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REVIEW ARTICLE

WHY THE MEDIAL PREOPTIC AREA IS IMPORTANT FOR SLEEP REGULATION

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Abstract : The medial preoptic area (mPOA) is one of the many areas in the brain that control sleep. Apart from sleep, the mPOA is important for the regulation of body temperature, and other important body functions aimed at energy homeostasis. In sleep regulation, the major function of this area is to maintain sleep. Though the mPOA controls sleep and body temperature through independent neuronal circuits, it is essential for organising the sleep architecture, as per the thermoregulatory requirement. The functional integrity of the mPOA may be essential for the regulation of energy homeostasis, in response to alterations in the ambient temperature, heat producing physical activity and sleep-wakefulness. Thus, the mPOA forms part of the brain that integrates regulations aimed at preservation of self. The mPOA is important for maintaining the "set point" for not only body temperature, but it is also important for maintaining the "set point" for several physiological parameters including sleep-wakefulness.

Key words : sleep, wakefulness, thermoregulation, body temperature, medial preoptic area, REM sleep, slow wave sleep, EEG, inter-relationship, lesion, stimulation

INTRODUCTION

There are currently two schools of thought questioning the importance of the mPOA in sleep regulation. There is a spurt of scientific literature describing some areas lateral to the mPOA as the most important structure responsible for sleep regulation. The second, which is more scientifically relevant, considers the mPOA as a brain region primarily responsible for thermoregulation, and that the changes in sleep brought about by the manipulation of the mPOA are the results of changes in thermoregulation. The space does not permit the listing of all these articles. This review, on the other hand, tries to address the current debate on the basis of experimental

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findings based on the work done by the author and his colleagues. It is important to emphasise from the very beginning that the neurones in the brain that are responsible for the regulation of sleep are not restricted to the mPOA. The neural structures around the mPOA like the septum and other forebrain structures are also very important for sleep regulation. Brain stem, thalamus and limbic structures also play a major role in the regulation of sleep. The brain stem structures are important for regulation of REM sleep. The mPOA is important for the regulation of sleep, and several important body functions like body temperature, locomotor activity, feeding and reproduction. It could be possible that all these regulatory functions are brought together at the mPOA to ensure their integration. On the other hand, it may not be out of place to imagine that all these functions are controlled by different neuronal circuits that happened to be placed at the mPOA by a kind of accident of nature. The present review tries to look at these possibilities and attempts to look at the role of the mPOA in the regulation of sleep. The readers can consult other reviews for a discussion of possible reasons for simultaneous changes in sleep and body temperature, produced on lesion and stimulation of the mPOA (1).

History

Regulation of sleep by the brain had attracted the attention of several scientists and philosophers from time immemorial. Earlier theories had considered sleep as a passive state. Bremar, on the basis of his findings on *encéphale isolé* and *cerveau isolé* preparations, had proposed that sleep is basically produced by reduction of afferent inputs (2, 3). Subsequent studies by Moruzzi and his co-workers had attributed prime importance to the brain stem reticular formation. According to Moruzzi and Magoun sleep results from deactivation of the brain stem reticular activating system (4). This theory of Moruzzi and his co-workers dominated the scientific literature so much that it over-shadowed some of the important findings that showed the role of the preoptic area (POA) in the regulation of sleep. In fact, the finding of Nauta regarding the importance of the POA was published even before the classical findings of Morruzi. It is really heartening to note that it was Moruzzi himself who subsequently placed before the world the importance of the POA in the regulation of sleep (5).

The post-mortem observations by von Economo in 1929 was probably the first milestone in understanding the involvement of the hypothalamus in the regulation of sleep. There were patients in whom insomnia was observed in addition to chorea. In these patients, there were inflammations in the rostral hypothalamus, the tuberal region and the adjacent portion of the striatum. From these observations, von Economo concluded that the rostral hypothalamic zone was a part of a "sleep regulating centre" which, when appropriately excited, actively inhibited the thalamus and cerebral cortex and caused "brain sleep". Therefore, he concluded that the rostral hypothalamus is a "*schlafsteuerungszentrum*" or "sleep centre".

