EXPLORING ALTERNATIVES TO TREE INJECTION

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Abstract. The history of injection practices in medicine and arboriculture is reviewed and the problems associated with these practices are discussed. Columns of occluded (compartmentalized) xylem and killed bark are typically associated with wounds caused by injection. These columns extend both up and down the trunk and may extend out into the roots. Forty percent or more of the transport system can be blocked. Typical wound responses are illustrated. In most cases, there are other methods for inducing the uptake of fertilizers, biocides, and growth regulators by trees. These alternatives need to be promoted and improved and new technologies need to be developed.

This article reviews the use of injections (includes implantation) to treat trees with fertilizers, plant growth regulators, herbicides, fungicides, and other substances. Long-term studies show that the wounds resulting from tree injection procedures (regardless of the substance injected) are associated with columns of occluded and discolored xylem. Often, there is decay involved as well. Examination of wounds that mimic those made by tree injection (holes made by increment borers, nails or bolts driven to install deer stands, maple tree taps, gunshot wounds, or yellow-bellied sapsuckers drilling to induce sap flow and attract insects) reveal similar columns of occluded xylem and decay. Unlike other wounding, tree injection places substances into the wound, causing additional injury.

There are significant qualitative and quantitative differences in the responses of different tree species (and even cultivars within species) to injection wounds and to the substances injected(35). These differences in response reflect differences in biochemistry, membranes, cell walls, anatomy, gross morphology, and the compounds used. Injecting diverse tree groups with the same apparatuses and the same substances is equivalent to using the same procedures to inject fishes, frogs, birds, duck-billed platypuses, elephants, cows, and humans. A description of the damage associated with tree injection procedures, the history of the transfer of injection technology from medicine to arboriculture, and a brief discussion of alternative methods for delivering substances to trees are the subjects of this paper.

Damage Associated with Tree Injection Procedures

Columns of discolored and occluded (compartmentalized) xylem and killed bark are typically associated with injection procedures (1, 5, 14, 24, 40, 57,59). These columns of occluded xylem can extend up the trunk from the injection site for 15 feet or more and down into the trunk flare and out the roots for several feet (Fig. 1a - d). The pattern of discolored tissue can be concentrated in a small column, ascending straight, spiralling, or spreading — varying among species and even within species of trees (13, 56, 60, 61).

Even before injection, trees have been wounded many times by natural agents. Fungi, bacteria and other organisms enter through these wounds and become sparse, quiescent residents in the bark, the sapwood, and the heartwood of apparently healthy trees. New populations of organisms can invade the tree at each injection site. The new and resident populations interact in ways that are not understood completely (39, 45, 46, 52). Then the populations can multiply rapidly, damage the tree, induce the secretion of phenols and other substances, and produce the wound responses described above.

Beiler (3) reported the following phenomena associated with injection-sites: distorted growth of the cambium; trunk splitting above and below injection sites (sometimes the splits resemble lightning strikes, sun scald, or frost cracks); weeping and fluxing of sap, associated with bacterial and other infections (wetwood); and ring shake. Our observations add decay, killed bark, cankers, and reduction of storage space for energy reserves to Beiler's list, particularly in trees that are already in poor condition when injected.

As previously noted, the responses to injection wounds are similar to those of sapsuckers and hunters (Fig. 2). In many cases, the wounds are covered by callus (woundwood) and new xylem and bark. The woundwood conceals the damage to the transport and storage systems of the tree (xylem and phloem). Twenty percent of the functional transport system can be blocked by a series of injections at eight-inch intervals around the base of a tree (Fig. 1). The columns of discolored wood, occluded xylem, killed bark, and disrupted parenchyma associated with injection holes that are drilled at angles between 30o and 45^{O} are particularly large. Such practices can disrupt the functional transport by 40% or more. Cankers can develop around the injection sites and completely girdle the tree.

