

## How to read an electrocardiogram (ECG). Part 1: Basic principles of the ECG. The normal ECG

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### Introduction

The electrocardiogram (ECG) is one of the simplest and oldest cardiac investigations available, yet it can provide a wealth of useful information and remains an essential part of the assessment of cardiac patients. With modern machines, surface ECGs are quick and easy to obtain at the bedside and are based on relatively simple electrophysiological concepts. However junior doctors often find them difficult to interpret.

This is the first in a series of articles that aim to:

- Help readers understand and interpret ECG recordings.
- Reduce some of the anxiety juniors often experience when faced with an ECG.

### Basic principles

#### What is an ECG?

An ECG is simply a representation of the electrical activity of the heart muscle as it changes with time, usually printed on paper for easier analysis. Like other muscles, cardiac muscle contracts in response to electrical *depolarisation* of the muscle cells. It is the sum of this electrical activity, when amplified and recorded for just a few seconds that we know as an ECG.

#### Basic electrophysiology of the heart (see Figure 1)

The normal cardiac cycle begins with spontaneous depolarisation of the sinus node, an area of specialised tissue situated in the high right atrium (RA). A wave of electrical depolarisation then spreads through the RA and across the inter-atrial septum into the left atrium (LA).

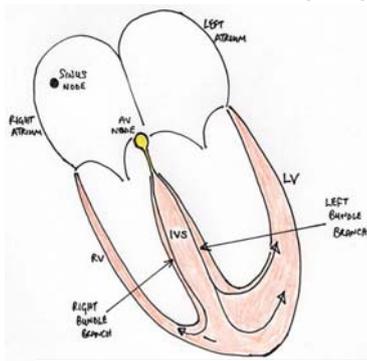


Figure 1. Basic electrophysiology of the heart

The atria are separated from the ventricles by an electrically inert fibrous ring, so that in the normal heart the only route of transmission of electrical depolarisation from atria to ventricles is through the atrioventricular (AV) node. The AV node delays the electrical signal for a short time, and then the wave of depolarisation spreads down the interventricular septum (IVS), via the bundle of His and the right and left bundle branches, into the right (RV) and left (LV) ventricles. Hence with normal conduction the two ventricles contract simultaneously, which is important in maximising cardiac efficiency.

After complete depolarisation of the heart, the myocardium must then *repolarise*, before it can be ready to depolarise again for the next cardiac cycle.

#### Electrical axis and recording lead vectors (see Figures 2 and 3)

The ECG is measured by placing a series of electrodes on the patient's skin – so it is known as the 'surface' ECG.

The wave of electrical depolarisation spreads from the atria down through the IVS to the ventricles. So the direction of this depolarisation is usually from the superior to the inferior aspect of the heart. The direction of the wave of depolarisation is normally towards the left due to the leftward orientation of the heart in the chest and the greater muscle mass of the left ventricle than the right. This overall direction of travel of the electrical depolarisation through the heart is known as the *electrical axis*.

A fundamental principle of ECG recording is that when the wave of depolarisation travels toward a recording lead this results in a positive or upward deflection. When it travels away from a recording lead this results in a negative or downward deflection.

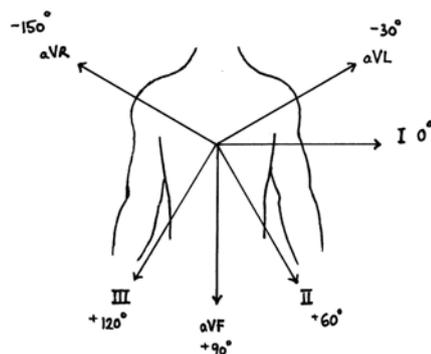


Figure 2. Orientation of the limb leads showing the direction from which each lead 'looks' at the heart

The electrical axis is normally downward and to the left but we can estimate it more accurately in individual patients if we understand from which 'direction' each recording lead measures the ECG.

By convention, we record the standard surface ECG using 12 different recording lead 'directions,' though rather confusingly only 10 recording electrodes on the skin are required to achieve this. Six of these are recorded from the chest overlying the heart – *the chest or precordial leads*. Four are recorded from the limbs – *the limb leads*. It is essential that each of the 10 recording electrodes is placed in its correct position, otherwise the appearance of the ECG will be changed significantly,

preventing correct interpretation.

