Much of medicine is concerned with choosing the right treatment, and cardiologists have done well in recent years to ensure the choice is supported by good evidence. However, the greatest choice often starts where the evidence finishes—namely between drugs of the same class. This article seeks therefore to offer the principles which govern when and how it is appropriate to differentiate drugs within a class, and discuss topical examples among the drugs commonly used in cardiology.

**GENERAL OVERVIEW**

The parameters which can reasonably be compared between drugs are shown in table 1. If this were all, it might be possible to devise semi-automatic algorithms to calculate which drug(s) have the highest score for any given indication. However, the relatively factual answers that could be filled in each cell of the table for a given drug are only part of the decision making process, and more judgemental are: (1) the strength of evidence for each of the answers; and (2) the second order issues of how to compare, for example, one drug of apparently superior efficacy with another which is better tolerated. Compliance is sometimes cited as a reason for choosing one drug rather than another; compliance is not itself a property of the drug, but a composite phenomenon reflecting the interplay between efficacy, tolerability, frequency or route of administration, and cost. Particularly contentious are questions of cost effectiveness. For example, the quality of the evidence for effectiveness may vary between drugs; or the cost of two drugs may be differentially influenced by factors like laboratory tests or number of visits, where savings can seem more virtual than real.

In this article I shall address some of the controversies regarding choice of drugs from commonly used classes in cardiology: angiotensin converting enzyme (ACE) inhibitors, statins, and β blockers. To illustrate how the parameters in table 1 will be used to resolve controversies, I shall first apply them to non-controversial examples of choices between drugs in a class.

**Efficacy**

Among diuretics, the loop diuretics cause more sodium (Na⁺) loss than thiazides because they inhibit a more proximal Na⁺ channel (the Na⁺K⁺2Cl⁻ transporter) than the NaCl co-transporter inhibited by thiazides. The term “high ceiling” diuretics refers to the relative shape of the dose–response curve for loop compared to thiazide diuretics (fig 1). Greater efficacy is not an automatic reason for preferring a drug, even when there is no counterbalancing disadvantage in one of the other parameters. When only modest Na⁺ loss is required, thiazides have the advantage that there is less scope for overdosing the patient.

**Potency**

This parameter can provide the best justification for differentiation within a class, but is also the parameter most often abused in providing spurious justification. In part, the latter occurs because potency and efficacy are often confused. Efficacy refers to the maximum response to a drug; potency refers to the physical mass of drug at which half maximal response occurs. When, loosely, doctors or lay people describe drug A as being “more powerful” than drug B, they are probably referring to efficacy. Under most circumstances the physical mass of drug required to achieve a response is not important. This is illustrated in fig 1, which compares the natriuresis achieved with furosemide (frusemide) or bendrofluazide. The latter is more potent, but the consequentially smaller size of bendrofluazide than furosemide tablets is rarely a reason to prescribe one rather than the other.

Nevertheless, there is a theoretical reason why potency might affect choice of some oral medications. One of the main factors to determine the potency of a drug is its affinity for the target molecule (for example, receptor, ion channel, enzyme). The affinity of a drug for its target is the ratio...
of its time-for-dissociation to time-for-association. The latter does not vary greatly, being caused mainly by diffusion. So in practice high affinity drugs are those which stick to their target for longer. It is often the case, therefore, that drugs with the lowest dose range within a class are those most likely to have sustained local actions, even when the drug has disappeared from the bloodstream.

**Pharmacokinetics**

A common reason for choice within a class is frequency of administration. Antibiotics yield a number of examples: once daily azithromycin compared to four times daily use of the older erythromycin; or twice daily doxycycline rather than four times daily tetracycline. Other examples are the development of slow release formulations of drugs (such as nitrates and calcium blockers) which permit less frequent dosing than required for the parent drug. Long lasting is not always better. Short acting nitrates and β blockade (esmolol) have specific roles in treatment. Insulin has been modified to provide short acting formulations for the convenience of covering individual meals.

