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CLINICAL RESEARCH

How robust are recommended waiting times to pacing after cardiac surgery that are derived from observational data?

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Aims For bradycardic patients after cardiac surgery, it is unknown how long to wait before implanting a permanent pacemaker (PPM). Current recommendations vary and are based on observational studies. This study aims to examine why this variation may exist.

Methods and results We conducted first a study of patients in our institution and second a systematic review of studies examining conduction disturbance and pacing after cardiac surgery. Of 5849 operations over a 6-year period, 103 (1.8%) patients required PPM implantation. Only pacing dependence at implant and time from surgery to implant were associated with 30-day pacing dependence. The only predictor of regression of pacing dependence was time from surgery to implant. We then applied the conventional procedure of receiver operating characteristic (ROC) analysis, seeking an optimal time point for decision-making. This suggested the optimal waiting time was 12.5 days for predicting pacing dependence at 30 days for all patients (area under the ROC curve (AUC) 0.620, $P = 0.031$) and for predicting regression of pacing dependence in patients who were pacing-dependent at implant (AUC 0.769, $P < 0.001$). However, our systematic review showed that recommended optimal decision-making time points were strongly correlated with the average implant time point of those individual studies ($R = 0.96$, $P < 0.001$). We further conducted modelling which revealed that in any such study, the ROC method is strongly biased to indicate a value near to the median time to implant as optimal.

Conclusion When commonly used automated statistical methods are applied to observational data with the aim of defining the optimal time to pacing after cardiac surgery, the suggested answer is likely to be similar to the average time to pacing in that cohort.

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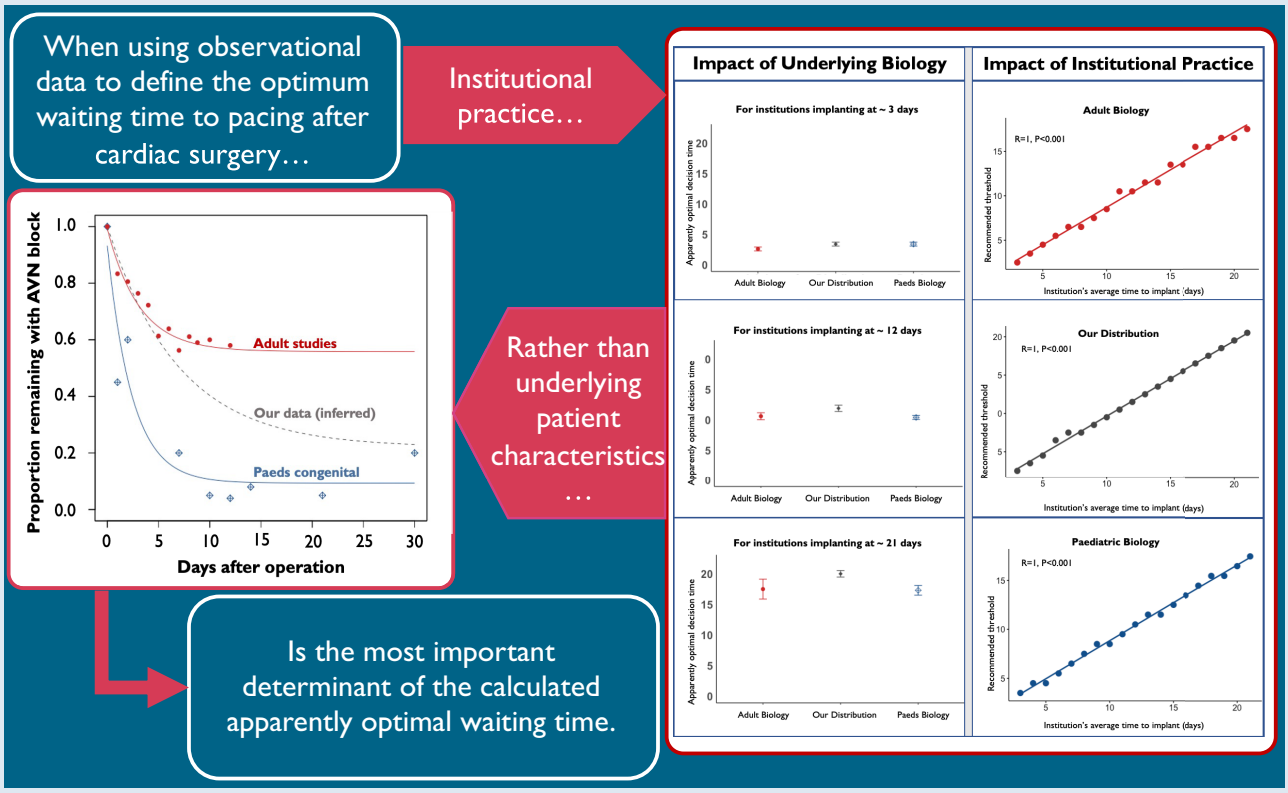
Graphical Abstract



Keywords Pacing • Cardiac surgery • Receiver operator characteristic curves • Statistical analysis • Simulation

What's new?

- The optimal timing of pacing after cardiac surgery is often debated in clinical practice.
- Guidelines suggest a wide array of waiting times that have been derived from observational studies.
- Our paper shows that answering this question using observational data may have intrinsic problems and hence using basic science to guide clinical practice may be of more value.

