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Investigation de la régulation vasculaire dans les artères et les veines de la rétine

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Investigation de la régulation vasculaire dans les artères et les veines de la rétine

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Sommaire

But. L'étude des changements des diamètres des vaisseaux rétiniens au cours de stress physiologiques ou de certaines pathologies a été le point de mire de plusieurs groupes de recherche. Toutefois, ces études sont principalement basées sur l'utilisation de photographies individuelles de fond d'oeil, ceci ne permettant pas l'étude de la dynamique des vaisseaux en fonction du temps. Le but de notre étude était d'établir la cinétique et la variation du diamètre des artères et des veines dans l'ensemble des quadrants de la rétine pendant, et suite à une période d'hyperoxie vasculaire.

Méthodologie. La dynamique des changements du diamètre des vaisseaux rétiniens a été évaluée avec le Retinal Vessel Analyzer (RVA), un système couplé à une caméra de fond d'oeil (Zeiss), qui permet la digitalisation des images du fond d'oeil en temps réel, de même que l'analyse post-acquisition. Vingt jeunes adultes ont participé à cette étude où le diamètre des vaisseaux a été mesuré en phases consécutives, respirant soit de l'air ambient ou de l'oxygène pur. Le taux de saturation en oxygène (SaO_2), la teneur en gaz carbonique en fin d'expiration ($EtCO_2$), la fréquence cardiaque, le rythme respiratoire et la pression sanguine ont aussi été enregistrés pendant toute la durée de l'expérience.

Résultats. L'hyperoxie systémique est corrélée avec une hausse de la SaO_2 et d'une diminution du $EtCO_2$. En réponse au stress hyperoxique, les veines et

artères rétiniennes, dans tous les quadrants, ont répondu par une vasoconstriction de l'ordre de 14.0 % et 8.8 %, respectivement. Suite à l'arrêt du stress hyperoxique, tous les vaisseaux ont progressivement récupéré leur diamètre de départ. La réponse vasoconstrictrice est semblable à l'intérieur des quadrants rétiniens.

Conclusions. Ces résultats indiquent que la variation du diamètre des vaisseaux rétiniens, durant la période d'hyperoxie, est similaire dans les quadrants rétiniens chez le jeune adulte en santé. Le stress hyperoxique vasculaire pourrait donc être utilisé afin d'évaluer l'efficacité de la régulation vasculaire lors du vieillissement ou de pathologies vasculaires oculaires.

Mots clés: vaisseaux rétiniens, Retinal Vessel Analyzer, hyperoxie systémique, autorégulation vasculaire.

Summary

Purpose. Several studies have investigated the changes in retinal vessel diameter during physiological stress or pathological conditions. However, these studies were principally based on individual fundus photographs and as such did not allow the evaluation of vessel dynamics over time. Our research objective was to detail the time-course and amplitude changes in the diameter of arteries and veins across all retinal quadrants, during and after an hyperoxic vascular stress.

Methods. The dynamics of changes in retinal vessel diameter were quantified with the Retinal Vessel Analyzer (RVA), a system coupled with a Zeiss fundus camera, that allows digitization of fundus images in real time, as well as post-acquisition analyses. Twenty young adults participated in this study where the vessel diameters were measured during successive phases of breathing either room air or pure oxygen. The oxygen saturation level (SaO2), end-tidal carbon dioxide (EtCO2), pulse rate (PR), respiratory rate (RR) and blood pressure (BP) were also monitored throughout testing.

Results. Systemic hyperoxia was accompanied by an increase in SaO_2 and a decrease in $EtCO_2$. During systemic hyperoxia, the retinal veins and arteries in all quadrants constricted by about 14% and 9%, respectively. Subsequently, during breathing of ambient air, all vessels progressively returned towards their baseline caliber. The degree of vasoconstriction did not differ across retinal regions.

Conclusions. These data indicate that the retinal vessels change caliber uniformly across retinal quadrants in the healthy young adult, during a systemic hyperoxic stress. This type of physiological vascular provocation could be used to investigate the quality of vascular regulation during aging and vascular pathologies of the eye.

Keywords: retinal vessels, Retinal Vessel Analyzer, systemic hyperoxia, vascular autoregulation

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20-HETE : Acide 20-hydroxyeicosatétraènoïque

BP : Pression sanguine (blood pressure)

BP diast : Pression sanguine diastolique (diastolic blood pressure)

BP mean : Pression sanguine moyenne (mean blood pressure)

BP syst : Pression sanguine systolique (systolic blood pressure)

CO_2 : Gaz carbonique

$EtCO_2$: Teneur en gaz carbonique en fin d'expiration

IOP : Pression intraoculaire (intraocular pressure)

IN : inféro-nasal

IT : inféro-temporal

O_2 : Oxygène

ONH : tête du nerf optique (optic nerve head)

OPP : Pression de perfusion oculaire (ocular perfusion pressure)

PR : Fréquence cardiaque (pulse rate)

RR : Fréquence respiratoire (respiratory rate)

RVA : Retinal Vessel Analyzer

SaO_2 : Saturation en oxygène

SN : supéro-nasal

ST : supéro-temporal

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Introduction

L'oxygène contenu dans l'air que nous respirons est essentiel au maintien du métabolisme cellulaire et biochimique. Sa distribution continue dans tous les organes et tissus est donc primordiale. C'est grâce à l'hémoglobine des globules rouges que le sang peut acheminer l'oxygène pour répondre à la demande métabolique de l'organisme. [1,2]

Le sang

Chaque cellule de l'organisme dispose d'un ensemble de processus chimiques intrinsèques nécessaires au maintien de son homéostasie. À cet effet, les substances essentielles comme les lipides, les protéines, les glucides, les vitamines, les sels, l'eau, l'oxygène et les hormones doivent être transportées vers chaque cellule et les déchets métaboliques comme le gaz carbonique et les composés azotés simples et solubles tels que l'urée doivent être éliminés. Le système cardiovasculaire est responsable du transport de ces substances par un système en circuit fermé de vaisseaux sanguins parcourant l'organisme.[1,2]

Chez l'humain, le sang est composé de diverses cellules en suspension dans le plasma. Il y a trois sortes de cellules sanguines; les érythrocytes (globules rouges), les leucocytes (globules blancs) et les thrombocytes (plaquettes), chacune ayant une fonction particulière.[1,2,3] Les érythrocytes ont pour fonction de transporter l'oxygène, ce qui s'effectue par l'hémoglobine qu'ils contiennent. Les leucocytes ont une fonction immunitaire, protégeant l'organisme en produisant des anticorps et en éliminant les déchets et les corps étrangers par phagocytose. Les thrombocytes jouent un rôle au niveau de la coagulation sanguine.[1,2,3]

