Primary roots

Introduction: This week's work concerns the structure of roots and its relation to function. In order to understand the root structure it is necessary to have a clear picture not only of the mature root, but also of its development, and we shall examine this carefully when considering all aspects of root structure and function. As you listen to the sound file, examine the figures in your study guide and online.

The first organ to emerge from the seed during germination is the young root or radicle, and this rapidly establishes contact with the soil. If it is in a suitable environment. The continued development of germination depends on water taken up by the radicle, so that the root system is generally-well established before the first green leaves develop.

Read the notes on *Functions of the root system* then return to the sound file.

Root morphology: The conducting system of a plant is comprised of *xylem* for conducting water and minerals and a few other things out of the root and up to the shoot; and the *phloem*, bringing organic foods down for the growth of the root system. Roots have two functions - one is scavenging nutrients and water from the soil, the other is anchorage so that the above ground parts can remain upright and gather light and disperse pollen and seeds.

A few roots are specialised for other functions. For instance carrots and turnips that we eat are fleshy storage roots, as are dahlia tubers and beetroot.

Types of root systems: There are a number of different types of root systems and these include tap, fibrous and adventitious root types.

Root systems are very extensive, but it is extremely difficult to form an accurate estimate because the fine ultimate branches are so easily broken and lost when a root is separated from soil. To make an accurate estimate the whole must be dug up and very gently washed free of earth. Even then the estimation of the size of the root system is difficult.

Root growth: Roots exploit all parts of the soil very thoroughly. Diffusion to the root is reduced to a minimum by the extensive ramifications of the young absorbing root system. One estimation is that a new plant root absorbs water for 24 hours, after which it has differentiated to a non-absorbing state, while new absorbing root has grown out. The zone of elongation is 2-4 mm, behind the tip. The distance of the elongating region behind the tip varies from species to species and with environmental conditions.

Behind the zone of elongation in the growing root is a short zone where root hairs grow out sideways. We do not need to make a fuss about the fact that root hairs only grow out behind the elongating zone - otherwise, of course, they would immediately be sheared off.

The anatomy and also the ultrastructural anatomy of root hairs has been well-investigated. The secretion of some components of the cell wall in the rapidly growing apex of a root hair occurs via the activity of the golgi apparatus, as in the developing xylem vessel.

Despite this knowledge of their anatomy, the activity of root hairs is barely known. It is easy to suspect that they help in absorbing soil water and nutrients, but their activity is very difficult to measure, and virtually no proper quantitative measurements of the physiological activity have been reported. Look at demonstration of root hairs.

The actual growing tip of a root has to physically push its way through the soil. To facilitate this the root cells divide and continuously replenish a root cap of cells which are continuously sloughed off the advancing tip. In addition slime is secreted which is presumably produced to act as a lubricant. These secretions also involve the golgi apparatus and have been extensively studied under the e.m.

Now read part one on root growth and do the self-test quiz.

Root anatomy: Now let us turn to the anatomy of roots.

Organisation of the root tip: Begin by examining a longitudinal section of broad bean or *Vicia* root tip (slide 1). The objective here is to identify the regions already discussed. Compare this section with the figure of *Vicia* provided in your notes and online. Begin by finding the zone of elongation. You can see roughly where this

begins, but look more carefully now and find the place where cells begin to be longer than those nearer the tip. This will be around 2 mm from the tip.

Vascular differentiation: Now, in your *Vicia* slide, try to find the differentiating xylem, this can be seen as a file of large cells. Follow a file of these cells up to the apex and examine the cells where these files converge - this is the apical meristem - the region where cells continuously divide to produce the root itself in one direction and the root cap in the other. A central group of cells in the apical meristem has been observed not to divide or to do so very rarely. This can be demonstrated also with radioactive isotopes of uridine which are incorporated into dividing nuclei. There is little or no incorporation in this quiescent centre confirming the lack of cell division. It is not understood what the function of the quiescent centre is. Look at the diagrams in your study guide (in Figures 2 and 3); these illustrates the way in which the products of the apical meristem differentiate.

