Title: Micro-computed tomography for plant identification in artefacts

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Abstract [Heading]

In New Zealand the identification of materials of construction of Māori textiles has important cultural and legal connotations. However the identification of aged and processed plant material in artefacts is difficult, compounded by the need for use of non-destructive analytical methods. This paper will discuss the application, efficacy and implications of a new method that uses micro-computed tomography (micro-CT) together with an identification key as evaluative criteria for the identification of plant material in artefacts. Case studies using Māori textiles will show how plant identification using micro-CT can aid in ascribing cultural context to artefacts with unknown provenance, and aid in rediscovery of cultural knowledge about plant use for artefact production.

Keywords: micro-computed tomography, plant identification, Māori textiles

Introduction [Heading]

The identification of aged, processed plant material used in artefacts is challenging, yet provides culturally important information of interest to indigenous communities, academics, arts practitioners, and conservators. A non-destructive method for identifying plant materials using micro-computed tomography (micro-CT) and an identification key based on diagnostic characteristics of three plants endemic to New Zealand was developed by the authors and showed good results (for full details of method and results see Smith, C. *et al*., 2013). This paper explores the application of the developed micro-CT technique for materials identification of museum artefacts, and discusses its efficacy in practice. Case studies of the identification of plants used to make Māori textiles will be used to show how to best use the technique. This new method, developed through interdisciplinary collaboration (botany, materials science, microscopy, conservation) has the potential to build on, and renew cultural knowledge about customary practice in Māori textiles by providing knowledge about plants. Importantly materials identification in the New Zealand context also has ramifications for ongoing custodianship and preservation of textile artefacts.

Plant materials identification [Heading]

New Zealand and international museums have extensive holdings of Māori artefacts, many of them made from unidentified plant materials. Correct plant species identification has important cultural implications; for example if newly discovered archaeological textiles contain plant species endemic to New Zealand it can indicate they are of Māori origin. However the identification of aged, processed plant materials (as in artefacts) is problematic. Positive identification of vegetable fibres and plant materials generally requires they be in good condition, displaying the diagnostic features (from known reference material) required for their identification. Specialised knowledge of plant anatomy is helpful, and a number of parts of the plant would typically be used by a botanist for identification to species level. However, artefacts are usually made from only one part of a plant, and then considerably altered from its original form. Artefact production usually requires processing of plants (like retting, cooking, harvesting, drying, heating, bleaching or dyeing) all of which can destroy the very diagnostic characteristics used to identify them (Norton, 1990). Often adequate reference material is not available. That identifying plants used to make artefacts is difficult is commonly accepted, however in New Zealand these problems are compounded by the similarity among endemic plants used to make dress and other textiles (such as *harakeke*, New Zealand flax, *Phormium tenax*, J. R. Forst & G. Forst; *tī kōuka*, cabbage tree, *Cordyline australis*, (Forst.f.) Endl,; *kiekie*, *Frecinetia banksii* A.Cunn.). These species are all monocotyledons and their leaves have very similar anatomical features, such as epidermal features, size and arrangement of vascular tissue, and appearance of mesophyll, making discerning among them challenging. For example in transverse section *harakeke* is characterised by its keyhole or molar tooth shaped fibre bundles, while those of *tī kōuka* are shorter and squatter with shapes described as molar tooth, truncated hourglass and small truncated ovals. The anatomical similarity of these plants (Figure 1) is then compounded by the unlikelihood of specimens from artefacts containing more than fragments of the full leaf section, making already similar landmark features even less discernable. In the context of cultural materials conservation the challenges of identification of materials are then often compounded by the desirability of use of non-destructive analytical methods where possible. A method for using micro-computed tomography (micro-CT) in combination with an identification key was developed by the authors as a viable solution to some of the issues of plant material identification in artefacts.