However, it was only in the thirties, when Ranson reintroduced the Horsley-

Clarke stereotaxic technique in neurophysiology, that an experimental approach to the study of sleep became possible. The importance of the POA in the induction of sleep, in animals, was experimentally substantiated by many studies (7–21). Nauta used the technique of "transverse sections", which was essentially a kind of mechanical damage that destroyed neurones and fibres in and around the section (7). Rats were awake for the entire survival time, averaging three days, when there was transverse section in the rostral half of the hypothalamus. After that the exhausted animal fell into a state of coma, which soon ended in death. He concluded that the rostral half of the hypothalamus, roughly corresponding to the suprachiasmatic area and the POA, is the site of a nervous structure which is of special importance for the "capacity of sleeping". In fact more rostral transverse lesions were never followed by insomnia. Nauta rightly pointed out that this fact alone disproved the irritative hypothesis (ie the observed effects are not due to stimulation of adjoining structures by mechanical irritation of the lesioned area).

Experimental techniques

As stated earlier, the mPOA is important not only for the regulation of sleep, but also for the regulation of several important body functions like control of body temperature, level of physical activity, energy homeostasis and reproduction. Many of these inferences are based on several experiments using classical electrolytic lesion and electrical stimulation techniques. Techniques are now available which can produce selective stimulation or destruction of either neurones or specific afferents. Results of studies using these techniques have improved our understanding, which will be discussed in the following sections.

Chemical stimulation technique: Chemical stimulation is an important technique in the investigation of brain functions. Local injection of chemicals has yielded information that is more revealing than that provided by classical electrical stimulation. Chemical stimulation is superior to electrical stimulation, as it is possible to stimulate or inhibit selectively certain groups of receptors, afferent fibres and neurones in an area. Usually neurotransmitters or their blockers are used for chemical stimulation. Chemicals other than neurotransmitters can also be used for chemical stimulation. The inferences from these studies can be used to understand the functional role of neurones in the injected areas. When applied in moderate amounts, the locally injected transmitter (or its blocker) can be presumed to act on the receptors situated on the neurones. These receptors could be either on the neuronal cell body, dendrite or on the afferent terminal situated in this area of injection. Though the responses elicited by the local injection could be used to explain the function of the injected area, they could also be used to elucidate the functions of the afferent terminals in this area. Unlike the electrical stimulation, the responses elicited by the injection of different chemicals could be of a different nature and pattern. The diversity of responses that could be elicited by various chemicals and their blockers are enormous. In addition, some chemicals might elicit a few functions that are totally

different from those resulting from other chemicals.

At the same time, it should be remembered that the local injection studies may be criticized for application of neurotransmitter agonists and antagonists in unphysiological amounts, and it may not mimic normal physiological action (22–26). So, any interpretation of the local injection studies should take into account all the evidences accumulated using other techniques.

Neuorotoxic lesion technique: The lesion technique is one of the most important tools for studying the function of any brain area. There was a decrease in sleep after classical lesions of the POA (7, 27–28). This lesion effect could be either due to the destruction of the POA neurones or nerve fibres, including the afferent terminals. The discovery that 6-hydroxydopamine (6-OHDA) which could selectively destroy catecholaminergic (CA) neurones, provided a very useful tool for investigations in this field. This toxin could be also used to destroy CA fibre tracts or afferent terminals. On the other hand, neurotoxins like N-methyl D-aspartic acid (NMDA) could destroy selectively the neurones, leaving most of the nerve fibres and the afferent terminals intact. Functional deficits produced by the destruction of neurones provided a very useful tool for understanding the functions of neurones in the area under investigation.