Santamour (36) described the pattern of utilization of starch and the formation of phenolic compounds as part of the wound response. He noted that starch is transformed into sugars in the interior of the trunk and these are used to form the walls of compartmentalization described by Shigo, Shortle, and their associates (40, 41, 42, 43). We suspect that once the wound response is complete, the compartmentalized wall blocks the penetration of oxygen to the ray parenchyma interior to the

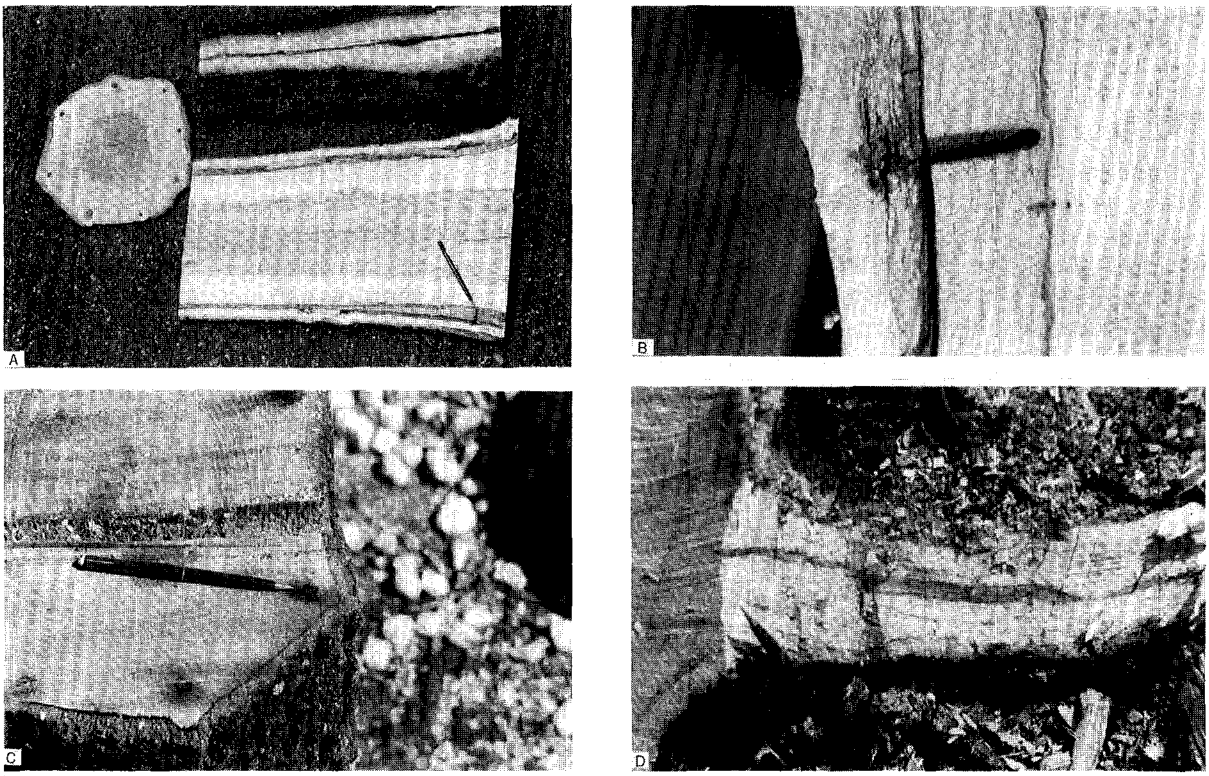

Figure 1. A. 1987 photo of transverse, radial, and tangential sections of stump portion of a willow oak tree that was injected in 1983. Revealed are the columns of compartmentalized-discolored wood that extend up into the crown of the tree and down and out into the roots. Every injection site on every tree treated displayed the same wound response. Rot was associated with most of the injection wounds. The injected solution contained dilute concentrations of iron, magnesium, and other elements. All of the injected trees remained chlorotic in spite of the treatment. B. Close-up of a radial section through an injection site. Callus overgrew the wound and a continuous cambium was reestablished quickly. Although the tree appeared to have "healed" from the outside, 20% of the transpiration column of the tree was lost as a result of the injection. C. Close-up of severed stump showing the distorted radial increment associated with each injection and its associated column of compartmentalized wood. D. Close-up of root-collar area showing the column of compartmentalized wood extending down from the injection site and out into the root. There is a loss of functional transport in roots as well as trunks.