Analytical methods [Heading]

Tomography uses X-rays to image an object in sections (therefore providing a view of internal structures), and is commonly used in medicine (for example computed axial tomography (CAT) or computed tomography (CT) scanning). The conservation literature reports the use of CT scanning to identify complex multi-media artefacts, particularly from archaeological contexts (for e.g. Stelzner, Ebinger-Rist, Peek and Schillinger, 2010) and the potential of micro-CT for examination of finer aspects of textiles, such as individual yarns and fibres (O'Connor and Brooks, 2007; O'Connor, et al., 2008). Micro-CT scanning is used on small specimens (maximum dimensions typically 70mm) and can produce images with resolution of 2-3 μm. Section data is collected using an X-ray source and detector, and can then be reconstructed using software to create a three-dimensional model of the object (Skyscan Pty Ltd, 2011). The technique is non-invasive, non-destructive, and requires no preparation of the sample, and is therefore of interest to conservators and *kaitiaki* (caretakers/guardians) of artefacts. In essence micro-CT scans provide a cross section view of the specimen, however without the difficulties commonly encountered when preparing transverse sections from aged, desiccated plant material from artefacts. Unlike preparing transverse sections, which requires a specific skill set and knowledge about fixing and staining of plant material to reveal characteristic features, a micro-CT scan 'slices' virtually through the specimen thousands of times. Multiple views of the internal structure of the plant specimen are provided, with no physical alteration of the specimen at all. Therefore use of micro-CT alleviated difficulties associated with viewing internal, diagnostic plant structures. However the similarities among New Zealand plants, and the nature of available reference material (un-aged, not processed) for comparison meant additional methods were required to identify these plants. Most of the artefact samples were only small parts of plants (rather than a full cross section from upper to lower leaf surfaces), and had been significantly altered by processing. Therefore individually discerning features of each of the plants were identified, including visual characteristics of plant tissue and fibre bundle shape, and the size range of characteristics like fibre bundles for each species. For full details of the identified measurable and visual characteristics of each of the three species *kiekie*, *harakeke* and *tī kōu*ka see Smith *et. al*., 2013. By using micro-CT transverse sections, and an identification key that uses these characteristic shapes and measures of key anatomical features of three New Zealand plants, the authors were able to identify aged, processed plant material from artefacts with a success rate of more than 50%.

Case studies – social and cultural implications of plant materials in artefacts [Heading]

Since development and publication of the method the authors have been asked to apply it to a number of Māori textiles. In New Zealand *taonga* (valued tribal possessions) such as textile artefacts, have an important place within *te ao* Māori (Māori world view) and are markers of *whakapapa* (genealogy) and key aspects of tribal and cultural identity. Consequently analytical methods that can provide some contextual information for Māori artefacts with no provenance in museums are of interest to communities and museum staff. Additionally when textiles are discovered that are possibly dated to before European contact, there is much interest in 'proving' that the textiles are of Māori cultural origin because this attribution has both legal and funding connotations. If a textile can be identified as of Māori manufacture there are implications for custodianship of the place in which it was found, and government funding can be provided for conservation of the artefact. Two completed case studies of the use of micro-CT will be discussed, as well as another in process, highlighting pitfalls for positive identification and best practice for use of the method.

Case study 1: *Kahu rāranga pūputu* (closely plaited cape; (ME00165 TePapa Tongarewa, National Museum of New Zealand) [Sub-heading]