**Tolerability and safety**

Can drugs within the same class vary in their tolerability and safety? Yes, for either pharmacodynamic or pharmacokinetic reasons. For example, metoclopramide and ondansetron are both anti-emetics which block the 5HT, receptor. But metoclopramide also blocks dopamine receptors and therefore at equi-effective doses to ondansetron causes akathisia. Pharmacokinetic differences are a more common cause of differences in tolerability. Short acting β blocking or vasodilator drugs are more likely to cause hypotension or reflex symptoms of tachycardia and flushing. Long acting sulfonylureas are more likely to cause hypoglycaemia. Drug interactions vary because the drugs are substrates for different isoforms of cytochrome P450; cimetidine but not ranitidine increases drug concentrations, whereas drug interactions vary because the drugs are substrates for different isoforms of cytochrome P450; cimetidine but not ranitidine increases drug concentrations, whereas

**Cost**

This is the parameter which will most immediately be perceived by doctor, patient, pharmacist or manager. It is hard to argue against a policy of always prescribing the cheaper of two drugs unless the more expensive has a proven advantage. On the other hand, drug costs are an artificial property of the drug in the sense that they vary with time and place of prescribing.

My example is taken from diabetes to illustrate the pros and cons of letting price influence choice within a class. Among sulfonylureas, generic glibenclamide is now the sulfonylurea of choice, but it is not promoted and therefore often replaced by branded drugs like glipizide or gliclazide. However, promotion of branded drugs is one of the main, if not always balanced, modes of education about drugs. When the UK prospective diabetes study showed metformin to be the drug of choice for type 2 diabetes, the take up was more rapid in the USA, where metformin was still a branded drug, than in the UK.

After this illustration of fairly non-contentious choices among drugs within a class, I turn now to recent areas of controversy among cardiovascular drugs.
ACE INHIBITORS AND ANGIOTENSIN BLOCKERS

Under this heading, I shall consider the choices within each of the two groups—ACE inhibitors and angiotensin blockers. But I shall also digress slightly from the main brief of the article to discuss whether there are important differences between them.

The mechanisms of action of the two groups of agents are illustrated in fig 2.

ACE inhibitors

The British National Formulary lists 11 ACE inhibitors. Captopril is the only ACE inhibitor which is not a pro-drug, acts immediately, and has much the shortest duration of action. The latter has relegated its use in Europe to that of a diagnostic agent only (including first dose use in heart failure); but worldwide, low cost makes captopril the most widely used drug of its class. Enalapril is also available in generic formulations, and its low cost is a definite advantage that needs to be offset if branded ACE inhibitors are prescribed in its place. Using the principles from the first half of the article, what could these advantages be? The main one is pharmacokinetic, since enalapril at lower doses needs to be given twice daily to provide effective 24 hour ACE inhibition. The duration of action of any ACE inhibitor is increased by increasing the dose, because this prolongs the time for which pharmacologically effective inhibition of ACE (> 95%) is present. However, enalapril at 40 mg daily no longer retains a cost advantage over branded drugs in the class. Although the most popular ACE inhibitors have only slightly longer

Figure 2  Mechanism of action of ACE inhibitors (upper panel) and angiotensin blockers (lower panel). ACE inhibitors achieve their effects both by inhibiting conversion of the inactive decapeptide angiotensin I (AI) to the active octapeptide angiotensin II (AII), and by inhibiting breakdown of the vasodilator nonapeptide bradykinin. Angiotensin blockers (ARB) act purely by antagonising actions of AII at the AT1 receptor on arteries and adrenal cortex. Both classes cause increased secretion of renin and AI, by removing the negative feedback of AII; however, AII increases in parallel during ARB treatment, but falls during ACE inhibitor treatment.
ACE inhibitors: key points

- For hypertension and heart failure, benefits are likely to be class effects, and there are no primary reasons for preferring individual drugs.
- For newer indications, in which only one drug has been tested, efficacy is probably a class effect but equal safety cannot be assumed.
- For these newer indications, the trial drugs, ramipril and perindopril, should be used unless greater cost reduces the number of patients who can be treated by more than the possible increase in safety.
angiotensin II concentrations acting upon the unblocked AT2 receptor in the brain; myocardial protection by ACE inhibitors is, with greater certainty, caused in part by bradykinin potentiation. The ONTARGET trial is comparing the two subclasses of drug, and the hypothesis that differences between them render a combination more effective than either alone. Pending further trial data, there is little support for using a sartan in heart failure patients unless the patient develops a cough on an ACE inhibitor; addition of one to the other begs the question whether the first was used at all. Since ACE coughers have so far been excluded from the class comparisons, there is no reason to delay prescribing sartans for such patients. Their efficacy should be established during next year by the subgroup of the CHARM study which is comparing sartan with placebo in patients intolerant of ACE inhibition.