Though the study of neurones is most important in this article dealing with the mPOA, we will first deal with the role of some of the afferents to this area, which are important in sleep regulation. The POA has noradrenergic (NE) terminals (29–30). It also has tyrosine hydroxylase, and its rate-limiting enzymes (31–32). There are alpha and beta-adrenergic receptors in the POA, though beta-receptors are relatively fewer in this area (33). These facts indicate a functional role for the NE terminals in this area. The evidences that helped us to understand the role of NE terminals can begin with a discussion on the changes in sleep-wakefulness after the destruction of NE fibres in the POA.

Changes in sleep-wakefulness after destruction of NE fibres in the POA

If there is deficit in any function after lesion of the mPOA, one could come to a conclusion that this area is involved in that function, though the corollary is not true. If there was only a transient deficit, it could be possible that the function was affected as a result of trauma of the operation. It could also mean that the there was compensation by the other areas. This point is very relevant in the light of a report that there was recovery of sleep deficit after the POA lesion (34). Even if there is compensation by the rest of the brain, after several weeks of the POA lesion, one should not be misled into thinking that the POA has no role to play in sleep regulation. This compensation only speaks volumes of the reserve capacity that could take care of sleep homeostasis.

There was a decrease in sleep after the destruction of the POA using the classical lesion techniques (7, 27–28). These lesion effects could be either due to the destruction of POA neurones or nerve fibres, including

the afferent terminals. The rats, whose CA afferents terminating in the POA had been destroyed by 6-OHDA, showed an increase in wakefulness (12, 35). Though the increase was small, the finding was reproducible and long lasting (19). Experiments in which rats were pre-treated with DMI, before the injection of 6-OHDA, prevented the destruction of NE fibres, and ensured that only dopaminergic fibres were destroyed in these animals. There was no alteration in sleep in these rats. The results suggest that it is the NE fibres, and not the dopaminergic fibres, which have a hypnogenic influence at the level of the POA.

Lesion of CA terminals of the POA produces an increase in body temperature, in addition to sleep changes. In one study, the rats preferred to stay at a lower ambient temperature during the period of increased body temperature, which was more prominent in the first week (36). Selection of a lower ambient temperature could be a behavioural correction to bring down the elevated body temperature. But this altered thermal preference obviously discards the possible impact of lower ambient temperature on sleep. Low ambient temperature produces a decrease in sleep (37). This suggests that the CA terminals of the POA help to interlink sleep with thermoregulation. The delicate homeostatic balance that ensures adequate sleep was disturbed after destruction of the CA terminals of the POA. The preference for colder temperature could be described as an attempt by the brain to regulate body temperature which had been disturbed by the lesion of CA terminals of the mPOA. The imbalance created by the lesion of CA terminals creates a situation where the animal neglects the homeostatic requirement of sleep. This does not mean that the CA terminals are not involved in the regulation of sleep and body temperature.

As the lesion studies have shown that it is the NE fibres that have a hypnogenic influence at the level of the POA, their possible role in the regulation of body temperature could be discussed. Chemical stimulation studies which will be discussed below show that there are separate sets of neurones and noradrenergic terminals in the mPOA for regulation of sleep and body temperature.

The changes in sleep and body temperature on local injection of neurotransmitter agonists and antagonists at the mPOA

Selective stimulation of different sets of neurones and receptors could be achieved by chemical stimulation of the mPOA. If changes in either sleep or body temperature can be elicited by one chemical (without affecting the other parameter), it can be put forward as an argument in favour of the assumption that these two functions are controlled by different sets of neurones. The changes in sleep and body temperature were studied in free moving animals, after the injection of neurotransmitters and their antagonists at the POA, through chronically implanted cannulae. Injections at the POA usually produced alterations in both sleep and body temperature more easily from the mPOA than from the lateral preoptic area.