This case study illustrates the problematic nature of recognition of plant material when it has been processed and aged. Also shown is that visual identification of materials requires substantiation by scientific analysis, which is unsurprising given the similarity of New Zealand plant species used in artefact production. *Kahu rāranga pūputu* are a form of Māori garment constructed from strips of leaf material, about which very little is known. Only six cloaks of this type have been identified in national and international collections and there is considerable speculation about their provenance and place in the development of Māori clothing. The *kahu rāranga pūputu* from Te Papa Tongarewa National Museum of New Zealand has recently been on display for the first time (see Tamarapa, 2011), and as these objects are so uncommon there is interest (from customary weaving practitioners, museum *kaitiaki*, conservators) in building knowledge about them. Conservators suspected the cloak may have been constructed from *kiekie*, a less-common material than *harakeke* (Figure 2). Consequently a large sample shed from artefact ME00165 into its storage container was provided to the authors for micro-CT analysis. A Skyscan 1172 micro-CT scanner at the Otago Centre for Confocal Microscopy (University of Otago, Dunedin, New Zealand) was used to scan specimens. X-rays were generated at an acceleration voltage of 38-40 kv and a current of 240-250 μV and were detected by a 10MPixel 12-bit CCD camera. Specimens were scanned over 180º with a rotation step of 0.4º. Raw x-ray attenuation data were reconstructed using NRecon software (Skyscan, 2011). While the sample provided was large, and itself had a sound and relatively complete appearance, micro-CT images clearly show how processing for artefact production radically affects the appearance of identified key characteristics in plants (Figure 3). A complete cross section of the leaf is not present, and diagnostic features like the shape of fibre bundles have been destroyed. However the identification key for New Zealand plants developed by the authors, still provided a way forward for discovery of the materials of construction, despite the fragmented nature of the plant materials from the *kahu rāranga pūputu*. Based on discerning visual criteria noted in the identification key the sample from the artefact was either from *harakeke* (Figure 4) or *tī kōuka* (Figure 5) as it had a clearly visible epidermis of different density to the mesophyll. The physical similarities of both *tī kōuka* and *harakeke* however mean that the only way to accurately discern between them, is to measure various features of the sample and compare its measurements with those of the same key features of reference material (for example the number of vascular bundles per mm, upper fibre bundle width, upper fibre bundle length; see Smith *et.al*, 2013). Comparison of the measurements of the specimen (carried out using Image J, a software program that enables, among other things, measurement directly from digital images; Rasband, 2008) with reference material indicated it was most likely the specimen was *harakeke* (based on vascular bundles per mm). Because the specimen was a fragment of epidermis with damaged fibre bundles it was also impossible to discern whether these were ranged along the lower or upper leaf surface, rendering several of the possible landmark measurements unusable. The ability to identify this specimen required use of both the identification key and reference measurements. Ultimately plant species identification was based on one criterion only, meaning this should be accepted with caution. Scanning and analysis of further specimens from this artefact is therefore recommended. Use of multiple samples is desirable for confident materials attribution, even in the context of museum artefacts.

Case study 2: Puketoi Station textiles (Otago Museum, Dunedin, New Zealand) [Sub-heading]

This case illustrates the importance of specimen handling in regards to environmental conditions and the consequent impact on data. Additionally the importance of direct sampling is highlighted, as opposed to use of specimens found in storage containers and packaging, assumed to come from the artefacts in question. The materials of construction of a large assemblage of dated pre-contact Māori textiles had been identified previously using visual means. Three artefacts constructed from leaf material were examined using optical microscopy (in situ examination and viewing of transverse sections), SEM and micro-CT, enabling comparison among methods and verification of plants used. Of particular note during this identification work were difficulties in gathering a clear artefact-free micro-CT scan. Whilst in previous trials, the gathering of readable data had proved fairly straightforward, many blurred, indistinct and unusable scans were produced during this analysis. Despite being securely held in position, it was clear from the images obtained that samples had moved whilst undergoing the hour-long process of CT scanning. Plant specimens had been transported to the micro-CT facility by hand in a closed container and placed directly in the instrument chamber for scanning. Analysis occurred during winter when a large differential existed between indoor and outdoor temperatures. After poor scan results were gained it was suggested that the specimens be transported wrapped, mounted on-site at the micro-CT facility, and then left in the scanner chamber overnight to condition to ambient conditions prior to scanning. This procedure resulted in vast improvements in scan quality. Clearly specimens that are exposed to fluctuations in relative humidity and temperature will move in the instrument chamber, and consequently produce blurred and unreadable micro-CT images. Therefore it is recommended that specimens are retained and examined under stable environmental parameters.

Additionally specimens used for this analysis had been gathered from storage containers holding the artefacts of interest, and were assumed to come from those artefacts. Yet in use of multiple methods for plant identification it became obvious that specimens were not all the same plant species, and were unlikely to have come from the same artefact. Different specimens may have come from various artefacts stored in the same container. Direct sampling from artefacts is therefore considered desirable, although problematic for museum artefacts. The next case study illustrates how views about direct sampling from artefacts can change, particularly when the information gained is seen to provide benefits to communities in regards to establishing ownership and funding streams for preservation.

Case study 3: Archaeological textile fragment [Sub-heading]

In New Zealand museums, in-situ methods of identification of plant material are considered preferable because of ethical frameworks around the primacy of the physical, spiritual and historic integrity of artefacts: indeed according to a Māori cultural standpoint, the smallest piece detached from an artefact can be considered as valued as the whole. Most New Zealand institutions express great reluctance for specimens to be sampled directly. That ethical considerations limit sampling from artefacts is an international phenomenon. This case study shows that when the perceived benefits of direct sampling are great, and ample communication and consultation take place, direct sampling from artefacts is possible.