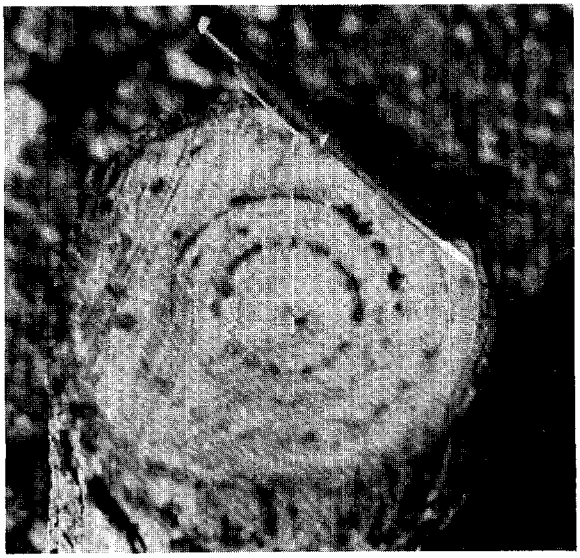

Figure 2. Cross section of the trunk of a hickory tree showing the columns of compartmentalized wood associated with the wounds inflicted by sapsuckers (note the discoloration around the growth rings — this is the source of much of the "ring shake" that makes defective lumber as well as weakens trees). The columns of occluded xylem associated with the wounds inflicted by sapsuckers, nails, increment borers, or other implements are essentially the same as those associated with injection wounds and are independent of the substance injected or the wounding agent.

column of occluded xylem. Hence, the ray parenchyma and other living cells in this sector die. The depletion of starch reserves, combined with other debilitation of the living tissue interior to the column of compartmentalized xylem, may explain Santamour's observation that breaching the walled-off zone with a second wound typically results in the rapid expansion of decay in the interior of the trunk (36).

Some nasty and complicated things happen when a tree is wounded. Drilling holes for injection ports is a form of wounding and is especially deleterious because toxic substances are forced into the wound. The concerns of many researchers (including among others: Anderson, Beiler, Campana, Chaney, Moran, Santamour, Shortle, Shigo, Stipes, and Wright) about tree wounds and the use of injections to treat trees with a variety of substances are more than justified (1, 3, 5, 6, 48, 49, 50, 59).

The History of Injection Practices in Medicine

Painting of tree wounds with tar or other noxious substances and the use of various gravity and pressure devices for injection has a long and murky history. Many of the practices used by arborists are borrowed from the Greek physicians of Alexandria and from the Romans. Arborists would do well to read Guido Majno's book The *Healing Hand — Man and Wound in the Ancient World* (18). This should be followed by reading the subject headings under injection in recent volumes of the *Index Medicus*. A visit to the audiovisual library of the local medical or veterinary medicine school will also yield valuable information. The abstracts in *Index Medicus* and the 107 slides in the slide tape review of *Injection Techniques in Relation to Carcass Damage, Cross Infection, and Injection Hazards* (28) should alert arborists to the diverse technology and hazards associated with injection practices in fields other than their own.

From Majno's book: Hippocrates wrote about the use of bladder and gravity-type syringes about 325 B.C. The first pneumatic syringe, called a pyulkos (Greek for "pus-puller") was made by Ktesibios, son of a barber in Alexandria about 280 B.C. These devices were used as flame throwers, enema bags, and as instruments to wash out wounds and to infuse wounds with creosote, honey, and various antiseptic substances.

From Garrison's, Glendening's, and Singer and Ashworth's books on the history of medicine (9, 10, 47): The first records of actual injection of substances into humans was with a gravity device for the relief of pain. The substance injected was a mixture of morphine and creosote. The hypodermic syringe was developed in France by Charles Gabrier Parvas in 1851. Alexander Wood in 1855, Fordyce Barker in 1856, and George Thomson Elliot in 1858 introduced the hypodermic method of injection to America. As with the apparatus for tree injection, history reveals many squabbles over patents for devices to be used in injecting humans and animals. A search of the medical literature reveals that, while there was no one person credited with "invention" of the hypodermic syringe, Alexander Wood is credited with developing and popularizing the hypodermic method.