The limb leads record the ECG in the coronal plane, and so can be used to determine the electrical axis (which is usually measured only in the coronal plane). The limb leads are called leads I, II, III, AVR, AVL and AVF. Figure 2 shows the relative directions from which they 'look' at the heart. A horizontal line through the heart and directed to the left (exactly in the direction of lead I) is conventionally labelled as the reference point of 0 degrees ( $0^{\circ}$ ). The directions from which other leads 'look' at the heart are described in terms of the angle in degrees from this baseline.

The electrical axis of depolarisation is also expressed in degrees and is normally in the range from  $-30^{\circ}$  to  $+90^{\circ}$ . A detailed explanation of how to determine the axis is beyond the scope of this article but the principles mentioned here should help readers to understand the concepts involved.

The chest leads record the ECG in the transverse or horizontal plane, and are called V1, V2, V3, V4, V5 and V6 (see Figure 3).

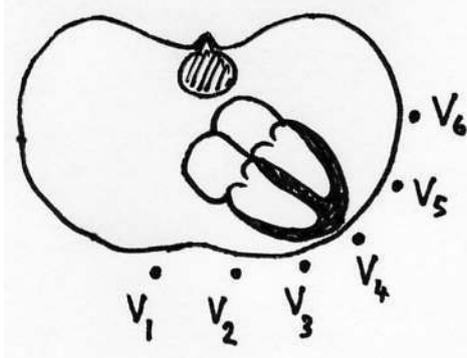


Figure 3. Transverse section of the chest showing the orientation of the six chest leads in relation to

### Voltage and timing intervals

It is conventional to record the ECG using standard measures for amplitude of the electrical signal and for the speed at which the paper moves during the recording. This allows:

- Easy appreciation of heart rates and cardiac intervals and
- Meaningful comparison to be made between ECGs recorded on different occasions or by different ECG machines.

The amplitude, or voltage, of the recorded electrical signal is expressed on an ECG in the vertical dimension and is measured in millivolts (mV). On standard ECG paper 1mV is represented by a deflection of 10 mm. An increase in the amount of muscle mass, such as with left ventricular hypertrophy (LVH), usually results in a larger electrical depolarisation signal, and so a larger amplitude of vertical deflection on the ECG.

An essential feature of the ECG is that the electrical activity of the heart is shown as it varies with time. In other words we can think of the ECG as a graph, plotting electrical activity on the vertical axis against time on the horizontal axis. Standard ECG paper moves at 25 mm per second during real-time recording. This means that when looking at the printed ECG a distance of 25 mm along the horizontal axis represents 1 second in time.

ECG paper is marked with a grid of small and large squares. Each small square represents 40 milliseconds (ms) in time along the horizontal axis and each larger square contains 5 small squares, thus representing 200 ms. Standard paper speeds and square markings allow easy measurement of cardiac timing intervals. This enables calculation of heart rates and identification of abnormal electrical conduction within the heart (see Figure 4).

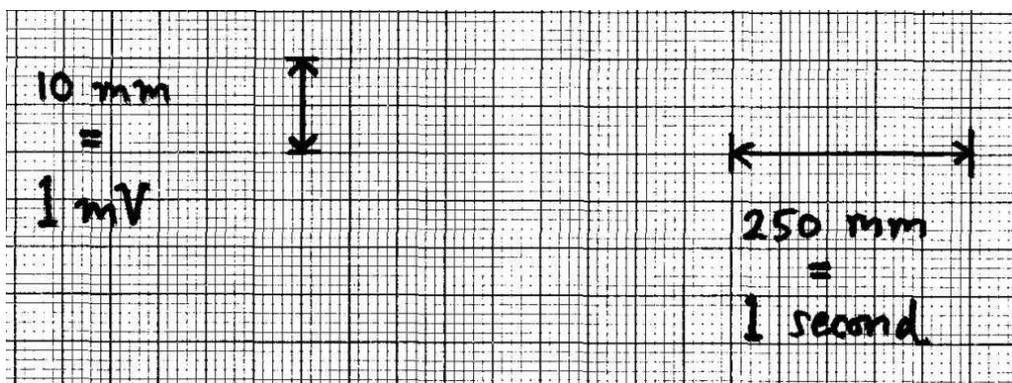


Figure 4. Sample of standard ECG paper showing the scale of voltage, measured on the vertical axis, against time on the horizontal axis

### The normal ECG

It will be clear from above that the first structure to be depolarised during normal sinus rhythm is the right atrium, closely followed by the left atrium. So the first electrical signal on a normal ECG originates from the atria and is known as the **P wave**. Although there is usually only one P wave in most leads of an ECG, the P wave is in fact the sum of the electrical signals from the two atria, which are usually superimposed.

