Conifer vs. Hardwood Anatomy

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• The important thing is not to stop questioning. Curiosity has its own reason for existing. One cannot help but be in awe when (one) contemplates the mysteries of eternity, of life, of the marvelous structure of reality. It is enough if one tries merely to comprehend a little of this mystery every day. Never lose a holy curiosity.

• The most beautiful thing we can experience is the mysterious. It is the source of all true art and science.

– Albert Einstein
– US (German-born) physicist (1879 - 1955)
Theory of Relativity:

Anatomical Comparison between Coniferous and Hardwood Trees

Image source: http://forestry.about.com/library/graphics/tree_shape.jpg
Wood Anatomy

Xylem = Wood, or water-conducting tissue
Phloem = Inner bark, or assimilate-conducting tissue

Sapwood – lighter color, functional xylem
Heartwood – darker colored wood near center of stem, non-functional, with tannins, resins, etc.

- In the final stage of development, vessel and tracheid cells die. A hollow, rigid cell wall remains, allowing water to freely pass through it.

Understanding the features of secondary vascular tissue is key to understanding the movement of injected materials in differing tree types

Esau, 1960

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Gymnosperms (conifers) have only **tracheids** for water transport. Angiosperms (flowering plants) have both vessels and tracheids, and primarily rely on **vessels** for water transport.
Wood Anatomy

Vessels

- ray cells
- simple perforation plate

Tracheids

Note pits in sides of cell walls; open end of vessel elements

Esau, 1960
Conifer Anatomy & Water Movement

It’s Really the Pits!

In Conifers, the xylem, or water-conducting tissue, is made up exclusively of tracheids.

Water-transport in conifers depends on very small columns of cells, without perforations at the ends as in vessels of hardwoods.

Tracheids rely on pits in their walls for the passing of water from cell to cell.
Hardwood and Softwood Cross-sections Compared

**Ash (Fraxinus sp.)**
Showing axial vessels, rays, springwood, summerwood.

**Pine (Pinus sp.)**
Showing annual rings and resin ducts.


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Conifer Anatomy

Lateral arrangement of cells & Lateral transport

- **Parenchyma** – living cells, thin, store starch and other materials, provide lateral transport. Tracheids and vessels are the primary water transport cells.

- **Rays** – for radial (inside/outside) movement of water and other materials.

- **Vascular cambium** – meristematic tissue that produces xylem and phloem. Occurs between the bark and wood; results in growth in diameter of trees.

Image source: www.nsci.plu.edu/~jmain/b359web/pages/vascamb.htm
Conifer vs. Hardwood Anatomy

- Parenchyma, uni-seriate and multi-seriate:

Tracheids, in tangential section of Pine, with uni-seriate rays.

Tangential section of the vascular cambium of Walnut (Juglans sp.), showing multi-seriate and uni-seriate rays.

Wood Anatomy

• **Spring (or early) wood** – larger xylem cells resulting from better growing conditions early in the growing season when moisture is generally plentiful and temperatures are ideal.

• **Summer (or late) wood** – smaller xylem cells produced latter in the growing season.

• **Annual rings** – caused by the transition from the summer wood of one growing season to the spring wood of the next.

• **Ring-porous** - pores in early wood larger than in late wood and appear in a ring. Common in oak, elm and ash.

• **Diffuse-porous** - spring wood pores the same size as late wood. Common in linden, maple, cherry, birch.

# Comparison of Tracheid and Vessels for Transport of Water from Root to Leaf

<table>
<thead>
<tr>
<th>Feature</th>
<th>Plant Group</th>
<th>Size and Shape</th>
<th>Relative Rate of low through conduit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracheid</td>
<td>Found in all vascular plants; the only type of water conducting cells in gymnosperms</td>
<td>Tapered cells with range of diameter of 10 - 50μm; End Walls Tapered. Walls contain pits—areas having only primary cells walls</td>
<td>Slower rate of transport due to smaller radius</td>
</tr>
<tr>
<td>Vessel Element</td>
<td>Found in angiosperms only; tend to be much more abundant than tracheid in angiosperms</td>
<td>Non-tapered cells; tend to be wider and longer than tracheid; Diameter range from 40-300 μm; End walls partially or totally lacking</td>
<td><em>Faster rate of transport due to larger radius</em></td>
</tr>
</tbody>
</table>