Introduction

Clinicians frequently debate the optimal timing of permanent pacemaker (PPM) implantation after cardiac surgery. While ~85% of patients use temporary pacing immediately after cardiac surgery, only ~2.5% of patients undergo PPM implantation.[1] Implanting a permanent system early shortens hospital stay, but delaying the decision allows many more patients to regain satisfactory conduction.

Recommendations of how long to wait before deciding on implantation vary from 48 h to 12 days.[1–8] Such guidance has been derived from observational studies by three main strategies: expert overview of the observations, testing of specific temporal cut points, and automated methods using receiver operating characteristic (ROC) analysis.

There are several reasons why the conclusions of these studies may differ. They use different endpoints (such as pacing dependence or conduction recovery, each of which has several possible interpretations)[1] and different follow-up durations.

In this study, we analysed observational data from our institution to identify an optimal time to wait after surgery before pacemaker implantation to predict pacing dependence and regression of pacing dependence by the 30-day pacing check. We then performed both a systematic review and modelling of simulated patients to put our data into the context of other similar studies.

Methods

Determination of predictors and optimal cut-off points of pacing dependence and conduction recovery

We retrospectively analysed data from all patients who underwent cardiac surgery at Harefield Hospital between 1 January 2015 and 1 January 2021. These data were collected from the electronic health records, local NICOR database, patient notes, and pacemaker follow-up reports. Operations eligible for inclusion were coronary artery bypass grafting (CABG), valve repairs and replacements, operations involving the thoracic aorta, left ventricular aneurysmectomy, atrial septal defect (ASD) closure, atrial fibrillation (AF) ablation surgery, left atrial (LA) appendage occlusion, acquired ventricular septal defect (VSD) repair, other congenital surgical correction, atrial myxoma surgery, and myomectomy. This included isolated and combined procedures.

Patients with a pre-operative pacing indication, a pacemaker that was already present but removed during surgery, and high-energy or cardiac resynchronization devices implanted for non-bradyarrhythmic reasons were excluded.

Pacing implantation was decided by normal clinical pathways by the usual clinical team. This observational study did not require patient-level consent because it was a retrospective audit into the post-surgical period authorized

by the Royal Brompton and Harefield audit team on 2 October 2021 (local ID 004337). No patient-identifiable information was used for analysis.

Implanted patients had routine pacemaker follow-up at 30 days. Pacing dependence was assessed during using the 'turn-down' method with pacing dependence defined over a 30-second period of observation without pacing. In that period, if there was no spontaneous ventricular activity above 40 b.p.m., or bradycardia with symptoms, the patient was classified as pacing-dependent. In patients who were pacing-dependent at implant, regression of pacing dependence was defined as not being pacing-dependent at the 30-day check.

Statistical methods

Data presented in tables are presented as the mean ± standard deviation, median ± IQR, or the quantity and percentage, as appropriate. Means were compared with Student's *t*-test if normally distributed or the Mann–Whitney *U* test if non-parametric. Counts were performed using both χ^2 and Fisher's exact test when the expected count in a category was less than five.

A multi-variate binary logistic regression model was built using the stepwise forward conditional method. A cut-off of $P < 0.05$ was used to assess for significance at every stage.

The cut-off times for the decision to implant a pacemaker were assessed using ROC analysis. The apparently optimal point was defined as the threshold that maximized the sum of sensitivity and specificity.

All statistics and simulation were performed using *R* (R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/) with some additional statistics performed using *SPSS* version 28 (IBM, Armonk, NY).

Comparison with published literature

We conducted a PubMed search using the Medical Subject Headings (MeSH) terms 'Cardiac Pacing, Artificial' (MeSH) OR 'Atrioventricular Block' (MeSH) AND 'Cardiac Surgical Procedures' (MeSH). This listed 1636 search results which were then screened by the authors.

Studies were eligible if they recommended a particular interval between surgery and implantation and presented the mean or median interval between surgery and implantation in their cohort.

Testing for an artefactual impact of local customs for timing of pacemaker implant

In light of the results of section 2, we hypothesized that the conventional statistical methods were artefactually biased to reporting a value near to the average time to pacing as the apparently optimal waiting time.

The clearest way to test this is by simulation since this allows us to separate the impact of underlying biology [time to recovery of atrioventricular (AV) nodal conduction in complete AV nodal block] from the impact of local habits for pacemaker implant timing.

We initially plotted the available data for both adults and children from previous studies on the subject.[3,6,9,10] Depending upon the paper studied, the endpoints used were either resolution of complete AV nodal block or resolution of pacing dependence in patients presenting with complete AV nodal block. Both adult and paediatric data fit an exponential decay model well.

The second stage was to understand the shape of AV nodal conduction recovery in patients presenting with complete AV nodal block in our data set. Although we do not have this data explicitly, it can be inferred by the recovery data between separate time points. If we assume a general exponential decay shape to the curve, which is the shape that fitted the 'adult studies data' closely, then the equation for the curve can be written as follows:

$$f(x) = c + (d - c)e^{-x/\alpha},$$

where c is the value below which $f(x)$ cannot fall, d is the value when $x = 1$, α defines the slope of the graph, and x is the number of days since surgery.

