TREE WOUNDS AND WOUND CLOSURE

by Dan Neely

Abstract. Wounds on trees mostly result as acts of nature but also are intentionally created by man. Closure of wounds occurs through production, differentiation, and maturation of callus parenchyma. The amount of callus produced is directly correlated with amount of radial stem growth at the wound site. Thus, those variables that stimulate or affect the vascular cambium also directly affect the time for wound closure. Wound width is the single most important wound dimension. Wounds 11/16 inch in diameter closed in one season when diameter growth was substantial, 1/2 inch wounds closed when growth was moderate, and 3/8 inch wounds closed when growth was modest.

Wounds on trees have received the attention of man for 4,000 years. During this time hundreds of materials have been applied to wounds to protect the exposed wood and to promote rapid wound closure. No material has been established to be consistently and statistically better than any other material, and no material has been proved to give better results than leaving wounds untreated. Tree wound treatment and cavity filling are arts, not sciences. Both have been standard practices of arborists for years and probably will continue to be in the future. These practices are cosmetic, not functional, and fortunately do little harm to wounded trees. With more and more scientific studies describing the effects of wounds on trees and adding to our knowledge on plant injuries, the use of cultural practices that are more beneficial to trees should be encouraged.

Mechanical injuries to trees result from many causes. Most occur as acts of nature, that is, breakage from wind, ice, snow, feeding by animals, or careless acts by man. Pruning wounds, however, are created intentionally by man to improve the plant, to make a site more safe, or to maintain utility services. Wounds also are created when chemicals are injected or implanted into trees for prophylactic or therapeutic treatment of nutritional deficiencies, insect pests, or disease organisms. Wounds, whether inflicted intentionally or unintentionally, heal in a typical manner. The object of this paper is to describe the procedure by which wounds heal and to detail studies related to the rate of closure.

Wounds on trees in which the wood has been exposed most often heal (close) through the production, differentiation, and maturation of callus. The term callus is used by botanists in two ways. It is defined as the accumulation of callous in sieve tubes of the phloem or as the thickened mass that develops at the base of a cutting or around a wound. Both constitute thickened masses (thus callus), but it is the second definition that is used in this paper.

When a portion of the plant that includes the xylem, vascular cambium, and phloem is cut away or removed, parenchyma tissue (callus) fills the space where the respective plant tissues are not in complete contact with each other. The parenchyma may be produced by the cells of the cambial zone and also by other living cells of the vascular region if they have no secondary walls. The parenchyma of the phloem rays and of the immature parts of the xylem rays have been associated with the production of callus.

The outermost cells on the cut or torn surface will be destroyed by dessication. The nearest intact cells capable of producing callus enlarge until their dimensions surpass those of other similar cells (hypertrophy). The increase in size may occur several cells in depth. The large cells then divide and produce many cells (hyperplasia). This process continues until the void is filled. About 3 weeks after the callus is formed, a vascular cambium becomes differentiated in it and is continuous with the previous vascular cambium.

When bark only is removed from a portion of the trunk and either the cambium zone or the immature xylem ray cells are not killed by dessication, a surface callus may develop rapidly, and the entire wound will be closed within a few weeks time. In most instances, however, the cambium cells are removed or destroyed, and callus develops from the margin of the wound. Callus will develop from around the margin of the wound toward the center of the wound.

The amount of callus growth at any point on the margin of the wound is largely regulated by the basipetal flow of products synthesized in the crown, especially carbohydrates and growth regulators. Wherever the flow is concentrated or heavy, the callus production will be great. Wherever the flow of synthesized products is not concentrated or is light, callus production will be limited.

When callus is produced, the differentiating cambium, xylem, and phloem tissues in it are always in continuity with the same tissues in the uninjured portion of the stem. When a periderm is present in the uninjured stem, it also will develop in maturing callus in line with the original periderm. The production of callus continues and progresses toward the center until the opening is closed. There is then a fusing of the tissues and a matching of xylem, cambium, phloem, and periderm. The wound is then healed, and annual growth rings are produced normally.

In the late 1960's I subjected to experimental evaluation in Illinois a number of characters of tree wounds for which data to substantiate our conclusions were lacking (2). The 3-year study was conducted at the Morton Arboretum, Lisle, Illinois, 25 miles west of Chicago.

The three species of trees used were white ash, honey locust, and pin oak. The trees were growing in square 100-tree blocks with 15 or 20 feet between trees. The oaks and ashes were planted in 1956 and the locusts in 1957. The trees were 15-20 feet tall in 1967.