La circulation sanguine systémique

La circulation sanguine doit être ininterrompue afin d'assurer le transport des nutriments et autres substances entre les diverses parties de l'organisme. La circulation systémique est assurée par la force de contraction cardiaque qui pousse le sang dans les artères puis vers les tissus, et par le retour sanguin à partir des tissus vers le cœur via le système veineux.[4]

Les artères qui acheminent le sang riche en oxygène du cœur vers les artérioles puis les tissus, sont constituées de trois couches cellulaires : un revêtement interne (intima), une couche intermédiaire (média) et une couche externe (adventice). La couche interne, l'intima, est composée d'un endothélium. L'intima réduit la friction du flot sanguin sur la paroi vasculaire et sécrète des substances limitant l'activation plaquettaire ainsi que la thrombose. La média est constituée de tissu élastique et de tissu musculaire. Le tissu élastique permet au vaisseau de contrebalancer la pression effectuée par le sang sur les parois vasculaires alors que les cellules musculaires lisses contrôlent le diamètre du vaisseau. L'adventice est une couche conjonctive faite de collagène qui empêche une distension excessive et permet l'ancrage du vaisseau aux tissus voisins.[1,2]

Les veines forment un système à faible résistance qui assure la collecte et le transport du sang des organes jusqu'au cœur. Leur structure est également composée de trois couches, mais les parois des veines possèdent cependant moins de tissu musculaire et élastique.[3]

Le sang circule dans les tissus à travers un fin réseau de vaisseaux, les capillaires artériels et veineux, dont les parois consistent en une couche unique de cellules permettant l'échange de substances entre le sang et les tissus. Tous les vaisseaux du système circulatoire systémique sont innervés par le système autonome.

Débit sanguin systémique

Le débit sanguin est le volume de sang qui s'écoule dans un vaisseau ou dans le système vasculaire en une période donnée. Il est très important, car il détermine l'apport d'oxygène et de nutriments à l'ensemble des cellules du corps, l'élimination des déchets métaboliques, les échanges gazeux dans les poumons, l'absorption et la distribution des nutriments contenus dans le système digestif, ainsi que le traitement du sang par les reins.[4]

La résistance périphérique est la force qui s'oppose à l'écoulement du sang et qui est générée principalement par la friction du sang contre les parois des vaisseaux. Quatre facteurs influencent la résistance vasculaire: la viscosité du sang, la pression différentielle à l'entrée et à la sortie du vaisseau, le diamètre et la longueur du vaisseau sanguin.[4] La viscosité est la résistance d'un liquide à l'écoulement. Le sang est considéré comme un liquide visqueux principalement à cause de l'importante concentration en globules rouges en suspension par millilitre de sang (environ $4x10^9$).[1] Si la viscosité du sang augmente, par exemple, à la suite d'un accroissement du nombre de globules rouges ou d'une perte en eau, sa résistance à l'écoulement augmentera. La pression dans un vaisseau donné peut influencer le débit sanguin en augmentant la force qui pousse le sang dans le vaisseau, mais aussi par l'effet de distension que cela

entraîne sur la paroi du vaisseau. Le diamètre du vaisseau est un facteur important parce que le sang y circule de façon laminaire, faisant en sorte que l'écoulement des liquides est plus lent près des parois à cause de l'effet de friction, et plus rapide au centre du vaisseau. La résistance est donc plus grande dans les artérioles que dans les grosses artères. La longueur des vaisseaux sanguins influence aussi la résistance périphérique, car plus un vaisseau est long, plus la résistance est grande.[4]

Il existe une relation étroite entre la résistance périphérique et le débit sanguin puisque ce dernier est directement proportionnel à la résistance périphérique, comme l'indique la loi de Poiseuille [4] :

$$\text{débit sanguin} = \frac{(\text{gradient de pression} \times \text{rayon}^4)}{(\text{viscosité} \times \text{longueur})}$$

Régulation du débit sanguin systémique

Le débit sanguin est relativement constant à l'état de repos, mais il peut varier considérablement d'un organe à l'autre selon le niveau d'activité organique ou tissulaire; il y a donc adaptation du débit sanguin aux besoins des tissus. Ceci s'effectue par deux mécanismes principaux de régulation vasculaire : la régulation nerveuse autonome et l'autorégulation.[1,2,3]

Régulation nerveuse autonome

L'innervation sympathique régularise le débit sanguin en agissant sur les terminaisons sympathiques (adrénergiques) par une stimulation des récepteurs qui sont vasoconstricteurs ou vasodilatateurs. La stimulation des voies sympathiques règle ainsi la fréquence cardiaque, la contractilité et le diamètre des vaisseaux sanguins. Ce système est stimulé, entre autres, par des barorécepteurs et des chémorécepteurs localisés dans les parois des vaisseaux sanguins. Les barorécepteurs sont sensibles à la pression et à l'étirement appliqués sur les parois, tandis que les chémorécepteurs s'activent en réponse à une variation du pH sanguin ainsi que des niveaux de gaz carbonique (CO_2) et d'oxygène (O_2).[1,2]

Autorégulation

L'autorégulation est l'ajustement du débit sanguin dans une région donnée de l'organisme qui s'effectue grâce à des mécanismes intrinsèques entraînant des modifications locales du diamètre des artérioles desservant les capillaires de l'organe. Plusieurs facteurs contribuent ainsi à influencer le débit sanguin dans un organe, comme la concentration des nutriments dans les cellules de l'organe, les niveaux d'O_2 et de CO_2, la variation du pH sanguin et la libération par les cellules endothéliales de différentes substances vasoactives (ex. : endothéline, oxyde nitrique).[1,2]

