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Monitoring of vital signs during dental care

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Advances in medicine have greatly increased the survival of patients with severe health problems and have significantly prolonged life in elderly individuals with systemic disorders. Concomitant advances in dentistry and evolving societal expectations regarding dental health and function have likewise ensured that these patients are increasingly retaining their teeth and/or seeking dental care. The administration of local anaesthetics and the performance of extensive dental procedures may cause stress and systemic disturbances in such patients. In order to avoid potentially serious reactions, dentists are obligated to monitor continuously their medically challenged patients. Monitoring provides three important benefits. First, it helps the dentist detect acute medical emergencies that may require an immediate response. Second, monitoring may reveal gradual deleterious trends that can often be easily reversed before a true emergency occurs. Third, monitoring can assist the dentist in evaluating the efficacy of any emergency treatments or preventive measures that are rendered. The purposes of this article are to: briefly review monitoring techniques and devices, discuss their suitability for use in the dental office, and provide some tips for their application during dental care. In overall decreasing order of routine importance, monitoring resources include the following: responsible personnel, non-invasive blood pressure monitor, pulse oximeter, ECG, and the pretracheal stethoscope or capnograph.

Key words: Vital signs, dental care

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Advances in medicine have greatly increased the survival of patients with severe health problems and have significantly prolonged life in elderly individuals with systemic disorders. Concomitant advances in dentistry and evolving societal expectations regarding dental health and function have likewise ensured that these patients are increasingly retaining their teeth and/or seeking dental care. The administration of local anaesthetics and the performance of extensive dental procedures may cause stress and systemic disturbances in such patients. In order to avoid potentially serious reactions, dentists are obligated to monitor continuously their medically challenged patients. Monitoring provides three important benefits. First, it helps the dentist detect acute medical emergencies that may require an immediate response. Second, monitoring may reveal gradual deleterious trends that can often be easily reversed before a true emergency occurs. Third, monitoring can assist the dentist in evaluating the efficacy of any emergency treatments or preventive measures that are rendered. The purposes of this article are to: briefly review monitoring techniques and devices, discuss their suitability for use in the dental office, and provide some tips for their application during dental care.

General considerations

Ideally, monitoring of medically challenged patients should include: the metabolism of important tissues to ensure their individual health; and the function of these tissues to ensure that their contributions to the body as a whole are being maintained. Practically, there is no method for doing this in the dental setting. What can be assessed are gross neurologic function and several basic processes involved with the delivery of oxygen and essential nutrients to the tissues including the removal of carbon dioxide and other waste products. These functions often result in signals (sounds, pressure changes, electrical currents, spectrophotometric differences) that can be accurately measured.

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Monitoring methods differ greatly in cost, invasiveness, reliability, and size. Some monitoring techniques are suitable for routine use in the medically challenged dental patient, others are best reserved for special situations.

Cost effectiveness

All monitoring techniques provide certain information at some cost. The decision to use a monitor should be based on the value of the information in helping to ensure safe dental treatment. Inherently, such decisions involve cost-benefit analyses. Using a basic economic model that ignores such important issues as human suffering associated with death and serious injury, the decision to employ a monitoring method can be represented by the equation:

$$C_p \leq C_d \bullet P_d$$

where C_p is the cost of monitoring a single patient, C_d is the financial cost of damages arising from a preventable incident, and P_d is the probability of such an incident. In the case of pulse oximetry used for intravenous sedation in dentistry, the estimated C_p is about \$0.30 (assuming a \$1,000 machine is used on 3,300 patients and discounting electrical, repair, and staff costs attendant to its use), the typical C_d (including malpractice and/or health insurance payouts involving mortality or permanent hypoxic injury) may approximate \$2,000,000, and the P_d can be conservatively estimated at 1 incident per 1,000,000 sedations. Since \$2,000,000/1,000,000 = \$2.00, pulse oximetry is highly justified for intravenous sedation even if one ignores the human costs of these rare tragedies.

No analyses of this kind have been performed for medically challenged patients undergoing routine dental care without conscious sedation or general anaesthesia. Until such information is available, it will be difficult to advocate the routine use of monitoring techniques that generate more than minimal costs per patient visit.

Invasiveness

Certain monitoring techniques, especially those measuring cardiovascular parameters such as stroke volume and pulmonary arterial pressures, require the insertion of probes or catheters and are generally unsuited for outpatient monitoring in the dental office. Their use demands considerable technical expertise; they are painful and sometimes potentially dangerous for the patient; and rigorous sterile techniques are often required for their use. In general, patients needing such techniques should only be treated in the hospital setting.