The tissues forming the body of the root begin to differentiate very close to the tip, i.e. within hours of their production by the apical meristem. Two main areas soon become distinct - the central core destined to produce the vascular tissue -and the outer cylinder of larger cells - designed to produce the cortex of the root.

Both of these divide further and differentiate. The central core is called the *provascular meristem*, and the outer cylinder is called the *ground meristem*.

The outermost layer - destined to become the epidermis - is called the *protoderm*, but the epidermis is still covered by a few layers of root cap cells one or 2 mm behind the tip.

The diagram (Figure 3) at plane of section A shows root cap cells surrounding the meristematic tip would show; at section B shows provascular and ground meristems distinguishable; at section C shows functional phloem differentiated before xylem; at section D shows differentiation of protoxylem as well as protophloem in alternating strands round the central cylinder; and at section E would shows later formed metaxylem differentiating inwards; and the mature primary root is shown differentiated at section F.

Note particularly that functional phloem occurs at less than 1 mm from the root tip, whereas functional xylem is first differentiated much further back from the tip.

Now ask yourself why phloem first differentiates near to the root tip and xylem first differentiates further back. Pause while you think of a possible reason.

The answer is related to the supply of nutrients to the root tip. The apex needs sugars and amino acids supplied in the phloem, and these can diffuse at adequate rates from the phloem sieve tube nearest the tip over the 1 mm to the tip, but a much longer distance would begin to limit the rate of supply. Minerals and water, on the other hand, are available in the soil and do not need to be supplied by the xylem- In short, the phloem must be functionally close to the growing apex because of diffusion limitations.

Primary root structure, endarch and exarch: There are two very important features of roots which distinguish them from stems and petioles etc. These can be called *diagnostic* characteristics.

First, in the stems and petioles primary xylem and phloem occur together in discrete vascular bundles. This is not the case in roots. In roots protoxylem and protophloem occur in separate strands alternately around the roots. *Alternating protoxylem and protophloem is found in all roots and nowhere else.*

Secondly, in roots the first protoxylem differentiates on the outside and the later formed metaxylem differentiates inwards on a radius towards the centre. In other words the sequence of xylem differentiation is centripetal. The word for this sequence is EXARCH derived from Greek, signifying that the first formed or oldest xylem is on the outside. This also is a diagnostic characteristic of roots.

All roots have alternating protoxylem and protophloem and exarch development of xylem.

Now read the section on *Endarch and exarch* of the manual and then return to the tape.

Now you are ready to look at some transverse sections and interpret what they show in three dimensions. First look at the which has 3 TS of *Vicia faba* mounted on it (slide 2). These correspond roughly to sections A B & D in Figure 3. Also look at the photomicrographs in Figures 4 and 5 and the online images of the three

sections so that you can identify the key features. In this series of slides the xylem is stained red and the phloem pale blue. Do this now, then return to the sound file.

In the slide of TS sections of *Vicia* root, notice that provascular cells are narrower than those in the ground meristem. This is because divisions along the length of the root (parallel to the surface) ceased earlier in the ground meristem but continued longer in the provascular meristem. Provascular cells are also longer than ground meristem cells, because transverse divisions continued in the ground meristem after they had stopped in provascular meristem.

In the most differentiated section, six protoxylem strands can be seen. These are often called protoxylem poles and the root is called hexarch. Dicot roots have 2 (diarch) , 3 (triarch) 4 (tetrarch) , 5 (pentarch) or 6 (hexarch) or 8 (octarch) protoxylem poles. when there are many protoxylem poles this is called polyarch, and this is typical of monocot roots.

Now examine the TS of mature *Vicia* root (slide 3). Compare this with the third section in slide 2 and make a note of any difference you see in the central vascular tissue. Pause the sound file while you do this.

In slide 2 the root is hexarch, while in slide 3 a root of the same species is tetrarch. This variation within a species or even within a single root is not atypical. However, *Vicia* (a eudicot) would never have a polyarch root structure which is found in monocots.