From our pacing data, we formed several simultaneous equations to compare the decay in AV node recovery between different time points, and from this, we can define the equation in the above terms, eventually forming an inferred curve for our data.

Having defined the relationship between days elapsed since surgery and likelihood of AV nodal recovery in patients with complete AV block, we then simulated populations of synthetic patients with different median days to pacing using a Poisson distribution.

The probability of recovery of conduction if paced on day x can be written as follows:

$$pRec(x) = \frac{\text{(proportion pacing dependent on day } x) - \text{(proportion pacing dependent on day } x + 30)}{\text{(proportion pacing dependent on day } x)}.$$

Therefore, using the distributions that we have modelled, the probability of recovery a patient with AV nodal block following the 'adult' distribution on day x can be written as follows:

$$pRec(x) = \frac{(55.8 + 43.4 * e^{-x/3.12)}) - (55.8 + 43.4 * e^{-(x+30)/3.12)})}{(55.8 + 43.4 * e^{-x/3.12)})},$$

which simplifies to

$$pRec(x) = \frac{(43.4 * e^{-x/3.12)}) - 43.4 * e^{-(x+30)/3.12)})}{(55.8 + 43.4 * e^{-x/3.12)})}.$$

Similar equations can be formed for the distributions based upon our data and the paediatric congenital distribution.

We ran this simulation for three versions of the underlying biology: an 'adult' biology based on published adult AV nodal recovery data, a 'paediatric' biology based on previously published paediatric AV nodal recovery data, and 'our data' biology based on our local results.

For each biology, we ran the simulation for 19 possible local average decision times for implantation of a pacemaker. For example, for the '3-day' local average decision time, simulated patients had their implantation at a distribution of times that averaged 3 days. The other 18 runs had average times of 4 days, 5 days etc. up to 21 days.

There were therefore a total of $3 \times 19 = 57$ runs of the simulation. To the results of each simulated run, we applied the standard statistical methods to find the apparently optimal decision time. We tested how these 57 resulting apparently optimal decision times were related to the 3 underlying biologies and to the 19 local average pacing times.

Results

Conduction at 30 days and its predictors

A total of 5849 operations meeting the study criteria were performed. Of these, 103 (1.8%) patients underwent pacemaker implantation for a new bradycardia indication in the post-operative period. Their baseline characteristics are shown in *Table 1*. A further 18 implanted patients underwent device implantation for other reasons (see Supplementary material online, *Table S1*).

Pacing dependence at 30 days

Patients undergoing surgery to the aortic valve or the thoracic aorta were more likely to be pacing-dependent at 30 days than those undergoing the other operations (see Supplementary material online, *Table S2*).

However, on multi-variate analysis, the only predictors of 30-day pacing dependence were time from surgery to implant in days [odds ratio (OR) 1.060 (1.002–1.122), $P = 0.043$] and pacing dependence at implant [OR 21.6 (6.7–70.2), $P < 0.001$].

The apparently optimal decision-making time, defined by the standard ROC method, was 12.5 days. This was the case both for the entire patient group [*Figure 1*; AUC 0.620 (0.511–0.730), $P = 0.031$] and for

Table 1. Baseline characteristics

Variable	All patients (n = 103)
Patient factors	
Age (years), mean (SD)	68.7 (11.8)
Creatinine clearance (mL/min), mean (SD)	78.0 (30.3)
Number of previous cardiac operations, mean (SD)	0.17 (0.38)
LVEF (%), mean (SD)	56.1 (11.0)
Previous congenital surgery, *n* (%)	2 (1.9)
GUCH, *n* (%)	3 (2.9)
Number of valves operated, *n* (%)	
0	8 (7.8)
1	68 (66)
2	22 (21.4)
3	5 (4.9)
Implant factors	
Pacing dependent at implant, *n* (%)	73 (70.9)
Days to PPM, median (IQR)	14 (10–24)
Days to PPM excluding IE, mean (SD)	14 (10–21)
Active IE (%)	16 (15.5)
Pre-operative ECG	
QRS duration (ms), mean (SD)	108.1 (24.6)
LBBB, *n* (%)	13 (12.6)
RBBB, *n* (%)	15 (14.5)
PR interval (ms), mean (SD)	192.0 (46.5)
Surgery details, *n* (%)	
CABG	30 (29.1)
Mitral valve surgery	41 (39.8)
Aortic valve surgery	65 (63.1)
Tricuspid valve surgery	20 (19.4)
Maze procedure	13 (12.6)
Thoracic aorta surgery	18 (17.5)
Pulmonic valve surgery	1 (0.97)
Indication for pacing, *n* (%)	
AV nodal block	79 (76.7)
Sinus dysfunction	7 (6.8)
Slow AF or tachybrady syndrome	17 (16.5)
Mobitz II	5 (4.9)

AF, atrial fibrillation; AV, atrioventricular; CABG, coronary artery bypass grafting; ECG, electrocardiogram; GUCH, grown-up congenital heart patients; IE, infective endocarditis; IQR, interquartile range; LBBB, left bundle branch block; LVEF, left ventricular ejection fraction; PPM, permanent pacemaker; RBBB, right bundle branch block; SD, standard deviation.