There is then a short, physiological delay as the atrioventricular (AV) node slows the electrical depolarisation before it proceeds to the ventricles. This delay is responsible for the PR interval, a short period where no electrical activity is seen on the ECG, represented by a straight horizontal or ‘isoelectric’ line.

Depolarisation of the ventricles results in usually the largest part of the ECG signal (because of the greater muscle mass in the ventricles) and this is known as the **QRS complex**.

- The Q wave is the first initial downward or ‘negative’ deflection.
- The R wave is then the next upward deflection (provided it crosses the isoelectric line and becomes ‘positive’).
- The S wave is then the next deflection downwards, provided it crosses the isoelectric line to become briefly negative before returning to the isoelectric baseline.

In the case of the ventricles, there is also an electrical signal reflecting repolarisation of the myocardium. This is shown as the **ST segment** and the **T wave**. The ST segment is normally isoelectric, and the T wave in most leads is an upright deflection of variable amplitude and duration (see Figures 5 and 6).

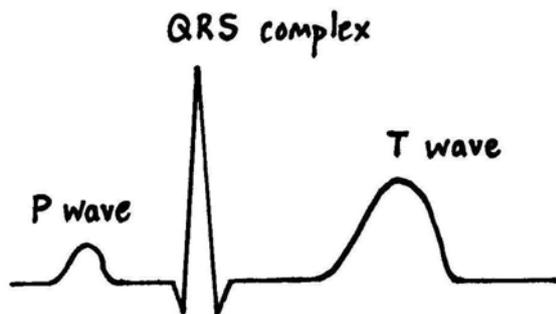


Figure 5. The major waves of a single normal ECG pattern

**Normal intervals**

The recording of an ECG on standard paper allows the time taken for the various phases of electrical depolarisation to be measured, usually in milliseconds. There is a recognised normal range for such ‘intervals’:

- **PR interval** (measured from the beginning of the P wave to the first deflection of the QRS complex). Normal range 120 – 200 ms (3 – 5 small squares on ECG paper).
- **QRS duration** (measured from first deflection of QRS complex to end of QRS complex at isoelectric line). Normal range up to 120 ms (3 small squares on ECG paper).
- **QT interval** (measured from first deflection of QRS complex to end of T wave at isoelectric line). Normal range up to 440 ms (though varies with heart rate and may be slightly longer in females).