Anatomie et Circulation rétiniennes

La rétine est un tissu photosensible constitué de 10 couches cellulaires interconnectées (Fig. A) ayant pour fonction ultime le traitement et l'acheminement de

l'information visuelle au cerveau: 1) La première couche est l'épithélium pigmenté, 2) la deuxième couche est constituée des cellules photoréceptrices, cônes et bâtonnets, qui transforment l'énergie lumineuse en énergie électrique et acheminent cette information via un relais de diverses interconnexions jusqu'aux cellules ganglionnaires. Les bâtonnets permettent la vision scotopique alors que les cônes permettent la vision photopique des détails, 3) la troisième couche est la membrane limitante externe constituée des segments internes et externes des photorécepteurs, 4) suivie de la couche nucléaire externe contenant les noyaux des photorécepteurs, 5) une couche plexiforme externe dans laquelle on retrouve les synapses entre les axones des photorécepteurs et les dendrites des cellules horizontales et bipolaires, 6) une couche nucléaire interne, formée par les noyaux des cellules horizontales, amacrines et bipolaires, 7) suivie de la couche plexiforme interne contenant les synapses entre les terminaisons des axones des cellules bipolaires et amacrines avec les dendrites des cellules ganglionnaires, 8) la huitième couche est constituée des noyaux des cellules ganglionnaires, 9) la neuvième couche est formée des axones des cellules ganglionnaires, la couche de fibres nerveuses qui iront former le nerf optique et 10) la dixième couche est la membrane limitante interne séparant la rétine du vitré.[2,5]

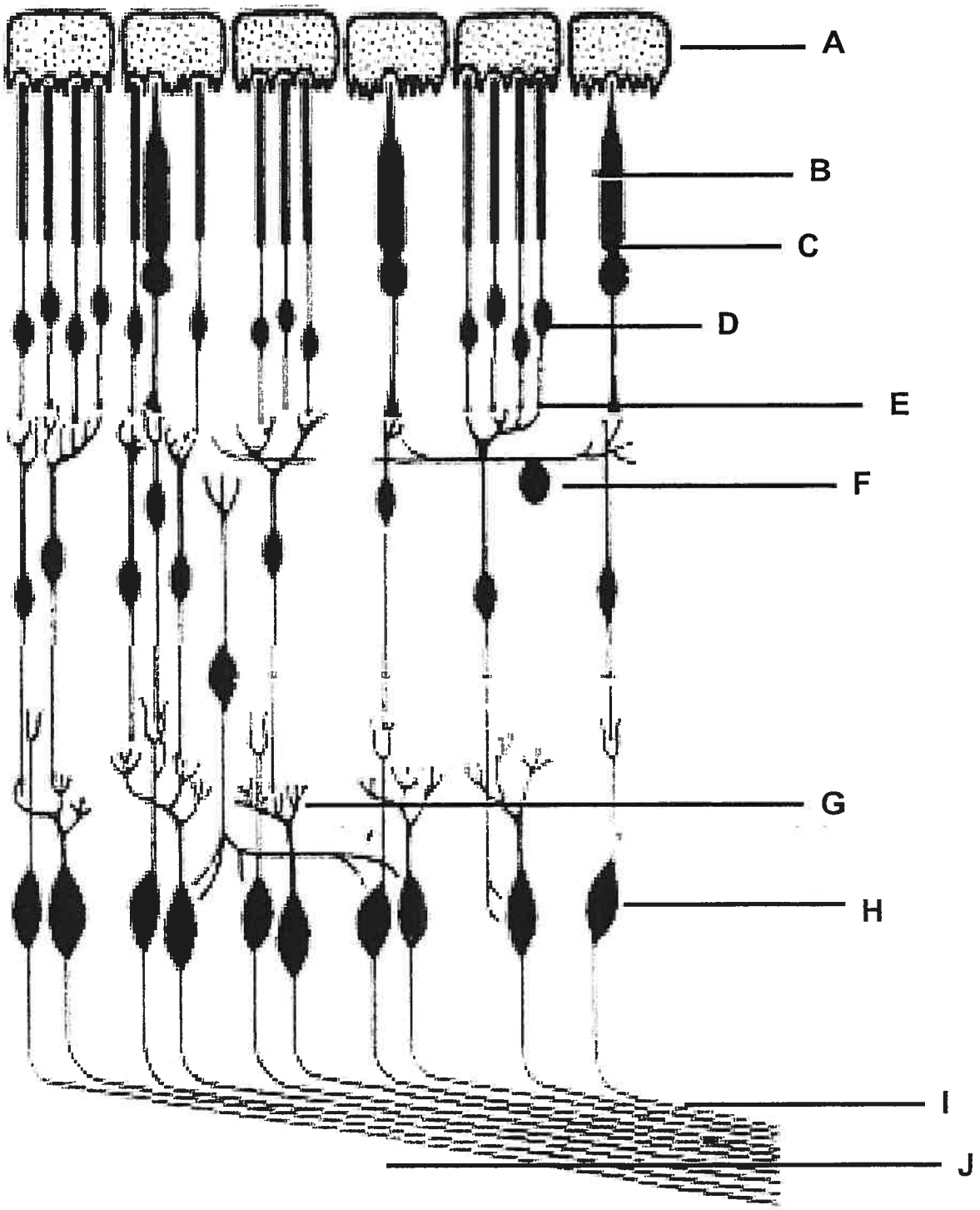

Figure A Représentation schématique de l'organisation cellulaire rétinienne : A) Epithélium pigmenté, B) Photorécepteurs, C) Membrane limitante externe, D) Couche nucléaire des photorécepteurs, E) Plexiforme externe, F) Couche nucléaire des cellules horizontales, amacrines et bipolaires, G) Plexiforme interne, H) Noyaux des cellules ganglionnaires, I) Fibres du nerf optique et J) Membrane limitante interne.

La rétine est alimentée par un double système vasculaire constitué par la circulation de l'artère centrale de la rétine et la circulation cilio-choroïdienne. Des différences tant anatomiques que fonctionnelles caractérisent ces deux systèmes qui partagent une origine commune, soit l'artère ophtalmique qui elle-même est issue de l'artère carotide interne. Les demandes métaboliques de la rétine sont très importantes d'où la nécessité pour la circulation rétinienne d'être constante, et ce, malgré les fluctuations des paramètres environnementaux (ex : luminosité) ou physiologiques (ex : variation de la pression artérielle systémique). La circulation de l'artère centrale de la rétine fournit environ 5 % de l'apport total sanguin de l'œil, mais ceci est contrebalancé par une forte extraction d'oxygène sanguin.[5,6]

L'artère centrale de la rétine, qui se divise en quatre branches principales allant nourrir chacun des quadrants de la rétine, irrigue les 2/3 internes de la rétine tandis que l'apport sanguin du 1/3 externe de la rétine et de l'épithélium pigmenté est assuré par la circulation choroïdienne. Le réseau de capillaires en provenance de l'artère centrale de la rétine est localisé plus superficiellement au niveau de la couche des fibres nerveuses et plus profondément dans la couche nucléaire interne. Les vaisseaux rétiniens nourrissant la partie nasale de la rétine sont plus courts et ont une trajectoire plus directe comparativement aux vaisseaux temporaux, dont la trajectoire forme un arc au-dessus et en-dessous de la région maculaire.[5,6]

