

## OBSERVATIONS ON CLONUS IN THE CAT'S SOLEUS MUSCLE

by

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It was pointed out by Denny-Brown (1929) that isotonic recording favours the appearance of clonus in the soleus muscle of decerebrate cats. I have found clonus prone to appear when the animals are decerebrated at the precollicular level. In such preparations, as is well known, the isometric stretch reflex tends to be small, in fact, it proved necessary to re-decerebrate intercollicularly in order to obtain the greater rigidity wanted for my work that at the time was devoted to a study of the relation between tension and extension (Granit, 1958). However, a number of precollicular cats were used in these experiments and on those I made some observations on clonus the chief interest of which lies in the simultaneous records of the discharge frequency of indicator spindle afferents and the tension measurements. Denny-Brown's very complete work was carried out at a time when the properties of the receptors and the role of the so-called Renshaw feedback were largely unknown.

### METHODS

Cats were decerebrated by suction at the precollicular level. Laminectomy was performed to lay bare the roots from L<sub>5</sub>

to pelvic end. A muscle spindle afferent was functionally isolated in a thin dorsal root filament, the other filaments being left intact. The limb was denervated with the exception of the medial and lateral gastrocnemius nerves. The gastrocnemius and soleus muscles were separated and the latter joined by a hook and a steel spring to the isometric strain gauge myograph, the limb itself being rigidly fixed at hip, knee and ankle. When isometric contractions were wanted for comparison the spring was removed. Bipolar needle electrodes in the belly of soleus recorded the electromyogram.

Now, in isotonic recording, when the spring is pulled out by shifting the position of the myograph stand, the muscle may shorten reflexly. When this happens and the spring in addition gives way it is necessary to record extension by a separate indicator and not rely on the scale alongside the isometric myograph. To this end the following adjustments preceded experimentation: zero extension was determined by adjusting the myograph until the pull was of the order of 20 g; a pointer movable on a mm scale was used to mark off the position of the tip of the hook that protruded from the piece of bone that was left attached to the distal end of the freed soleus tendon. Thus, when in the experiment the myograph was shifted, the pointer was replaced accordingly and the movement of the bony attachment read off on the mm scale.

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Negative values of extension may be obtained, for example if the muscle is activated at zero extension (e. g. by a pinna reflex) because the muscle then shortens reflexly.

## RESULTS

It is not possible to explain what particular state of imbalance makes clonus appear in some precollicular animals and not in others but it is often possible to produce clonus by activation when none is present to stretch by itself. By activation is meant a number of taps on the tendon of soleus or, preferably, on the tendon of gastrocnemius. Thus in the experiment of Fig. 1, records 1, when the muscle was extended 3.5 mm, there was no reflex response. Then the tendon of the synergic gastrocnemius was hooked up to a stand and nine taps delivered. Of these the three

last ones are shown in the record. The taps started a clonus at about 8 per sec with bursts of the indicator spindle averaging 200 impulses per sec as against 15 per sec at the equivalent isometric length. When, in the same experiment, the muscle was pulled out 6 mm, the clonic response started spontaneously at a rate of 8-9 per sec. The recording being isotonic very little tension was developed, only 45 g. It is therefore doubtful whether the inhibitory Golgi tendon organs, which are tension recorders, reached their threshold of excitation.

Another experiment is shown in the records 2 and 3. Extension is 4.8 mm and with this amount of stretch clonus sometimes started spontaneously, sometimes needed activation by a few tendon taps. It was observed for 20 min in all and may well have gone on indefinitely. The upper pair of records compare electromyogram and myogram, the lower pair electromyogram