Trunk and branch pruning wounds were made in early May 1967 and 1968. The width of each wound was measured to the nearest millimeter and recorded on the day the wound was made. The amount of healing was determined from measurements of the width of wound exposed in the fall of 1967, 1968, and 1969. The trunk circumference of each tree was measured with a steel tape at the same times. Results of the study were summarized as follows:

Shapes of wounds. Wounds of three shapes were inflicted on each tree. In 1967 the shapes were an ellipse with pointed ends, a circle, and a square. All were 2 inches wide. In 1968 the shapes were the ellipse, the half-ellipse (a D-shaped wound), and the half-ellipse with interior bark flap (a C-shaped wound). All ellipses were 4 inches long.

The elliptical, circular, and square wounds all healed at approximately the same rate. The only consistent exception occurred in 1967 with the square wounds. Callus first formed at the corners will less callusing along the sides. Since closure was determined from measurements at the widest point of exposed wood, the square wounds appeared to close less rapidly than did the round or elliptical wounds.

Of the wounds made in 1968, the narrow C-shaped wounds all closed within two growing seasons, while many elliptical and half-elliptical wounds remained open. Assuming equal growth on the identically shaped sides of wounds, the straight sides of the D-shaped wounds grew at one-half the rate of the elliptical sides, and the inner bark flaps on the C-shaped wounds grew at one-fourth the rate of the elliptical sides. Regardless of shape, the narrower the wound, the less the time required for closure.

Facing direction of trunk wounds. Wounds on each tree were made facing the four cardinal directions. Measurements of the wounds yielded similar data for north-, west-, south-, and east-facing wounds on all three tree species. The direction the wound faced apparently had no effect on the amount of closure.

Season of wounding. On each of 10 trees of each tree species, one wound was made in spring, another in summer, another in fall, and another in winter. At the end of the first growing season, after the spring wound was inflicted, the spring wound callus had covered 12-18 mm of wood and the summer wounds only 2-6 mm of wood. At the end of the second growing season the winter wounds had healed more than the fall wounds and almost as much as the summer wounds. Dieback at the wound margin is apparently more severe around fall and summer wounds than it is around winter and spring wounds.

Branch-pruning wounds. On nine ashes and nine oaks, six branches were pruned from each tree. On three trees of each species the branch stubs were 2 inches long, on three trees the stubs were 1 inch long, and on three trees the pruning cuts were through the branch collar almost flush with the tree trunk. On ash the pruned branches were ¾-1½ inches in diameter and on pin oak the branches were ¾-1 inch in diameter.

Only when the pruning cuts were through the branch collar was there consistent, rapid, and regular healing during the 3 years of this study. Even though the wounds through the collar were 50 percent wider on oak and 100 percent wider on ash than wounds on the branch stubs, the collar wounds healed in much less time.

Height of wounds. The lower trunk wounds in this test were approximately 2 feet from the ground, the middle wounds were approximately 4 feet from the ground, and the upper wounds approximately 6 feet from the ground. All wounds on each tree healed at approximately the same rate regardless of height.

A second purpose of this study was to determine the relationship between tree vigor and rate of wound closure. Preliminary data were obtained from the 1967 and 1968 tests on wound facing direction and the 1967-1969 test on wound dressings (Fig. 1). These data indicated that width of wound closure was directly correlated with radial tree growth at the wound site. This was true for the first, second, and third years after wounding. It was also true regardless of tree species. All 2-inch wide wounds closed approximately 2.7 mm per mm of radial growth on oak, locust, and ash.

A second study was conducted at the Illinois Natural History Survey arboretum and at the Morton Arboretum in 1970, 1971, and 1972 to confirm or refute the hypothesis that wounds on all species and sizes of trees closed equal amounts per unit of radial growth (3). Four species of trees were wounded at each site with 1-inch, 2-inch, and 3-inch wide elliptical wounds. Wound closure data and trunk diameter data were collected as before. Unfortunately, the hypothesis was not confirmed.

Growth and wound closure on the 10 trees of each species demonstrated biological variability. Callus tissue from the wound margin almost covered the exposed wood of the small wound in 1 year, the medium wound in 2 years, and the large wound in 3 years. On each species the relationship of radial growth and wound closure was determined for small wounds in 1970, medium wounds in 1970 and 1971, and large wounds in 1970, 1971, and 1972 by using a linear regression model. The lines of regression of radial growth on closure of pin oak was typical of results from all six species (Fig. 2). The points marked by the small circles and connected by the broken lines show the locations of the arithmetic means of data from 10 trees. The six lines of regression are almost parallel. This indicates uniform closure for each additional unit of radial growth for the three sizes of wounds for each of the 3 years.