Reliability

Monitors used in the office setting must be able to function well over time, without the need for repair, and despite rough handling and a lack of regular maintenance. Unlike the hospital, backup monitoring equipment is rarely available in the dental office, and regularly scheduled maintenance is unlikely to occur. Machines that autocalibrate or do not require calibration to remain accurate over time are clearly preferred over devices that need careful, repeated adjustments to yield acceptable results.

Size and portability

Office-based dentistry is usually practiced within the limited confines of the dental operatory. Besides the dental chair, delivery unit, and light—and the patient, dentist, and one or more assistants—the operatory must increasingly house such additional paraphernalia as digital x-ray units, surgical microscopes, laser devices, and audiovisual systems. Space is at a premium, and the smaller the monitoring machine the better. Battery-powered monitors are also preferable since electrical outlets are often in short supply and electrical cords may interfere with movements of both patient and practitioner. In addition, small size and battery power enhances monitor portability. The ability to move a monitor from one operatory to the next permits greater flexibility in its use and reduces the need for purchasing additional machines.

Specific monitors

Central nervous system

Verbal contact

In conventional office-based dentistry, maintaining verbal contact is essential to monitoring central nervous system function of the patient. Conversation requiring simple, quick responses may be conducted during the appointment without interrupting dental treatment. Unfortunately, dentists concentrating on the procedures they are performing may neglect communicating with their patients. Coma scales (e.g., the Japan Coma Scale or the Glasgow Coma Scale) are often used in medicine for evaluation of consciousness; in dentistry, simple verbal contact is normally sufficient to monitor the adequacy of central nervous system function in the outpatient setting.

Electroencephalography

Electroencephalography (EEG) commonly uses numerous electrodes placed at specific points on the scalp to detect the combined electrical activity of all the neurons of the brain. Interpretation of the complex signals that are recorded requires extensive training and the assistance of computers to parse the EEG into its component waveforms. The recording device needs electrical isolation and is difficult and time-consuming to set up. The patient must remain quiescent for a period of time to get valuable data; small movements, even the stimulus of noises associated with dental treatment, adversely affects EEG evaluation. Thus, the EEG is clearly unsuitable for monitoring during routine dental treatment.

Bispectral index (BIS)

The bispectral index (BIS) is a dimensionless number from 1 to 100 that is mathematically derived from the EEG as recorded by a multielectrode adhesive strip placed on the forehead of the patient. The BIS monitor was initially developed for medical anaesthesia to help ensure unconsciousness in patients receiving general anaesthesia and to help maintain the desired levels of central nervous system depression throughout the case[1]. The relatively few evaluations of BIS monitoring in dentistry have focused on using the device to indicate consciousness in patients receiving intravenous or inhalation sedation[2-7]. Purchase and supplies costs and the physical size of the original device have discouraged widespread adoption of the BIS monitor in dentistry. Moreover, since the BIS number is derived from the EEG, the patient must stay quiet with the eyes closed. Drilling and jaw movement may interfere with the BIS reading, and the electrode patch is a minor irritant to some patients. However, continued reductions in size and cost and minimisation of movement and stimulus artifacts may eventually transform the BIS monitor into a cost-effective device for dentistry, at least for patients receiving conscious sedation, deep sedation, or general anaesthesia.

Respiratory system

Respiratory sounds

Respiratory sounds are generated by the movement of air during breathing and therefore indicate the presence of ventilation. Evidence of partially obstructed airflow (e.g., snoring, wheezing,) or complete airway obstruction (no sound) can be easily determined by auscultation of respiratory sounds using a precordial stethoscope. Typically, a stethoscope bell is placed in the supersternal notch using a double-sided adhesive ring and attached via a single flexible tube to a custom-moulded earpiece. No monitor of respiratory function can match the cost effectiveness and speed of problem detection of the pretracheal stethoscope. It is the only monitor that quickly detects partial airway obstruction and the presence of foreign matter (e.g., secretions) in the airway. It is, of course, limited by observer vigilance. In one study, an average of 34 seconds lapsed before apnoea was detected by stethoscopy, with 2.3% of episodes requiring more than 4 minutes for detection[8].

Respiratory rate

The respiratory rate is a vital sign that can be easily determined by, for example, visual inspection of the patient or nitrous oxide reservoir bag, listening with a precordial stethoscope, or evaluating impedance changes recorded by chest electrodes. As a measure of ventilation, respiratory rate is limited by the possibility of unsuccessful ventilatory efforts because of an obstructed airway or by inadequate strength of breathing efforts. Nevertheless, cognisance of a patient's breathing rate and pattern is an excellent way to detect physical manifestations of stress in the medically challenged patient.