La choroïde est une membrane mince fortement vascularisée située entre la rétine et la sclère, et dont la fonction est d'approvisionner les couches externes de la rétine en

oxygène et substances nutritives. Les artères postérieures ciliaires courtes, en provenance de l'artère ophtalmique, fournissent l'apport sanguin à la choroïde. La choroïde se compose de deux couches distinctes de vaisseaux sanguins : une couche externe de vaisseaux de plus gros calibre et une couche interne, la choriocapillaire, qui possède une densité élevée de capillaires et est apposée sur l'épithélium pigmenté de la rétine. Le diamètre des capillaires de la choriocapillaire, est variable (20 à 50 μm). Leur densité est maximale dans la région maculaire, dont les besoins métaboliques sont élevés, et ils sont distribués selon un gradient décroissant du centre vers la périphérie de la rétine. De par leur fonction, l'ultrastructure des capillaires de la choriocapillaire est différente de celle des capillaires rétiniens, ces derniers formant la barrière hématorétinienne et possédant une paroi non fenestrée. Les capillaires de la choriocapillaire ont une paroi fenestrée facilitant les échanges métaboliques. Environ 80 % du débit sanguin oculaire parvient à la choroïde par la circulation cilio-choroïdienne. Ce fort volume sanguin, en plus d'aider au contrôle de la température de l'œil, est aussi essentiel pour répondre à la demande en nutriments et en oxygène de la rétine.[5,6]

Régulation du débit sanguin rétinien

Les vaisseaux sanguins de la rétine ne sont pas innervés par le système nerveux autonome.[7] Les études ont démontré que la circulation rétinienne a une bonne capacité d'autorégulation vasculaire, c'est-à-dire l'habileté de maintenir un débit sanguin constant malgré un changement de pression de perfusion oculaire. Cette autorégulation est effectuée par des facteurs locaux tels que l'endothéline, l'oxyde nitrique et le système rénine-angiotensine [8,9,10] qui altèrent la résistance des vaisseaux.

Hyperoxie

L'hyperoxie est définie comme étant une hausse de la tension d'oxygène dans le système vasculaire. Frayser et Hickham (1965) ont démontré que l'inhalation d'oxygène pur générait une vasoconstriction des vaisseaux rétiniens.[11] Ces données ont été appuyées par d'autres travaux démontrant une vasoconstriction[12] des artères rétiniennes ainsi qu'une diminution du débit sanguin.[13,14,15] Les mécanismes sous-jacents à la vasoconstriction induite par l'oxygène demeurent non élucidés. Il a été démontré que les récepteurs à l'endothéline jouent un rôle dans la vasoconstriction induite par l'hyperoxie chez le sujet sain.[16,17] Des études animales ont indiqué que la tromboxane-A_2, le 20-HETE et le cytochrome P450 joueraient un rôle dans la vasoconstriction induite par l'hyperoxie.[18,19] Finalement, l'alcalinisation intra- et extracellulaire observée en période d'hyperoxie pourrait influencer le débit sanguin rétinien en agissant sur les péricytes.[20,21,22]

Jusqu'à tout récemment, le diamètre des vaisseaux rétiniens était généralement déterminé à l'aide de mesures effectuées sur des photographies monochromatiques du fond d'œil testé. Ces photographies étaient prises sous forme de diapositives puis numérisées et analysées.[23] Cette méthode longue et fastidieuse nécessitait la prise de plusieurs mesures et des corrections étaient nécessaires pour compenser le grossissement de la caméra. Ce type d'analyse ne permettait pas l'évaluation en temps réel de la dynamique des vaisseaux dans les divers quadrants de la rétine.

Le Retinal Vessel Analyzer (RVA) est un système de mesure des vaisseaux rétiniens qui a été développé récemment.[24,25] Ce système a la capacité de mesurer le diamètre des vaisseaux rétiniens en temps réel. Il est composé d'une caméra de fond d'œil, d'une caméra vidéo, d'une carte d'acquisition numérique, d'un ordinateur, d'un logiciel d'acquisition et d'analyse d'images, d'un système d'enregistrement et de stockage des images et de deux moniteurs, l'un permettant de visualiser le fond d'œil et l'autre de mesurer les vaisseaux sanguins. L'acquisition des images se fait en temps réel à une fréquence de 25Hz et le système permet leur analyse en temps réel. Une analyse subséquente en post-acquisition peut aussi être effectuée à partir des données enregistrées. Il s'agit d'un avantage considérable, puisque les analyses de l'ensemble des vaisseaux rétiniens se feront dans les mêmes conditions expérimentales.

Projet de recherche

Le but de cette étude est d'évaluer la régulation vasculaire des vaisseaux rétiniens en mesurant les variations du diamètre des artères et des veines en présence d'hyperoxie systémique à l'aide du RVA. Une meilleure compréhension de la régulation vasculaire dans chacun des quadrants rétiniens chez le jeune adulte en santé est essentielle pour nous aider à définir, ultérieurement, les anomalies de régulation vasculaire accompagnant les pathologies oculaires d'origine vasculaire, ou le vieillissement.

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Systemic hyperoxia and retinal vasomotor responses

Abstract

Purpose. Several studies have investigated the changes in retinal vessel diameter during physiological stress or pathological conditions. However, these studies were principally based on individual fundus photographs and as such did not allow the evaluation of vessel dynamics over time. Our research objective was to detail the time-course and amplitude changes in the diameter of arteries and veins across all retinal quadrants, during and after an hyperoxic vascular stress.

Methods. The dynamics of changes in retinal vessel diameter were quantified with the Retinal Vessel Analyzer, a system coupled with a Zeiss fundus camera, that allows digitization of fundus images in real time, as well as post-acquisition analyses. Twenty young adults participated in this study where the vessel diameters were measured during successive phases of breathing either room air or pure oxygen. The oxygen saturation level (SaO2), end-tidal carbon dioxide (EtCO2), pulse rate (PR), respiratory rate (RR) and blood pressure (BP) were also monitored throughout testing.

Results. Systemic hyperoxia was accompanied by an increase in SaO_2 and a decrease in $EtCO_2$. During systemic hyperoxia, the retinal veins and arteries in all quadrants constricted by about 14% and 9%, respectively. Subsequently, during breathing of ambient air, all vessels progressively returned towards their baseline caliber. The degree of vasoconstriction did not differ across retinal regions.

Conclusions. These data indicate that the retinal vessels change caliber uniformly across retinal quadrants in the healthy young adult, during a systemic hyperoxic stress.