STATINS

This is the easiest of the classes discussed here to prepare a scoresheet for each drug, using the parameters listed in the first part of this article.

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**Table 2** Semi-quantitative method for choosing among statins

<table>
<thead>
<tr>
<th>Category</th>
<th>Parameter</th>
<th>Simvastatin</th>
<th>Pravastatin</th>
<th>Atorvastatin</th>
<th>Rosuvastatin</th>
<th>Cerivastatin</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pharmacodynamic</strong></td>
<td>Efficacy</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Reduced mortality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reduced morbidity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surrogate (LDL reduction)</td>
<td>8</td>
<td>7</td>
<td>8</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Potency</td>
<td>4</td>
<td>3</td>
<td>7</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td><strong>Pharmacokinetic</strong></td>
<td>Route of administration</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Frequency of dosing</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Drug interactions</td>
<td>6</td>
<td>8</td>
<td>7</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td><strong>Tolerability</strong></td>
<td>Safety</td>
<td>9</td>
<td>8</td>
<td>8</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Side effects</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Per drug/injection</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Per treatment (including</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td>9</td>
<td>7</td>
</tr>
</tbody>
</table>

The table scores five of the statins out of 10 (= most desirable) for each of the parameters by which drugs should be compared. The scores are not themselves definitive, but illustrate how a doctor can summate available evidence to choose the best drug, depending on the weight attached to each of the parameters.
studied. The more interesting questions are whether 40 mg of either drug confers maximal benefit, and whether LDL reduction explains the entire benefit of both drugs. Body count (alias outcome) trials are notoriously poor at inferring mechanisms. The similar relative benefit of simvastatin at all baseline concentrations of LDL in the Heart Protection Study might argue either for the importance of even “normal” concentrations of LDL, or for a non-LDL based action. Further outcome trials with both drugs are in progress to address these possibilities: SEARCH, which compares 80 mg with 20 mg of simvastatin; PROVE-IT, which compares pravastatin and atorvastatin at non-equieffective doses. If some or all statins owe part of their clinical benefit to anti-inflammatory effects outside of hepatocytes, pravastatin’s lower efficacy in lowering LDL would be less important.

Further trials in progress should resolve whether greater LDL reduction matters, and whether some or all statins have benefits other than LDL reduction. If the rank order of observed reduction in cardiovascular mortality is flatter and appears to be simvastatin, pravastatin, atorvastatin, the starting dose of atorvastatin, 10 mg, is less important than the drug’s potency and its main competitors. Cerivastatin was withdrawn following deaths from severe myopathy. Before then, it had the apparent attraction of being cheaper than other statins, and was assumed to have the same long term benefits as seen for other drugs which reduced LDL. Why cerivastatin was less safe remains uncertain, as indeed does the mechanism of the myalgia and myopathy seen in a small proportion of patients on any statin. The unpredictability underlines the importance of having empirical data for individual members of a drug class. Cerivastatin's high potency was consequent on a high affinity for its target molecule, the enzyme HMG-CoA reductase. As discussed earlier, high affinity is usually a consequence of slow dissociation of a drug from its target and it may be that either the long lasting enzyme inhibition—or cellular compensation for this—led to the toxic consequences.

**β BLOCKERS**

β Blockers, the oldest of the three classes discussed in this article, have the broadest range of indications, embracing hypertension, angina, and (for a few members of this class) heart failure. Figure 4 illustrates their mechanism of action. Although the parameters used to compare drugs are the same as before, there are clear pharmacological differences within the class (fig 5). These differences do not themselves justify choices, but they explain some observed differences in the selection parameters.

The first β blocker, propranolol, is still used widely worldwide, and—unlike captopril—long acting formulations have helped to preserve a significant if minor share of β blocker use even in developed countries. Since the more popular alternative in this case is an equally cheap old drug, atenolol, the difference in use reflects a real difference in tolerability rather than the legacy of successful marketing. The difference in tolerability is due to two major differences in pharmacology: receptor subtype selectivity and lipid solubility. Indeed, had the manufacturers not been so keen in the late 1970s to promote atenolol as having, unlike propranolol, no dose-response curve, they would have introduced it at 25–50 mg doses rather than the supramaximal doses of 100–200 mg that lose the benefits of β selectivity.