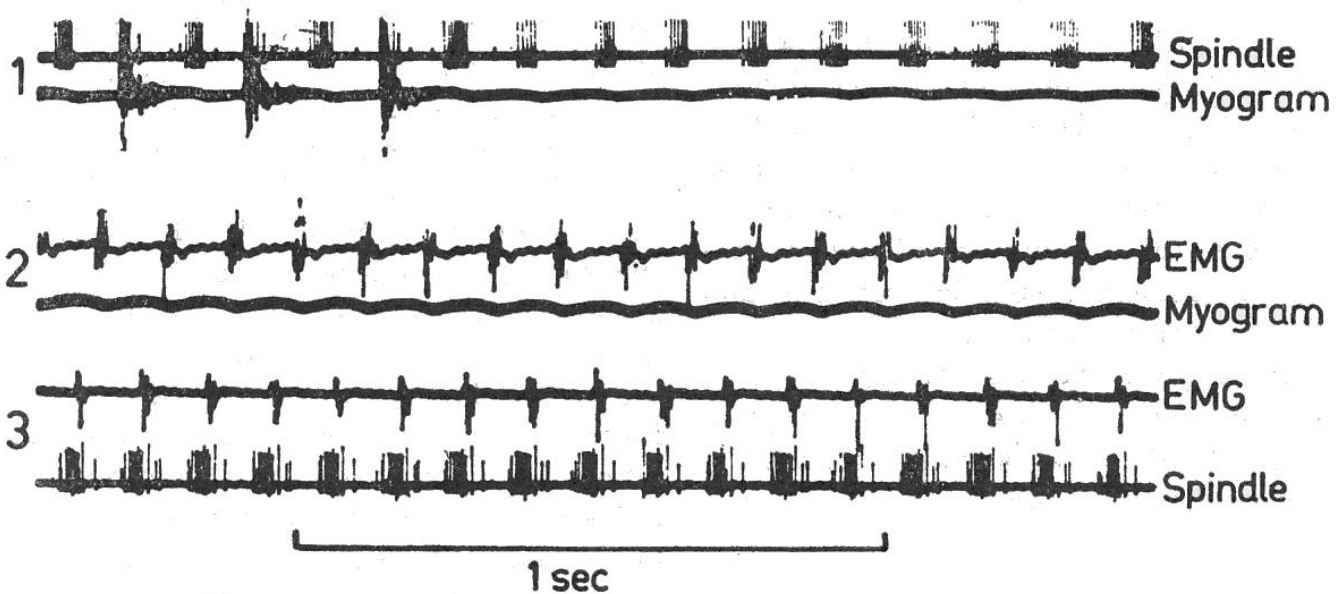


Fig. 1.—Precollicular decerebration of two cats (1 and 2, 3). Soleus muscle, attached by spring (9 g/mm) to isometric myograph. Clonus mainly a variation of muscle length with tension oscillations of the order of 20-40 g. 1, upper record, large spindle afferent isolated from dorsal root; lower record myogram. Records begin with three taps on spring which are the last three of a series of nine. Lasting clonus around 8/sec thereby initiated when muscle was set at 4.8 mm extension, as in record. At 6 mm extension similar clonus started spontaneously. Frequency of spindle discharge in the groups averages 200 impulses/sec. 2 and 3, another preparation with spontaneous clonus at about 9/sec starting at 6.6 mm extension and observed during 20 min. Frequency of clonus in the end around 10/sec. Spring used but not essential since similar clonus started when muscle loaded with weights over a pulley (Table 1). 2, electromyogram and myogram. 3, somewhat later; myogram replaced by isolated spindle afferent discharging in bursts at an average rate of 400 impulses/sec.

gram and spindle response which occurred in bursts averaging 400 impulses per sec. In these phasic bursts the spindle fired at ten times faster frequencies than in static isometric stretch, for which at this length the value was 40 impulses per sec. Records 2 and 3 show that the spindle discharge preceded the electromyogram and was stopped abruptly by the contraction. This is, of course, what should be expected from spindle properties. Unexpected is only the very high afferent discharge frequency. The rate of clonus in records 2 and 3 was around 9-10 per sec. Tension varied only by 20 g.

The animal used in this experiment had such a reliable clonus that it proved possible to investigate it under various conditions. Firstly, it was ascertained that the spring was not a necessary condition. When the muscle was extended by weights hung over a pulley (Table 1), clonus appeared with the same regularity as when springs of variable stiffness were used. Under isometric conditions clonus always failed to appear nor could it then be produced by activation.

If in the midst of clonus a pinna reflex was induced, the muscle contracted. During this contraction clonus disappeared but reappeared on the slowly falling phase of the protracted pinna reflex, and then generally at a slightly faster rate (Table 1).

