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Copy to Dr. A. M. Richards
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Dear Henry:

I shall not relate to you the long and devious route over which we travelled in order to resolve our pressure problem. I shall merely summarize our findings and illustrate our solution.

It became obvious to us after frequent correspondence and verbal consultation with their "experts" that Statham understands their gauges well and Honeywell understands their recorder well but neither understands the response problems of an entire manometric system consisting of catheter, gauge, amplifier or gauge control module and recording galvanometer. Neither group was able to help.

Statham P23Db and P23Gb gauges are very fast, resonating at 225 and 450 cps but their damping is much less than 10% of critical. In agreement with Burns'(Statham's engineering consultant) predictions we found the following:

a) Statham P23Db transducer plus 80 cm of 18 gauge thinwall teflon catheter has a resonant frequency of 83 cps (predicted 80 to 90 cps) and damping < 10% of critical. This frequency could only be reached after flushing the system with alcohol followed by meticulous flushing with <u>boiled</u>, distilled water. Using Abbott normal saline, we never exceeded 30 cps even though no bubbles were visible in catheter or gauge.

b) Hydraulic damping decreases the frequency much more rapidly than the damping ratio: An 80 cps system with < 10% damping falls to 10 cps in achieving 30% of critical. We attempted damping by using 27 gauge needles soldered together and placed in the system but this did not work. According to Hanson only a certain diameter and length of <u>capillary</u> will work for a given gauge but air trapping then becomes a problem.

We tried two solutions which are popular in Rushmer's and Scher's groups; namely inserting a section of compliant tubing which is damped until damping = 70% of critical or until the pressure <u>looks</u> good. Due to the cold-flow characteristics of plastic tubings such as tygon we found that after 20 to 30 min. damping soon became 120 to 130% of critical. Electrical damping is equally dangerous and based on misconceptions. If resistancecapacitance damping circuits are used phase shift is considerable and is frequency dependent. Also most filters have slow rates of cutoff of higher frequencies. Introduction of another second order system makes simple frequency response analysis impossible. Unless the resonant frequency of the gauge plus catheter greatly exceeds the cutoff frequency of the filter--absolutely nothing is gained--much is lost. Using the analogue computer we found that resistance damping alone of the recording galvanometer to even 20 times critical would not secure an optimally damped system (galvos are usually damped to 64% of critical.

Knowing the resonant frequency of the catheter is the key. Since the gauge alone is much faster, the catheter sets the frequency of both. Knowing this the logical solution is to select a galvanometer which either cannot follow or will greatly attenuate catheter + gauge resonant frequency. Thus if the catheter + gauge resonate at 80 cps, a 40 cps galvo will be 12.8 db down at this frequency or will attenuate catheter vibration, (motion artefact, etc.) by 77%.

As I said it is hard to exceed 25 to 30 cps using commercial saline solutions as we do in our experiment, thus using a 40 cps galvo will allow resonance amplification of catheter motion artefact.

We found that Baxter and Cutler, unlike Abbott, seal their saline while it is hot and then in cooling forms a partial vacuum, thus air is not redisolved. Preflushing our gauge with sterile ethanol and filling with Baxter saline has allowed us to exceed 50 cps and go as high as 73 cps. We determine this before and after each experiment using a sterile replica of the subject's aortic catheter before. We replaced the 200 cps galvo provided by Honeywell with a 40 cps--but since the resonant frequency of the catheter is usually so close to 40 cps we could still record much artefact. To Honeywell's horror we borrowed an 18 cps galvo and that worked. We read Hanson, MacDonald, Fry and Wood very carefully and concluded this is fast enough for aortic pressures even if the fundamental frequency is 3 cps (i.e., HR = 180). As HR increases pulse pressures more closely approximate a sinusoidal wave form and require fewer harmonic components to reproduce. I have enclosed some records with explanation which I think beautifully illustrate the problem and solution.

One thing we have learned after having done several hundred dynamic calibrations of one gauge plus a catheter is that determination of the frequency response before or after a study and calling that the frequency response of the system for an entire series of experiments is a snare and a delusion. It is very easy to make a 200 or 300 % error and many records show it.

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Please let us know if we can be of further aid.

Sincerely yours,

Larry

Loring B. Rowell, Ph.D.
Research Assistant Professor

LRB:p

P.S. Beware of fitting catheters to Clay-Adams or BD adapters; they trap air bubbles and greatly decrease the frequency responses. We force our #18 catheters over #17 blunt needles and put heavy tygon over the needle-catheter junction.

Also, most BD stopcocks leak either initially or after one use. We have to disassemble them, lap them with fine abrasive and then grease them under sterile conditions with sterile silicon grease before each experiment.

(A)

time lines = 0.01 sec

Here is transient response of gauge + catheter into a 200cps galvo*
Note there is nearly 100% overshoot thus damping → zero
resonant freq = 50cps

* damping of recording galvo ≅ 64% critical

Here is the transient response of same gauge and catheter - few minutes later with an 18cps recording galvo (64% critical damping)

Note the transient response is that of an optimally damped system with another 2nd order system superimposed and resonating at 50 cps but the 50cps freq is greatly attenuated

The result as you can see ~~will~~ be loss of catheter artifact.

This record is from an actual experiment during which we measured aortic pulse waves at 200 beats/min without artifact

Sorry

this is not correct - for the experiment we had ~~was with~~ a 73cps gauge thus the record with the 18cps galvo was even cleaner - nevertheless this record (from a calibration study) would have given essentially artifact free pressures.

Rec 2* ... P23Db 1008 - Gauge refluxed = Baxter saline + cath reflux ... M 200 Galvo - Carrier Ampl Cliea ff, gain = 40

Rec 3 Feb 12 ... P23Db 1008 - Same gauge-cath system used for Rec № 2 ... M 18 galvo - Unamplif Press channel

(B) See Record A first

Here is the transient response of same gauge and catheter seen in record (A) – apparently "air-freed"
note the resonant frequency is only 30 cps. This is what we usually get actually they are somewhat slower on the average – using Abbott saline

Now note the entirely different transient response using the 18cps galvo (same system again, minutes later)

The 18cps galvo can now follow more easily the slower resonant frequency of gauge + catheter.

Thus we have 2, 2nd-order systems one optimally damped at $f_0 = 18$cps and the other very underdamped at 30 cps. The catheter now resonates at 30cps and the galvo now only attenuates the artifact by about 60% as opposed to greater than 90% when $f_0 = 50$cps (gauge + cath resonant freq i.e)

aortic Pressures during exercise looked terrible in this study.