# Core Body Temperature Evaluation: Suitability of Measurement Procedures

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**SUMMARY**

**Infrared Core body temperature ($T_c$) is regulated to achieve the homeostatic balance between production and dissipation of heat. This parameter is one of the most important factors to monitor and study the regulation of human temperature. It helps at studying the cognitive response to high temperatures' exposure and it is one of the best physiological indicators used to avoid heat injuries in different activities independently from individual characteristics such as: age, height, body weight or body fat. It has also been used in several studies, both in the laboratory and in the real work context, including athletes, students, and military forces. The main goal of this study was to select the most suitable method and equipment for measuring core temperature in occupational environment. This study was based on literature review from large databases and scientific journals. The literature reviewed confirmed that the gold standard methods for $T_c$ measuring (rectal and esophageal) have some advantages but also limitations, especially due to discomfort caused by sensors implantation. Alternatively, it is possible to use thermal ingestible sensors without the limitations of the other methods. This technique was applied, tested and validated by several researchers and approved by the ethic committees. However, there are still doubts about the scope of its applicability. According to all the information collected, it was concluded that the most suitable procedure to measure core temperature in occupational activities is the TIS. For this reason, the authors believe that the intra-abdominal temperature measurement with TIS is, from the available methods, the most suitable for the measurement of $T_c$ in the workplace. The method was, therefore, selected for further research.**

## 1. INTRODUCTION

All human body activities produce heat that has to be dissipated into the environment in order to prevent an excessive increase of core temperature ($T_c$) and to maintain body temperature equilibrium. This capability to sense, regulate and maintain $T_c$ within a range pre-determined of about 37ºC (2, 18, 31), is a fundamental characteristic for human survival. For this reason, it is said that man is an homeothermic being. What is achieved is a dynamic equilibrium and not a steady state (31). A deviation of ± 3.5 °C from the resting temperature of 37 °C ($T_c$) can result in physiological impairments and fatality. It is in this moment necessary to distinguish between core (inner) and shell (outer) temperature. Core temperature refers to the abdominal, thoracic and cranial cavities, while shell temperature ($T_s$) refers to the skin, subcutaneous tissues and muscles (22).

The core temperature is achieved by autonomous mechanisms that, actively, balance the production and loss of heat. These mechanisms are mainly controlled from the hypothalamus and depend on the input signal from the different parts of the body via the afferent neurons Insler & Sessler (15).

It is known that the hypothalamus plays a key role on temperature control using signals received from sensors spread throughout the body to act in several physiological mechanisms. It is composed of several parts and two of them are in charge of thermoregulation:

- Anterior hypothalamus - acts in a situation of overheating and is responsible for the activation of the heat loss mechanisms, such as sweating and vasodilation;
- Posterior hypothalamus - acts as a protection mechanism against the cold, triggering actions such as vasoconstriction to reduce losses to the environment, and shivering to increase heat production.

The efferent defenses may be divided into autonomous responses (e.g., sweating and shivering) and behavioural responses (e.g., seek for warm environments, clothing). Autonomous responses are about 80% dependent on core temperature and largely managed by the anterior hypothalamus. On the other hand, the behavioural changes are about 50% determined by skin temperature and largely controlled by the posterior hypothalamus Insler & Sessler (15).

There is consensus among the authors that the control of core temperature is one of the best ways to reduce the risk of heat damage (13, 22) and to evaluate human performance (37). This last author also says that the state of alertness, performance and $T_c$ are related, concluding that the neurobehavioral

reactions change according to the internal biological rhythm and the wakefulness time.
When core temperature nears the circadian peak there is an improvement in performance factors (such as working memory, attention and subjective visual attention), but reaction time is 10% slower. When core temperature is low, near its circadian minimum, a worse performance occurs. These results show that an increase in $T_c$ associated with the internal biological clock, are correlated with a better performance and alertness. It has long been shown that there is a positive relationship between daily rhythms of $T_c$, neurobehavioral performance and alertness in humans (37).
In extreme occupational environment (hot or cold), all these issues are critical because they can make the difference between sickness and health, or have influence on the occurrence of accidents. So, the main objective of this study was to select the method and the device most suitable for the measurement of core temperature ($T_c$) in occupational environment. For this was performed a comprehensive survey and compared the different methods and measurement techniques.