Legislation protects artefacts discovered in New Zealand, and if they are identified as Māori, special provisions are made under law relating to funding (money provided for conservation treatment) and for guardianship (the *rūnanga* or tribal group in within whose *rohe* or tribal boundary the artefact was discovered are acknowledged as customary owners). Government agencies, like the New Zealand Historic Places Trust, therefore require expert opinion that discovered artefacts are of Māori origin. When considering small woven textile fragments, with structural characteristics indistinguishable from those of other cultural attribution, the identification of endemic New Zealand plants as the material of construction can form part of evidence of proof of Māori manufacture. Several large woven plant material fragments were discovered in a high-impact tourist region of the South Island of New Zealand in 2011. The New Zealand Historic Places Trust is interested in pursuing micro-CT as a means to identify the materials of construction in these artefacts, because of the important implications of this knowledge. In consultation meetings with relevant *rūnanga* members the instrumental technique was explained, as well as the odds of successful identification. The lack of alteration of the specimen during analysis, despite the necessity of its physical removal from the artefact itself, was perceived of as desirable. Overwhelmingly there has been support in pursuing this means of plant identification as the information possibly derived from analysis has extremely important cultural implications.

Availability and practicality [Heading]

In recent years developments in technology (improved resolution of micro-CT, computing hardware and software for reconstruction of gathered data) and consequent reduction in price of scanners, have made micro-CT a potentially more accessible analytical technique. A micro-CT scanner is nonetheless very expensive, and this is evidenced by how few cultural institutions have their own instrument (among them Natural History Museum, UK; Transvaal Museum, SA). Reduction in cost and efficiency have however meant that many universities, particularly those offering medical and dental training, have onsite micro-CT facilities that may provide access to conservators interested in materials identification. Importantly CT scanners are relatively simple instruments to operate, and sample preparation is straightforward. As in all imaging techniques, however, difficulties lie principally in interpretation of images gained. Settings and scan times must be tailored to the research, where resolution gains must be weighed against consequent scan time. Additionally handling of specimens (no fluctuations in relative humidity, positioning in scanner, securing against movement) all impact on the quality of the data gained. While a relatively simple analytical method, practitioner experience with the materials in question and the data gained from them undoubtedly affect the achievement of good results. Working with an experienced microscopist, familiar with a variety of materials and problem-solving issues such as those encountered in these case studies, would undoubtedly benefit most researchers.

Conclusion [Heading]

When used in combination with an identification key developed by the authors, micro-CT showed much promise as a tool for ascribing cultural identity to artefacts with no provenance. However the variability in results gained in specific identification projects highlights a number of factors which impact on the ability to positively identify plant materials. Control of environmental parameters for specimens is essential. Identification of the plant material present is reliant on both the amount and type of potentially diagnostic material that remains in specimens from artefacts. For some New Zealand plant species, small amounts of complete plant tissue is adequate for identification (for example kiekie has a characteristic ovoid vascular bundle with a clearly visible hole), while for others comparison with measurements from reference material is necessary due to their marked similarity. What is also clear is that the available reference material for comparison is limited. Some measurements taken from artefacts do not fall into the range set as characteristic of one plant species, providing no clear result. The natural variability of plants means that for reference measurements to account for variability, a greater number of specimens need to be taken. Ultimately the importance of materials identification, and consequent rediscovery of cultural information held in Māori artefacts has been amply proved by the number of requests for application of the technique. Refining methodological approaches and expanding reference material are ongoing research goals to enable solving questions around materials attribution and related cultural and social knowledge about the use of plants in Māori textiles.

Acknowledgements [Heading]

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Equipment

SkyScan 1172: Skyscan, Kartuizersweg 3B, 2550 Kontich, Belgium.

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List of figure captions

1. Stained transverse sections of *harakeke* (above) and *tī kōuka* (below) showing molar tooth shaped fibre bundles in both plant species

2. Reference micro-CT image of *kiekie*

3. Micro-CT image of specimen from *kahu rāranga pūputu* (ME00165, Te Papa Tongarewa National Museum of New Zealand)

4. Reference micro-CT image of *harakeke*

5. Reference micro-CT image of *tī kōuka*

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