How Much Does the Type of Tympanostomy Tube Matter? A Utility-Based Markov Decision Analysis

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Abstract

Objectives. To use a utility-based Markov decision analysis model to compare outcomes of short-term grommet tympanostomy tubes (TTs), intermediate-type tubes, and permanent T-Tubes and to use a detailed sensitivity analysis to determine the most important factors influencing outcomes with one type of TT versus another.

Study Design. Markov cohort analysis.

Setting. Hypothetical cohort.

Subjects and Methods. A Markov cohort decision analysis model was created using computer software (TreeAge Software, Inc, Williamstown, Massachusetts) comparing the 3 types of TT. Published data were used to determine key baseline model parameters. The model featured potential complications including eardrum perforation, early TT extrusion/blockage, and the need for possible repeat TT placement after extrusion. Outcomes were quantified using a 0.95 (1 procedure, full recovery) to 0.6 (failed myringoplasty) utility scale. Utility values were discounted over time to incorporate real-life inconvenience.

Results. The intermediate TT accumulated superior total utility in 2-, 4-, and 6-year models (2.48, 3.96, and 5.27 total utility) compared with grommets (2.32, 3.82, 5.18) and T-Tubes (2.42, 3.86, 5.18). Examining a hypothetically otherwise healthy 3000-child cohort, T-Tubes resulted in an increased overall persistent perforation rate (7.9% vs 0.2%, P < .001, χ²). Sensitivity analysis indicated that the rate of repeat TT placement, the utility assigned to having a functional tube in place, and the inconvenience utility discount factor over time were the driving factors of the model.

Conclusion. The intermediate TT may produce optimal outcomes as it combines a balance of a lower perforation rate than T-Tubes and a longer period of ventilation than grommet tubes.

Keywords

otitis media, tympanostomy tubes, decision analysis, Markov model

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The otolaryngologist performing bilateral myringotomy and tube placement (BMTT) has many different tympanostomy tube (TT) options available. The decision of which tube to use is sometimes based simply on experience and personal preference. When taking a more evidence-based approach, there are tradeoffs between different types of tubes in terms of expected period of ventilation and tympanic membrane perforation rate. The traditional compromise faced by the otolaryngologist considering TT type is that the longer ventilation period provided by the permanent type T-Tubes (Figure 1A) is offset by their increased complication rates (eg, perforation, tympanosclerosis, chronic otorrhea).1,2 Alternatively, the lower complication rates of shorter-lasting grommet-type tubes (Figure 1B) are offset by their overall shorter period of ventilation,3 which may then lead to repeat surgeries for persistent Eustachian tube dysfunction (ETD). More recently, intermediate-type tubes (Figure 1C) have entered the market and become widely available. These tubes may combine the best of both traditional options, providing a more prolonged period of ventilation while maintaining lower complication rates. However, there are insufficient data when assessing this possibility versus the traditional alternatives.

Despite the prevalence of TT insertion as one of the most common procedures in the world, and as the most common ambulatory procedure performed in the United

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The purpose of this study is to apply the limited pub-
cost-effectiveness, quality-adjusted life-years, and utility
decisions in otolaryngology using outcome measures such as
This technique has already been used to assess other clinical
States,4 there is a paucity of primary data regarding which
tube design may provide the best utility for the pediatric
patient. If one type of TT were found to be superior by even
a small margin, the overall gains at a population level could
be enormous. A comprehensive, randomized, prospective
study that could assess the performance and complication
rates of grommet, intermediate, and permanent TTs over the
necessary follow-up period (3-5 years) in pediatric patients
would be a very significant contribution to the medical com-
community. However, such a trial is very daunting in terms of
informed consent requirements, logistics, and cost. Given
these factors, it is unlikely such a study would ever be
completed.