**Different types of β blocker**

There are two β receptor subtypes, β₁ and β₂. Non-selective β blockers like propranolol and timolol block both receptors to a similar degree (fig 5). β Selective blockers, like atenolol,
metoprolol and bisoprolol, block the $\beta$, receptor at lower doses than they block the $\beta_1$ receptor. It is important to recognise that selectivity is a relative property, being measured as the ratio of drug concentration required to block the two receptors, and therefore any benefits of selectivity are progressively lost as the dose is increased. The term “cardioselective” was wrongly introduced as synonymous with $\beta_1$, selective, on the mistaken assumption that the human heart does not have $\beta_2$, receptors. Both are present, although the latter are probably of importance only during secretion of high concentrations of adrenaline—in heart failure and during myocardial infarction.\(^{16,28}\) Therefore the so-called cardioselective blockers may actually be less efficacious than non-selective $\beta$ blockers in patients with, or at risk from, these conditions.\(^{27}\) Atenolol, the least lipophilic $\beta$ blocker, is rapidly washed out of the heart after disappearing from the bloodstream.\(^{29}\) Because of cross talk between the components of the cyclic AMP signalling system coupled to both $\beta$ receptors, atenolol not only fails to block but actually potentiates cardiac responses to adrenaline.\(^{29,30}\)

### Choice of $\beta$ blockers in ischaemic heart disease

In the heyday of $\beta$ blocker trials in the 1980s, in-house comparisons of drugs were uncommon, so that we do not know how much theory affects practice. But post-hoc comparison of the many secondary prevention trials of $\beta$ blockers showed most benefit from propranolol and timolol, and the least from the now obsolete practolol.\(^{15,19}\) Although atenolol is the most widely used $\beta$ blocker, it was never tested for secondary prevention, and when used in acute treatment of myocardial infarction achieves only modest protection, mainly from cardiac rupture rather than arrhythmias.\(^{31,32}\) On the other hand, except for those with ancillary vasodilator properties (fig 5), non-selective $\beta$ blockers have a lower tolerability than $\beta_1$, selective, almost certainly because in patients with normal cardiac output this is reduced more by blockade of both than one receptor subtype. Consequently tiredness and cold extremities are more likely to occur. Use of $\beta$ blockers after myocardial infarction has tended to suffer from the lack of evidence for their role in the era of thrombolysis and ACE inhibition. The more recent CAPRICORN study showed that carvedilol, which blocks the three major adrenoceptors—$\alpha_1$, $\beta_1$, and $\beta_2$—does improve overall survival, although the trial’s impact was diminished by a change in planned end points during the trial.\(^{33}\)

### Choice of $\beta$ blockers in hypertension

In hypertension, where the efficacy of blood pressure reduction is due mainly to blockade of the renal $\beta$ receptor on the renin secreting juxtaglomerular cells, there is no need to contemplate use of non-selective $\beta$ blockers. In our crossover studies, bisoprolol was as well tolerated as any other class of antihypertensive drug.\(^{34}\) However, the LIFE trial has recently shown that the prototype $\beta$ blocker, atenolol, is problematic in hypertension, and reminded us how little evidence there is of long term efficacy with atenolol.\(^{12}\) In combination with another older drug, hydrochlorothiazide, atenolol was less effective than the comparator in preventing diabetes; this is probably because both older classes reduce blood flow to skeletal muscle, whereas the newer antihypertensives increase flow. Even more serious was the excess of strokes on atenolol, by almost twofold in patients with stiff arteries (isolated systolic hypertension).\(^{35}\) This excess may be caused by the unique property of $\beta$ blockers (unless they have additional vasodilating activity) that central systolic pressure is reduced less effectively than appreciated from measurements in the brachial artery.\(^{36}\) By slowing heart rate, most $\beta$ blockers allow reflection of the systolic pulse wave from a stiff aorta to return before the end of systole and thus augment the central aortic pressure.\(^{37}\)

### Choice of $\beta$ blockers in heart failure

There have been few such dramatic discoveries in therapeutics than heart failure’s change from absolute contraindication to major indication for use of $\beta$ blockade. The small choice of licensed drugs for this indication belies the competition, as cardiologists grapple with the clinical significance of pharmacological differences. Three drugs—carvedilol, bisoprolol, and a controlled release formulation of metoprolol—demonstrated large reductions in mortality, with the first two receiving regulatory approval for “adjunct use” in heart failure.\(^{38,39}\) It is likely, therefore, that benefit is a class effect. However, one other $\beta$ blocker, bucindolol, was ineffective.\(^{40}\) This negative result was attributed to a partial agonist effect, although this property of bucindolol has been questioned (see below).\(^{41}\) Because of the bucindolol result, because of the well known dangers of inappropriate $\beta$ blocker use in heart failure, and because the mechanism of benefit remains poorly understood, heart failure is the clearest example of where only individual proven drugs should be used.