## 2. METHODS

This study was based on a literature search in major databases such as Pub Med, Web Science and Scientific Journals, which allowed us to identify, select and analyse relevant papers. The research has been developed by combining a set of keywords that were predefined: *Core Temperature; Ingestible Temperature Sensor; Temperature Capsule, Thermoregulation, Heat*. Some books based on recognized scientific literature and standards related to the subject were also analysed.
According to the objective of this paper, only studies with ethics committee approval or, at least, informed consent, have been considered to decide the most appropriate methods of behavioural procedures. The selection criteria of these methods include: calibration; real time data acquisition; real time monitoring; reliable and precise sensors; comfort in use; less invasive method compared with those used for the same purpose, easy to manage and adaptable to rest and exercise situations.

## 3. CORE TEMPERATURE

According to Parsons (31), core temperature has no definition. However, it is generally considered an internal temperature or the temperature of the vital organs including the brain. An alternative definition for $T_c$ is provided by ISO (16). By this standard, the *internal body temperature* or *core temperature* refers to the temperature of all tissues located at a depth sufficiently distant from the outer surface of the body in order to do not be affected by temperature gradients occurring in the superficial tissues. The same standard refers that differences in internal temperature may be possible, depending on local metabolism, on the concentration of vascular networks and on local variations in blood flow. For this reason, $T_c$ has not a single value, constant, uniform and measurable as such, but depends on the location of the measuring point. His value can be measured in different parts of the body as, for instance:

- esophagus: esophageal temperature ($t_{es}$);
- rectum: rectal temperature ($t_{re}$);
- gastrointestinal tract: intra-abdominal temperature ($t_{ab}$);
- mouth: oral temperature ($t_{or}$);
- tympanum: tympanic temperature ($t_{ty}$);
- auditory canal: auditory canal temperature ($t_{ac}$);
- urine temperature ($t_{ur}$).

Clinically, it is taken into consideration the temperature of the blood in the pulmonary artery (PA), as measure of brain temperature (2, 11) and tracheal temperature. These methods have many applications in physiology and medicine. In general, the brain temperature is not measured directly due to possible damage by the introduction of temperature probes. Likewise, at this level, it is assumed that the brain temperature is equal to core temperature. However, during hypothermia or hyperthermia, the brain and core temperatures are very different (2).
The pulmonary artery catheters allow the measurement of central blood temperature, which is also considered the gold standard for measuring core temperature. Thus, pulmonary artery catheter measurement is usually used as a reference for all other devices. The obvious disadvantage of monitoring pulmonary artery temperature is the high cost and invasiveness of the catheter and the difficulty of its insertion. So, although considering the temperature in the pulmonary artery the gold standard for $T_c$, this measurement method is invasive, and not suitable for non-surgical applications.
According to Matsukawa et al. (24), in clinical measurement, to detect thermal perturbations, continuous core temperature monitoring is often used when general anaesthesia is administered for more than 30 min. In this situation, tracheal temperature has been proposed as an easier alternative in patients requiring endotracheal intubation.
The different techniques of internal temperature monitoring, differ in difficulty of implementation and in degree of tolerance or acceptance by different individuals. The standard ISO 9886 (16) refer that depending on the technique used, the temperature measured can reflect:

- "*the mean temperature of the body mass, or*
- *the temperature of the blood irrigating the brain and, therefore, influencing the thermoregulatory centre in the hypothalamus.*

*This temperature is usually considered for evaluating the thermal stress endured by an individual*".

The measurement of skin or axillary temperature is another way to obtain a value. This kind of measure is influenced by skin blood flow and environmental conditions. Parsons (31) and Ribeiro (34) state that the temperature measured at the surface of the skin is about 4 to 5 ºC less in relation to the core temperature. This temperature can be measured in different places such as the: forehead, arm, forearm, chest, back, the thigh and leg, through sensors glued to the skin. The same authors consider the axillary temperature as a close estimation to $T_c$, despite measuring a value that is less than the oral or rectal temperature. However, in spite of being easy to use, its value lacks scientific objectivity.