Carbachol (acetylcholine agonist) and noradrenaline (NE) administration at the

mPOA produced hypothermia and arousal (10–11, 38–41). Application of alpha adrenergic antagonists phenoxybenzamine and phentolamine at the mPOA produced opposite changes in sleep and body temperature, i.e. there was injection bound sleep and hyperthermia (10, 39). These findings after the application of adrenergic antagonists supported the possible role of the noradrenergic system at the mPOA in the regulation of sleep and body temperature. The neurotransmitters and their antagonists, injected at the mPOA, did not always produce simultaneous alterations in sleep and body temperature. Administration of serotonin at the mPOA produced hyperthermia without any change in sleep-wakefulness (42). Clonidine (α_2 agonist) administration at the mPOA produced arousal (43), but it was not effective in producing any change in temperature (44). Even in those instances where changes were produced in sleep-wakefulness and body temperature, there were differences in the temporal sequence of events. Arousal induced by carbachol and NE outlasted the reduction in body temperature (11, 41). Sleep induced by phenoxybenzamine and phentolamine was far shorter than the duration of temperature change (11). It can be concluded from these observations that the mPOA is involved in the regulation of sleep-wakefulness and thermoregulation through different neuronal circuits.

It could be possible that the hypothermia produced by adrenergic and cholinergic agonists was brought about by stimulation of the neural circuit involved in heat dissipation. Going by the classical concept, the POA is the most important area of the brain for heat dissipation function (45). However this concept is now questioned on the basis of neurotoxic lesion studies (17). The arousal induced by adrenergic and cholinergic agonists needs to be explained. One simple explanation is that the mPOA is involved in the arousal mechanism. However, it may not be right to jump to such a conclusion as is shown by subsequent studies, which will be discussed later. As in the case of classical electrical stimulation, it is much easier to elicit arousal than sleep, after local intracerebral application of any chemical.

Possible role of noradrenergic system at the mPOA in the regulation of sleep

In an area innervated by noradrenergic fibres, locally applied NE could act on both post-synaptic and pre-synaptic receptors (46). A pre-synaptic site of action of hypothalamically-injected NE was suggested (47). Studies using α_2 adrenergic agents provided some insight into the mechanism of action of NE. Application of NE at the mPOA in normal rats produced arousal. NE injected at the mPOA can act on α_1 or α_2 adrenergic receptors, apart from β-receptors, and many other receptors about which very little is known. The α_2 receptors are predominantly present in pre-synaptic terminals. Clonidine administration at the mPOA produced arousal (43). This injection can result in the activation of pre-synaptic α_2 receptors, and bring about decreased release of endogenous NE at the synaptic cleft (44). This decreased release of endogenous NE produced arousal in sleeping animals (43). Yohimbine, an α_2 antagonist, blocks the pre-synaptic receptors and facilitates the release of endogenous NE

from nerve terminals. It was proposed that this NE acts on α_1 receptors to induce sleep (43). A recent finding from our laboratory had shown that α_1 agonist, methoxamine, injection into the mPOA produced sleep (Vetrivelan, Mallick & Kumar – unpublished report).

The roles of noradrenergic terminals in the mPOA in regulating sleep

A clear indication regarding the roles of noradrenergic terminals in the mPOA in regulating sleep came from the studies in which noradrenergic agents were applied at the mPOA, in animals with and without lesion of the noradrenergic fibres projecting to the mPOA (21, 35). It was suggested that the clonidine and NE injection at the mPOA could result in the activation of pre-synaptic α_2 receptors, and bring about decreased release of endogenous NE at the synaptic cleft. In order to test this proposition further, adrenergic agents were locally administered at the mPOA in rats, whose noradrenergic fibre terminals were degenerated.