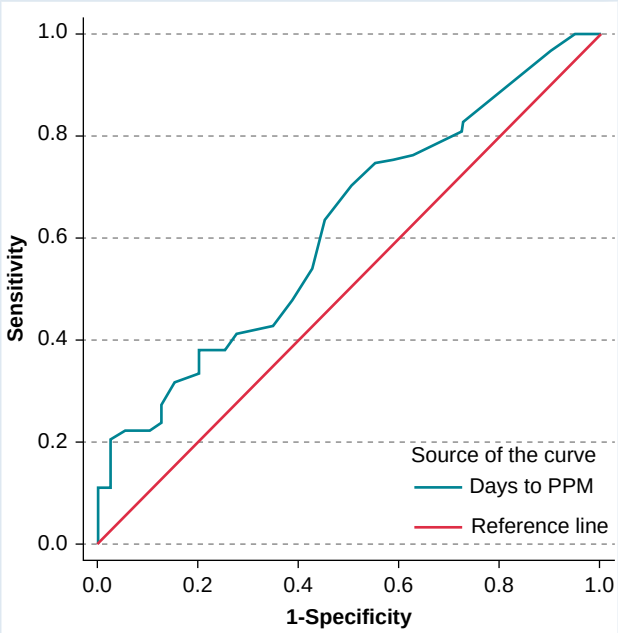


Figure 1 Receiver operator curve days to permanent pacemaker vs. pacing dependence at 30 days. PPM, permanent pacemaker.

the subset with AV nodal dysfunction at implant [*Figure 2*, AUC 0.706 (0.579–0.834), $P = 0.001$].

Regression of pacing dependence by 30 days

Of the subset of patients who were dependent at implant, 15/73 (20.5%) recovered from pacing dependence by Day 30. No patients meeting the study criterion for regression of pacing dependence had a nevertheless unsatisfactory rhythm such as asymptomatic complete heart block with a rate above 40 b.p.m. Of the 15 patients who lost pacing dependence at the 30-day follow-up, 11 were in sinus rhythm with 1:1 conduction and 4 were in atrial fibrillation with a ventricular rate of >40 b.p.m. and no symptoms.

No patient or operation characteristics predicted who would recover (*Table 1*), but those that recovered received their device earlier after surgery (11.3 ± 9.3 vs. 21.5 ± 14.8 days, $P = 0.007$).

Viewed as a predictor, the earlier after surgery the pacemaker was implanted in these pacing-dependent patients, the greater the odds that pacing dependence will have resolved by 30 days (OR for recovery per extra day 0.906 (0.831–0.989), $P = 0.027$). For example, at 30 days, initial pacing dependence had resolved in 50% of patients implanted in the first week after surgery, 27% of those implanted in the second week, and under 8% for those implanted after Day 15.

The apparently optimal decision-making time, defined by the standard ROC method, was again 12.5 days [*Figure 3*, AUC 0.769 (0.634–0.904, $P < 0.001$)]. This was the case both for the entire patient group and for the subset excluding patients with active infective endocarditis at implant because they are mandated to receive a pacemaker 4–6 weeks post-operatively [*Figure 4*, AUC 0.80 (0.685–0.915), $P < 0.001$]

Comparison with published literature

The systematic literature search revealed nine eligible publications with a total of 11 implant times that were either recommended or tested in the publication (*Table 2*).

The data from these studies[2–5,9,11–13] and ours are shown in *Figure 5*. The studies with positive findings are marked with a green filled triangle, and the two studies with non-significant results are marked with a red disc.

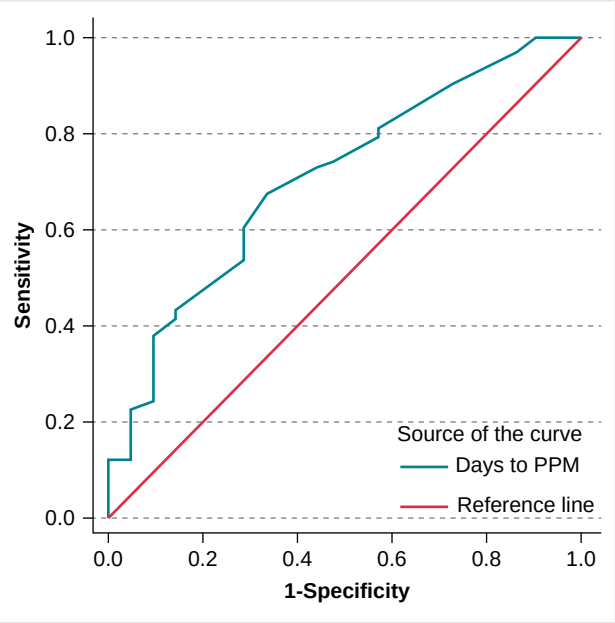


Figure 2 Receiver operator curve days to permanent pacemaker vs. pacing dependence at 30 days in those with atrioventricular nodal block at implant. AV, atrioventricular; PPM, permanent pacemaker.