Once clonus had been started by extending the muscle by the necessary amount, it proved possible, with some caution, slowly to return to zero extension while all the time maintaining the clonic state, though in the end at a slightly lower frequency. At zero extension tension changes could hardly be seen myographically (sensitivity 30 g = 1 mm on the film) and therefore must have been minute; changes of length were wholly dominant. The minute tension changes definitely argue against significant participation of inhibition from the high-threshold Golgi tendon organs which are tension recorders. Clonus did not occur in slack muscle.

The frequency of clonus at different extensions was tested by hanging weights over a pulley. The results obtained are shown in

TABLE 1

Weight (g)	Extension (mm)	Rate of clonus (per sec)	Same on falling phase of pinna reflex
50	1	9.2	12.0
100	4	10.2	12.0
200	5.6	9.8	12.8
300	8.5	10.3	13.0
500	10.6	10.0	12.0

The maximum frequency of 13 per sec was obtained on the falling phase of the slow pinna reflex. This also is the highest value seen in these experiments. Ordinarily values around 8-11 per sec were obtained. The load on the muscle is of negligible significance by comparison with the time properties of the stretch circuit.

## DISCUSSION

When considering the circuit of the stretch reflex schematically, it is perhaps less surprising that it oscillates in clonus than that it does not always do so when recording is isotonic. Assume the spindles to start a contraction. This will cause a shortening of the muscle and unload the spindles which therefore are silenced. The motor output will rapidly be blocked by recurrent inhibition. In the next phase the muscle is pulled out by spring or weight. This stretches the spindle and starts a fresh discharge followed by a new contraction etc. The repetition frequency of this process will be determined by what is likely to be its slowest component, the recurrent inhibition (Renshaw, 1941, 1946; Eccles, Fatt and Kojima, 1954), while the muscle itself delivers

the necessary energy for the maintenance of the oscillatory state. Muscle twitch time is stable, 55-60 msec to maximum; the recurrent circuit, however, is characterized by cumulative inhibition (Granit, Pascoe and Steg, 1957) and, depending upon conditions, inhibition may last from 40-100 msec.

Actually all stretch reflexes are oscillatory, as easily seen by using high myographic sensitivity (Granit, 1958), and though this rhythm is highly asynchronous, it is possible in it to detect the characteristic basic frequency of clonus which agrees with the Horsley-Schäfer rhythm of 9-10 per sec in mammalian muscle (see e. g. Hammond, Merton and Sutton, 1956). A value of 10 per sec is also a good average for efferent frequencies in individual soleus motoneurons (Denny-Brown, 1929; Granit, 1958 and unpublished observations) and this period is determined by their after-hyperpolarizations (Eccles, Eccles and Lundberg, 1958) cooperating with recurrent inhibition.

In clonus there is an additional element of synchronization. Only a theoretical explanation can be given of why an irregular asynchronous rhythm becomes regularized. Inhibition by the recurrent collaterals seems the most probable cause because this process, at least when set up by a sufficient number of neurones, is followed by a rebound rise of excitability in the ventral horn cells (Granit, Pascoe and Steg, 1957) and also is capable of varying in duration.

It is not possible to ascribe clonus specifically to a high level of tonic gamma activity because when  $\gamma$  bias was raised by means of the pinna reflex (Granit, Job and Kaada, 1952), clonus stopped. With high  $\gamma$  bias the spindles also fire *during* contraction so that recurrent inhibition is effectively antagonized. This is probably why the high level of gamma activity of the intercollicular animal tends to make it respond with ordinary stretch reflexes rather than with clonic ones, howsoever recorded, whether isometrically or isotonicly against spring

or load. Denny-Brown (1929) found clonus to be an essentially spinal mechanism of inhibition followed by rebound though capable of being influenced from above.

In the two experiments presented, the indicator spindles fired at slow rates until the clonic process got under way. A surprising fact of these experiments lies in the high phasic discharge frequencies the spindles acquired and maintained in each burst despite modest  $\gamma$  bias. The burst itself occurs on the falling phase of the contraction when the stretch receptors are pulled out and hence stimulated. One might explain these high discharge frequencies by special  $\alpha$  activation of the intrafusal muscles for which we now have evidence (Granit, Pompeiano and Waltman, 1959, *a, b*) but such an explanation may not be necessary and would presuppose a temporal dissociation between extra- and intrafusal alpha events for which, at the moment, there is no experimental support.