From the Index *Medicus* (54): Injection technology is highly developed and complex. Injection sites include intra-arterial, intra-artingular, intralymphatic, intra-muscular, intra-peritoneal, intrathecal, intra-venous, intra-ventricular, intra-dermal, intra-cranial, subcuticular, and others. Each of these diverse sites of injection calls for specialized apparatus and is associated with all sorts of possibilities for introducing disease organisms by cross infection. The side-effects of injection include all sorts of undesirable trauma and disease (e.g. AIDS, hepatitis, air blockages, hemorrhages, paralysis). Every issue of the Index *Medicus* includes several pages of abstracts that vividly describe things that can go wrong when injection procedures are used. See for example: Sharma *et al.* (38), and Newton (20).

It is small wonder that the medical profession seeks constantly to develop alternative methods for getting therapeutic substances into patients: nitroglycerine patches to apply to the skin; formulations that can be absorbed through nasal membranes; coated pills that will pass through the digestive juices of the stomach; and non-toxic plastics that degrade in a controlled fashion to release therapeutic drugs slowly and uniformly (15).

Researchers of arboriculture can discover useful techniques by examining the literature of medicine. However, experience shows clearly that there are hazards and serious side effects involved even in medicine.

Pre-1950 Reviews of the Use of Injections for Trees

There are hundreds of publications related to the methods and purposes of tree injection. Only a small fraction are cited in this paper which focuses on the problems associated with the technique and the initiation of alternative methods. Interested readers may quickly discover additional references by referring to the literature cited in this paper.

May (19), Roach (26, 27), Rumbold (29, 30, 31), and Sachs (32) described early investigations using injection and infusion procedures to introduce substances into trees, including much literature published between 1158 and 1938. Most of the injections before 1890 were done by researchers concerned with determining how, where, and how rapidly substances move in plants (11, 32). Various dyes and salts were the substances most commonly injected. The reviews of May and Roach include excellent illustrations of apparatuses used to inject trees. They delve back to references as early as 1158, when "Hadje de Granada attempted to impart flavors, odors, and purgative and medicinal qualities to flowers and fruits by placing various substances in the pith of roots and shoots" (8). Leonardo da Vinci injected arsenic into peach trees in order to make the fruits poisonous (52). Hales (11) did many experiments in the early 1700's, one of which was to inject camphor into trees. He could smell the camphor when it reached the buds.

The reviews of the controversy over injections in the latter part of the nineteenth and the early twentieth centuries are particularly interesting. Iron sulfate (to treat chlorosis), potassium cyanide (to control insects), and aspirin (to control diseases) were the chemicals most commonly injected during this period. Russians were the pioneers in the use of injections for therapeutic purposes (37) and German, French, English, Italian, and American workers borrowed from the Russian publications. As with current practices, the results of these early attempts to use injections to treat trees were inconclusive. Some workers reported positive results, others reported no effect or incomplete coverage, and many reported serious damage to the trees. Perhaps the materials were injected too rapidly, or the concentrations were too high, or both.

The research summarized by Roach, Rumbold, and May described the early efforts to control insects, diseases, and mineral deficiencies by injection and revealed the same mixed results and many of the problems that are encountered by horticulturists and arborists in the 1990's. Rumbold's 1920 review and research were concerned with finding methods to treat the chestnut blight (30). Roach focused on the problems of nutrition of apple trees (27).

There was great concern that the uptake of air in the process of injection would block normal transport. This led Caroline Rumbold (29) to develop special modifications of tin cans and Mason jars and to devise special clamping devices to make the injection wound below the surface of water or the solution being injected. Recent publications on xylem transport in trees describe the problems that result when air is allowed to enter the vascular system (60, 61). Perhaps some of the controversy and disagreement among researchers stems from a failure to recognize differences in anatomy among species.