According to an analysis by Kelly (17), the temperature can be controlled in different parts of the body. The choice of the measurement place is the result of the convenience and reliability required.

In Kelly's (17) literature review, it is stated that $T_c$ is a complex and nonlinear variable that is affected by many internal and external factors. It is known that in homoeothermic animals, the core temperature undergoes slight changes, not only from species to species but also, although to a lesser extent on a smaller scale, among individuals. In people, the normal value for oral temperature is 37ºC, but the normal human $T_c$ undergoes a regular circadian fluctuation of 0.5ºC to 1.0ºC. $T_c$ depends more on the time of the day than on the activity, except in activities which imply a heavy workload. It is usually lower while sleeping, slightly higher in the relaxed awake state and it rises with activity (15).

Also according to Kelly (17), the mean expected difference between the minimum and maximum core temperature over any 24-hour period is about 1.0 °C in most individuals. However, research suggests that, more than any $T_c$ value by itself, the variation of its value over 24 hours can be an important factor in assessing the health of each individual. Thus, bigger differences are consistent with better health. Two of the factors that can have an effect on $T_c$'s range are: the physical fitness and the age. The existing studies suggest that a better physical fitness and younger age are characterized by larger temperature amplitudes, while poor fitness and advanced age are characterized by lower amplitudes (17).

The variability is more pronounced in the morning and early afternoon (until about 2p.m.) and again in the evening (after 7p.m.). Axillary temperatures change ±1.0-1.5°C for a period of one hour, while the rectal temperature remains relatively stable ±0.1-0.3 ºC (17). The range between 36.2 ºC and 37.5 ºC is considered the normal core temperature and it is proved that $T_c$ increases with mental exertion, constipation, and urinary retention. It was also shown that there are changes in core temperature in both, healthy and unhealthy subjects, according to the time of day (17).

## 4. CORE TEMPERATURE MEASURING TECHNIQUES

There are numerous methods for measuring internal core temperature, some are more convenient to measurement than others which are more acceptable by individual.

### 4.1 Esophagus: esophageal temperature ($t_{es}$)

According to ISO 9886 (16), this temperature is measured with a transducer that is introduced in the lower part of the esophagus, at the level of the heart, to reflect the internal blood temperature. For example, the aorta's blood that goes to the brain and the rest of the body (31). In this position, the transducer registers variations in arterial blood temperature with a very short response time. With this method, the measured temperature can be affected by breathing and also by the saliva swallowed. So, the measurement temperature is not given by mean value of recorded temperatures, but by peak values. This situation is more evident in cold environments, where the saliva could be chilled due to temperature. However, this method is considered by the ISO 9886, the one which more accurately reflects changes in temperature of blood leaving the heart and, in all likelihood, measures the temperature of the blood that irrigates the thermoregulatory centres in the hypothalamus (16). Although, according to this standard, esophageal measurement is uncomfortable and the individual should be warned of this. It is recommended that the probe be introduced via the nasal fossae rather than through the mouth. It is also recommended that the tip of the probe be coated with an analgesic gel in order to reduce discomfort when going down. This method is used in laboratory experiments but, due to the caused discomfort it is not very accepted by subjects and non-physicians researchers. It is also disadvantageous because swallowed drink, food and saliva influence the readings (31).

### 4.2 Rectal Temperature ($t_{re}$)

Rectal temperature ($t_{re}$) is independent of ambient conditions. In this case the probe is inserted into the rectum to a depth of, at least, 100 mm. This sensor will be surrounded by a large mass of abdominal tissues with low thermal conductivity. Slight temperature differences may be registered depending on the depth of insertion of the transducer. Therefore, the depth should remain constant throughout the measurement period. The measurement of rectal temperature should be avoided in person's suffering from local lesions. Typically insertion is done by flexible and unbreakable probes.