Decision analysis is a robust analytic method used to
assess clinical alternatives with competing tradeoffs to esti-
mate which option is most favorable. This approach is ideal
for comparing clinical options for which there exist outcomes
data but for which a direct comparative study is problematic
if not practically impossible. Markov modeling is a specific
type of decision analysis that allows for investigation of
health states as they change over a designated time period.5
This technique has already been used to assess other clinical
decisions in otolaryngology using outcome measures such as
cost-effectiveness, quality-adjusted life-years, and utility
units.6,8 The purpose of this study is to apply the limited pub-
lished outcomes data for grommet, intermediate, and perma-
nent TTs in a Markov model decision analysis using
comparative outcomes and complication rates to determine
which tube may provide the best utility for a theoretical
cohort. Subsequent sensitivity analysis was then performed to
determine the key factors related to the outcome.

Methods
This study uses only published data and therefore was
exempted from institutional review board review at our
institutions. A thorough literature review was conducted (MEDLINE
PubMed, Cochrane Databases) to determine initial model
parameters and appropriate ranges such as typical ventila-
tion period, early TT extrusion rates, retained TT rates, and
tympanic membrane perforation rates for 3 types of TTs:
short-acting grommet tubes (eg, a Pope TT), permanent TTs
(eg, a Goode T-Tube), and the more recent intermediate TT
(eg, a Triune tube; see Figure 1 and Table 1). Other
known complications of BMTT such as cholesteatoma, otor-
rhea, and tympanosclerosis were excluded from this analysis
because of their low prevalence and/or because the rates of
each would be expected to be very similar for each TT type
and therefore would be negligible in a comparative analysis.

A Markov cohort decision analysis model was created
using TreeAge Pro (TreeAge Software, Williamstown,
Massachusetts, 2008) comparing the 3 types of TTs in a
hypothetical cohort of 3000 otherwise healthy children with
chronic otitis media and without additional contributing fac-
tors such as cleft palate, immunodeficiency, and so forth.
Markov modeling assumes that a patient is always in one of
multiple discrete health states and that he or she transitions
from one to another for a predetermined length of time, or
cycle. In our model, children entered at BMTT and exited at
1 of 3 possible end states: (1) successful tube extrusion,
with resolution of disease; (2) membrane perforation,
repaired with myringoplasty; or (3) permanent perforation,
with failed myringoplasty (Figure 2). Figure of complete
model is available as an online supplement (Supplemental
Figure S1 available at www.otojournal.org). Children could
cycle through the model multiple times, with the possibility
of needing additional operations (repeat TT placement, myr-
ingoplasty, or surgical tube removal) prior to finishing in
one of these end states if they were not cured with their first
tube insertion.

Each end state was assigned a utility value. Patients accu-
mulate utility based on the health states they progress through
and for the total amount of time, or number of cycles, spent
in that state. The utility values assigned to each end state
were based on a commonsense approach to what a typical
patient/parent would consider reasonable (Table 2). These
assigned values were reviewed for appropriateness by 2 oto-
laryngologists who were not involved in the study. Utility
values were generated by ranking and quantifying possible
clinical outcomes on a 0 to 1 scale. This model’s anchor
states ranged from 0.95 (best outcome; 1 procedure with full
recovery) to 0.6 (worst outcome; failed myringoplasty).
Utility values were discounted using an exponential decay
formula for multiple operations to mimic real-life inconve-
niences for having additional surgeries.
The model was developed in sufficient detail to mimic several real-life outcomes for patients undergoing BMTT (Figure 3). Additional features of the model included (1) the possibility of additional TTs after initial extrusion if ETD persisted, the probability of which was decayed over time using exponential decay to simulate increasing age and the subsequent decreased benefit of TTs. (2) The possibility of early extrusion or blockage of TTs and the need for TT replacement after 1 year. Early extrusion after a period of less than 1 year was not modeled as this is considered to be a rare event and subsequently would not be expected to be significantly different between the 3 tube types and would be negligible in a comparative analysis. (3) The possibility of retained TT with need for removal and possible persistent tympanic membrane perforation.