As part of her efforts to control the chestnut blight, Rumbold injected over 40 substances into the trunks of more than 150 orchard-grown chestnut trees ("Paragon" Chestnuts, 6" to 8" dbh) (30, 31). The substances injected included simple salts, various chromates, salts of silver and mercury, phenols, citric acid, salicylic acid, and infusions made from healthy and diseased chestnut bark. Her meticulous drawings and photographs illustrate some of the damage associated with tree injection practices. None of the injected trees recovered during the five years of her investigations (1915 to 1920) and the work was abandoned "without conclusive results".

Roach (26), who did all of his research with apples, reported that when air is not allowed to enter the injection hole, the flow of fluids into the tree under suction "proceeds practically as rapidly as under small positive pressures of liquid". The container of solution was located below the injection hole and uptake was the result of the cohesion of the uninterrupted column of water and the normal pull of transpiration. Interruption of the water column with air increased greatly the resistance to this process. If air was allowed to enter the injection hole, uptake under "negative pressure" stopped. However, under positive pressure, uptake was resumed even after air had been allowed to enter the injection hole for several days. Roach commented on the extra work involved in making injections by methods that excluded air from the system and favored injection with pressure.

All three reviews provide illustrations of injection apparatuses as well as detailed instructions for their use. Roach described methods for applying direct pressure to the injection apparatuses using grease guns, bicycle pumps, reservoirs from gasoline lanterns, and air compressors (27). He managed to blow the bark off trees and split the wood! Roach emphasized the importance of placing injection holes properly and insuring that the drill bits are sharp and clean. Otherwise, either the injection would fail or only part of the tree would be treated. He also described attempts to scrape away lichens and sterilize the bark prior to drilling.

Roach observed that "occasionally efforts to treat whole trees by injection failed" and attempted to find the cause of failure. He observed that injected dyes moved both up and down in the xylem and that roots in wet layers of the soil did not take up the dye while roots in the dry layers of the soil did. He hypothesized that soil moisture conditions might relate to the effectiveness of injection procedures. Some of Roach's work deserves further investigation to determine the patterns of apoplastic (in cell walls and in intracellular spaces) and symplastic (within cells) movement in trees.

May (19) cautioned that too much pressure may blow the bark off the tree and that "treatment year after year could cause considerable damage; the holes may become starting points for the development of rots. Some of these difficulties could be avoided by boring no deeper than necessary, boring at different levels on the trunk, and exercising care to sterilize and seal holes at the end of each treatment". It is clear from May's writing that he was well aware of the problems and controversies that previous workers had encountered in attempting to treat trees by injection.

Eventually, the practice of tree injection fell into disrepute and was essentially abandoned by 1918 when the authors of the USDA Farmers Bulletin (24) cautioned orchardists that "such treatments are entirely without merit in controlling insects and disease and are often decidedly injurious to the trees treated". This Farmers Bulletin included photographs of the damage to apple trees that had been injected with cyanide.

Recent Reviews of the Use of Injection Practices in Trees

The onset of Dutch elm disease in the United States led to a renewed interest in tree injection. May's 1941 review *Methods of Tree Injection* (19) was at least partially written in response to this renewed interest. The annotated bibliography *Tree Growth Regulators* (4) and the papers presented at the *1978 Symposium on Systemic Chemical Treatments in Tree Culture* (12) describe most of the substances, apparatuses, and techniques for currently injecting substances into trees.

The substances used range from antibiotics and fungicides (e.g. aureomycin and benomyl), essential elements (e.g. iron and manganese), growth inhibitors, and metabolic poisons (e.g. paclobutrazol and maleic hydrazide). Many of the substances appear to function as intended and at least induce remission of disease (e.g. Dutch elm disease and lethal yellowing of palms), reduce chlorosis caused by element deficiencies, inhibit branch elongation, and modify fruitfulness.

The apparatuses range from devices that are simple combinations of bags, tubes, and needles (functionally identical to the apparatuses used by early Greek physicians), to devices that include pumps capable of forcing fluids into trees under pressure.