The noradrenergic terminals in the POA come mainly from the lateral tegmental noradrenergic cell groups in the medulla. The fibres of the medullary noradrenergic group ascend through the ventral noradrenergic bundle (VNA) to reach the POA. So, the noradrenergic fibres in the POA can be destroyed by injecting 6-OHDA at the VNA (12, 44, 48). NE injection at the mPOA induced sleep in the VNA lesioned animals. As the pre-synaptic adrenergic receptors were not available at the mPOA in these rats (as the noradrenergic terminals had already degenerated), the response elicited must have been due to the action of NE on the post-synaptic receptors (12). Local application of clonidine and yohimbine, in the rats with noradrenergic fibre lesion, further clarified the concept (43–44). Though arousal was produced in normal rats by the injection of clonidine, at the mPOA, it did not have the same effect on the rats with noradrenergic fibre lesion. Injection of yohimbine, at the mPOA, induced sleep in rats with intact noradrenergic fibres. However, the sleep inducing effect of this drug was very much attenuated in the lesioned animals. From these findings it can be concluded that the afferent noradrenergic inputs, ending on the mPOA neurones are activated during sleep.

Separate noradrenergic terminals in the mPOA for regulating sleep and body temperature

Application of adrenergic agonists at the mPOA in the rats with noradrenergic fibre lesion brought about sleep and decreased body temperature. It could be argued that the decreased body temperature was a result of sleep. It could be also argued that the decreased body temperature and sleep are actively produced by multimodal neurones of the mPOA, and that thermoregulation and sleep regulation are inter-linked at this area of the brain. Local application of clonidine and yohimbine, helped in the clarification of this point (43–44). Though arousal was produced in normal rats by the injection of clonidine, at the mPOA, it did not have the same effect on the rats with noradrenergic fibre lesion. Clonidine did not alter the rectal temperature in normal rats but it induced hypothermia in the noradrenergic fibre lesioned rats. Injection of yohimbine, at the mPOA, induced sleep

in rats with intact noradrenergic fibres. However, the sleep inducing effect of this drug was very much attenuated in the lesioned animals. There was no significant change in body temperature, in both normal and noradrenergic fibre lesioned animals, after yohimbine administration. On the basis of these findings, it was suggested that there are two separate groups of afferent noradrenergic inputs, ending on the mPOA neurones. One of them, terminating on sleep inducing neurones, is activated during sleep. Those afferents, which synapse on the temperature regulatory neurones, are suggested to be normally inactive and may be activated only when the heat loss mechanism is to be stimulated (44). An intact catecholaminergic pathway within the anterior hypothalamus is required for the rat's physiological control of heat loss in a warm environmental temperature (49). It can be concluded that there are separate sets of noradrenergic terminals for the regulation of sleep and body temperature.

The possible conclusion that that there are separate sets of noradrenergic terminals for regulation of sleep and body temperature should not be taken to mean that there are no interactions possible between these two control systems. The lesion of CA terminals of the POA produces an increase in body temperature, in addition to sleep changes. During this period of increased body temperature, which was more prominent during the first week, the rats preferred to stay in a lower ambient temperature (36). Selection of a lower ambient temperature could be a behavioural correction to bring down the elevated body temperature. But this altered thermal preference obviously discards the possible impact of lower ambient temperature on sleep. Low ambient temperature produces a decrease in sleep in normal rats (37). This suggests that the CA terminals of the POA help to interlink sleep with thermoregulation.

Sleep changes after destruction of the mPOA neurones

After dealing with the afferent fibres terminating in the mPOA, and the various receptors on the mPOA neurones, the changes in sleep produced by the destruction of the mPOA neurones can be discussed. There was a reduction in sleep and an increase in wakefulness after the destruction of the neurones in the mPOA. There was more reduction in daytime sleep, resulting in a change in night-day sleep ratio. There was a significant decrease in the duration of slow wave sleep (SWS) episodes. The decrease was found in the duration of both S1 and S2 episodes. The number of SWS episodes, primarily the short duration episodes, showed an increase on all the days after the lesion. There was also an increase in the number of wakeful episodes. Decrease in the durations of sleep episodes indicated that there was impairment in the ability of the animal to maintain sleep.