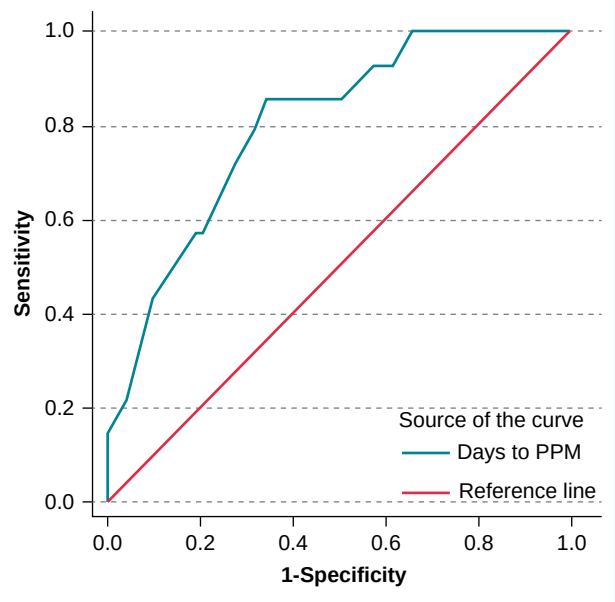


Figure 3 Receiver operator curve looking at recovery of atrioventricular nodal conduction as a function of days to permanent pacemaker implant, including infective endocarditis patients. AV, atrioventricular; PPM, permanent pacemaker.

Notably, in all the positive studies, the decision time recommended by the study was virtually identical to the average time to implant in that study's population ($R = 0.96$, $P < 0.001$).

The two studies with non-significant results were very far from the line of identity. In other words, they were each testing a decision time that was much further from their own institution's average time to pacing (mean absolute deviation 15 days) than the studies with significant results were (mean absolute deviation 0.84 days, $P < 0.001$).

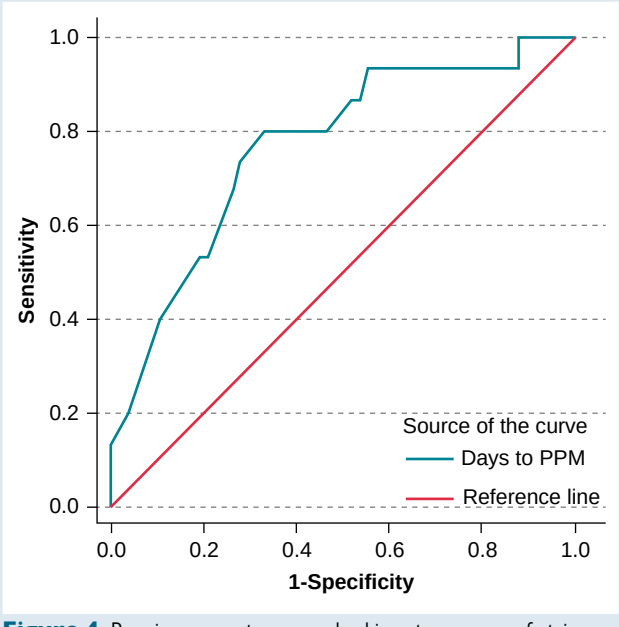


Figure 4 Receiver operator curve looking at recovery of atrioventricular nodal conduction as a function of days to permanent pacemaker implant, excluding active infective endocarditis patients. AV, atrioventricular; PPM, permanent pacemaker.

Is underlying biology or observed average time to pacing the primary driver of different recommendations of optimal waiting times before pacing?

The simulation allowed us to study this question by building populations with three different underlying biologies and exposing them to hospitals with 19 different institutional practices of average time to implant. In the resulting $3 \times 19 = 57$ simulations, we could visualize the relative impact of biology and observed institutional practice on the apparently optimal time to implant that is returned by standard statistical procedures.

Two of the underlying biologies were found in the literature and represented adult AV conduction recovery[3,6,9] and paediatric AV conduction recovery.[10] The third was derived our institutional data presented in our initial results section. The time courses of recovery of all three biologies are shown in *Figure 6*.

There was no significant relationship between the underlying biology and the apparently optimal time to pacing ($df = 2,54$, $F = 0.384$, $P = 0.683$). *Figure 7* (left panel) illustrates this with simulations of institutions that implant at about 3 days (top panel), institutions that implant at about 12 days (middle panel), and institutions that implant at about 21 days (bottom panel).

In contrast, differences in institutional practice had a very powerful effect on apparently optimal time to implant ($R = 0.985$, $P = <0.001$). *Figure 7* (right panel) shows this with all 57 simulations: 19 with the 'adult biology' (top panel), 19 with 'our data biology' (middle panel), and 19 with 'paediatric biology' (bottom panel).

Table 2 Suggested or tested thresholds assessing either pacing dependence or conduction recovery

Paper	Suggested/ tested (days)	Average time to pacing (days)	Outcome assessed	Tested or suggested
Glikson 1997 Broad complex	6	6.4	PD	Suggested
Glikson 1997 Narrow complex	9	9.9	PD	Suggested
Bis *et al.* 2021	6	7	PD	Significant
Bis *et al.* 2021	6	7	CR	Significant
Waddingham 2021	5	7	PD	Significant
Our data	12.5	14	PD	Significant
Our data	12.5	13	CR	Significant
Merin 2009	5	13	PD	NS
Kim 2001	7	8	CR	Suggested
Baraki 2013	5	5	PD	Suggested
Huynh 2009	7	6.1	PD	Suggested
Raza 2011	7	7	PD	Suggested
Viktorsson 2020	30	8	PD	NS

CR, conduction recovery; PD, pacing dependence; NS, not significant.