Tree injection techniques have been modified over time to facilitate forcing solutions into the trunk flare via holes made with various types of drill bits. Emphasis is currently placed on creating smaller diameter and shallower holes with bits that make smooth clean cuts through the bark and cambium (23). Little or no emphasis is placed on preventing air from entering into the tree either before, during, or after the injection. Although some authors (cited earlier) expressed concern about the problems of pathogens that commonly invade tree wounds, none described attempts to sterilize injection sites, drills, and needles or to use aseptic or antiseptic techniques at any stage in the injection process. We recognize that there may be established populations of microorganisms in the bark and xylem of trees and that aseptic and antiseptic techniques may be impossible. Drills and injection apparatuses are seldom if ever sterilized before they are used, creating a potential for transfer of disease organisms from one tree to another. The inability of arborists to prevent or cure infections should make arborists reluctant to wound trees. Differences in anatomy and physiology among species are generally ignored. The same apparatuses and techniques are used for all species including palms, which are atypical because they do not have a cambium layer.

Additional articles on the use of injections to control insects and diseases are found in the more recent volumes of the *Journal of Arboriculture*, which contain one to three articles per year on tree injection, its effectiveness, ineffectiveness, and the closing or lack of closing of injection wounds. Several authors have reported that while injected substances were effective in slowing and perhaps eliminating Dutch elm disease, the sites of injection were usually associated with extensive columns of occluded wood and/or decay and cankers (14, 25, 52, 59).

Particular attention should be given to two articles. In Wound response of Ulmus ame*ricana I: Results of Chemical Injection in Attempts to Control Dutch Elm Disease* (1) the authors noted that "the extensive amount of discolored wood associated with injected fungicide indicated that precautions must be taken such that injections will not limit future distributions of fungicide, decrease storage and transport capacities, and predispose trees to other infectious agents." In *Glitches and Gaps in the Science and Technology of Tree Injection* (50), Jay Stipes forcefully brought out the many things we do not know about the movement of fungicides in trees, the potential for modifying fungicidal molecules to make them more mobile in the tree, the physiological effects of chronic exposure of trees to fungicides, the persistence of fungicides after injection, and alternative methods for inducing the uptake of fungicides (e.g. infusion). The point is made that we are putting a technology into commercial practice when we are not sure whether or not it does more harm than good.

The mixed results, problems, disagreements, and polemics over tree injection in 1990 are very similar to those described in 1941 (19), 1938 (26), 1918 (29, 30), and 1894 (37). Perhaps the parallels reflect the facts that we are still using essentially the same apparatuses and many of the same chemicals that were used by our predecessors, and we continue to ignore the fundamental differences in the anatomy and physiology of plants and animals as we try to apply the technology of veterinary and medical practice to the culture of trees.

The results of injection practices are as inconsistent today as when May, Roach, and Rumbold wrote their reviews. The long multiple rows of elm trees at Blenheim (Marlborough's palace and estate outside of Oxford, England) were injected to control Dutch elm disease in 1974. By 1984, they had all died from the disease. Injections to protect live oak trees in Texas from oak wilt had a short term effect, but after 15 months there was no significant difference between treated and untreated trees (16). Trees that are chlorotic because they are growing in small holes in the pavement (containers that are too small) or in soil with high pH or high salt concentrations often fail to respond to injection with iron or other elements.

Exploring Alternatives to Injecting Substances into Trees

Arborists frequently inject substances that horticulturists apply as basal or foliar sprays. Zinc, copper, manganese, and iron are examples of nutrients that can be painted on, sprayed on, or applied to foliage, twigs, branches, and trunks of trees. The plant growth regulator paclobutrazol (Clipper®) is applied as a soil drench, basal spray, or foliar spray by orchardists, but is frequently injected by arborists. The glitches and gaps in Clipper injection technology, improper dosages in particular, have led to disappointing results and some liability problems when utility companies were attempting to control tree growth (50).