Look further at the *Vicia* root section in slide 3. The particular feature you should note here is the centre of the stele (that is the vascular tissue) consists of parenchyma, and in this section it is breaking down to leave a hole in the centre. This breakdown does not always happen in *Vicia*. In other species of dicot the roots frequently have metaxylem vessels extending to the centre of the root.

Now that the tissues in *Vicia* have been identified we can examine the individual cells. Examine the cortical cells first. Work out from staining whether the walls are lignified or not, and write down on the name of the cell type.

Yes, the cells are parenchyma. Note the thin cell walls and the air spaces between cells. You probably will not be able to see the very thin almost transparent layer of cytoplasm in the cells.

Endodermis: The next thing to examine is the endodermis. First find its position at the junction of stele and cortex. Examine the diagram in your study guide from which you will understand that the endodermis is a single layer of cells in a cylinder round the stele. Its chief anatomical characteristic is the Casparian strip, which occurs on radial walls of the endodermal cells. It is generally seen as a slight thickening of the radial walls. Locate the endodermis on the TS mature Vicia root (slide 3) and find the Casparian strip. Look at the demonstration slide of a Casparian strip and the online images. Ask the demonstrator for help if necessary.

The strip is a bit of slightly thickened wall impregnated with suberin. Suberin is a fatty, water insoluble substance, and where it is impregnated water cannot pass between cells. The Casparian strip lies around all the endodermal cells and presents a complete barrier to movement of water through the extracellular spaces between cells. This seals off the extracellular spaces of the cortex from those of the stele, and means that everything crossing the stelar boundary has to do so through the protoplast of the endodermal cells, and therefore can be subject to control by cells.

The next thing to find and examine in the Vicia root TS is the pericycle which is a thin layer of cells between the endodermis and the xylem and phloem. The pericycle is one to several cells wide, and is composed simply of parenchyma which are often larger than the endodermal cells and the parenchyma cells of the stele. Cells of the pericycle retain the potential for division, and the lateral roots start as new meristematic areas in the pericycle.

Finally while examining this slide, note one feature of root structure which is the relatively wide cortex and central stele of conducting tissue. Shoots generally differ in having vascular bundles peripherally placed in the ground tissue, but some stems that we shall see have a central core or stele, so this feature does not identify a root. You should always look for exarch xylem and alternating protoxylem and protophloem to identify a root with certainty.

Now do the self-test quiz.

Having examined *Vicia* roots in detail, we now shall examine a range of species with different root types. While doing this, fill in self-test quiz 4 which is in the form of a table listing the characteristics of the roots you will be examining. First we shall examine *Ranunculus* another dicot and then compare *Ranunculus* and *Vicia* with *Iris*, a monocot.

Slide 4 is of *Ranunculus* (or buttercup). Look at the micrograph of *Ranunculus* in your study guide. Examine the demonstration plant now to see if these are adventitious or tap roots.

Now fill in self-quiz 3, referring to slide 4 for the answers.

The main striking difference is that in *Ranunculus sp.* the metaxylem extends into the centre of the root while in *Vicia sp.* the centre was composed of parenchyma. The second difference is the heavily thickened endodermis. This secondary thickening is lignified and suberised and covers the whole cell, and it should not be confused with the Casparian strip opposite the protoxylem poles are cells in the endodermis which have not got thickened cell walls. Solutes must be able to pass through these, and they are called passage cells.

The difference between *Vicia sp*. and *Ranunculus sp.* may be associated with the fact that in *Vicia* secondary growth may occur, and when this happens the cortex and endodermis are sloughed off eventually. In *Ranunculus sp.* on the other hand there is no secondary growth (one can see what looks like an incipient cambium, but this does not develop) . The mature, nongrowing *Ranunculus sp.* root seems to seal off the stele almost completely in the older part of the root where it mainly functions to conduct solution in the xylem, rather than to absorb.

Monocot and Eudicot roots: Now examine, the TS of *Iris* root, looking at the associated figures in the manual. Fill in the line for *Iris* in the table and then return to the tape.