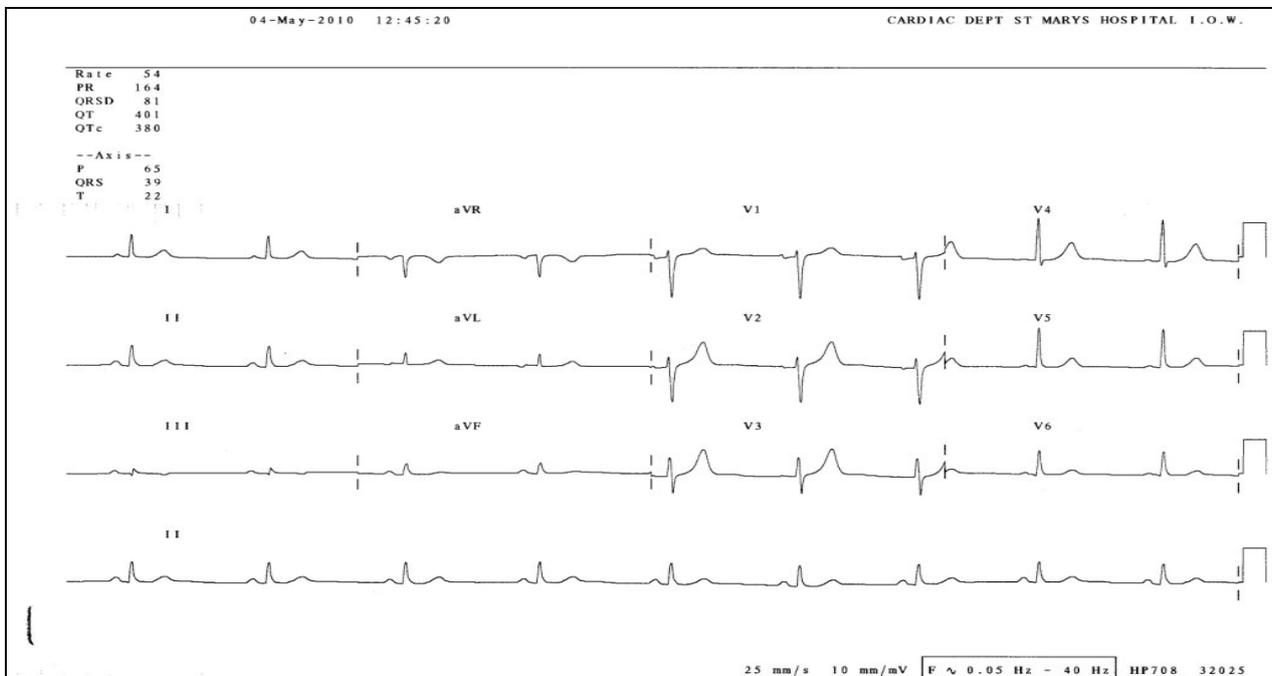


Figure 6. Example of a normal 12 lead ECG; notice the downward deflection of all signals recorded from lead aVR. This is normal, as the electrical axis is directly away from that lead

**Heart rate estimation from the ECG**

Standard ECG paper allows an approximate estimation of the heart rate (HR) from an ECG recording. Each second of time is represented by 250 mm (5 large squares) along the horizontal axis.

So if the number of large squares between each QRS complex is:

- 5 - the HR is 60 beats per minute.
- 3 - the HR is 100 per minute.
- 2 - the HR is 150 per minute.

## Evidence-based medicine - searching the medical literature. Part 2

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In the last issue I covered the use of PubMed to retrieve *primary sources* of evidence (individual research studies). However, if you need quick or more definite answers to your clinical questions you may prefer to start with *secondary sources* - where individual studies have already undergone analysis and have often been compared with others to provide a summarised, more definitive conclusion. In Figure 1 this is referred to as '*filtered information*', although of course individual studies published in journals will often have been peer reviewed before publication, so have undergone a basic level of filtering.

As explained by Dr Hakim in the editorial of Southern Sudan Medical Journal 3(1) there is an agreed hierarchy of 'levels of evidence', those nearer the top in Figure 1 are likely to provide the most reliable evidence - and it is these that we will concentrate on here.

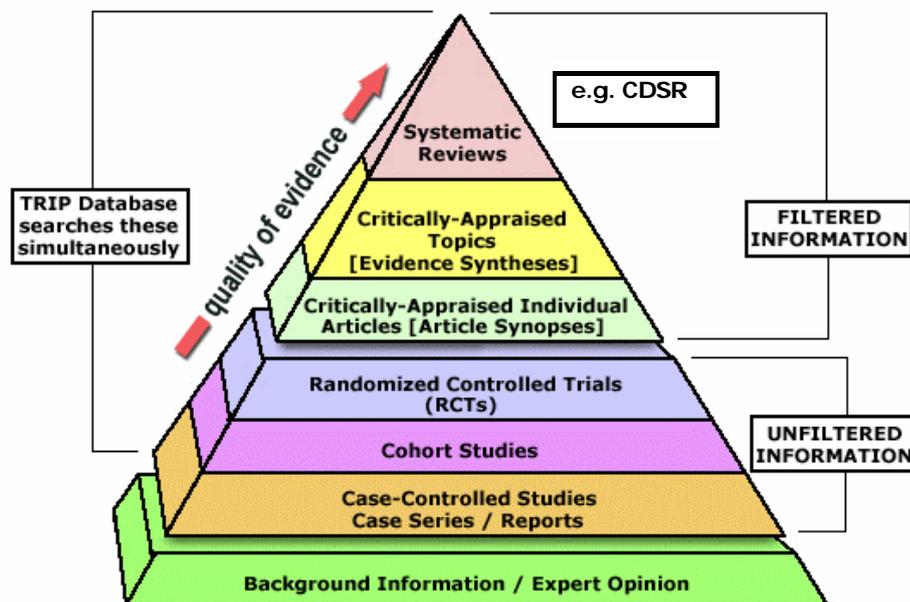


Figure 1. Hierarchy of levels of evidence (Source: [www.ebmpyramid.org/samples/complicated.html](http://www.ebmpyramid.org/samples/complicated.html))