Temporal sequence of changes in body temperature and sleep after destruction of the mPOA neurones

Hyperthermia during the first week after the mPOA lesion was severe. This was followed by a constant mild hyperthermia during the subsequent weeks (15, 17). On the other hand, there was no variation in the magnitude of reduction in sleep

throughout the post-lesion period. Thus, there was no temporal correlation between sleep and temperature changes after the mPOA lesion. Though this shows that there are neurones in the mPOA which play a role in the regulation of sleep and body temperature, it does not either support or disprove the multimodal neurone theory. It suggests that the change induced in one parameter is not totally dependent on the other parameter. At the same time, one cannot rule out the possibility that the differences in the compensations might have contributed to the differences in the sleep and temperature changes.

The changes in body temperature on destruction of the POA neurones

It is evident from the observations presented so far that understanding the role of mPOA on sleep regulation is incomplete without a detailed analysis of the role of this area in thermoregulation. The classical electrolytic lesions of the POA, which destroyed the cells and fibres of passage, produced increased body temperature with impaired heat defence abilities in rats (45). It was suggested that the hyperthermia resulted from impaired heat defence abilities. This lesion effect could be either due to the destruction of the POA neurones, nerve fibres of passage and the afferent terminals. After selective destruction of the mPOA neurones (using local injection of NMDA) there was increase in body temperature. This increase was more marked during the initial one or two weeks. This was followed by a phase during which the body temperature was reset at a level that was higher than normal but lower than that during the initial week after the lesion. The shift in core temperature could be either due to a failure in thermoregulatory ability, or a change in the “set temperature” for thermoregulation. This hyperthermia produced by the NMDA lesion of the mPOA was without impaired heat defence abilities (17). The thermoregulatory ability was tested by noting the changes in the rectal temperature of the rats when they were kept for two hours inside hot (37°C) and cold (6°C) chambers. The mPOA lesion did not produce any change in the response pattern of rectal temperature on heat exposure. This showed that the ability of the animal to regulate its body temperature, when exposed to a hot environment, was not affected. On the other hand, its ability to maintain a stable rectal temperature, on cold exposure, was affected after the mPOA lesion, as the rectal temperature showed greater reduction in the lesioned animals. Though the rectal temperature was drastically lowered during the initial half an hour of exposure to cold, it was maintained at this lowered level on continued exposure to a cold environment. So, the mPOA neuronal lesion produced an increase in the range of thermostat setting, rather than a failure in thermoregulation per se. In other words, in the mPOA lesioned rats, there was a change in the “set temperature” for thermoregulation, and they were able to defend their temperature within this reset range. Though the concept of “set point” was primarily used for thermoregulation, it can be used to explain the derangements of several functions (including sleep-wakefulness) after the mPOA lesion.

After the mPOA lesion, the thermo-regulatory responses actively contribute towards maintaining their body temperature at a higher level, as the hyperthermia was

accompanied by a thermal preference for a higher temperature. So, it may be hypothesized that the mPOA acts as a fine-tuning centre for all components of energy balance, and it must be regulating thermoregulation to maintain the body in an energy conserving state. In the absence of this fine-tuning mechanism, after the lesion of the mPOA, the animals tend to select a higher environmental temperature, as they cannot make a correct assessment for proper regulation of their energy balance (50).

Effect of ambient temperature on sleep

Ambient temperature has a prominent effect on sleep. The changes in sleep-wakefulness were studied in rats when they were exposed to different ambient temperatures of 18°C, 24°C and 30°C (37). There was an increase in REM sleep and SWS, and a decrease in wakefulness at higher ambient temperatures. The increase in sleep was primarily due an increase in the duration of sleep episodes. The increase in the amount of sleep with enhanced ambient temperature may be considered as an adaptation to thermal load aimed at energy conservation (51). It was suggested that when the ambient temperature is low, the central nervous system has to call for an increase in the relative amount of arousal, at the expense of the sleep stages, especially desynchronised sleep, in order to maintain the body temperature (52). An increase in arousal in cold is necessary for the production of more heat by increasing motor activity. REM sleep, in which the regulation of body temperature is said to be suspended, is incompatible with low ambient temperature, during which appropriate thermoregulatory responses are needed to protect the animals from hypothermia (53). In other words, the functional state of wakefulness enables the organism to optimise thermoregulation.