Between the two licensed drugs there are some interesting differences, as apparent in fig 5. Plasma noradrenaline is one of the major prognostic factors in heart failure, maybe contributing to arrhythmias and cardiomyocyte apoptosis.\(^{42}\) If noradrenaline is not just a marker of risk, the question is whether its adverse effects are on only some or all adrenoceptors. Figure 4 suggests that stimulation of all might be adverse except for the negative feedback $\alpha_1$, autoreceptor. When vasodilators were introduced for heart failure, $\alpha$ blockade was found to increase ejection fraction and improve early symptoms whereas mortality was unaltered—perhaps because of the baroreflex induced secretion of catecholamines.\(^{43–45}\) $\beta$ Blockade also increases catecholamine concentrations, by reducing their clearance. In theory,
β BLOCKERS: KEY POINTS

- Variation in the number of adrenergic receptors blocked provide genuine differences in pharmacological profile
- Lack of direct comparisons mean choices are based on these pharmacological differences when supported by indirect evidence from comparison of different trials
- Non-selective β blockers (for example, timolol) are most likely to be beneficial in ischaemic heart disease, by protecting against adrenaline’s activation of cardiac β receptors
- Selective blockers (for example, bisoprolol) are drugs of choice in young hypertensives in whom blood pressure reduction is caused by renin (β1) blockade, and side effects are caused by reduction in cardiac output (β1 and β2 blockade)
- Only carvedilol (β1, β2, and α, blockade) and bisoprolol are licensed for heart failure. Comparison of outcome trials suggests rank order of efficacy follows the number of receptors which are blocked

Therefore, a drug with the early benefit of α blockade, and later benefit of protecting all adrenoceptors from catecholamine excess, might maximise potential efficacy and safety. This multiple receptor blockade is achieved by carvedilol, which also blocks the low affinity (previously called β2) site on β1 receptors that seems to have been the site of activation by bucindolol. The rank order of β blocker efficacy in outcome trials correlates with the pharmacological notional rank order for the “net” number of receptors blocked. Carvedilol reduced mortality by 65% in the first outcome trials and by 27% in a trial restricted to patients with New York Heart Association (NYHA) functional class III or IV. Bisoprolol and metoprolol CR both reduced mortality by 34% in trials of NYHA II–IV. However, comparisons of trials cannot prove a hypothesis, and against the case for efficacy should be offset the greater cost and dose frequency of carvedilol. In assessing overall cost effectiveness, this example illustrates the influence of strength of evidence. If COMET, the first outcome trial ever to compare β selective (metoprolol) and non-selective (carvedilol) β blockade, confirms the superiority of the latter, it will be possible to calculate the number of lives saved per annum for each extra pound spent on the more expensive agent.

SUMMARY

Choices between drugs can be made on a rational basis, by reference to a small number of parameters that characterise clinically relevant properties of a drug. Most drugs within a class are interchangeable. However, there are well substantiated exceptions, which are used in this article to illustrate how more controversial claims for superiority within a class can be resolved.

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16. First comparison of antihypertensive drugs to show a difference in primary outcome. The combination of β blockade and diuretic appears undesirable in older patients at risk of stroke or diabetes.
18. Another landmark study showing the importance of treating risk, rather than risk factor. LDL reduction from any level achieved large reductions in coronary disease and stroke.
22. This clinical study of patients undergoing cardiac catheterisation confirmed the in vitro prediction that humans have functioning β1 as well as β2 adrenoceptors in the heart. The β2 receptors are activated by high concentrations of adrenaline in patients with myocardial infarction or heart failure.
27. The first of several double blind, placebo controlled outcome studies to demonstrate substantial reduction in mortality when patients with heart failure are treated with β blockade.

Additional references appear on the Heart website—www.heartbmj.com supplemental
A RATIONAL BASIS FOR SELECTION AMONG DRUGS OF THE SAME CLASS

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