According to Parsons (31), this measure gives a value of the mean core temperature. However, it may not be representative of brain temperature. It will also be affected by "cold" blood or "hot" blood

from the legs during vasoconstriction or vasodilation respectively.
Although rectal temperature has a value close to $T_c$, the readings can be affected by the presence of stools and bacteria. Under these conditions can be generated heat, raising the $t_{re}$ above $T_c$.

4.3 Urine temperature ($t_{ur}$)

The bladder and its content may be considered as being part of the core of the body. Therefore, the measurement of urine temperature during its discharge can provide information concerning $T_c$. The measurement is done by means of a temperature transducer inserted in a collecting device. By definition, the measurement possibilities are dependent on the quantity of urine available in the bladder.
According to ISO 9886, the collecting device and the transducer should be thermally insulated, having both a very short time response. *The temperature should be recorded during and directly under the urine stream and not in the collected urine.* In the present state of knowledge, it is recommended to perform measurements with an air temperature between 15 °C and 25 °C.
The bladder temperature can be measured with a Foley catheter with an attached temperature thermistor or thermocouple. Although bladder temperature is a close approximation of core temperature, the accuracy of this method decreases with urine output.

4.4 Intra-abdominal temperature ($t_{ab}$)

This temperature is measured by a TIS that is swallowed by the subject. During its transit through the intestinal tract, the recorded temperature will vary according to its location: near large arterial vessels or organs with high local metabolism, or, conversely, close to the abdominal walls (16).
When the transducer is located in the stomach or duodenum, temperature variations are similar to those of esophageal. As the thermal ingestible sensors (TIS) goes through the intestine, the temperature characteristics become closer to the rectal temperature. Consequently, the interpretation depends on the time elapsed since the TIS swallowing and on the gastrointestinal transit speed for a given subject. According to present knowledge, this measure seems to be independent of ambient climatic conditions, except when a strong radiant heat impinges on the abdomen.
The abdominal temperature is representative of the central trunk and the TIS are used for recording $T_c$ for long periods, e.g. in astronauts in space missions (31).

4.5 Oral temperature ($t_{or}$)

The mouth is one of the common places to measure the core temperature in clinical context. Oral temperature requires about 5 minutes to achieve a stable value. This value are about 0.4ºC below intra-pulmonary artery (IPA) (22). In this method, the transducer is placed underneath the tongue, being in contact with the lingual artery. It will then provide a satisfactory measurement of blood temperature which influences the thermoregulatory centre.
However, the measured temperature depends on the external conditions and can also be influenced by breathing rates. When the mouth is open, the heat exchanges by convection and evaporation on the surface of the oral mucosa, contribute to a reduction in temperature in this cavity. Even when the mouth is closed, the temperature can be significantly reduced due to a decrease in face temperature (16, 22).
The transducer should be placed under the tongue, at the side and close to the base of the tongue. The mouth must remain closed throughout measurement time. The transducer should be small in size, flat and of low thermal capacity. The probe must be flexible enough so that it can remain near to the lingual artery without discomfort.
The measured value just can be considered as a satisfactory approximation of the $T_c$ under the following conditions:

- Ambient temperature above 18 °C;
- The mouth remains closed, before transducer insertion, at least in the:
  - 8 minutes before the measurements, if the air temperature is between 18 °C and 30 °C;
  - 5 minutes, if the air temperature is higher than 30 °C;
  - 15 minutes after drinking, eating or smoking for the last time.

Some authors use the method, and according to Casa et al. (6), the oral thermometer is often used to obtain core temperature in individuals at rest. However, its clinical validity is relative. Results can be contradictory as a consequence of mouth temperature be affected by actions like eating, drinking, breathing, swallowing saliva, and also by ambient temperature that can change facial temperature (6). The same point of view was supported by Kelly (17) on a literature review, where the oral temperature was considered inaccurate. This temperature, although having some parallel in terms of amplitude and "acrophase" with the $T_c$, tends to be lower than rectal temperature (17).

4.6 Tympanic temperature ($t_{ty}$)

According to ISO_9886, this method aims at measuring temperature on the tympanic membrane whose vascularisation is provided in part by the internal carotid artery that also supplies the hypothalamus. As the thermal inertia of the eardrum is very low due to its low mass and high vascularity, its temperature reflects the variations in arterial blood temperature which affects the thermoregulatory centres (16). As in other methods to get the $T_c$, the tympanic temperature is also influenced by the local exchanges of heat.