### The Cochrane Database of Systematic Reviews (CDSR)

CDSR is one of several databases within The Cochrane Library, found at [www.thecochranelibrary.com](http://www.thecochranelibrary.com). The Full Text version is available to those eligible through HINARI<sup>1</sup> or ISAP<sup>2</sup>. Alternatively everyone can access free Summaries via [www2.cochrane.org/reviews/](http://www2.cochrane.org/reviews/) but searching on this view is not as successful. The Cochrane Reviews are only available via the websites above, they are not published anywhere in print, so if you come across a reference to one (e.g. from PubMed), you will have to search here for the full text.

The Cochrane Reviews aim to:

- investigate the effects of interventions on prevention, treatment and rehabilitation or
- assess the accuracy of diagnostic tests for particular conditions and for specific patient groups.

Although the Cochrane Collaboration is based in York, UK, the researchers are truly international and aim for global coverage and inclusion of issues relevant to all countries and contexts. As the CDSR title indicates, reviews in this database adhere to a strict and rigorous 'protocol' set out for how the research articles are found, reviewed (critiqued/appraised) and the results calculated. This means all are done by the same *systematic* method to remove bias and ensure the quality of reviewing is maintained. This is not necessarily the case with reviews from other organisations or authors.

About 4,000 Cochrane Reviews are completed and another 2,000 are in progress (labelled 'Protocols') – but progress can be slow as most reviewers are volunteers. Therefore it is best to ignore or filter out the Protocols (marked with light blue) when searching.

The other limitation on finding a Cochrane Review is that they only review *controlled trials* - so any

subject where this is not a suitable methodology is not included. To see a list of subjects covered browse by topic/Cochrane Group. [If you are in the Full Text version the topics should be listed on the left-hand side of the screen, if looking at the free Summaries click By Topic, then for sub-topics click here].

Instead of searching through the topics you can enter a key word in the search box. This is the best way to search on the Full Text version. But it is not so useful on the free Summaries website where you get many repeat hits. If you use a phrase enter it within quotation marks e.g. "breast feeding". This is good practice in all website searches to avoid the two words being found independently of each other. If you put in more than one word the results will be Reviews with both words included somewhere, but in any keyword search there will be quite a few false hits. However it is usually easy to skim down the results titles quickly to pick out relevant ones.

*Note:* if you are using the Full Text version of CDSR make sure that you have some hits beside the Cochrane Reviews heading in the top panel of the screen. If there have been no hits the results listed will be from one of the other databases, and not be Cochrane Reviews.

Results will be listed in 'best match' order, but there are options to change to 'date' or 'alphabetical' order at the top of the list on the right-hand side. Changing to Date order will display the most recent first. However it is important to check the dates of each Review very carefully as they give two dates - one when that version was published online, and one when the content was last reviewed as being up-to-date, and these may be very different. Some Reviews will indicate that they have been withdrawn, although still showing on your hitlist.

Whether in the Summaries or the Full Text version, click on the Review's title to see the abstract. This gives:

- The type of review (e.g. Intervention) title.
- Authors and their contacts.
- The Cochrane Group it is part of.
- Date of publication.
- Date of currency review.

The citation is also written out. Copy this exactly when referencing the Review in any context - numbers and all!

Moving down the abstract you will note that the 'method' section explains how the literature search was done (search strategy) and the criteria by which papers were included in the Review. It is vital for a rigorous systematic review that all published and

unpublished studies are included, so database searches and hand searches of journals will have been done, plus following up contacts. Each individual research paper will then have been critically appraised for the quality of study design and how it was carried out, against the agreed Cochrane set protocols.