The six lines of regression in every instance were less steep than the broken lines connecting arithmetic means. In a particular year the slower growing trees healed more rapidly than the mean would indicate and the faster growing trees healed less rapidly than the mean would indicate.

An analysis of covarience on the 1970 data from large wounds on six species of trees strongly rejected the hypothesis that species had no effect upon closure rate. (The F ratio was determined to be 6.45; the tabular F value at the 1% level equaled 2.9). In this test the covariance of closure and radial growth was not the same for all species of trees. The amount of closure of soft maple and American elm per unit of radial growth was substantially greater than the amount of closure for the other four species. The amount of closure per unit of growth on ash, pin oak, tulip tree, and honey locust trees was relatively uniform for all wound sizes and all years.

The data suggest that within a season the large wounds healed at a more rapid rate than the medium-sized wounds, which in turn healed faster than the small wounds. The data also suggest that within a wound size the wounds healed at a more rapid rate in the first season than in the second season, and in the second season faster than in the third season. The observation that wound size affected amount of closure and that time for closure affected amount of closure were both supported statistically by one-way analysis of variance tests.

Since the correlation between wound closure and radial growth at the wound site has been confirmed, there are a number of characteristics of the vascular cambium in trees that should be noted (1). Each of these characters has a bearing on the amount of wound closure that can be expected.

In the temperate climatic zones, little or no cambial activity is present during winter. The resumption of cambial activity in the spring has often been found related to the new primary growth from buds. In many dicots cambial activity in the spring begins beneath the emerging new shoots and spreads basipetally toward the main branches, the trunk, and the root. As an example, the data from the sycamore maple in England indicate that in this tree 9 to 10 weeks elapse between the initiation of xylem differentiation in the twigs (late in April) and that in the roots (early in July). Activity ceases in the same order. The formation of xylem stops in the twigs in late July, in the roots in late September. This tree has diffuse porous wood. The conifers and dicots with ring-porous wood show an early and more rapid spread of cambial reactivation (1- to 3-week time span) throughout the shoots, trunk, and roots in the presence of only a small amount of bud growth.

The rate of the downward progression of the xylem wave in stems is modified by site and environmental conditions. In suppressed trees it moves more slowly. At the base of the stem the diameter increase begins later and ends sooner than in dominant trees. In stressed situations and in older trees, many trees which form complete xylem increments in the upper stem often do not form any annual rings in the lower stem.

Discontinuous rings, rings that do not encircle the stem, occur commonly in arid zones, over-