Still according to ISO_9886, tympanic temperature can only be used when tympanum and walls of the auditory canal are in perfect conditions. All deposits of wax should be removed. The tympanic temperature can be measured using a thermistor or a thermocouple. Contact between the transducer and the tympanum is easily identified by the sensation felt by the subject. The shape of the transducer and the stiffness of the probe are critical factors in avoiding injury to the tympanic membrane. The transducer should have a low thermal capacity so as to cause a minimal disturbance to the thermal equilibrium of the tympanum.

Tympanic temperature is only an acceptable indicator of $T_c$ if:

- the initial position of the transducer is maintained throughout the measurement period;
- the auditory canal and the outer ear are thermally isolated from the exterior environment;
- the environmental conditions around the subject's head, are:
  - air temperature between 18 °C and 58 °C;
  - air velocity less than 1 m/s;
  - mean radiant temperature close to air temperature.

If the working conditions involve direct thermal radiation or a strong convection in the head (air speed greater than 1 m/s), a correct measurement can only be achieved placing a helmet covering a large surface of the head.

Tympanic temperature may also be measured using a non-contact infrared radiation (IR) thermometer. In order to apply this equipment, in addition to the above-mentioned conditions, it should be ensured that the device only measures the tympanic membrane temperature and not the walls of the auditory canal. The factors that interfere with the use of the method are:

- an angle too wide of the optic sensor;
- no control over sensor focus;
- an auditory canal narrow and/or bent;
- hair in the auditory canal;
- presence of cerumen;
- difficulty in insulating the auditory canal.

For these reasons, the values recorded with IR devices used discontinuously are often invalid. If used, the environmental conditions around the head of the subject should not be outside a range between 18°C and 30ºC, air velocity less than 0.2 m/s and the mean radiant temperature close to air temperature.

According to Ribeiro (34) tympanic temperature measurement is very easy to apply and provides results in seconds. Nevertheless, it is not clear if it reflects or not the brain temperature, seen that there are contradictory opinions (31).

4.7 Auditory canal temperature ($t_{ac}$)

According to ISO 9886 (16), *the transducer is, in this case, located against the walls of the auditory canal immediately adjacent to the tympanum. These are vascularized by the external carotid artery and their temperature is affected by both, the arterial blood temperature at the heart and by the cutaneous blood flow around the ear and adjacent parts of the head. A temperature gradient is thus observed between the tympanum and the external orifice of the auditory canal. Insulating the ear adequately from the external climate may reduce this gradient*. This method is very similar to the tympanic temperature (16).

According to ISO_9886, preference must be given to the measurement of the temperature in the auditory canal compared with tympanic measurements. The procedure for placing the transducer is the same as for $t_{ty}$ but, once in contact with the tympanum, the transducer is pulled about 10 mm. Alternatively, the transducer can be inserted through an ear mould, in such a way that, when the mould is fitted into the auditory canal, the transducer is placed at less than 10 mm from the tympanum.

The conditions of use are identical to those presented for the tympanic temperature, except that the maximum difference between the air temperature and $t_{ac}$ is 10 °C. However, even with the strict observance of all the procedures, this method only provides an approximation to core temperature. When all procedures cannot be met, $T_c$ should be measured at another place ($t_{re}$ or $t_{es}$).

## 5. RESULTS AND DISCUSSION OF THE SUITABILITY OF MEASUREMENT PROCEDURES

From what has been described above in relation to measurement techniques, their advantages and limitations, three of them were chosen to discuss, analyse and select the most suitable for use in occupational environment. These techniques were: the measurement of esophageal, rectal and intra-abdominal temperature. On these, the values are not affected by temperature gradients that occur in the superficial tissues. Thus the impact of environmental conditions is minimized. In this selection were valued the reliability, usability in outpatient as well the accuracy level.

In this research were analysed three recent reviews, four papers with the comparison between the three methods and twenty–one papers based on studies that made measurements with at least, one of these three techniques, as shown in table 1.