This type of physiological vascular provocation could be used to investigate the quality of vascular regulation during aging and vascular pathologies of the eye.

Keywords: retinal vessels, Retinal Vessel Analyzer, systemic hyperoxia, vascular autoregulation

Introduction

The retinal vasculature does not have sympathetic innervation[1], it maintains optimal nutrition and oxygenation to the retina through vascular autoregulation (AR). AR is the ability to keep blood flow constant in spite of altered perfusion pressure, or to adjust blood flow to the metabolic requirements of a given tissue[2]. These mechanisms are mediated by factors such as the pH level, various endothelial vasoactive agents (endothelin, nitric oxide), or the oxygen and carbon dioxide tension[3].

Ocular hemodynamic responses and retinal vessel reactivity can be studied with the use of various non provocative procedures such as aerobic exercise[4,5], altered body position[6], cold pressor stimulation[7], or blood gas perturbations[8,9].

Pure oxygen breathing provocation has often been used to demonstrate retinal vascular AR[10-13], seen as a vasoconstriction of retinal vessels[10,14-16] or a decrease in retinal blood flow[15,16]. Pure oxygen breathing has also been used to reveal abnormal AR in ocular diseases such as diabetic retinopathy[17] or glaucoma[18]. Other studies have used pure oxygen breathing and reported either regional retinal differences in vascular reactivity[13,19], or no such regional differences[20].

The investigation of retinal vascular reactivity in the various regions of the retina is particularly important in view of reports indicating that various vascular-related ocular diseases may affect a portion of the retina and/or visual field to a larger degree. In glaucoma, it has been reported that the superior visual field was affected more often than the inferior visual field[21] and that retinal vessel narrowing with progression of

disease was more pronounced in the inferior retina[22]. In diabetes, it has been reported that vascular anomalies were more frequent in the superior retina[23], although it has also been shown that reductions in visual field sensitivity tended to be localized in the superior quadrants[24].

To our knowledge, only one study has investigated the human retinal vessel reactivity to systemic hyperoxia in all retinal quadrants[13]. The authors used the retinal vessel analyzer (RVA)[25,26] to study the effect of prolonged hyperoxia on the time-course of retinal vasoconstriction. They reported a greater vessel reactivity to oxygen in the temporal *vs* nasal arteries and veins. Unfortunately, no data were presented for the individual quadrants, or the superior *vs* inferior retina. Furthermore, no attempt was made to evaluate the time-course for recovery from the vascular stress.

Our objective was to detail the time-course and amplitude changes in the diameter of arteries and veins across all retinal quadrants, during and after an hyperoxic vascular stress, using the RVA system.

Methods

Subjects

Twenty (9 men, 11 women) healthy non-smoking subjects (mean age: 24.1 ± 2.9 years) participated in the present study. All subjects had 6/6 visual acuity, good systemic and ocular health and were not taking any vasoactive medication. Subjects were instructed to abstain from alcohol and beverages containing caffeine for 24 h before the study day. Each subject signed a written consent to participate after the nature of the

study and experimental protocol were explained in detail. All experimental procedures conformed to the tenets of the Declaration of Helsinki for human research.

Subject preparation

The cornea from the right eye was anesthetized with 1 drop of proparacaine HCl 0.5% and the intraocular pressure (IOP) measured by applanation tonometry. The right pupil of each participant was then dilated with 1 drop of tropicamide 1% and 1 drop of phenylephrine 2.5%. The subject was asked to sit on a stool located in front of the RVA system to be used in the study and to relax for at least ten minutes to stabilize the systemic blood pressure (BP) and pulse rate (PR) prior to the experiment.

Continuous blood pressure measurement

A continuously recording non-invasive BP system (Colin NIBP 7000, San Antonio, Texas) was used to monitor the BP throughout the experiment. To this effect, a standard cuff was positioned over the brachial artery of the subject's right arm, which was resting comfortably at heart level on the RVA camera table with the palm of the hand facing upwards. Furthermore, a retainer system was positioned under the right forearm and hand, and was held in place around the arm with two bands of velcro to prevent movement of the wrist during recordings. A piezoelectric sensor was then placed over the radial artery, with the sensor positioned just on top of the area where the arterial pulse was best detected. Both the cuff and sensor were connected to the central NIBP unit which was interfaced with a Macintosh computer containing the Acknowledge software analysis package (BioPak, Santa-Barbara, USA) used to record the real-time (25Hz) analog signal from the sensor throughout testing. This analog signal was

digitized and fed into four additional acquisition channels to allow simultaneous measurements of the systemic systolic and diastolic BP, as well as the quantification of the BP mean and the ocular perfusion pressure (OPP). The OPP was derived on-line from the BP mean data and the IOP that had been entered beforehand in the software for each subject. The following formulaes were used for deriving the BP mean and the OPP: BP mean = BP diast + (BP syst – BP diast) /3 and OPP = 2/3 BP mean – IOP. Once the experimenter activated the NIBP system, the BP was first measured from the brachial artery. The sensor positioned on the wrist then adjusted itself to this BP level, by moving the piezoelectric detector over the radial artery to find its optimal position. The BP from the brachial and radial arteries were measured automatically by the NIBP system until there was good agreement between measurements. Once this calibration was achieved, the brachial cuff was removed and all subsequent BP measurements were taken continuously from the radial artery throughout the experiment.

Gas breathing system and physiological variables

While the NIBP calibration was being performed, the experimenter placed an eye patch over the left eye of the subject and adjusted the mask on his face. This soft rubber mask (7930 series; Hans-Rudolph; Kansas City, Missouri) was placed over the mouth and nose, after a nose clip had been installed, to ensure that breathing would be through the mouth only. The mask was held in place with a headband attached on each side of the mask with velcro bands and tight clips. The subject was then asked to position his head on the forehead and chin rest of the fundus camera. Two one-way valves located on either side of the mask allowed the test gas to be inhaled on one side and exhaled on the other side of the mask. A 3.4-inch diameter plastic tube was

attached on the incoming side of the mask, while the other end of this tube was either left open to the ambient air or was connected to a 10 liter reservoir bag (non-diffusing gas collected bag; 6015 series; Hans-Rudolph; Kansas City, Missouri) filled with 100% oxygen. A tygon tubing connected a cylinder tank containing pure oxygen to the reservoir bag. The small plastic tube on the outgoing side of the mask was left open to the air. A fine cannula (no 1606, Salter Labs, Arvin, California) attached to this tube, just after the location of the one-way valve, was connected to a capnograph/oximeter system (model 7100 CO_2SMO, Novametrix, Trudell Medical, Montreal) to sample the air exhaled by the subject. This provided measurements of the end-tidal carbon dioxide ($EtCO_2$) and respiratory rate (RR). A red/infrared sensor attached to the CO_2SMO system was positioned on the middle finger of the left hand for oxygen saturation (SaO_2) and PR measurements. The $EtCO_2$, RR, SaO_2 and PR were monitored continuously throughout the experiment.