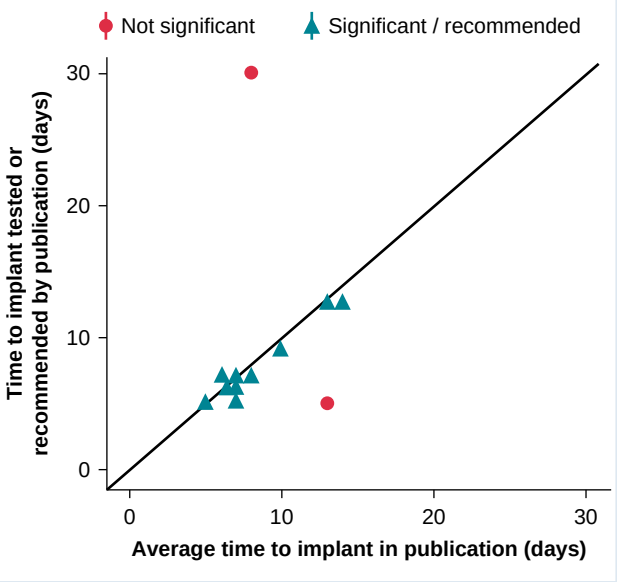


Figure 5 In the publications that recommended an apparently optimal time to implant (▲), this was always close to the average time to implant in that publication ($R = 0.96$, $P < 0.001$). In the publications that tested a time and found it to be unsatisfactory (●), this was always far from the average time to implant in that publication.

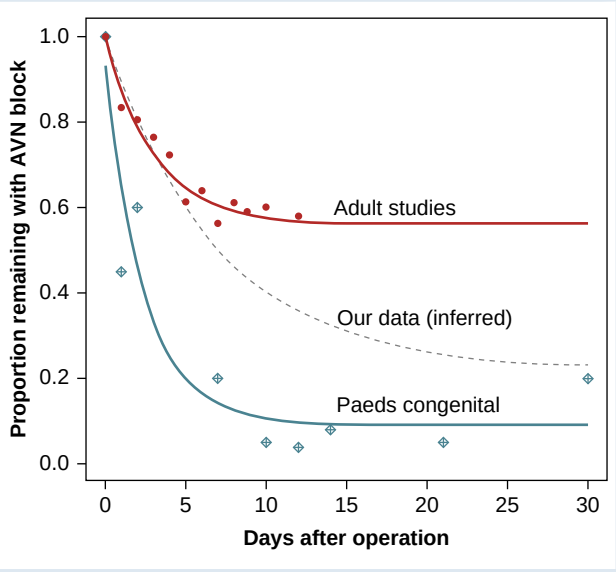


Figure 6 Post-operative atrioventricular conduction recovery for different patient distributions.

Discussion

The conventional analysis of our institution's data showed a consistent apparently optimal time for pacemaker implantation at 12.5 days, regardless of whether the endpoint was pacing dependence or regression of pacing dependence and regardless of the composition of the cohort in terms of pacing indication and presence of infective endocarditis.

However, our systematic review showed that while studies varied in the apparently optimal time that they reported, this apparently optimal time was always very close to the observed average time to pacing in that particular cohort. We therefore conducted a third analysis that used simulation to test whether this relationship was mechanistic or merely a coincidence. We found that regardless of the actual underlying biology of AV nodal conduction recovery, the suggested optimal time to pacing is always near to the observed average time to pacing in the studied patient cohort.

Apparently optimal implant times at our institution

We found that time to implant predicted both pacing dependence and regression of pacing dependence at 30 days. Using standard methods, we found that 12.5 days was the apparently optimal time to implant, regardless of patient subset.

This was longer than the recommendation of most published studies. It was similar to our institution's median time to implant of 14 days. This coincidence does not seem to have been noted before.[1–8] We explored this first by examining the other studies.

The apparently optimal implant time is always similar to the studied cohort's average time to pacing

The systematic review of the previous studies showed a striking relationship between the average time to pacing in a patient cohort and the recommended time to implant arising from that study ($r = 0.96$, $P < 0.001$).

Even more striking was that, in the few cases where a study tested a pre-specified waiting time that happened to be far from that cohort's average, the result was always negative.[2,13]