Table 1 - Studies of Core Temperature Sort and Ethical Committee.

| Authors | TS* | EC** | IC*** |
|---|---|---|---|
| | Intra-abdominal | | x |
| | Rectal | x | x |
| | Intra-abdominal | x | x |
| | Intra-abdominal | x | x |
| | Intra-abdominal | x | x |
| | Intra-abdominal | x | x |
| | Intra-abdominal | x | x |
| (Nybo et al. 2002) | Esophagus | x | x |
| | Esophagus | x | x |
| | Intra-abdominal | x | x |
| | Intra-abdominal | x | x |
| | Rectal | x | x |
| | Rectal | x | x |
| | Intra-abdominal | x | x |
| | Intra-abdominal | x | x |
| | Rectal | x | x |
| | Intra-abdominal | x | x |
| | Esophagus | x | x |
| | Esophagus | x | x |
| | Intra-abdominal | x | x |
| | Intra-abdominal | x | |

* TS – Temperature Sort

**EC- Ethical Committee

***IC-Informed consent

## 5.1 Comparing rectal, esophageal and intra-abdominal temperature

Kolka et al. (23) compared esophageal and intra-abdominal temperature in women in moderate exercise. TIS were taken two hours before the test. It was found that the mean resting $t_{es}$ was 37.11±0.21 ºC and the mean resting $t_{ab}$ was 37.17±0.27ºC. The combination of exercise (225±30 W.m$^{-2}$), ambient temperature ($T_a$ = 30°C) and clothing, caused an increase in $t_{es}$ to 38.67±0.28°C and an increase of $t_{ab}$ to 38.71±0.33°C for one hour of treadmill walking. This study data suggest that, under controlled experimental conditions, the TIS provides accurate measurements.

In the same year, O´Brien et al. (30) compared the results between the measurements of $T_c$ obtained using a TIS system, with those obtained from esophageal and rectal temperature. This study showed that TIS system provides a valid measurement of $T_c$ during both, rest and exercise, in cold as well as warm conditions. Nevertheless, the authors refer the need for a further study, to better quantify the variation in $T_c$ measured by the TIS as it goes through the gastrointestinal tract. The TIS system is particularly appropriate for monitoring $T_c$ in field environments where other techniques are not feasible O´Brien et al. (30).

Another study, conducted by Lee et al. (21), aimed at determining if the intra-abdominal temperature could be an acceptable alternative to esophageal and rectal temperature in order to evaluate the thermoregulation over supine exercise. It was concluded that $T_c$ measurement using a TIS may be more appropriate in exercise testing, circadian monitoring, protective clothing monitoring and testing, and other field environments, such as microgravity, where instrumentation for measurement of $t_{re}$ or $t_{es}$ may not be feasible. The facility of TIS use, and the few health concerns, compared with thermistors in the esophagus and in rectum make it the ideal candidate for studies involving exercise or occurring in an uncontrolled environment. However, the delay in detecting increases in $T_c$, suggests that this technique may not be appropriate to prevent heat injury when the core temperature changes quickly. Measurement of $t_{ab}$ may be an acceptable alternative to $t_{es}$ and $t_{re}$ with an understanding of its limitations (21).

On the other hand, Casa et al. (6) concluded that compared with rectal temperature (the criterion standard) intra-abdominal temperature measurements are the alternative with the necessary accuracy to measure core temperature. Likewise, according to the Byrne's review (5), the TIS represent an alternative to esophageal and rectal temperatures as an index of core temperature during exercise. Different relationships between these three indices have been observed in validation studies using small sample sizes, varied protocols and several statistical methods of comparison. Consequently the TIS applications shows excellent applicability for ambulatory field based applications. Rectal and intra-abdominal temperatures are considered comparable in terms of measure, amplitude, and acrophase.

Monitoring core temperature is one of the best methods to reduce the risk of heat injury in different activities once it avoids illnesses related with warm temperatures (25). Despite the different methods to measure $T_c$, the TIS were the one that gained an widespread acceptance in recent years. The advantages of continuous measurement of $T_c$, over different physical and cognitive activities has also been described by several authors (32).