Retinal Vessel Analyzer (RVA)

The RVA system has been designed to allow real-time (25 Hz) recordings and post-acquisition analyses of the diameter of the retinal arteries and veins. It is composed of a Zeiss fundus camera (Zeiss Model FF 450, Jena, Germany), a high resolution black and white CCD video camera, a digitizing acquisition card, a video recorder storage medium, a computer, two monitors for fundus image viewing and software acquisition/analysis display and a dedicated software.

The experimenter finalized the adjustment of the camera settings and eye alignment in preparation for the protocol. The subject was asked to follow a pointer

located within the optics of the fundus camera in order to position the optic nerve head (ONH) in the center of the viewing monitor screen so as to prevent vignetting of the image during recordings. The brightness and focus of the 30° field live image recorded under red-free illumination were then adjusted to optimize the contrast and focus of the retinal vessels on the display screen. Once all these adjustments were completed the experimenter positioned a square box over the retinal region of interest containing the vessel to be analyzed on-line during the experiment. A cursor was then placed over the vessel of interest to draw a parallelogram measuring about 0.5 mm in length on that vessel. This automatically started the on-line, real-time acquisition and analysis of the vessel diameter along the 0.5 mm distance identified, as a function of time. Simultaneously, an event marker was put on the NIBP and CO_2SMO systems to indicate the start of the experiment. All three recording systems were continuously monitored by the experimenter throughout testing. Feedback to and from the subject was also provided throughout testing to insure subject's comfort, proper chin and forehead positioning and quality of fixation. The subject was encouraged to blink normally throughout testing. The RVA software automatically corrects for slight alterations in luminance created by small eye movements, and it does not acquire data during blink artefacts. The RVA images were stored on a s-VHS videotape. Post-acquisition analyses could be made after the test session by re-playing the live fundus images from the videotape. To that effect, a new 0.5 mm long parallelogram window was positioned on any other vessel of interest for analysis. All vessels analyzed were located within a one disc diameter distance from the ONH border. For each subject, one artery and one vein was analyzed in each of the supero-temporal (ST), supero-nasal (SN), infero-temporal (IT) and infero-nasal (IN) quadrants of the retina.

Test gas

All testing was performed in a quiet dimly illuminated laboratory, at ambient room temperature and at sea level atmospheric pressure. The test protocol was divided into three consecutive phases where the subject had to inhale: 1) room air for 2 minutes, 2) 100% oxygen for 12 minutes, and 3) room air for 12 minutes, through the face mask. These three phases were considered as the baseline, pure oxygen and recovery phases, respectively. At the end of the baseline phase, the reservoir bag filled with oxygen was connected to the mask to start the pure oxygen experimental phase, and it was quickly disconnected once the recovery phase was started. Event markers were positioned on each of the NIBP, CO_2SMO and RVA systems to indicate the beginning and the end of each test phase. All data were stored on their respective storage medium as soon as the experiment was completed.

Data analyses

All data for the SaO_2, $EtCO_2$, PR, RR, BP mean, BP syst, BP diast and OPP were transferred on an Excel spreadsheet from the CO_2SMO and NIBP systems, respectively. Data for each variable were group-averaged across subjects, as a function of time into the experiment. Another analysis was performed, where all data contained in each of the experimental phases were group-averaged together for each subject and for each physiological variable obtained. However, for the SaO_2 and $EtCO_2$, only the data having reached a steady-state level during the pure oxygen phase were averaged together for that particular experimental phase. All data were then group-averaged across subjects for each variable.

All data for the retinal artery and vein diameters measured in the four retinal quadrants were transferred on an Excel spreadsheet from the RVA system. For each subject and for each vessel, the data were normalized to a common baseline level by assigning 100% to the mean value averaged over the 120 sec baseline period. All normalized data were then group-averaged across subjects for each vessel measured in the various retinal quadrants as a function of time into the experiment. An analysis of the following parameters (see Figure 1) was also performed on the raw data for each subject and each vessel measured: 1) average of all data during the baseline phase, 2) time delay before vasoconstriction during the oxygen phase, 3) slope of the vasoconstriction, 4) latency before achieving a plateau in vasoconstriction, 5) average of all data in the pure oxygen phase contained between the values for the slopes of the vasoconstriction and recovery from vasoconstriction, 6) time delay before the recovery from vasoconstriction, 7) slope of the recovery from vasoconstriction, 8) latency before

achieving a plateau in recovery, and 9) average of all values in the recovery phase contained in the plateau located after the slope of recovery from vasoconstriction. For each subject, the inflexion points in the data sets, at the beginning and end of pure oxygen breathing, were used as reference values for the determination of the slopes. All these data were further group-averaged across subjects for each parameter measured. Figure 1 shows a schematic representation illustrating where the various parameters were measured. These data were derived in order to obtain a better appreciation of the amplitude and time response of the retinal vessels to pure oxygen breathing.

Statistical analyses

All data are expressed as the mean ± the standard error of the mean (SEM) values. Analyses of Variance (ANOVAs) and Student t-tests were used for data comparisons between the various parameters and across subjects. The differences were considered significant for an alpha level of 0.05.

Results

Figure 2 presents a typical fundus picture as seen on the monitor screen during the RVA recording, highlighting the region of interest (square box) and the acquisition window (parallelogram) where the vessel diameter was measured. The group-averaged data obtained for the various physiological variables measured throughout testing and collapsed within each of the three experimental phases are presented in Table 1. The group-averaged SaO_2 increased ($p< 0.0001$) from 97.4% to 98.7% during systemic hyperoxia and returned to its baseline value during the recovery phase. The group-averaged $EtCO_2$ decreased ($p< 0.0001$) by 9.6 % from 39.5 mmHg to 35.7 mmHg during

pure oxygen breathing and was back to baseline value during the recovery phase. The group-averaged PR, RR, BPmean, BPsyst, BPdiast and OPP were not altered ($p > 0.05$) throughout the experiment. Figure 3 presents the group-averaged time-course data for the $EtCO_2$ (A), SaO_2 (B), PR (C) and RR (D), whereas Figure 4 presents the BPmean, BPsyst, BPdiast and OPP data.