The model was designed to quantify expected total cumulative utility for a hypothetical cohort of 3000 children (1000 for each type of TT) who underwent BMTT with a cycle length of 1 year. The model was then run for 2-, 4-, and 6-year permutations. Several assumptions were made in model development and progression: (1) all retained TTs that did not extrude were removed at the end of the trial period, (2) TTs that extruded early or were blocked were always replaced, (3) all patients who developed recurrent otitis media after tube extrusion elected for replacement of ear tubes, and (4) tympanic membrane perforations were always followed by myringoplasty with a possible failure of the procedure. Adenoidectomy as an elective procedure that is often added to tube replacement surgery was not included in the model as it is an elective surgery and would be expected to be equally considered in the instance of each tube and therefore would be negligible in a comparative analysis. One- and 2-way sensitivity analyses were performed on all model parameters to identify parameters that most influenced model results.

Statistical analysis was performed with the assistance of computer software (STATA 8.2, College Station, Texas).

### Table 1. Key Model Parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Starting Value, %</th>
<th>One-Way Sensitivity Analysis Range, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grommet tube perforation rate</td>
<td>2</td>
<td>0-10</td>
</tr>
<tr>
<td>Intermediate tube perforation rate</td>
<td>2</td>
<td>0-10</td>
</tr>
<tr>
<td>T-Tube perforation rate</td>
<td>12</td>
<td>0-20</td>
</tr>
<tr>
<td>Grommet and intermediate tube myringoplasty success rate</td>
<td>90</td>
<td>70-100</td>
</tr>
<tr>
<td>T-Tube myringoplasty success rate</td>
<td>75</td>
<td>50-100</td>
</tr>
<tr>
<td>T-Tube removal eardrum repair success</td>
<td>85</td>
<td>50-100</td>
</tr>
<tr>
<td>Intermediate tube removal eardrum repair success</td>
<td>90</td>
<td>50-100</td>
</tr>
<tr>
<td>Intermediate tube early extrusion rate</td>
<td>5</td>
<td>0-20</td>
</tr>
<tr>
<td>T-Tube early extrusion rate</td>
<td>5a</td>
<td>0-20</td>
</tr>
<tr>
<td>Probability of the need for another set of tympanostomy tubes after extrusion</td>
<td>20b</td>
<td>0-50</td>
</tr>
</tbody>
</table>

*aRate increased with exponential growth with each model cycle simulating 1 year.

*bRate decreased with exponential decay with each model cycle simulating one year.

### Table 2. Model Utility Values.

<table>
<thead>
<tr>
<th>Condition/Endpoint</th>
<th>Starting Value</th>
<th>One-Way Sensitivity Analysis Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only 1 set of tubes required, complete resolution of otitis media</td>
<td>0.95</td>
<td>0.80-1.0</td>
</tr>
<tr>
<td>Tube currently in place, no complications</td>
<td>0.90</td>
<td>0.75-1.0</td>
</tr>
<tr>
<td>Tubes extrude when expected, tympanic membrane perforation but successful myringoplasty</td>
<td>0.85</td>
<td>0.70-0.95</td>
</tr>
<tr>
<td>Tubes do not extrude when expected and must be removed, but successful myringoplasty</td>
<td>0.75</td>
<td>0.60-0.90</td>
</tr>
<tr>
<td>Unsuccessful myringoplasty, persistent tympanic membrane perforation</td>
<td>0.65</td>
<td>0.50-0.90</td>
</tr>
<tr>
<td>Utility penalty for needing another set of tubes</td>
<td>0.1</td>
<td>0.00-0.20</td>
</tr>
<tr>
<td>Time decay of utility endpoint values with each model cycle simulating inconvenience over time</td>
<td>0.05</td>
<td>0.00-0.20</td>
</tr>
</tbody>
</table>
Data analysis included simple descriptive statistics and contingency table analysis using Fisher exact test. A P value of less than .05 was considered significant.

