Quantification of ancient and modern wood microstructure using microCT

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Aims

The wood of plants is composed of xylem, a complex tissue containing several different cell types. Some of these cell types, termed tracheary elements, are specialized for water transport. Tracheary element structure determines wood hydraulic function, including water transport efficiency and the ability to resist the formation and spread of air emboli during periods of water stress (1). Relationships between cellular structure and function as determined in modern plant species may be used to infer the functional traits of ancient wood. We examined the relationship between hydraulic transport function and hydraulic conductivity estimates based on microCT and anatomical measurements in modern species. We then examined samples of ancient (2-45 million year old) mummified wood from several different species non-destructively, using microCT. Ancient wood structure and microstructure were examined. Structural traits were used to evaluate potential functional differences between species.

Method

Modern plant samples were prepared by cutting wood samples from larger plants while samples were submerged in water to prevent air entry and to preserve the “native” state of the water within conduits in the wood. Wood hydraulic functional parameters were determined using standard methods (2). Modern plant samples were measured on specimens grown either in pots or from trees growing on an irrigated university campus in California, USA. Ancient wood samples included both wood fragments and larger wood pieces that were originally collected from Ellesmere Island, Canada by other researchers and which ranged in age from 2-45 million years old (3,4).

Both modern and ancient samples were scanned using an HRCT system (Bruker Corporation, SkyScan 2211, Massachusetts, USA) at the California State University, Bakersfield (CSUB) Biology 3D Imaging Center. Samples were scanned using either the CCD or flat-panel detector and were scanned at a range of different resolutions. Samples were reconstructed using the SkyScan reconstruction program NRecon and analyzed using SkyScan CTan software.

Following HRCT imaging, and for a subset of samples, thin cross sections were prepared from near the scanned area by hand using a razor blade (GEM Single edge stainless steel PTFE coated blades, Electron Microscopy Sciences, Hatfield, PA, USA) and mounted on slides in glycerol. Photos of the sections were taken using a digital camera attached to a microscope (Zeiss Stereo Discover V.12 with Axiocam HRc digital camera, Carl Zeiss Microscopy, LLC, Thornwood, NY, USA).

Results

Estimates of function based on microCT analysis predicted wood hydraulic function as measured using functional methods on modern wood samples. For modern wood samples, estimates of wood hydraulic transport based on microCT analysis of conduit structure were correlated with functional conductivity measures ($P<0.01$, $r^2 = 0.66$). However, the relationship between estimated and functional conductivity differed from a 1:1 relationship (slope = 0.35) likely because of additional resistances along the hydraulic pathway that are not included in anatomical estimates. This may include resistances associated with water transfer between cells and from the presence of some non-conductive or blocked tracheary elements.

Two different categories of ancient wood types were examined. The first type contained a tracheary element type, termed tracheids, which form relatively homogenous wood structures (Fig. 1). Within scanned samples, different growth rings were clearly visible, with each band (Fig. 1b) indicating one year of wood growth. Growth bands were relatively narrow, consistent with a short growing season as would be expected for the northern latitude of the origin of the samples. Cellular structure of ancient wood (Fig. 1c) appeared very similar to the structure of modern wood samples (Fig. 1d).

