derived REIG and measured occlusion for Open, Tulip, and 4VH conditions. The chart illustrates the comparison between REIG 1-3 kHz and measured occlusion.]
Thin Wire S — MSGBF and OE

Derived REIG and Measured Occlusion

- Open
- Tulip
- 4VH

(REIG 1-3 kHz) (Measured Occlusion)
Derived REIG and Measured Occlusion

- Solid S
- Hollow S
- Power Dome S
- Solid Tube
- Hollow Tube
- Power Dome Tube
- Solid P
- Power Dome P
- Standard Mold/Tube

REIG 1-3 kHz
Measured Occlusion
Question #3: How important is real ear verification when fitting thin tube and thin wire hearing aids?
Sources of first fit error

- Individual differences: Error in the manufacturer’s estimate of the acoustics of YOUR patient
- Earpiece differences: Error in the manufacturer’s estimate of the acoustics of YOUR patient’s earpiece
Manufacturer Simulated Real Ear Measures (SREM) are Poor Predictors of Actual Hearing Aid Performance Even for THE AVERAGE INDIVIDUAL


Aarts & Caffee, 2005
Sources of first fit error

- Individual differences: Error in the manufacturer’s estimate of the acoustics of YOUR patient
- Earpiece differences: Error in the manufacturer’s estimate of the acoustics of YOUR patient’s earpiece
- Fitting range error: The instrument may not be capable of providing the gain necessary to fit the hearing loss.
- Feedback restriction: The instrument may not be capable of providing the necessary gain before feedback.

It is difficult to infer from our data WHICH source of error was dominant in any given condition.
Accuracy of 1st Fit 1-3 kHz

- Standard Tube Average 1-3 kHz
- Thin Tube Average 1-3 kHz
- Thin Wire S Average 1-3 kHz
- Thin Wire P Average 1-3 kHz
Accuracy of 1st Fit: 250-750 Hz
Question #4: How realistic are the manufacturer’s suggested fitting ranges for RIC vs. RITA instruments?
Candidacy for Thin tube/thin wire Fittings

- Manufacturer suggested fitting ranges are very aggressive for both thin tube and thin wire hearing aids.
- How realistic are these fitting ranges?
What influences the fitting ranges?

**Thin Tube**
- Max gain/output limited by restricted tubing diameter

**Thin Wire**
- Max gain/output limited by receiver size

**Both**
- Max gain/output dependent upon retention coupling used
- Vent effects will reduce low frequencies
- MSGBF will limit high frequencies
Fitting ranges—Audiograms based on data
Derived Fitting Ranges

- Standard deviations were established for the REAR data for each condition
- 1 SD was subtracted from the average REAR for each condition
- These adjusted REAR values were converted to REAG by subtracting the spectrum of the input stimulus
- Using the NAL-NL1 standalone software v1.4, the audiogram was adjusted until the prescribed NAL-NL1 REAG targets matched the measured REAG data in order to establish a clinically appropriate conservative fitting range
Fitting range for standard CFA mold

Measured fitting range

Oticon fitting range

**Standard CFA 3mm**

**Oticon Power BTE13**
Thin Tube—non-custom molds

Non-Custom Molds

Oticon fitting range—Corda
Thin Tube—Custom Molds

Custom Molds—Hollow

Oticon Fitting Range—Corda
Thin Tube—Custom Molds

Solid #85 No Vent vs. 3mm vent

Oticon Fitting Range--Corda
Thin Wire—Standard Receiver
Non-Custom Molds

Non-Custom

Oticon fitting range S-rec
Thin Wire—Standard Receiver
Custom Molds

Custom—Hollow molds
Oticon fitting range S-rec

[Graphs showing thin wire and oticon fitting range]
Thin Wire—Standard Receiver
Custom Molds

Custom—Solid mold #89
NV vs. 3mm vent

Oticon fitting range S-rec

![Graph of Thin Wire-S Solid](image1.png)

![Graph of Oticon Thin Wire S-rec](image2.png)
Thin Wire Power Receiver
Non-Custom Molds

Non-Custom molds

Oticon Fitting Range P-rec

Thin Wire-P Tulip Dome

Oticon Thin Wire P-rec
Thin Wire Power Receiver
Custom Molds

Custom--#88 NV vs. 3mm vent

Oticon Fitting Range P-rec
1. Are there differences in maximum available gain/output based on receiver location (RIC vs. RITA)?
   - In general, thin-tube fittings resulted in more gain and output than thin-wire S-receiver fittings.
   - A power receiver was needed to provide more gain/output

2. What are the effects of custom and non-custom earpiece configurations on maximum stable gain?
   - Max achievable gain before feedback is highly dependent upon the earmold chosen
   - In general custom molds provide better FB control compared to non-custom domes
   - 4VH and hollow molds provided a surprisingly large increase in maximum stable gain over open-fitting with non-custom domes
3. **What are the effects of custom and non-custom earpiece configurations on occlusion?**

- Hollow molds provide a greater venting effect and reduction in occlusion than solid molds.
- A hollow mold with a 1mm vent was equivalent to a 3mm vent in a solid mold; however, the reduction in the measured occlusion was greater compared to the solid mold with a 3mm vent.
- Measured occlusion was no greater than that measured with non-custom domes.
4. How accurate is the manufacturer’s prescribed 1st fit algorithm in approximating the NAL-NL1 targets for RIC and RITA aids?
   • 1st fits rarely fit target. Verification is critical.

5. How realistic are the manufacturer’s suggested fitting ranges for RIC vs. RITA instruments?
   • Manufacturer-published fitting ranges are poor predictors of hearing aid appropriateness.
Reasons for considering a custom earmold for thin tube/thin wire fittings

- More available gain before feedback
- Hollow earmolds are an option to achieve more gain before feedback while still maintaining a reduced OE
- Better retention
  - 19-15% of all OC fits using a non-custom eartip have retention problems of various degrees (Taylor, 2009)
- Easier insertion
Study Limitations

- Study limited to Oticon Agil Pro aids in three different receiver configurations.

Future Directions

- Replication with alternative hearing aids, particularly those with a more aggressive feedback cancelling systems.