Results

The final model schematic is shown in Figure 2. Using the baseline values of all of the key parameters, the intermediate tube option accumulated the highest total cumulative utility in the 2-, 4-, and 6-year model permutations (Table 3). The margin by which the intermediate TT was superior over the alternatives increased going from the 2- to 4-year time frame and remained the same in the 6-year model. Examining a hypothetical 3000-child cohort (1000 children receiving each TT type), T-Tubes resulted in an increased overall perforation rate (after failed myringoplasty) versus intermediate and grommet TTs (7.9% vs 0.2%, P < .001 Fisher exact test).

Extensive sensitivity analysis was performed. One-way sensitivity analysis was performed on all the parameters, as indicated in Table 1. Three parameters were found to be most influential over the final model results. The probability of needing more TTs after the initial placement was a key determinant in the model results. As the probability of needing more TTs was reduced to zero, the grommet tube option became the superior option, with highest utility (Figure 3). The utility value assigned to having a patent, functioning TT was also a key parameter affecting model results. At low utility values, the grommet tube was the dominant option, but as this assigned utility increased, the intermediate and ultimately the T-Tube options became dominant (Figure 4). Lastly, the utility penalty assigned to needing another set of tubes was also a model determinant. As this penalty diminished, the grommet option became more and more attractive, although it still trailed the intermediate tube option (Figure 5).

A tornado diagram plotted the change in total cumulative utility over the specified range of the parameters of interest. This diagram helped determine which single parameter was most important in determining the final model results. The tornado diagram showed that the assigned utility to having a functioning tube in place was the most influential parameter followed by the starting probability of needing more ear tubes (Figure 6). Two-way sensitivity analysis was then

<table>
<thead>
<tr>
<th>Tympanostomy Tube Type</th>
<th>2-Year Model</th>
<th>4-Year Model</th>
<th>6-Year Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grommet</td>
<td>2.322</td>
<td>3.824</td>
<td>5.181</td>
</tr>
<tr>
<td>Intermediate tube</td>
<td>2.483</td>
<td>3.956</td>
<td>5.274</td>
</tr>
<tr>
<td>T-Tube</td>
<td>2.416</td>
<td>3.863</td>
<td>5.175</td>
</tr>
</tbody>
</table>
performed on these 2 key parameters and found that the grommet had increasing superiority as the probability of needing more tubes and the assigned utility of having functioning tubes in place decreased. As the probability of needing additional tubes increased and the value of having a functional, patent TT increased, the intermediate and T-Tube options began to dominate (Figure 7).

**Discussion**

This study uses utility-based Markov decision theory modeling to assess outcomes for a hypothetical 3000 pediatric patient cohort over 2-, 4-, and 6-year periods. Using reference values for all key model parameters, the intermediate-type TT was the superior option over each time frame progression. The differences between the cumulative utility for the various TT types were small, but when potentially translated to the large numbers of patients who undergo TT placement each year, small differences can end up having an enormous impact. The intermediate tubes appeared to provide the highest levels of utility because they offer a longer period of ventilation than the grommet tubes while having lower perforation rates than T-Tubes.2,9 In doing so, the intermediate tubes provide an optimum tradeoff, minimizing the indications for additional surgeries: they reduce the need for repeat TT insertion relative to the grommet by virtue of their longer ventilation period, and they reduce the need for myringoplasty and surgical tube removal relative to the T-Tubes because of their lower perforation rates. Sensitivity analysis indicated that the utility assigned to having a functioning tube in place was the most influential model parameter. This is not surprising and embodies the essence of the decision of which TT type to use in a given patient. The relevant questions are, “How significant is the quality-of-life impairment resulting from otitis media for the patient/family?” and “How detrimental would a TT extrusion be where otitis media is still an active problem?” Caregivers report lower quality of life for themselves and their children when their children have middle ear disease.19,20 Disutility can also come from inconveniences such as additional cost, missed days of school, and missed days of work for caregivers. If this is not a big concern compared with other issues for a specific patient, a grommet tube may be a reasonable choice. If this is a very large concern, a permanent tube may be the more appropriate choice in the context of an informed consent discussion about the risks of perforation. An intermediate tube, of course, combines these features and would be an optimal choice for most.