*flow /unit volume is proportional to the fourth power of the radius and pressure gradient according to Poiseulle’s equation: \((Jw) = \Delta P \pi r^4 / 8\eta\)
• In 1839 and 1840 Gottfried H.L. Hagen in Germany and Jean L.M. Poiseuille in France independently found:

- An empirical equation for flow rate through capillaries as a function of capillary size
- The rate to be proportional to the fourth power of the radius of the capillary: \( (Jw) = \Delta P \pi r^4 / 8\eta \)
Applying the Hagen-Poiseuille equation to tracheids and vessels produces some highly significant results:

<table>
<thead>
<tr>
<th>Conduit Type</th>
<th>Relative Diameter</th>
<th>Relative Flow Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracheid</td>
<td>(20 μm) 1x</td>
<td>1x</td>
</tr>
<tr>
<td>Vessel</td>
<td>(40 μm) 2x</td>
<td>16x</td>
</tr>
<tr>
<td>Vessel</td>
<td>(80 μm) 4x</td>
<td>256x</td>
</tr>
</tbody>
</table>
The Rate of Uptake in Maple is ~15X that in White Pine

In field studies, Norway maple with vessels 2X the diameter of white pine tracheids took up 15x faster than that of the conifer. Here, maple took up an average volume of 320mL MIN-jet Iron in 5 minutes compared to 90 minutes required for White pine.
Rate of Uptake in Ring Porous Trees

Uptake of Minjet Fe in Quercus palustris (Pin oak)
20mL/DBH" Rate

In Pin oak, the average uptake = 187mL/minute, that is >80X rate of conifers, resulting in a 2-minute infusion for a 320mL dose. The variation in uptake requires a difference in approach to tree treatments: conifers require 6-9 injection devices, dense, slow growing hardwoods require 3-6 Tree I.V.s and Ring porous trees one Air/Hydraulic device suffices.
The pattern of branch attachment in conifers

- Conifers have a whorled branch arrangement

Branch Stem Attachment

- Function in non-infested trees

- A branch supplies carbohydrates to the stem BELOW the branch

- The differential growth of branch to stem results in the formation of the branch-stem collar

Image source: http://ceres.ca.gov/foreststeward/html/prune2.html
Branch Stem Attachment

- An exploded view of branch-stem attachment
- Illustrated is three annual branch increments with their associated stem collar

Image source: http://www.tlcfortrees.info/images/BranchCollarExpanded.jpg
Branch Stem Attachment

- A tree with a branch torn from it
- Note the pattern of attachment in the exposed xylem illustrating the branch relationship to the main stem

Image source: http://www1.br.cc.va.us/murray/Arboriculture/pruning.htm
Branch Stem Attachment

• In functioning limbs translocation of photosynthate is primarily downward.
• When a branch is compromised by infestation, carbohydrates are drawn off.
• Above, functioning branches supply the stem below.
• This results in a differential growth of the branch collar, isolating the infested branch.
Branch Stem Attachment

• The infested branch growth is reduced.
• Reduced needle surface and shoot extension results in reduced transpiration
• Although the sapwood connection is maintained, and the branch is able to take up solutes and water from below, the more extensive the infestation, the less likely the branch will recover
• Early treatment is therefore imperative.
Anatomy, CODIT and Trunk Injection

- Translocation of injected dye (P) occurs in the sapwood
- Translocation does not occur in the heartwood (H)
- Wall 2, (radial) is the second weakest in CODIT response
- Drilling deeply is therefore not recommended

Quercus rubra
Implications for Trunk Injection

• Tracheids are very small in hemlock—allow more time for uptake
• Uptake occurs at a slower rate compared to hardwood trees
• Use a larger injection interface—
  – a #3 or #4 Arborplug is recommended to take advantage of a greater cross section of tracheids for reducing time of uptake
• Use more injector units—
  – expect to use 6 to 9 Tree I.V. per applicator in hemlock (depending on tree size)

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