The baseline diameter of all retinal arteries and veins had been group-averaged across subjects for each retinal quadrant, as explained in the methods section. The diameter of all retinal arteries and veins were further analysed for each hemi-retina. To that effect, the baseline vessel diameter for each of the nasal and temporal, and then superior and inferior, arteries and veins were combined and group-averaged across subjects. These analyses showed that, overall, the baseline temporal vessels were larger than the nasal vessels, whereas the superior and inferior vessels did not differ in size, for each retinal quadrant and hemi-retina. Table 2 presents the summary statistics for these analyses.

Figure 5 and Figure 6 present the percent change in group-averaged diameter for the arteries and veins, respectively, in each of the ST (A), SN (B), IT (C) and IN (D) retinal quadrants throughout testing. These data indicate that systemic hyperoxia was accompanied by an averaged venous constriction of 15.5 %, 13.9 %, 12.0 % and 14.9 % as well as an averaged arterial constriction of 8.7 %, 9.0 %, 8.9 %, 11.0 % for the ST, SN, IT and IN retinal quadrants, respectively ($p < 0.0001$ for all vessels). Furthermore, the degree of vasoconstriction between the veins across retinal quadrants did not differ ($p > 0.05$), nor did it differ between the arteries across quadrants ($p > 0.05$). Of the eight

vessels analysed, only three had recovered their baseline value by the end of the experiment, the diameter of the other vessels remaining slightly below baseline value.

The results presented in Figure 5 and Figure 6 have been reorganized and are displayed in a different format in Figure 7. This figure shows the percent change in group-averaged diameter for the arteries (left panel) and veins (right panel) throughout testing, comparing the vessel reactivity in the temporal *vs* nasal (top panel) and the superior *vs* inferior (bottom panel) retina. This format presentation highlights the fact that there were no substantial differences in the degree of vasoconstriction of the retinal veins and arteries between the temporal *vs* nasal retina ($p > 0.05$) or superior *vs* inferior ($p > 0.05$) retina.

An analysis was performed to derive the percent change in retinal artery and vein diameter throughout the experiment, for each quadrant, comparing the vessel reactivity between men and women. Although the degree of vasoconstriction for all the arteries and veins differed from their baseline values (for all data $p \leq 0.006$) for both men and women, the degree of vasoconstriction for the veins and the arteries did not differ between men and women in any of the four quadrants ($p > 0.05$). Furthermore, the degree of vasoconstriction for the veins and the arteries did not differ across quadrants for either men or women ($p > 0.05$).

An analysis of the slope of the vasoconstriction (Fig. 1, #3), which was derived from each subject's data for arteries and veins in each quadrant and subsequently group-averaged across subjects, revealed that the slopes did not differ ($p > 0.05$)

between veins and arteries in any of the four retinal quadrants. The slope of the recovery from retinal vasoconstriction (Fig. 1, #7) differed between the arteries and the veins in the ST ($p < 0.0001$) and SN ($p = 0.005$) quadrants, but did not differ in the IT and IN quadrants ($p > 0.05$).

The averaged time delay between the start of pure oxygen breathing and the retinal vasoconstriction (Fig. 1, #2) was 16.4 +/- 2.0 sec for the arteries and 25.1 ± 2.6 sec for the veins. This time delay did not differ between arteries and veins in any of the retinal quadrants ($p > 0.05$) except for the SN quadrant ($p = 0.022$). The averaged latency between the start of pure oxygen breathing and the plateau of vasoconstriction (Fig. 1, #4) was 194.2 ± 12.4 sec and 274.9 ± 15.4 sec for the retinal arteries and veins, respectively. This latency differed between arteries and veins in the ST ($p < 0.001$), IT ($p = 0.006$) and IN ($p = 0.025$) quadrants, but not in the SN quadrant ($p > 0.05$). The averaged time delay (Fig. 1, #6) between the end of pure oxygen breathing and the start of recovery from retinal vasoconstriction was 25.0 ± 1.9 sec and 35.2 ± 2.3 sec for the retinal arteries and veins, respectively. This time delay differed between arteries and veins in the ST ($p = 0.016$) and IN ($p = 0.037$) quadrants but not in the SN and IT quadrants ($p > 0.05$). The averaged latency between the cessation of pure oxygen breathing and the recovery plateau (Fig. 1, #8) was 288.9 ± 10.1 sec and 306.4 ± 9.3 sec for the retinal arteries and veins, respectively. This latency did not differ between the arteries and veins in any of the four retinal quadrants.

Discussion

Systemic hyperoxia was achieved during pure oxygen breathing, as indicated by the increased SaO_2 level. Since no attempt was made to achieve isocapnia in the current study, systemic hyperoxia was accompanied by a decrease in $EtCO_2$, which likely represents the reduced affinity of hemoglobin for CO_2 known to occur when the oxygen partial pressure is increased[27]. Both the SaO_2 and $EtCO_2$ resumed their baseline values after discontinuation of pure oxygen breathing. The change in $EtCO_2$ was not accompanied by a modification in the RR. There were no overall alteration in the group-averaged PR during systemic hyperoxia, even if temporal variations were observed.

In the current study, the BP measurements were acquired continuously at 25 Hz throughout testing. Lovasik et al (2003)[5] were the first to use this NIBP technology to reveal the presence of choroidal blood flow regulation, showing a 43% increase in OPP without a paralleled alteration in choroidal blood flow. To our knowledge, no previous study has detailed the time-course of pure oxygen breathing on the OPP. Our results clearly indicate that the systemic BP and the OPP remain fairly constant throughout the hyperoxic vascular stress. Although the IOP was not measured continuously during testing, an earlier study had shown that pure oxygen breathing reduces IOP by only 1mmHg, a change that would not modify the OPP substantially[8].

Earlier studies have reported that retinal blood flow was higher in the temporal versus the nasal retina, but similar between the superior and inferior retina[20,28,29]. Although blood flow was not measured in the present study, our results indicate that the

baseline vessel diameters were larger in the temporal versus the nasal retina, but similar between the superior and inferior retina. This was the case for the comparisons of vessels across retinal quadrants, as well as comparisons looking at the temporal *vs* nasal or superior *vs* inferior hemi-retinas. Our data therefore support these previous findings, considering that blood flow is a function of the fourth power of the radius of a vessel[30]. These regional differences in retinal blood flow have been attributed to the fact that the temporal retina is larger than its nasal counterpart and contains the highly-metabolic macular area[31,32].