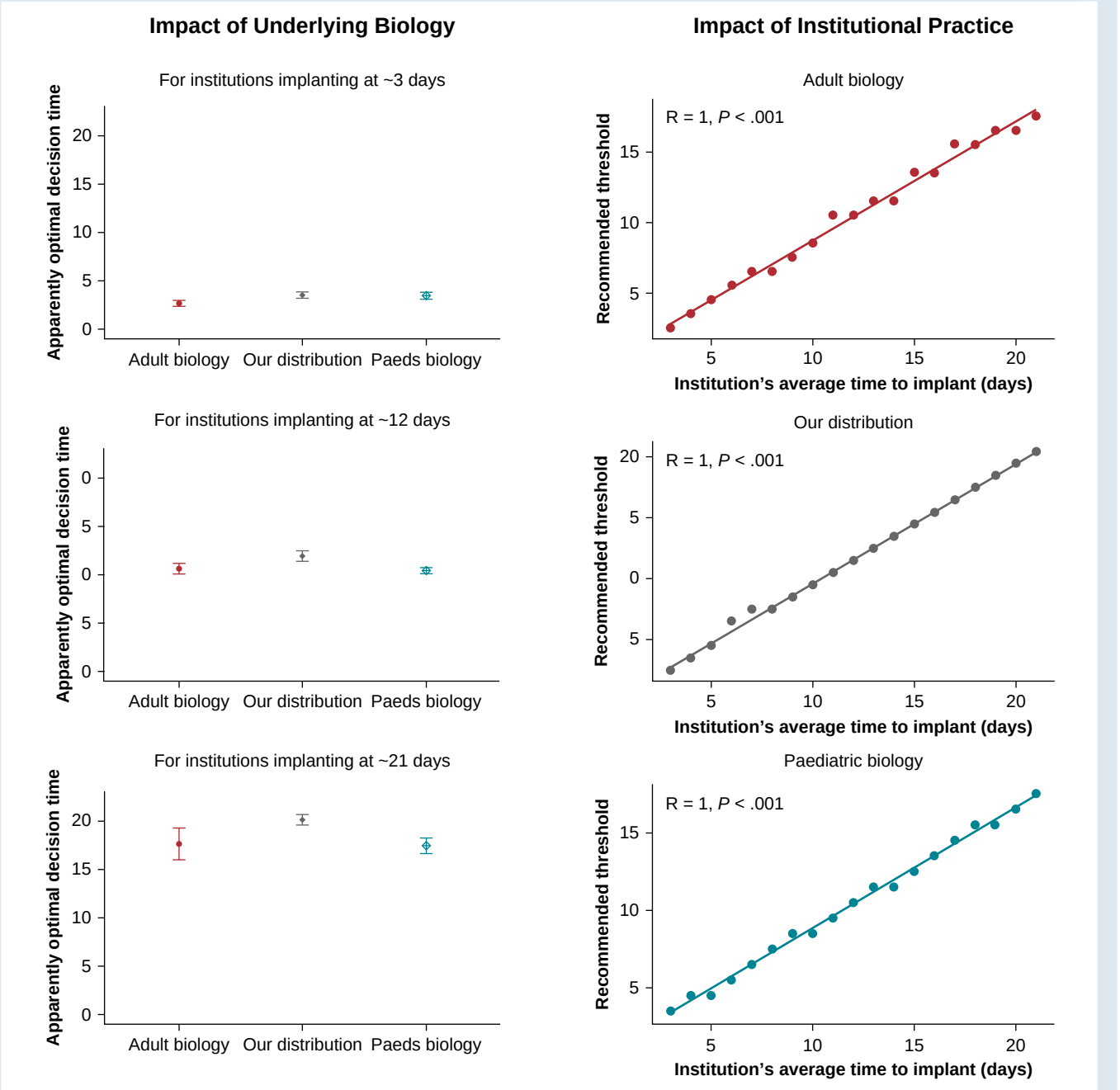


Figure 7 (Left panel) Plot of apparently optimal decision time by underlying biology for simulated populations with underlying average time to pacing of 3, 12, and 21 days respectively. There was no significant difference in the apparently optimal decision time between different underlying biologies ($P = 0.586$). (Right panel) In contrast, there is almost a perfect correlation between the average time to pacemaker implant and the apparently optimal decision time ($R = 0.985$, $P = <0.001$ for the amalgamated population).

Mechanism for apparently optimal time to pacing matching observed practice

There are two main explanations for this relationship. The first is that institutional practice evolves over time to become suited for their own patient population. The second is that the process of finding the apparently optimal implant time is inherently biased to returning that institution's average time to implant as that suggested optimal time.

Simulation can help to distinguish between these two possibilities because it allows us, without endangering patients, to try different underlying biologies and different institutional practices. Therefore, we proceeded to simulate 57 different patient populations in the manner described in the Methods section, with 19 different institutional practices (i.e. different average times to pacing) across three different underlying biologies of AV nodal conduction.

Simulation shows that local practice, and not biology, is the sole determinant of a locally calculated 'apparently optimal time to pacing'

In an imaginary world, where different large-scale randomized trials are available for every possible time point of decision, it would be easy to identify the optimal time for the decision for implantation: it would be the time used in the trial arm that had the best results. Importantly, though, even without conducting such trials, we can confidently state that in a fast-resolving condition, the optimal time should be early, and in a slow-resolving condition, the optimal time should be later.

In reality, such trials are impractical and instead researchers often analyse observational data to try to identify the best time point for implantation. Here too, while we cannot know from first principles what these optimal time points should be, we can know that the optimal time for fast-resolving conditions should be earlier than for slow-resolving conditions.

The simulation allows us to simulate any combination of local practice (of average time to pacing) and biology (of underlying conduction recovery) and examine the impact on the resulting 'apparently optimal time to pacing'. This revealed that local practice of average time to implantation overwhelmingly determined the results of standard statistical procedures to find the optimal time to pacing ($r = 0.985$, $P < 0.001$). There was virtually no effect of changing the biological rate of recovery of the conduction system ($P = 0.683$).