The changes in sleep-wakefulness were also studied during the exposure of the animals to different ambient temperatures after the destruction of the mPOA neurones by NMDA. The mPOA neuronal destruction produced a decrease in sleep at all the three different ambient temperatures. There was a decrease in sleep, particularly the deeper stages of sleep (deep SWS and REM sleep) after the mPOA lesion (13–14). But, there was a linear increase in sleep with higher temperatures (37). The sleep induced by higher temperatures in the lesioned rats was qualitatively different from that in the normal animals. In the latter, there was an increase in long duration SWS episodes with higher ambient temperature. But on the other hand, after the mPOA lesion, 30°C ambient temperature produced an increase in the number of short duration SWS episodes. It has been reported that the mPOA is important for the maintenance of sleep, as it was the sleep duration, which was primarily affected by the mPOA lesion (15). The warm environment could increase the amount of sleep, even after the mPOA lesion, but the higher ambient temperature was effective in initiating sleep rather than in maintaining it. In other words the ability to maintain SWS was affected after the mPOA lesion, and this ability could not be restored by exposure to a warm environment. The findings indicate that the mPOA is essential for sleep maintenance and improving the quality of sleep with higher ambient temperatures. It can be

concluded that the mPOA is essential to increase sufficiently the duration of sleep episodes (especially SWS) by thermal stimulus, though sleep could be induced through structures other than this area. In other words, the mPOA is essential for organising the sleep architecture (especially SWS), as per the thermoregulatory requirement.

Effect of mPOA lesion on sleep when the rats had the freedom to select an ambient temperature

Changes in sleep-wakefulness were studied before and after the lesion of the mPOA by NMDA, when the rats had the freedom to select an ambient temperature. When given a choice of 24°, 27° and 30°C ambient temperatures, rats preferred 27°C before lesion, but the preference shifted to 30°C after lesion. The sleep which was fragmented and reduced after lesion, recovered in quanity after three weeks. But, the sleep remained fragmented, and it never reached the prelesion level. In spite of the increased body temperature and locomotor activity after the lesion, the animals actively chose to stay in a higher ambient temperature. This selection of higher ambient temperature probably helped in improving the sleep, but it could not increase the duration of SWS. These lesioned animals, when placed in an environment having 27°C (i.e. their preferred ambient temperature before lesion) showed significantly less sleep than when they had the freedom to select an ambient temperature (Ray, Mallick & Kumar – unpublished report).

Energy homeostasis and sleep regulation

Though there was no significant persistent change in food intake, there was a reduction in the body weight of the rats after the mPOA lesion with NMDA, and electrolytic lesion of the POA (15, 54). Higher locomotor activity and increased body temperature, after the mPOA lesion, produced increased energy expenditure. This might have resulted in a decrease in the body weight because there was no concomitant compensatory addition in energy intake (food intake), in spite of the increase in locomotor activity, rectal temperature and awake period. Therefore, after the lesion, the animal did not recognise low energy reserves, and so it did not bother to conserve energy. Thus, it can be hypothesised that the mPOA lesioned animals had lost the mechanism for the fine-tuning of food intake, in response to the alteration in body homeostasis. The functional integrity of the mPOA may be essential for the regulation of food intake, in response to alterations in the temperature, locomotor activity and sleep-wakefulness. It can also be argued that the mPOA would normally facilitate sleep, an energy-conserving state, when energy reserves are at a critical level (15, 55). Thus, the mPOA forms part of the brain that integrates regulations aimed at “preservation of self”. Though it may be hypothetical at this stage, it can be presumed that this area, which plays a major role in the regulation of reproduction, is the region where “preservation of self” is integrated with the “preservation of species”. The mPOA is important for maintaining the “set point” for not only body temperature, but it is also important for maintaining the “set point” for several physiological parameters including sleep-wakefulness.

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