## Validity of thermal ingestible sensors

According to the Kelly's review (17), and considering the differences from thermometer placement in terms of convenience and reliability, the conclusion was that intra-abdominal temperature, obtained via a TIS, is considered to be relatively convenient and nearby rectal temperature. Although rectal temperature be an internal measure, very reliable and generally considered, the "gold standard" is the least suitable for ambulatory use (17).

Byrne & Lim (5) compared the correlation between core temperature measurements recorded simultaneously from intra-abdominal, esophageal and rectal temperature. They used criteria such as: calibration, time of ingestion, size of sample, protocol, environment and statistical analysis. From the twelve analysed studies, two were only abstracts and ten validated studies. Nine of them used ingestible sensors in sports or occupational tasks involving physical activity. From those nine studies, the data collection was done continuously in four and intermittently in the other five. It was also concluded that the $t_{ab}$ measured with the TIS as valid values for $T_c$ and shows an excellent utility for ambulatory field based applications (5). For the purpose of discussing thermoregulation mechanisms during exercise, Lim et al. (22) concluded that intra-abdominal temperature measurement, using TIS, provide an acceptable level of accuracy to $T_c$ measuring, without causing discomfort to the user. This way of measuring the $T_c$ also allows continuous measurement in the field. This has allowed to gain a wide acceptance in the last decade (22).

Also Goodman et al. (13) proposed the validity and the reliability of the use of $t_{ab}$ via TIS to measure $T_c$. However, the effect of elapsed time between TIS ingestion and $t_{ab}$ measurement has not been thoroughly studied. The timing for ingestion of TIS is critical for accurate and reliable $T_c$ monitoring. This study shows that $t_{ab}$ measured 5 h after ingestion may still differ significantly (>0.25°C) from $t_{ab}$ measured 29h after TIS ingestion. Gastrointestinal mobility is highly variable and strongly influenced by many factors difficult to control. It is also known that measurement quality improves when there is an interval of more than 5 hours between the TIS intake and measurement. It was suggested that coaches, athletic trainers, and researchers must balance their need for accuracy and safety with the limitations of ingestion of a TIS (13).

## 6. CONCLUSION

The conclusion drawn was based on a synthesis of analysed papers and according to the main objective, that was to select the best option to measure the $T_c$ into occupational environments, the most suitable procedure is to measure the $t_{ab}$ with a TIS.

The core temperature measured with a TIS provides a valid indication of $T_c$ (6). Works performed by different researchers suggest that there is a good correlation between rectal and intra-abdominal temperature. After a careful analysis of all papers collected, it was also concluded that, the method with less technical limitations, and less invasive, is the TIS.

The results show that this system provides a valid measurement under conditions of decrease, increase and steady state of $T_c$. This also makes it possible to detect thermal complications at occupational context, without movement restrictions, such as in sports science, safety, hygiene and occupational health, military and even in the laboratory. It allows a continuous data acquisition, and a real time monitoring of $T_c$. According to the research the temperatures considered with less accuracy are tympanic, oral and axillar. For this reason, they reproduce $T_c$ with difficulty. Comparatively to rectal temperature, considered the *gold standard* method of $T_c$ measurements, thermal ingestible sensors (TIS) present one of the best possible approximations (22, 25).

Lee et al. (20) suggests that further, data must be collected in order to know (TIS) location in the body so as to be interpreted in relation to the thermal response at the site under the specific experimental conditions. This is also Goodman's et al. (13) opinion, which refers that the timing for ingestion of a TIS is critical for accurate and reliable $T_c$ monitoring.

According Brake & Bates (4), intra-abdominal temperature is an effective method of profiling the core temperature of workers in difficult occupational settings (4).

Finally, according to Byrne et al (5) and Mckenzie & Osgood (25) can be concluded that the TIS are of the best methods to measure core temperature.

According to all information collected, the authors of this paper conclude that for the measurement of $T_c$ in occupational context, the best option is the use of $t_{ab}$, measured with TIS. The method was, therefore, selected to be used in the next research works.

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