Tidal volume, minute volume

Spirometry can be used to measure adequacy of ventilation when the patient is attached to a breathing circuit that supplies all air to the patient. The minute volume, representing the total gas inhaled in 1 minute, is equal to the product of the respiratory rate and the tidal volume (the mean volume of each breath during the measurement period). Commonly present on hospital anaesthesia machines, spirometers are generally not available in dental offices and not indicated for routine monitoring.

Pulse oximetry (SpO_2)

Pulse oximetry is a valuable measure of arterial blood oxygenation and has become a standard monitor whenever parenteral sedation or general anaesthesia is administered. The pulse oximeter uses two light-emitting diodes, one producing visible red light at 660nm, and the other infrared radiation at 940nm. Visible red light is absorbed more by reduced haemoglobin than by oxyhaemoglobin, whereas the reverse relationship holds with the infrared wavelength. Because oxygen bound to haemoglobin normally constitutes about 98% of all oxygen in blood, pulse oximetry provides an accurate indication of the total amount of oxygen available for delivery to tissues and generally yields a good estimate of the arterial oxygen tension (PaO_2).

Although highly reliable, pulse oximetry is subject to certain variables that can influence measurements[9]. Movements causing venous pulsations can confuse the pulse oximeter into recording extra "beats" of poorly oxygenated blood. Inadequate peripheral pulses because of low blood pressure, peripheral vasoconstriction (from peripheral vascular disease, high anxiety, or cold ambient temperatures), or physical obstruction (pressure occlusion of the arterial supply) may preclude effective measurement. Excessive ambient light, severe anaemia, abnormal haemoglobin (e.g., methaemoglobin), injected dyes, and light-absorbing nail polishes or coverings can also cause misreadings.

End-tidal carbon dioxide

The ability to detect expired carbon dioxide (CO_2) by capnography has been a major boon to anaesthesiologists in the operating room. Historically, one of the major causes of preventable mortality was unrecognised oesophageal intubation, which is now readily recognised by a lack of CO_2 in the expired air. Experimentally, using a pulse oximeter to detect oesophageal intubation (by the developing hypoxia) took an average of 7.5 minutes versus less that 30 seconds with a capnograph[10].

The end-tidal CO_2 tension ($EtCO_2$), which is the CO_2 content in the last part of the exhaled air, is normally about 35-40mm Hg. The $EtCO_2$ usually correlates well with the arterial CO_2 tension ($PaCO_2$). An increase in the $EtCO_2$ demonstrates a decrease in ventilation, and *vice versa*. However, there are circumstances (shunting of blood, inadequate ventilation depth to exhale unmixed alveolar air) in which the $EtCO_2$ is significantly lower than the $PaCO_2$. Both increases and decreases in $EtCO_2$ indicate potential problems with ventilation.

Although capnography can provide an accurate assessment of the adequacy of ventilation on a breath-to-breath basis, it is not clear if a true benefit is realised in the dental office in which medically challenged patients are receiving dental care without general anaesthesia. If the patient responds easily to voice stimuli, it is unlikely that there is an acutely elevated $EtCO_2$[11]. If the $EtCO_2$ is reduced by hyperventilation, less costly means of evaluating the respiratory rate should be sufficient to detect the problem.

Blood gas analysis

Before pulse oximetry and capnography, the only practical method available to accurately measure oxygenation and ventilation was to take an arterial blood sample and perform a blood gas analysis yielding the PaO_2, $PaCO_2$, and bicarbonate concentration. Technical skill is required to obtain the necessary arterial sample, and a medical laboratory must be nearby to test the sample for blood gases. Neither of these resources is typically available to the dental office.

Circulatory system

Heart sounds

Heart sounds are used to assess the heart rate and rhythm and can provide some qualitative information regarding the cardiac output. Heart murmurs and other abnormal sounds often suggest disturbances in cardiac valve function (e.g., mitral valve regurgitation or aortic valve insufficiency) or blood flow abnormalities (e.g., ventricular septal defect or hypertrophic subaortic stenosis). Heart sounds are auscultated by the use of a stethoscope; the precordial stethoscope described previously may be used to monitor heart sounds continuously.

