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NMR "Gating" Really Means "Synchronization"

TO THE EDITOR "Gating" is an inaccurate term for cardiac synchronization of nuclear magnetic resonance (NMR) imaging. It is important to distinguish between "gating" and "triggering". Gating is used to enable or inhibit the acquisition of data while triggering is used to initiate an episode of data acquisition. Perhaps because in scintigraphic imaging the synchronization of data acquisition to physiological cycles is strictly by gating, the term "gating" is used by many practitioners in NMR imaging both for cardiac and respiratory "synchronization". However, there are fundamental differences between scintigraphic imaging and NMR imaging that make "NMR gating" a misleading term, at least for cardiac synchronization.

1. The total duration of data collection for both scintigraphic imaging and NMR imaging typically spans many cardiac and respiratory cycles. Long data collection allows either an improved signal-to-noise ratio, improved spatial resolution, or both. When the organ being imaged is in motion, the acquisition of data must be synchronized to the periodic motion of the organ to minimize motion artifacts in the image. Cardiac gating, and to a lesser extent respiratory gating, have a long history in nuclear medicine [for a brief discussion, see (*1*)]. Recently, this experience in physiological synchronization has been applied in NMR imaging to improve the images of organs exhibiting periodic motion [for example, see (*2*)]. Synchronization is extremely important in NMR imaging because the effects of motion may be to render the moving organ invisible, not just blurred, and artifacts from moving structures (like the heart or blood) may obscure adjacent stationary structures.

2. The "event" in scintigraphic imaging is the emission and detection of a gamma ray resulting in a "count". The event occurs spontaneously and essentially instantaneously. The instrumental conditions under which events are observed is constant.

Unlike radioactive decay, the NMR event will not occur unless the nuclear spins are properly prepared and stimulated. The NMR event is an induced event; it is not spontaneous. The event in NMR is one cycle of preparation, evolution, and read-out of the spin system. This cycle is repeated many times (typically 128 or 256 times) in the acquisition of the dataset from which a single-slice NMR image is reconstructed. Because of the need for spatial encoding of the data, the characteristics of the instrument (e.g., the phase-encoding gradient strength) change for each event or cycle. Depending on the details of the procedure, the duration of each NMR event ranges from about 20 msec to 3 sec with all but the newest techniques taking longer than 300 msec per cycle. Except for the rapid scan techniques, this duration is of the same order of magnitude as the R-R interval (600–1000 msec) and similar to the period of the respiratory cycle (3–5 sec). Even though the NMR event is rather long, the actual duration of data collection may be relatively brief. An NMR image is made from a set of spin echoes acquired under different conditions of the instrument. The duration of the temporal window within which the data from a spin echo are collected usually ranges from 10 to 40 msec. However, because the NMR phenomenon is stimulated and requires a rigid recipe for the preparation, evolution, and read-out of the spins, the length of the event is defined by the duration of the entire cycle of preparation, evolution, and read-out and not by the interval of data acquisition.

3. Because scintigraphic events are spontaneous and virtually instantaneous, and the camera does not change for different events, it is sufficient to turn the data acquisition on during the desired part of a physiological cycle and to turn acquisition off in undesirable phases of the physiological cycle. Apparently, the term "gating" came naturally to the originators of this technique (*3*). The gating device acts as a switch which allows counts detected during a defined interval of the physiological cycle to be added to the image matrix while counts occurring outside the interval are excluded from the image.

The synchronization of the NMR event to the cardiac cycle reflects the need to stimulate the event and the uniqueness of each event. If an NMR acquisition were truly gated, a free-running NMR acquisition would have its data stored and the instrumental conditions would be changed only when the event occurred at the proper point in the R-R interval. With most NMR imaging techniques, the duration of the event is close to that of the R-R interval. Thus, it would require many R-R intervals for the NMR event to come into phase with the cardiac cycle and be accepted by the gate. Instead, the "gate" is used to stimulate the NMR event so that it begins at a well-defined point in the cardiac cycle.

The newer rapid NMR imaging techniques, with an event duration as short as 20 msec, offer an approximation to "list mode" acquisition. However, each event still requires different instrumental conditions. Hence, a retrospective gating technique such as "list mode" will not work for NMR without modification. The uniqueness of the NMR events means that many events would have to be acquired for each set of instrumental conditions in order to assure that one could retrospectively find enough different events at a given point in the cardiac cycle from which to reconstruct an image. Two approaches to pseudo-list mode acquisition using rapid imaging are to collect data in a completely free-running manner and to assemble images after the fact using mathematical interpolation to compensate for the missing data (*4*) or to resynchronize the free-running acquisition at each R-wave (*5*). This second approach avoids the problem of missing data lines by keeping track of which data remain to be collected and adjusting the instrumental parameters accordingly. This can result in a moderate increase in overall data acquisition time.

Cardiac synchronization has been emphasized in the previous paragraphs because synchronizing the NMR event to the respiratory cycle is essentially gating. Combined cardiac and respiratory synchronization in NMR imaging illustrates this point. The simplest method of respiratory synchronization is to inhibit the triggering of the NMR cycle during the

undesired part of the respiratory cycle. Since the cardiac cycle and the respiratory cycle are independent this has the undesirable effect of allowing different degrees of longitudinal magnetization recovery for different cycles of the data and thus produces a nonuniform T_1 weighting in the data. A method developed by Ehman (*6*) uses the cardiac cycle to trigger the preparation part of the NMR cycle and uses the respiratory cycle to inhibit the collection of data during the undesired portion of the respiratory cycle. The variation in the T_1 weighting is reduced to that arising from the variation in the R-R interval. Thus, the parts of the NMR cycle which depend on precise timing are synchronized rigidly to the R-R interval while the acquisition of data and changing of the instrumental conditions are truly gated by the respiratory cycle.

With the exception of Ehman's combined cardiac and respiratory gating technique, the best justification for the use of the term "gating" in NMR imaging is its brevity and familiarity. While convenience of expression probably outweighs concerns for precision, it is necessary to remember that the term is capable of misleading the unwary. NMR gating is the synchronization of an actively stimulated phenomenon to physiological cycles, not a spigot turning on and off a stream of spontaneously occurring independent, instantaneous, stochastic events. NMR gating does not produce snapshots. The effects of motion on the NMR image, such as phase shifts, still are present in a gated image. They simply have been made more consistent from cycle to cycle of the NMR data collection.

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EDITOR'S NOTE: Leon Axel, MD, Chairman of the American College of Radiology (ACR) Subcommittee on Nomenclature and Phantom Development, has written the Journal requesting that the reader's attention be drawn to the ACR's recently completed 2nd edition of the *Glossary of MR Terms* (Edition 2. Reston, Virginia: American College of Radiology, 1986). In an editorial appearing in *Radiology* (1987;162:874), Dr. Axel discusses some of the changes in the new edition. The reader is directed to the Glossary and the editorial for more information on this important and timely topic.