There are many opportunities for applying substances to specific sites on the trunk and branches of trees (7, 53). Examination of the innermost layers of bark reveals that they are often alive, unsuberized, and full of living tissue that is amply supplied with air passages. Wine-bottle corks (the outer bark of *Quercus suber*) are full of holes (Fig. 3a-b). With only a moderate effort it is possible to blow air through them (11, 17). There are opportunities for applying substances in bark fissures and to the thinner portions of the bark on the upper trunk and limbs of trees. The orange colored tissue between the scales of oak bark is alive and often contains chlorophyll (21). The bark of many trees has rays that extend back through the scales and into the cambium. All of this ray tissue may not be alive, but is easily visible with a 25x microscope. Bark varies tremendously in different parts of a given tree, among trees, and among genera and species of trees.

Spraying is not the only possible method of application. Substances can be painted on or applied in slow-release patches (just as patches of gauze impregnated with nitroglycerine are now applied to humans with heart disorders). It has been demonstrated that good control of boxwood (Buxus) psyllids and leafminers was achieved by bark applications of concentrated Cygon 2E ® (51). Some of the new medical methods of applying therapeutic agents in various polymers may be useful in arboriculture [see *New methods of drug delivery* (15)]. Different species and different problems will require different technologies. It is not likely that the techniques for treating oak trees to control the wilt fungus will be the same as those for treating beech trees for bark aphids. As with smallpox vaccinations, the scraping of a crevice or thin area of the bark may allow penetration of many substances. Non-phytotoxic lanolin, paraffin, oils, and various wetting agents may speed the penetration of a selected substance. The studies of Sachs and his colleagues need to be expanded (2, 33, 34).

A marvelous old prof, Dr. Karl "Pappy" Sax (former director of the Arnold Arboretum), routinely controlled peach borers by simply applying moth crystals over their entrance holes and holding the crystals in place with a generous daub of mud. One of the authors (Perry) has repeatedly used the same technique to control bark beetles in southern pines. This "folk lore" procedure needs to be tested with proper experimental designs. We may find that similar fumigation techniques will work with bark beetles and other insects.

Roots are the most obvious absorbing organs for trees. When soil application is inappropriate or too expensive, selected roots may be carefully dug up and inserted in tubes containing solutions

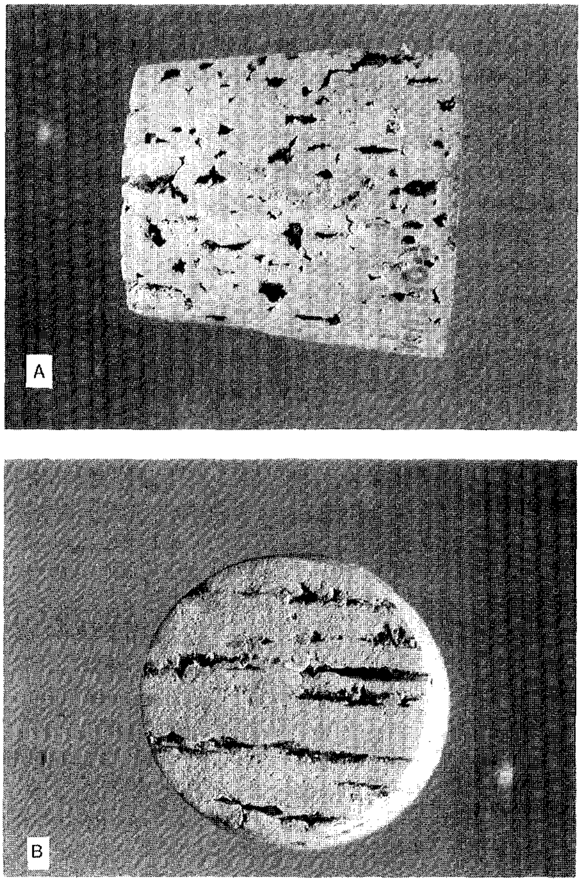

Figure 3. A and B. Two views of a typical cork. Corks are produced from the bark of the cork-oak (*Quercus suber*). The side view of the cork is the tangential section and the top view of the cork is the transverse section. Note that the holes in the bark are oriented in the radial direction so that vital gas exchange is possible through the thick portions as well as the crevices of the bark. Vintners make sure that the ends of the holes run across the neck of the bottle and that the cork is a tight fit. Otherwise the wine will spoil. Bark varies in thickness and properties in different parts of a given tree and between species. Both gases and fluids move into and out of bark (11, 22).