Blood pressure

Blood pressure is a vital sign that must be evaluated in medically challenged patients. Two basic factors govern the blood pressure: the cardiac output and the peripheral vascular resistance. In turn, the cardiac output is a product of the heart rate and stroke volume, and the peripheral resistance is a function of the diameter and compliance of the vasculature and the viscosity of the blood. Alterations in both cardiac output and peripheral resistance may occur in response to the stress of dental treatment. Certain medical emergencies such as vasovagal syncope (fainting) and hypertensive crises are closely related to changes in blood pressure. *Table 1* classifies blood pressure for adults according to standards published by the United States National Heart, Lung, and Blood Institute along with general recommendations for dental care[12,13].

The most basic monitor to measure blood pressure is the manual sphygmomanometer. Each dental office should have a sphygmomanometer in good working order and every dentist should know how to measure the blood pressure and use the data in developing an optimal treatment plan for the patient.

Automated blood pressure monitors are commonly used in dental settings. Most of these devices can measure the blood pressure automatically (i.e., without having to inflate the cuff manually) at preset intervals

Table 1 Classification of blood pressure for adults and recommended actions by the dentist

Category	SBP (mm Hg)*		DBP (mm Hg)*	Recommended action
Optimal	<120	and	<80	Regular dental care
Normal	<130	and	<85	Regular dental care
High-normal	130-139	or	85-89	Regular dental care; advise patient of blood pressure status
Hypertension				
Stage 1	140-159	or	90-99	Regular dental care; recommend physician consult
Stage 2	160-179	or	100-109	Noninvasive elective care or definitive emergency care; refer to physician for evaluation and treatment
Stage 3	≥180	or	≥110	Noninvasive emergency care only; refer to physician for immediate follow-up
Hypertensive crisis	>220	or	>120	Hospitalisation and immediate blood pressure reduction if signs and symptoms of organ damage; otherwise refer to physician for immediate follow-up

*SBP, systolic blood pressure; DBP, diastolic blood pressure.
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(i.e., every few minutes). They provide reasonably accurate data compared to manual sphygmomanometers and are preferred in patients with hypotension. Since a small computer is usually incorporated in such machines, they can often save, output, and print the data on command.

In recent years, novel blood pressure monitors have become commercially available. They include finger cuff blood pressure monitors like the Finapres (USA) and U-vision (Japan) devices and several wrist cuff monitors. The Finapres monitor can assess blood pressure continuously. These alternative devices are easy to use and reasonably priced, but accuracy of the data is inferior to that of standard blood pressure monitors.[14]

Continuous blood pressure monitoring can be obtained using arterial catheterisation, typically of the radial artery in the wrist or the dorsal artery of the foot. Artery catheterisation also permits the sampling of arterial blood for blood gas analysis (PaO_2, $PaCO_2$, pH, bicarbonate, etc.). However, as it is painful, invasive, and must be performed under sterile conditions, it is not used in office-based dental practice.

Electrocardiography

The electrocardiogram (ECG) is an excellent monitor for high-risk cardiac patients receiving even routine dental care. It is a non-invasive monitor that can be applied to patients of all ages. The ECG can detect cardiac arrhythmias, myocardial ischemia, conduction defects, hypertrophy/enlargement of the atria and/or ventricles, and certain electrolyte imbalances. The conventional 12-lead ECG is standard for diagnosis of cardiac abnormalities; it is not indicated in the dental office setting.

The three-lead ECG is normally used for all patients receiving general anaesthesia and to monitor severely ill patients undergoing procedures while awake. The adhesive electrodes are placed on the right upper, left upper, and left lower aspects of the chest. As it may be inconvenient or inappropriate to apply chest leads in the dental office setting, they are instead often put on the right and left wrists and left ankle. Recent ECG monitors can delete artefacts associated with this peripheral lead placement.

Modern ECG devices, some of which are battery operated, are relatively small and easy to use. Some machines are even able to detect arrhythmias automatically. Simple, modified ECG monitors are expected to be available in dental settings because of their unique ability to display cardiac arrhythmias and detect ischemic changes in the myocardium.

Echocardiography

Ultrasounds can record the motion of cardiac contraction and relaxation, valvular function, and blood flow. Echocardiography is a very effective diagnostic aid when an evaluation of cardiac function is needed. Since it is performed by the simple application of a probe on the skin, it is classified as a non-invasive monitor. Echocardiography has little place in office-based dentistry because the machine is large and expensive, application of the probe and evaluation of the images requires extensive training and experience, and exposure of the chest is not commonly accepted in the dental setting.

Body temperature

Body temperature is a vital sign that provides some information regarding the overall metabolic status of the patient. Its use in routine dentistry is restricted to evaluating patients for fever before dental treatment.

