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Transcutaneous bilirubinometry

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ABSTRACT

Although the modern era of transcutaneous bilirubin monitoring (TcB) began only about 35 years ago, this screening tool is now widely used in newborn nurseries and outpatient clinics, offices, and emergency departments to obtain a rapid and non-invasive estimate of the degree of hyperbilirubinemia. TcB devices have become more sophisticated, and major breakthroughs include the following: (a) ability to report a bilirubin value rather than an index value, (b) enhanced correction for chromophores other than bilirubin, and (c) technologic improvements including interface with electronic medical records. Good agreement with laboratory bilirubin measurement has been demonstrated, and the ability of TcB screening to predict and decrease the incidence of subsequent hyperbilirubinemia has been well-documented. To date, it has not been shown that this screening results in improved long-term outcomes.

Introduction

Transcutaneous bilirubinometry (TcB) developed due to several converging influences and factors: (a) the recognition that yellow skin color is due to the deposition of bilirubin,[1] a chromophore molecule that, with advancements in optical science, could be quantitatively measured; (b) the development of the concept that visible assessment of neonatal jaundice is unreliable[2,3]; (c) clinical refinements in assessing jaundice based on age in hours (rather than days)[4]; (d) an increased recognition of cases of kernicterus, which led to requirements that birthing centers have a more formal screening approach along with parental education regarding jaundice[5]; and (e) the increasing emphasis on non-invasive screening methods (e.g., pulse oximetry for CCHD screening).

The estimation of total serum bilirubin (TSB) transcutaneously in newborn infants has made screening straightforward for most birthing centers and in the outpatient setting.[6] TcB devices are widely used throughout the world, because of their (a) ease of use, (b) non-invasive nature and reduction in the number of inpatient TSB determinations,[7,8] (c) reduced expense when compared to a serum bilirubin, (d) immediate results, and (e) superior performance over visual assessment of jaundice.[9–13] The purpose of this review is to address questions relating to transcutaneous bilirubinometry: the physics, biology, and history of this science; the devices that are currently available; results of investigations that compared TcB devices and laboratory TSB in term and preterm infants; the development of TcB nomograms; and the ongoing issue of whether TcB screening is useful in the prevention of the deleterious effects of hyperbilirubinemia.

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What are the relevant optical principles involved in TcB determinations?

Obtaining a TcB measurement is a rather simple and straightforward process; however, the physics and biology behind TcB measurements is complex. A thorough discussion of this topic is beyond the scope of this review, and the interested reader is referred to a recent, more detailed discussion of these issues.[10] Here, the basic principles involved are discussed briefly.

Significant differences in design exist among TcB devices; however, all of them utilize the principle of analysis of skin remittance (diffuse reflectance) spectra. The skin is exposed to light of varying wavelengths issued by the device, and the device has the capability of analyzing the light that is returned to it after it has been "processed" in the skin and subcutaneous tissue. The spectra of the returned light will depend on the concentration of various cutaneous chromophores, such as melanin, collagen, oxygenated and reduced hemoglobin, and of course, bilirubin.[14] Technically, the word "chromophore" refers to the part of a molecule that, because of absorbance and reflection of particular wavelengths, imparts its color; the term often is used to refer to the entire molecule. The difference in absorption spectra due to the various chromophores will allow the calculation of their concentration through the reflected light analysis by using a device-specific algorithm and a microcomputer.

For the purpose of optical measurements, human skin can be adequately regarded as a layered structure consisting of epidermis (~0.1-mm thickness), dermis (~0.5-mm thickness), and subcutaneous tissue. Short wavelengths in the optical spectrum (400–600 nm) are predominantly absorbed by various specific chromophores such as hemoglobin, melanin, bilirubin, and other pigments. The reflection and subsequent collection of these wavelengths by the measuring device is important to correctly determine the baseline absorption of the various pigments; this allows isolation of the chromophore of interest, i.e., bilirubin. Bilirubin has an absorption peak around 450–500 nm, while absorption of melanin gradually decreases as wavelengths increases from <400 nm to ~840 nm. Because the epidermal melanin is just a thin layer on the tissue surface, it acts as an attenuation filter for light entering and exiting the skin and can be factored into the internal algorithm[14–19] (Fig. 1).