of the substance. Walter Lyford (unpublished) of the Harvard Forest kept roots immersed in jars of water in a crude shelter that was just warm enough to prevent freezing. He demonstrated that the twigs and branches of trees transpire actively during January and February — whenever the air temperatures were above 10o C. Treatment of a few small absorbing roots on each major woody root of a tree should be more than sufficient to allow the uptake of several hundred milliliters of solution, even in the winter.

High calcium concentrations, high pH, and high salt concentrations in the soil can block the uptake of iron, magnesium, and other cations by plants even though these elements are present in ample supply. Simple application of granular sulfur to the soil to lower the pH can make iron and magnesium more available for uptake by plant roots, eliminating the need for injecting trees to treat the chlorosis associated with mineral deficiencies (58).

Leaves absorb liquids as well as gases. One thinks of spraying whenever one thinks of foliar application of growth-regulating substances. However, the senior author has induced stunted and distorted growth of trees by immersing single leaves in test-tubes containing parts per million solutions of abscisic acid and gibberellic acid (23). Surrounding twigs with cotton soaked with the same solutions was equally effective. Roach (27) described similar methods for leaves. There is no reason why a variety of organic and inorganic substances cannot be applied with infusion techniques.

About 20% of the chlorophyll in a mature tree is located in the trunks, branches, and twigs (21). Absorption, leakage, and transpiration of substances goes on during all months of the year. Twig temperatures on a sunny winter day are 10° to 15° F. above air temperature. Photosynthesis proceeds whenever the twig temperatures are above 32° F. (21). Twigs and branches are neglected sites for specific application of growth regulating substances and other agents.

A walk in the woods after heavy rains reveals that the upper trunks of many trees remain dry throughout the deluge. Water runs down the branches and accumulates in the zones of the branch bark ridges and crotches that are described by Shigo (42, 43). These convoluted and especially porous zones associated with branch crotches and bark ridges are likely to be good sites for applying substances to be absorbed by the tree. Timing of application can be important. In the spring when leaves are forming, some bark tissues are not yet suberized.

Summary

Wounds of any kind serve as potential invasion courts for pathogens and harm trees. We must develop appropriate methods for applying or inducing the uptake of substances into trees without wounding or harming them. The differences in the anatomy of trees and animals make direct borrowing of the medical practice of injection inappropriate. Transport processes proceed at a slower pace as well as in different ways than in animals.

The differences in anatomy and physiology among tree species also make any generalized technology inappropriate. To use the same procedures to treat a pine tree, an oak tree, and a maple tree is anatomically and physiologically equivalent to using the same procedures to treat a chicken, a snake, and a horse. In view of the consistent damage associated with injection wounds, the injection of substances into trees should be an act only of desperation or last resort. Foliar and basal spraying with appropriate wetting and chelating agents, topical application to the upper trunk, branch crotch areas, and smaller branches and twigs, or ground application with modification of soil pH are among the potential alternatives available for treating trees with iron and other elements. For purposes of fertilization, injection is an unnecessary as well as a harmful procedure.

We must be patient and not try to speed up treatments by using high pressure injection and high concentrations of chemicals. It is small wonder that there are adverse reactions to such treatments. Arborists must honor the patterns and rates of transport that are characteristic of trees if bark splitting, extensive cambial damage, blocked xylem, and bark lesions are to be avoided. Appropriate treatments for trees with different wood, bark, and leaf anatomies are not likely to be the same. We should do our borrowing from the medical and veterinary professions with greater care and use more creativeness in adapting appropriate new methods for treating trees. There are economic limits to what we can do in arboriculture. However, we must recognize that our science and technology cannot progress until we have the ability to customize our practices to the species level or even to an individual tree.

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