A consequence of the present findings is that in some precollicular animals lacking stretch reflexes such reflexes may be produced in the isotonic state by starting the self-oscillation, called clonus, by some tendon taps. Isometric stretch reflexes are also temporarily favoured by these means but, when the muscle is allowed to shorten, self-excitation within the loop helps to maintain the state of raised excitability over a much longer time. Thus, after activation, one may obtain isotonic stretch reflexes with a strong regular oscillatory component at 9-10 per sec at a time when the isometric stretch reflex fails to appear. The isotonic stretch reflexes then have a fluctuating background of general electromyographic activity. Such cases may have some pathological interest. They represent an uneconomic way of using the reflex loop, because excessive spindle frequencies are necessary for each gram static tension produced.

In sum, clonus is a transient increase of gain across the loop or a change of time

constants. Gain may be temporarily increased (i) at the spindle end if the fast alpha control of the spindles had undergone "release" or (ii) at the motoneurone end if the Renshaw cells of the recurrent collaterals had been "released" from some component of central control or motoneurone excitability. <sup>more</sup> Neatly balanced to give the recurrent inhibition-excitation period the correct time constant. As pointed out, the recurrent inhibition is followed by a brief rebound exaltation of motoneurone excitability (Granit, Pascoe and Steg, 1957) and this will provide the regular, transient increase of loop gain at the right moment, while the preceding recurrent inhibition allows the muscle to drop back to zero extension and thereby to pull hard on the spindles. Essentially this is Denny Brown's 'rebound', here ascribed to a specific site and process. At the time (1929), as stated, the reflex effects of the different sense organs were unknown. The present results show that the Golgi tendon organs are of little significance and that the peripheral support comes from the large, excitatory spindle afferents.

### SUMMARY

Precollicular decerebrate cats in isotonic recording easily give clonus of the soleus muscle at 8-11 per sec but fail to do so when the attachment of the muscle is rigidly isometric. Clonus, within 50-500 g, is independent of load.

Clonus can be obtained at zero extension when tension changes are of the order of 10 g and therefore insufficient to stimulate the Golgi tendon organs.

The spindles discharge to the relaxation phase of the muscle contraction when they are pulled out by spring or load. Their impulses occur in brief bursts within which frequencies rise to average rates of 200-400 per sec.

These bursts cause synchronous activation of a number of motoneurons followed

by silent period owing to unloading of the spindles and activation of recurrent inhibition.

Clonus is regarded as a consequence of the transient rebound exaltation of motor neurone excitability —increase of loop gain—, which is known to follow after the phase of recurrent inhibition if level of general excitability is good (Granit, Pascoe and Steg, 1957).

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### SUMARIO

En gatos con descerebración precuadrigeminal se obtiene fácilmente el clonus a 8-11 por segundo del músculo sóleo cuando el registro es isotónico; cuando la fijación del músculo es rígidamente isométrica, dicho clonus no aparece. Entre los 50 y 500 gramos, el clonus no depende de la carga.

Con estiramiento cero, el clonus puede obtenerse con cambios de tensión del orden de los 10 gramos y, por consiguiente, incapaces de estimular los órganos de Golgi.

Los husos descargan en la fase de relajación de la contracción del músculo cuando son estirados por un resorte o peso. Sus impulsos aparecen en andanadas breves dentro de las cuales su frecuencia alcanza un promedio de 200-400 por segundo.

Estas andanadas provocan la activación sincrónica de un cierto número de motoneuronas y, a continuación, un período de silencio debido a la liberación de los husos y a la intervención de la inhibición recurrente.

El clonus es interpretado como una consecuencia de la exaltación transitoria y de rebote de la excitabilidad de la motoneurona —aumento de la amplificación del arco— que se sabe sigue a la fase de inhibición recurrente siempre que el nivel de excitabilidad general sea bueno (Granit, Pascoe y Steg, 1957).

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