This means that the commonly used approach to formulate recommendations for the optimal time to pacing is faulty. This finding mirrors our previous finding in a different field, namely that when identifying apparently optimal prognostic thresholds, where it was found that the most commonly used methods in the medical literature for finding an optimal prognostic threshold in a continuous variable are, in fact, simply returning the middle of the distribution of patients in the study.[14]

Implications for clinical practice

Guidelines often cite these studies of apparently optimal times to pacing. Superficial readers might incorrectly assume that these studies are somehow establishing, from observational data, what is the best time to implant. In reality, these studies are, without necessarily realizing it, reporting as the apparently optimal time to pacing whatever the average time to pacing is at their own institution. So, while it is perfectly reasonable to cite these studies, it would be preferable to make clear that these values are, in effect, a survey of practice by experienced physicians at these centres, rather than a valid analysis of the optimal time to pacing. This also explains why the results differ between centres: whatever a centre's typical time to pacing is that time will turn out to be apparently optimal.

One contribution of our study is that it could liberate future guideline writers from feeling constrained to treating the published apparently optimal pacing times as the basis for their recommendations. For example, they might recommend waiting until the conservative end of the spectrum of reasonable times, if they wish to minimize implantation during the early steep part of the recovery curve while also minimizing futile waiting in the later flat part of the recovery curve (*Figure 6*). However, as we have shown there is inherent bias in the recommendations based upon observational studies, there is no need to match these recommendations exactly.

This vacuum will be difficult to fill with randomized controlled trials (RCTs) because of the extreme challenge posed by the different time courses of the two types of harm from a sub-optimal decision, in addition to the relative rarity of PPM implantation.[15] Implanting too late leads to immediate complications from prolonged hospital stays for temporary pacing. In contrast, however, implanting too early gives its undesirable effects many years later, through LV dysfunction from pacing, or the costs of serial replacement of an unnecessary pacemaker. This temporal asymmetry means that the duration is the overwhelming determinant of its headline outcome: a short trial is guaranteed to favour early implantation. The best compromise may be prospective data collection on AV conduction recovery after different surgeries to model what proportion would recover on each day were a pacemaker implanted, which would extend the work of previous studies[6] with daily pacing checks after implanted patients to accurately define conduction recovery curves.

It should also be remembered that the progress of conduction recovery is not a dichotomous one. Meeting our study criterion of being independent of pacing does not mean that conduction is normal nor satisfactory because a patient may still have a pacing indication. For example, a hypothetical patient with initial asystole whose conduction then improved to asymptomatic complete heart block with a ventricular rate just above 40 b.p.m. would be classified by our study as having regression of pacing dependence, although of course the end result remains highly unsatisfactory.

However, the principle of our study is likely to apply for any diagnostic criteria for adequacy of conduction since the modelling was not based on any specific electrical definitions but merely on the artefactual statistical significance that arises from the common approach to analysing such observational data. In other words, changing the outcome measure from 'regression of pacing dependence' to a different definition of conduction recovery may change the absolute numbers in each category but is unlikely to change the observed pattern where the average time to pacing in that institution is still reflected in the apparently optimal time to pacing.

Limitations

While in our local study, we had a clear definition of pacing dependence, we had to accept in the systematic review some variation in its meaning. Future work to create a universal definition of pacemaker dependence would be welcome.

This article focuses on pacing dependence and its regression over time. However, regression of pacing dependence is not equivalent to the pacemaker being unnecessary. Pacemaker necessity in these patients does not yet have a clear definition.

Waddingham *et al.*[11] used their own definition to assess pacing practice after surgery. This essentially classed necessity as pacing dependence *or* a pacing percentage of >1% in either atria or ventricles. The second part of this definition ingeniously recognizes inconsistent conduction but is nevertheless affected by the base rate. For example, our mean base rate was 59 b.p.m., and many such patients receive beta-blockade. At that base rate, even with perfect conduction, many might receive more than 1% pacing.

Newer devices provide the ability to examine pacing data retrospectively with more granularity than presented here. For example, Massoullié *et al.*'s recent study of high-grade conduction block in patients presenting with left bundle branch block after transcatheter aortic valve implantation (TAVI) utilized Microport devices that store electrograms around mode switches for high-grade AV nodal block.[16] This allows more accurate adjudication of pacing necessity. The same approach could be used in future studies of pacing after cardiac surgery.

Conclusions

We should continue to use our clinical judgement to decide when to make the decision to implant pacemakers after surgery. Running conventional statistics on case series, as we did in the first section of this manuscript, and has been done by others, produces a false confirmation that the studied practice is optimal.

Nevertheless, it would be difficult to design a RCT to define this optimal time because the harm from implanting too late will occur early in follow-up, whereas the harm from implanting too early will accumulate only very slowly over the long term. The choice of follow-up duration will therefore determine the resulting optimal time to implant. Moreover, whatever the headline result of the trial, individuals who will have less exposure to long-term consequences (e.g. the very elderly) would have an earlier optimum than an all-comer RCT would report, and those with more exposure would likely have a later optimum.

With observational data not being as helpful as often presumed and useful RCT data unlikely to arise, the best course of action may be to individualize the decision based on our understanding of conduction recovery patterns and expectation of long-term complications.

Supplementary material

Supplementary material is available at *Europace* online.

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Author contributions

A.T.: concept, design, data collection, data analysis, statistics, data interpretation, drafted article, critical revision of article, and statistics. I.C.: data analysis and critical revision of article. R.H. and N.G.: data collection and critical revision. R.L., S.B., and M.M.: concept, data interpretation, and critical revision. D.F.: concept, design, re-drafting, statistics, and data interpretation.

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Data availability

The data underlying this article may be shared on reasonable request to the corresponding author.

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