How did transcutaneous bilirubinometry and other non-invasive techniques develop?

The first major study to determine skin color in jaundiced patients in a more quantitative fashion than visual assessment alone was performed by Rowntree and Brown.[20] Their skin "tintometer" had nine separate color intensities with 10 distinct plaques that covered an entire scale of color variation such as cyanosis and redness, as well as jaundice. Davidson et al.[21] described the relationship between the degree and appearance of visible jaundice with the patients' serum bilirubin values.

In the late 1960s, Kramer[22] introduced the use of "dermal icteric zones" to estimate the circulating bilirubin level. These were four surface areas on the newborn skin generically identified with the head, the zone from neck to umbilicus, the zone from umbilicus to ankles, and feet. Mechanisms were proposed regarding the cephalo-caudal progression of neonatal jaundice,[23–26] and the relationship between progression of jaundice from one zone to another and the serum bilirubin concentration was demonstrated. The first commercially available instrument utilizing the above-described factors and to assist in the visual evaluation was the Perspex Icterometer™.[27] This device, a Plexiglas strip with five colored stripes painted with customized shades of yellow pigment, is still sold, but its use is limited by subjectivity.[28,29]

Ballowitz and Avery[30] performed early work in describing the relationship between serum bilirubin and cutaneous bilirubin as determined by spectral analysis. Subsequently, Hanneman et al.[31,32] at the Mechanical Engineering Department of Purdue University developed more sophisticated instrumentation for obtaining spectral reflectance of human newborn skin. By analyzing a combination of five separate wavelengths, they achieved a correlation coefficient of 0.93 between their method and TSB.

Yamanouchi et al.,[33] in collaboration with the Minolta Camera Company Ltd, developed a prototype device with a digital-processor that illuminated the skin and measured color intensity. This device provided a numerical index that was correlated with TSB[34]; however, providers needed to translate this numerical index value into a serum bilirubin equivalent through the use of a graph or conversion equation. Subsequent modifications were developed and marketed as the JM-101™ and JM-102™. Similar to the prototype, these devices gave an index value that required conversion to the estimate for TSB.

What TcB devices are currently available?

Modern TcB meters differ primarily on the specific algorithms of the melanin subtraction and isolation of the remaining chromophore peaks to isolate the contribution by bilirubin.

Dräger jaundice meter

The Dräger JM-103™ was the next-generation in the Minolta line (JM-101™ and JM-102™). The JM-103™ incorporates

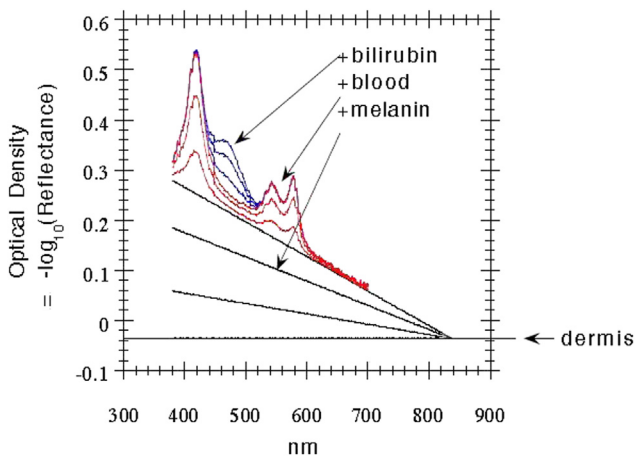

Fig. 1 – Schematic representation of melanin subtraction. (Reproduced with permission from the Society of Photographic Instrumentation Engineers.[14])