Core temperature: The tympanic membrane provides an accessible site for the measurement of core body temperature. Since it can be measured within a few seconds, the tympanic thermometer has become commonplace. Patients receiving general anaesthesia are often monitored by oesophageal or rectal thermometers, but neither is acceptable for routine dentistry.

Skin temperature: The axilla is a good skin site for estimating core body temperature. It is, however, difficult to monitor axillary temperature continuously in the dental setting.

Essential monitoring for dental care

Patients with pre-existing medical conditions that place them at special risk from the stress of dental procedures must receive some basic level of monitoring to ensure safe treatment. Monitoring should include the continuous assessment of neurologic function, breathing, and cardiovascular activity. For the most part, the dentist and staff involved in treating the patient can perform these basic monitoring duties without the need for costly monitoring equipment. However, certain resources are generally useful, and others are especially indicated in selected situations. In overall decreasing order of routine importance, monitoring resources include the following: responsible personnel, non-invasive blood pressure monitor, pulse oximeter, ECG, and the pretracheal stethoscope or capnograph.

Responsible personnel

When the dentist is focusing on complex dental procedures, he/she cannot simultaneously monitor the patient's status on a continuous basis. In this situation, patient safety is optimised by assignment of the primary monitoring responsibility to another individual[15]. Whether this individual is a staff member or another dentist, he/she must be familiar with the systemic evaluation of the medically compromised patient and be trained in the application and interpretation of whatever monitoring devices are being used on the patient. The individual should continuously assess the patient's respiration and level of consciousness by visual inspection or other means, continually monitor heart rate by palpation or other means, and, as necessary, take the arterial blood pressure. In cases where a single person cannot be designated as the primary monitor, all personnel involved in patient care must assume the collective responsibility of the monitoring the patient.

Non-invasive blood pressure monitor

The non-invasive blood pressure monitor is a simple, excellent device for assessing cardiovascular function. Each dental clinic should be equipped with a properly functioning sphygmomanometer and an assortment of arm cuffs suitable for the patients treated at the facility. (A stethoscope is also required for manual sphygmomanometers). Each dentist and employee who may serve as a primary monitoring person should know how to measure blood pressure with every type of blood pressure monitor present in the office. The baseline blood pressure should be recorded for each patient with significant cardiovascular history and as necessary during and after treatment to help ensure an uneventful outcome.

Pulse oximeter

Although the pulse oximeter is not commonly found in the dental office, it has potential value in treating medically challenged patients, especially those with advanced cardiopulmonary disorders. Application of the machine and interpretation of pulse oximetry data are so easy that not only the dentist but also the dental hygienist and assistant can use the device successfully. The pulse oximeter also serves as an excellent heart rate monitor, and devices equipped with a plethysmograph yield some information about the beat-to-beat stroke volume (which can oscillate with certain arrhythmias). Finally, the monitor itself is reliable, relatively small, and increasingly inexpensive.

Electrocardiograph

The ECG is a rarity in the typical dental office. Cost, but more importantly unfamiliarity in its use and interpretation, has limited its acceptance in clinical dentistry. Nevertheless, the ECG is uniquely suited for detecting arrhythmias and ischemic changes of the myocardium in patients with advanced heart disease. It is hoped that advances in automatic ECG interpretation will extend the benefits of ECG monitoring to more patients receiving potentially stressful dental care.

Pretracheal stethoscope/capnograph

The precordial stethoscope and the capnograph represent opposite extremes in cost with respect to monitoring ventilation. Although a primitive monitor by modern standards, the precordial stethoscope is the only device that provides instantaneous information regarding airway patency, ventilatory effort, and cardiac rate and rhythm. A major problem in the conscious patient is that verbal responses may be deafeningly loud. Unfortunately, encouraging patient silence potentially limits basic assessment of neurologic function. The capnograph avoids this limitation but remains problematic for most dental offices because of its dubious cost/benefit ratio. An example where the benefits of the precordial stethoscope or capnograph may outweigh their limitations is in the patient with advanced dementia who is incapable of verbal responses on command.

Vital signs monitor

No consideration of monitoring equipment would be complete without some mention of devices that can monitor multiple vital signs and related variables. For convenience, several manufacturers provide machines that can simultaneously monitor heart rate, blood pressure, ECG, respiration rate, SpO_2, $EtCO_2$, and body temperature. Monitoring of these diverse parameters is assisted by their presentation on a single screen, often coupled with the ability to store hours of information, display trends over time, and print out a time-based record of the data. Such devices are expensive but may be justified for offices with a high percentage of medically compromised patients.

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