The 'results' section will give an overview of how many of the trials met the strict inclusion criteria (others having been rejected), and the outcome of *meta-analysis* of the data. A meta-analysis is a way of combining data from more than one trial to calculate a statistic of net overall benefit of the treatment or intervention<sup>3</sup>

The 'conclusion' is then stated giving a balanced and impartial summary of effectiveness based on all existing research. Sometimes insufficient data will have been found to come to a conclusion. So there is usually a further conclusion that more research is needed.

Using the Full Text view there is a clickable index of the contents of the paper on the left-hand panel, or the option to show the Review in pdf. As mentioned above, the 'method' section is about the literature review and the 'results' section gives details of why each paper was included or rejected.

*Beware:* many of the Reviews are more than 20 pages long, plus additional tables and charts. So do not press the print button before thinking!

To print just the sections you need (e.g. abstract, background, discussion, conclusions, references) either:

- Choose the pages from the pdf version or
- Highlight sections with your mouse and use file/print/selection (as with printing from any website).

Note that the references listed first are those of studies *included* followed by those rejected.

More detailed 'advanced' searching, saving searches etc. is possible on the Full Text view (see the top right-hand corner), but usually the simple searching with keywords or by topic is sufficient.

### Other sources of secondary evidence

There are many other sources of summarised and reviewed literature. All aim to give quick and easy answers to common clinical questions from a single search site. As indicated in Figure 1 some of these (such as TRIP) include references to secondary evidence such as the Cochrane Reviews together with primary studies and other literature. There are usually filters on the screen to choose which type of information you require. Simple keyword searching is all you need - but remember those "quotation

marks" for phrases and the wildcard/truncation symbol \* to get any ending on the stem of a word e.g. surg\* (for surgery, surgical - but possibly getting unwanted surging, surged, etc.).

#### Freely available

- **TRIP** (Turning Evidence into Practice) [www.tripdatabase.com](http://www.tripdatabase.com) - note the new tick box at the bottom of the filter column on the right to limit to items directly relevant to developing countries.
- **NHS Evidence** [www.evidence.nhs.uk](http://www.evidence.nhs.uk) - parts of this are restricted, but much of the information is freely available.
- **Bandolier** [www.medicines.ac.uk/bandolier/knowledge.html](http://www.medicines.ac.uk/bandolier/knowledge.html).
- **Intute** [www.intute.ac.uk](http://www.intute.ac.uk) - this has some reviews and articles amongst other more varied web resources. If you have a good internet connection there is also a useful 'virtual training suite' giving further guidance in web searching for medical information and training resources.

#### Via HINARI

- **Best Practice** [bestpractice.bmj.com](http://bestpractice.bmj.com).
- **Clinical Evidence** [www.clinicalevidence.bmj.com](http://www.clinicalevidence.bmj.com)

and much more...

#### More local evidence

For a more local flavour try these free resources - both give primary research and some reviews:

- **AIM** (African Index Medicus) - an African equivalent of PubMed

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[indexmedicus.afro.who.int](http://indexmedicus.afro.who.int) abstracts and some full text available. Click **Database** on the left-hand panel.

- **AJOL** (African Journals Online) <http://ajol.info/> - abstracts and 3 free full text articles per month - use the search box on the top right, or Browse the Journals by topic, country or alphabetically.

So, there is lots of good quality evidence available to apply to your practice... Obviously secondary evidence will not be available to answer all your questions, but if it is then it will be more reliable than one individual study. Happy searching!

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#### Notes

1. HINARI (Access to Research Initiative) provides free or very low cost online access to the major journals in biomedical and related social sciences to local, not-for-profit institutions in developing countries (including Southern Sudan). [www.who.int/hinari/about/en](http://www.who.int/hinari/about/en)
2. ISASP (International Network for the Availability of Scientific Publications) see this link for more detail about availability in Sudan [www.inasp.info/file/c09571fe8890329e7f72f9e2436f1079/Sudan.html?country=700a088657db6c6153375b7fa8c05836](http://www.inasp.info/file/c09571fe8890329e7f72f9e2436f1079/Sudan.html?country=700a088657db6c6153375b7fa8c05836)
3. For more information on meta-analysis see [www.medicines.ac.uk/bandolier/painres/download/whatis/Meta-An.pdf](http://www.medicines.ac.uk/bandolier/painres/download/whatis/Meta-An.pdf)