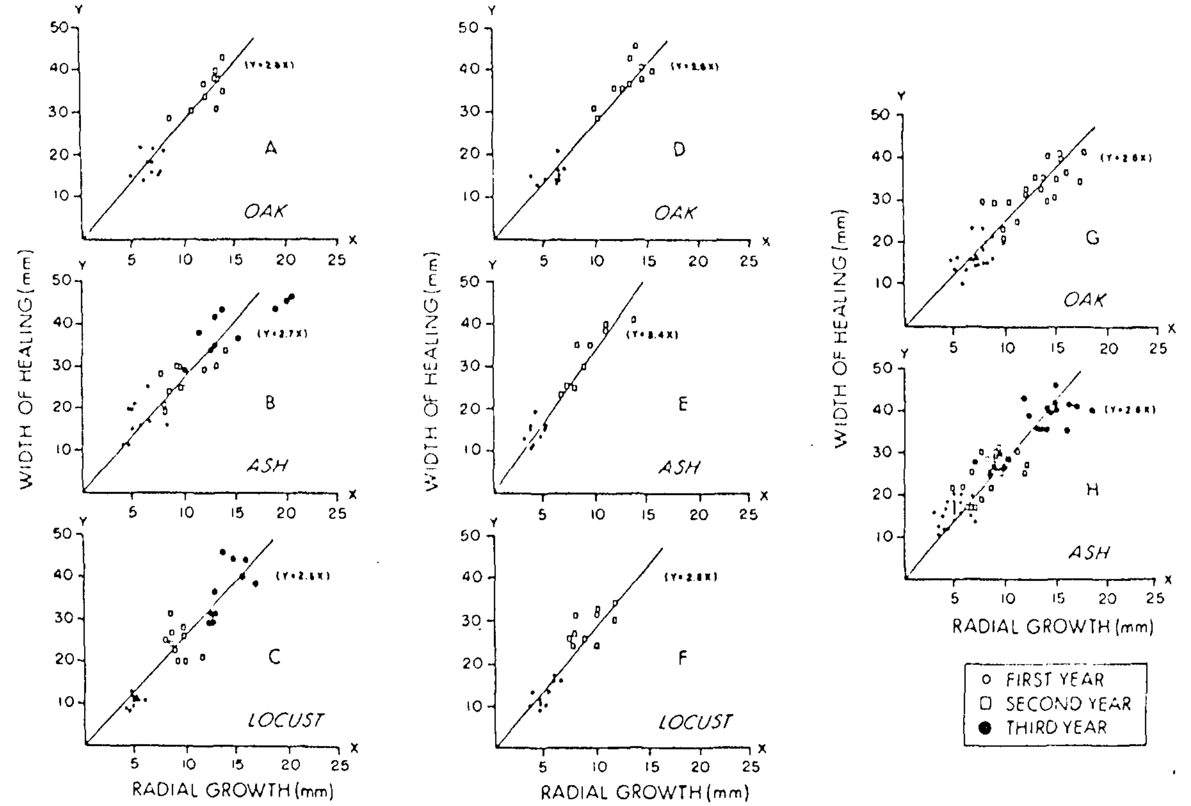

Fig. 1. Amounts of closure of 50-mm wide elliptical wounds and amounts of radial growth. (A-C) Data from the 1967 test on facing direction of wounds. (D-F) Data from the 1968 test on facing direction of wounds. (A-F) Each point represents an average of 4 wounds on 1 tree. (G-H) Data from the wound dressing test. Each point represents an average of 3 wounds on 1 tree.

mature trees, heavily defoliated trees, suppressed trees of the understory, senescing branches, and stems with one-sided crowns. These discontinuous rings are more likely to be found in the roots and lower stem than in the upper stem of a tree. This results in one-sided growth of the tree.

It is difficult to quantify accurately for any species the days of cambial growth during the year. It varies with the parts of the tree, tree species, crown class, and environmental conditions. Trees have been divided into three classes: those that produce most of their growth in (1) May and June, (2) May, June, and July, and (3) May through September. In tropical trees cambial growth may continue for all or most of the year.

The annual xylem sheath laid down by the cambium varies in thickness at different stem heights in a consistent way. The annual ring is quite narrow at the uppermost internode of the twig. Ring width then increases for a few internodes and becomes thickest at the stem height where there is maximum leaf volume. Below the crown the variation in ring thickness with stem height depends on crown development. In open-grown trees the ring may be uniformly wide at all levels in the stem below the crown. In dominant trees in forests the ring narrows below the crown and thickens again near the stem base. In suppressed trees the annual ring narrows rapidly below the crown and may not show any thickening near the base of the stem.

Cambial growth is largely regulated by the flow of products synthesized in the crown. Thus, the distribution of the crown will affect cambial growth and may be influenced by environmental fluctua-