The other key relevant question is, “What are the implications of a tympanic membrane perforation and/or a failed myringoplasty?” For cases in which the potential impairment is considerable, selecting a grommet tube even with the potential need of repeating the procedure in the future may be the best choice. The sensitivity analysis results in Figure 5 act as a guide of sorts for this decision process, with the grommet tube being an ideal choice for which there are less significant quality-of-life concerns, the permanent tube being ideal for cases in which there is more aversion to quality-of-life impairment, and the intermediate tube being the middle ground that would likely apply to most scenarios.

Sensitivity analysis also indicated that the probability of having persistent otitis media was a key parameter driving overall model results. This risk can be considered to be directly related to the age of the patient. The risk of otitis media is well established to decrease with increasing age as Eustachian tube function improves.21 Consequently, the age

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**Figure 6.** A tornado diagram depicting the 3 parameters that have the most influence on the overall utility within the model. The utility assigned to having a functioning tube in place was the most influential parameter. The black vertical bars indicate a change in the overall model results as corresponding to the 1-way sensitivity analysis as depicted in Figures 3, 4, and 5.

**Figure 7.** Two-way sensitivity analysis of the probability for needing replacement ear tubes as well as the utility assigned to having a functional tube in place.
of the patient should also be a key factor when selecting TT type. The sensitivity analysis of this parameter depicted in Figure 4 acts a guide of sorts when considering this issue. When the probability of persistent otitis media is low (ie, older children), a grommet tube may be a reasonable choice. When the probability is higher (ie, younger children), which is the more common scenario, the intermediate tube becomes the better choice. Interestingly, from the point of view of this factor alone, the permanent tube is never the optimal choice. However, in reality, this decision must be made in the context of other issues, and therefore, the 2-way sensitivity analysis is perhaps more pertinent. Considering the 2-way sensitivity analysis depicted in Figure 7, it appears at first glance that the grommet tube is the optimal choice for most scenarios. However, the most common scenario for BMTT is a younger child in a family who wants to minimize quality-of-life impairment and maximize quality-of-life benefits, which is when the intermediate tube is most beneficial. This, of course, is the reason the intermediate tube option was the dominant option in all 3 time progressions of the overall model. Nevertheless, there may be other less common circumstances in which selection of another TT type may be appropriate and the otolaryngologist should be familiar with the pertinent factors to optimize this decision.

This study has important limitations to recognize. A key limitation of Markov models is that their accuracy and performance depends on input parameters and that model outcomes will change with variation in these input data. This model used multiple publications to determine model inputs to obtain generalizable outcomes and to minimize the effect of any single data source. However, there is always concern when combining data from numerous authors with separate patient populations and outcome criteria. This is a restraint inherent in the Markov decision model. Consequently, extensive and rigorous sensitivity analyses were conducted as described above to test the model’s robustness. Second, several assumptions must be made to construct a model that is practical and manageable. This of course will not perfectly mimic real-life situations including patient-specific factors, and preferences and the overall results can be affected. Lastly, the epidemiologic fallacy principle is germane in the context of interpreting decision analysis results. Markov models are constructed to assess outcomes at the population level, but these results may not be perfectly applicable on the individual patient level. Individual judgment on behalf of the otolaryngologist and thorough informed consent discussion with the patient/parent(s) is indispensable. Despite the inherent weaknesses, the current study model has produced results that should be useful for otolaryngologists to consider as they approach TT-type decisions for individual patients.

**Conclusion**

Utility-based Markov decision analysis suggests that intermediate-length TTs provide the best overall utility compared with short-term grommets and permanent T-Tubes. Subsequent sensitivity analysis suggests that the rate of needing subsequent TTs, the utility of having functional tubes in place, and a utility decay inconvenience factor were the driving factors of the model results.

**Author Contributions**

Grace Baik, conception, design, data acquisition, data analysis, manuscript preparation and review; Scott Brietzke, conception, design, data acquisition, data analysis, manuscript preparation and review, supervision.

**Disclosures**

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**Supplemental Material**

Additional supporting information may be found at http://otojournal.org/supplemental.

**References**