The main difference between *Iris* and the, dicot roots is that *Iris* has about 11 protoxylem poles in the root. This number or more is called polyarch, and is typical of monocot roots, and can be used to distinguish them from dicot roots. Notice that the metaxylem vessels that develop towards the centre of the root are fewer in number than the protoxylem poles - this is inevitable geometrically. The centre is filled with lignified parenchyma, which is frequently found in the stele- It should not be confused with elongated fibres or irregular sclereids.

The endodermis of *Iris* is thickened at maturity, as in the *Ranunculus* sp. root, but in Iris and other monocots the endodermis is thickened on the inner and radial walls only, giving a U-shaped appearance with the U opening outwards. This contrasts with the 0-shaped appearance of a secondarily thickened dicot endodermis such as *Ranunculus.*

Passage cells occur opposite the protoxylem poles as normal. They are difficult to investigate physiologically and their function can only be guessed at. Now do self-test-quiz 5.

Smilax, (slide 6) is another example of a monocot root. There are two transverse sections on this slide, one young, and one mature with a fully thickened endodermis. Complete self-quiz 3 for *Smilax* and then return to the tape.

In the mature root of *Smilax*, all the endodermis is heavily lignified, including the passage cells.

Cortical cells adjacent to the endodermis and the multiseriate pericycle, as well as the central parenchyma have also become lignified.

There are three slides of *Agapanthus* sp. Root for you to examine, the sections are from very young and old roots. There is a demonstration plant of *Agapanthus*; look at this and then examine the *Agapanthus* slides and trace the development of the root. Figures of the old *Agapanthus* root, and are provided in the study guide for reference.

The distinction between protophloem and metaphloem in the old *Agapanthus* root is very clearly shown. Metaxylem vessels are scattered through the central core, a feature not unusual for some monocotyledons.

Aerial roots: Aerial roots show other structural modifications. Examine the demonstration slides and note particularly the velamen or exodermis. Refer to the study guide and your textbook for details of these tissues. Now do self-quiz 6.

Lateral roots: Mature primary roots produce secondary or lateral roots as shown in the diagram in your study guide. Their origin is in the pericycle where local meristematic activity resumes, resulting in the formation of a root primordium. This primordium grows like a normal. root, pushing its way out laterally through the cortex from which it finally emerges, complete with all its own tissues including root cap. The pericyclic origin of lateral roots facilitates connection and continuity between vascular tissues. of lateral and main roots, so that water conduction is continuous from the finest roots to the main root and stem axis.

Look at the slide of *Vicia* TS (slide 10) with a lateral root and see what stage of development it has reached. It may be only a young primordium still within the cortex or it may have emerged from the cortex. Notice that the centre of the lateral root is directly opposite a protoxylem pole. There is a definite pattern of development of lateral roots which is illustrated in the diagram in your study guide.

Further information on lateral roots can be found from doing your own reading. A summary of the variations in basic root patterns is shown and illustrated by Figure 7. Read the section in your notes about *Patterns of primary root structure* and apply it to the examples you've looked at. For instance: the root of *Ranunculus* is similar to diagram A and that of *Vicia* is similar to diagram B.

You now have enough information to summarise characteristic features which distinguish the root of a dicot from that of a monocot. Make a list of these features, and then compare your list with the list at the end of the notes.

Also look at the demonstration of types of roots and sections stained with different reagents in which xylem is stained red, green-blue or yellow. This will help you to achieve the aim of distinguishing cells and tissues by their shapes and patterns, not just by their staining reactions.

You have now completed the study of primary structure of plants and should be able to carry out an anatomical investigation of any plant at that stage of growth

Are you clear about what is a diagnostic feature for determining whether an organ is a root? Are you able to differentiate between a monocot and dicot root by diagnostic features, and list the other supportive features?

Introduction to Cambia: To finish this week's work we are going to introduce you to secondary growth. ReaIntd through the introductory material in your manual. We will be looking at secondary growth in detail in the next anatomy session.

When you have done that you are finished. Please clear up your carrel and leave it ready for the next person to use.
O.K. thats it for this time -