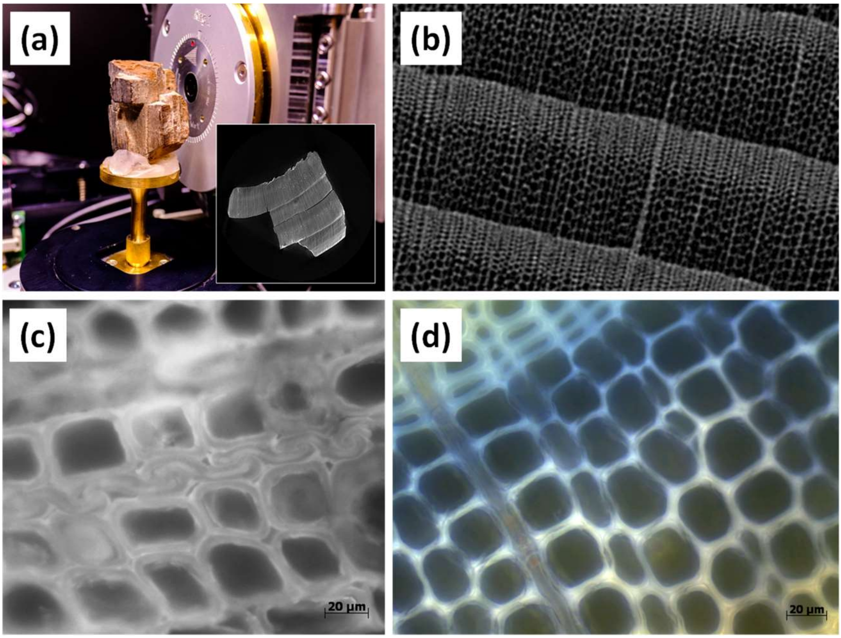

Figure 1: MicroCT scanning of a ~45 million year old wood fragment using a Bruker SkyScan 2211 (a). An image from the microCT scan of this entire sample is shown in the inset (a, inset). When scanned at higher resolution, the narrow bands of growth that indicate each year of wood formation (i.e., annual growth rings) were visible within the microCT scans (b). At even higher resolution, the structure individual tracheary cells was visible. The structure of cells within ancient wood samples (c) is similar to those in modern wood samples (d), as shown in these images from light microscopy.

The second type of wood was more complex and included large tracheary elements, termed vessel elements, which were embedded in a network of smaller cells (Fig. 2). Within scanned samples, different growth rings were clearly visible, with each band (Fig. 2b) indicating one year of wood growth. Again, growth bands were relatively narrow. Non-destructive microCT scans enabled the evaluation of internal wood structures without damaging the samples (Fig. 2b). All of the dominant cell types within the wood tissue were able to be resolved, including large vessels, smaller fibers, and rays (Fig. 2c). Standard anatomical techniques, which are destructive, revealed the same structures (Fig. 2d).

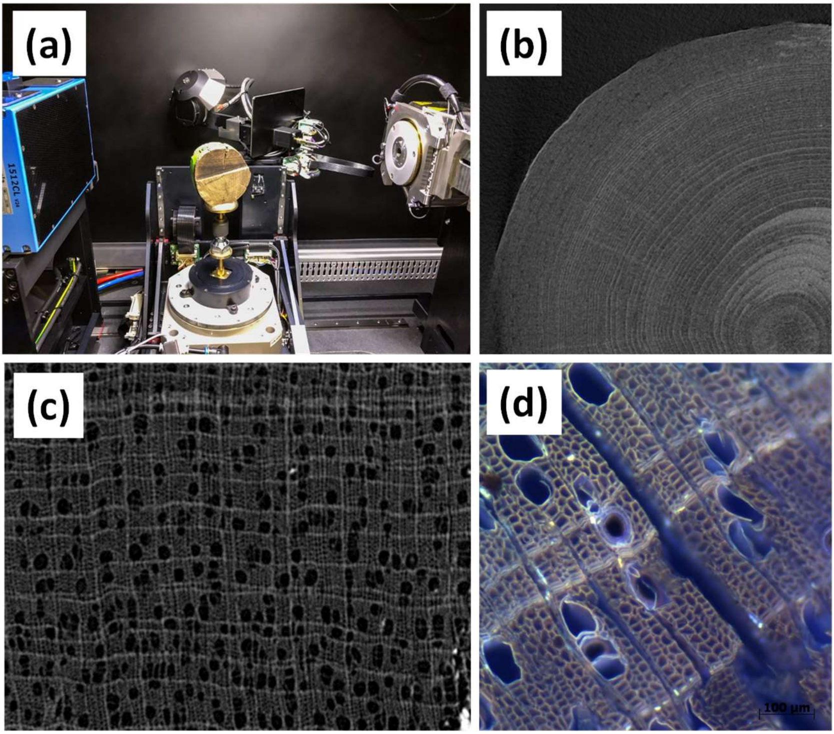

Figure 2: MicroCT scanning of a ~2-5 million year old section of wood using a Bruker SkyScan 2211 (a). An image from the microCT scan of this sample shows clear details of the internal wood structure of this sample, including many numerous thin bands that indicate the age of the tree when it was buried and preserved (b). The shown sampled tree was over 80 years old. When scanned at higher resolution, the narrow bands of growth that indicate each year of wood formation (i.e., annual growth rings) are visible within the microCT scans as are the larger cell types (vessels) that are responsible for the bulk of water transport through this type of wood tissue (c). An image from this sample obtained using light microscopy is also shown for reference (d).

Conclusion

The use of microCT imaging allowed ancient wood samples to be non-destructively imaged. The information gathered from these scans permitted the determination of tree age of some samples, analysis of annual wood growth increments, and analysis of the structure of water transport cells. Within an ancient forest, species varied in their wood properties. Additional analyses of these and similar samples may provide valuable information about past climatic conditions (5) and the evolution of tree function (6).

References:

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