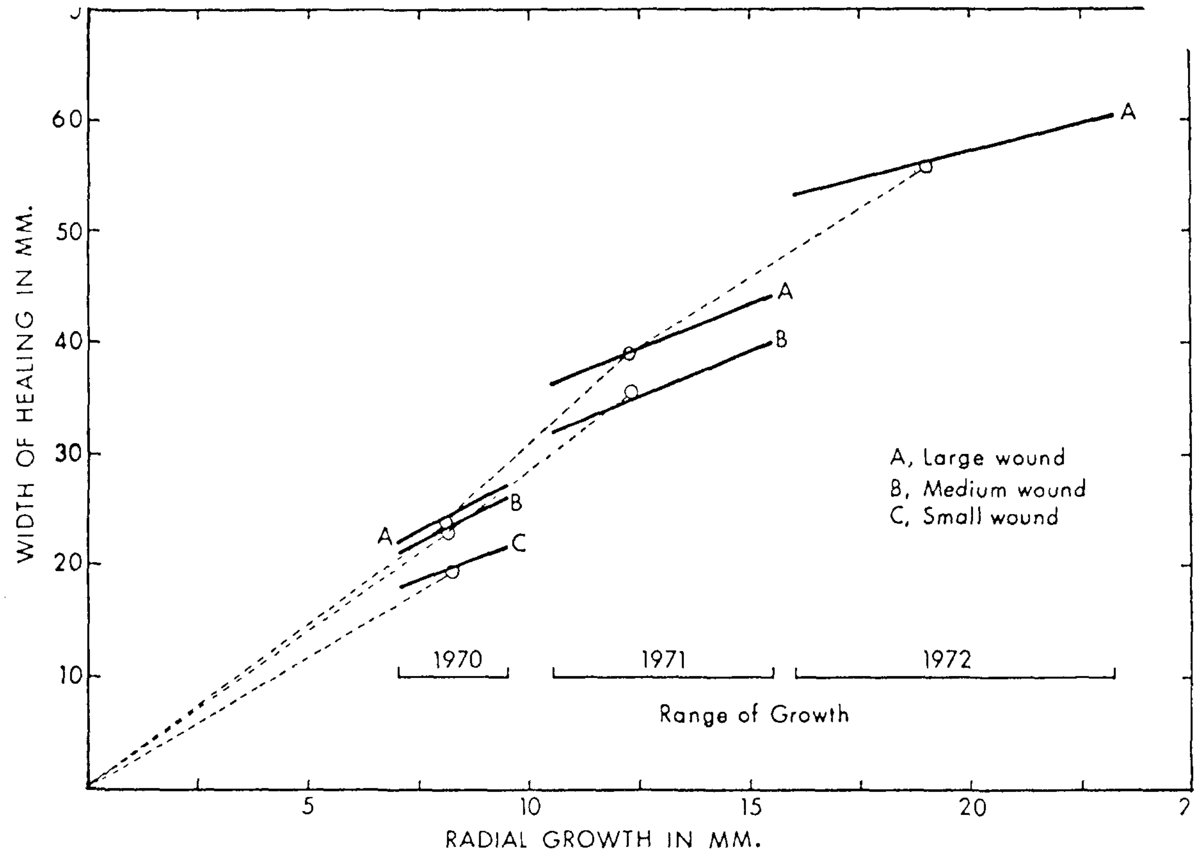

Fig. 2. Lines of regression of radial growth on closure of large (75 mm), medium (50 mm), and small (25 mm) wounds on pin oak at the Morton Arboretum, Lisle, Illinois, (average for 10 trees).

tions, plant competition, site, management practices, and catastrophic events, such as premature defoliation. Among the most important environmental factors that play a contributory role are light, water, temperature, mineral supply, composition of the atmosphere above and below ground, soil physical and chemical properties, insects, diseases, other plants, and various animals. Cambial growth also may be greatly modified by cultural practices, reproductive growth, and shoot growth.

Wounds are being created intentionally by arborists and homeowners and various chemicals are being injected or implanted into tree trunks. How injurious are the wounds themselves? How does the wound size affect tree growth? How many wounds can be inflicted on a trunk and not cause significant injury? How does annual wounding affect tree growth? The answers to these and other questions are being sought currently in studies at the Illinois Natural History Survey arboretum and the Morton Arboretum. Only preliminary results from 2 years' data are now available.

Elliptical wounds 1 inch wide and circular wounds 11/16, 1/2, and 3/8 inch in diameter are inflicted on six species of trees. Each tree receives one wound per inch of stem diameter around the circumference of the stem. One whorl of ellptical wounds and four whorls of circular wounds are to be made in each of the 4 years of the study. Annual growth of each tree is measured and recorded, as is the amount of wound closure of elliptical wounds and the number of wounds closed on circular wounds.

Preliminary results of the study indicate that:

1. All species of trees did not close wounds with equal rates of radial growth. Sycamore, pin oak, and white ash appear to close with less radial growth than do tulip tree and honey locust.

2. The amount of wound closure is correlated with radial trunk growth in all species.

3. The whorls or circles of wounds on the trunks did not reduce radial growth of the trees after 2 years' treatments.

4. Wounds 3/8, 1/2, and 11/16 inch in diameter closed in the first season: 3/8 inch with modest radial growth, 1/2 with moderate radial growth, 11/16 inch with substantial radial growth. Wounds 1 inch wide usually required two seasons to close.

These studies give us additional information on correlations of cambial activity and wound closure. We can better understand the relationships. With additional time and data we will be better able to determine when and where intentional wounding is beneficial or injurious to the tree. One specific research area that needs attention is the amount of dieback that occurs at the wound margin soon after wounding. Other than the associations of dieback with the season of the year and vigor of the tree, little is known. Another research project that will require extensive experimentation is the phytotoxic effects of chemicals placed on or in tree wounds. These must be studied singly. Only when we are certain that the advantages of wounding outweigh the disadvantages of wounding should we continue with this cultural practice.

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