Our results indicate that systemic hyperoxia induces a vasoconstriction in the arteries and the veins in each of the four retinal quadrants. On average, the veins constricted by 14.0% and the arteries by 9.4%. These results compare well with those found in other studies having used pure oxygen to investigate vessel reactivity. These studies have reported a 14.9% decrease in retinal vein diameter[33], a 12% reduction in artery and vein diameter[10], or a 13-15% and 11-12% reduction in retinal vein and artery diameter, respectively[13] with systemic hyperoxia.

The degree of hyperoxic-induced vasoconstriction was found not to differ between veins across retinal quadrants, nor did it differ between arteries across quadrants. An additional analysis, looking at the temporal *vs* nasal retina and superior *vs* inferior retina also indicated that there were no regional differences in the degree of hyperoxic-induced arterial and venous constriction across retinal sectors. Our results differ from those published recently by Kiss et al (2002)[13], who also used the RVA system to investigate the vessel reactivity to an oxygen-induced vascular stress. These

authors reported that the retinal vasoconstriction achieved by the nasal arteries and veins was less pronounced than the one observed in the temporal vessels. Unfortunately they did not provide data on the vessel reactivity in each quadrant, even if these measurements were likely performed to derive the sectorial analyses. The degree of vasoconstriction by quadrant would have better revealed the actual vessel reactivity, since the combination of more data points in the sectorial analysis may have increased the chances of finding a difference by decreasing the overall variance. Our data are more in line with those presented earlier by Rassam et al (1996)[20]. Even if their data are more static in nature, having used vessel measurements from retinal photographs, they found that systemic hyperoxia induced a similar degree of constriction between the temporal and nasal vessels. Our data further indicate that there were no differences in the level of vasoconstriction across retinal quadrants or between the superior *vs* inferior retina. Overall, our data indicate that in the young healthy adult, there is no heightened susceptibility across the retina to a very potent metabolic, short-lived vascular stress. Future studies should be performed to verify if vascular regulation is also uniform and identical across retinal quadrants during pressure-related vascular provocation, such as happens during altered ocular perfusion pressure.

We have made an effort in the current study to recruit an equal number of men and women. Although we are not aware of any study indicating that the retinal vessel anatomy would be different across the retina between men and women, a few reports have discussed gender-related ocular blood flow results. A few studies have shown that females have a higher pulsatile ocular blood flow than males[34-36]. On the other hand, it has also been reported that the subfoveal choroidal blood flow[37], the blood flow and

vascular resistance in the ophthalmic artery[38], and the blood flow velocity in the ophthalmic artery, central retinal artery, central retinal vein and short posterior ciliary arteries[39] were not different between men and women. Our current results provide new information showing good vascular autoregulatory capacity of the retinal arteries and veins across retinal quadrants that is similar between men and women.

Our data show that the rate of vasoconstriction was slightly faster than the rate of recovery from vasoconstriction for the retinal arteries and veins as indicated by an evaluation of the slope of the data. This denotes a greater ability for retinal vessels to constrict rather than dilate quickly in the presence of a vascular stress. Similarly, the time needed to achieve maximal vessel constriction was shorter than the time taken to recover from this level of vasoconstriction. The short time delay before the initiation of retinal vasoconstriction and recovery from vasoconstriction corresponded rather well to the time-course of systemic hyperoxia. Overall, in spite of a few differences, the time-response dynamics of the arteries and veins was quite similar across retinal quadrants. Our data indicate that it takes about three to four minutes for retinal vasoconstriction to develop fully in the presence of systemic hyperoxia, a finding that is in line with published data[13]. Furthermore, our results provide new data indicating that the recovery from vasoconstriction takes a minimum of 4 minutes, but for most vessels, full recovery has not yet been achieved by that time.

This study provided a high-resolution detailed time-course evaluation of vessel reactivity to demonstrate that vascular autoregulation is present and uniform across retinal quadrants. These data are important since they provide the basis for further

studies investigating retinal circulation in various diseases leading to vascular ocular disorders.

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TABLE 1. Group-averaged results (n= 20) ± the standard error of the mean value (SEM) for the various physiological variables obtained throughout the experiment.

Physiological variables	Baseline (Air – 21% O_2)	Hyperoxia (100% O_2)	Recovery (Air – 21% O_2)
SaO_2 (%)	97.4 ± 0.21	98.7 ± 0.15*	97.6 ± 0.20
$EtCO_2$ (mmHg)	39.5 ± 0.94	35.7 ± 1.10*	38.5 ± 0.76
PR (bpm)	73.2 ± 2.75	71.5 ± 2.62	74.0 ± 2.62
RR (breaths/min)	14.7 ± 0.90	13.9 ± 0.96	14.3 ± 1.02
BP mean (mmHg)	83.7 ± 1.90	83.9 ± 2.33	84.3 ± 2.40
BP syst (mmHg)	120.0 ± 2.93	120.8 ± 3.52	122.5 ± 3.19
BP diast (mmHg)	63.2 ± 2.19	63.6 ± 2.17	62.8 ± 2.64
OPP (mmHg)	40.6 ± 1.29	40.1 ± 1.58	40.1 ± 1.71

* indicates data that differed at the 0.05 level.

TABLE 2. Summary statistics comparing the baseline vessel diameter for the arteries and veins across the various retinal quadrants and hemi-retinas, highlighting the difference between the nasal and temporal vessel size and the similarity between the superior and inferior vessel size.

Retinal regions	**Diameter (RVA unit)**	***p***
IN arteries SN arteries	109.0 ± 3.6 105.86 ± 3.2	NS
IT arteries ST arteries	124.72 ± 4.5 120.73 ± 3.3	NS
IN arteries IT arteries	109.0 ± 3.6 124.72 ± 4.5	0.0568
SN artery ST artery	105.86 ± 3.2 120.73 ± 3.3	0.0004
IN veins SN veins	110.95 ± 2.4 115.18 ± 3.8	NS
IT vein ST veins	141.7 ± 5.9 142.7 ± 4.6	NS
IN veins IT veins	110.9 ± 2.4 141.7 ± 5.9	0.0008
SN veins ST veins	115.18 ± 3.8 142.7 ± 4.6	0.0001
I arteries S arteries	116.65 ± 3.1 113.48 ± 2.5	NS
I veins S veins	126.91 ± 4.0 129.30 ± 3.7	NS
N arteries T arteries	107.33 ± 2.2 122.44 ± 2.7	< 0.0001
N veins T veins	113.13 ± 2.3 141.99 ± 3.6	< 0.0001

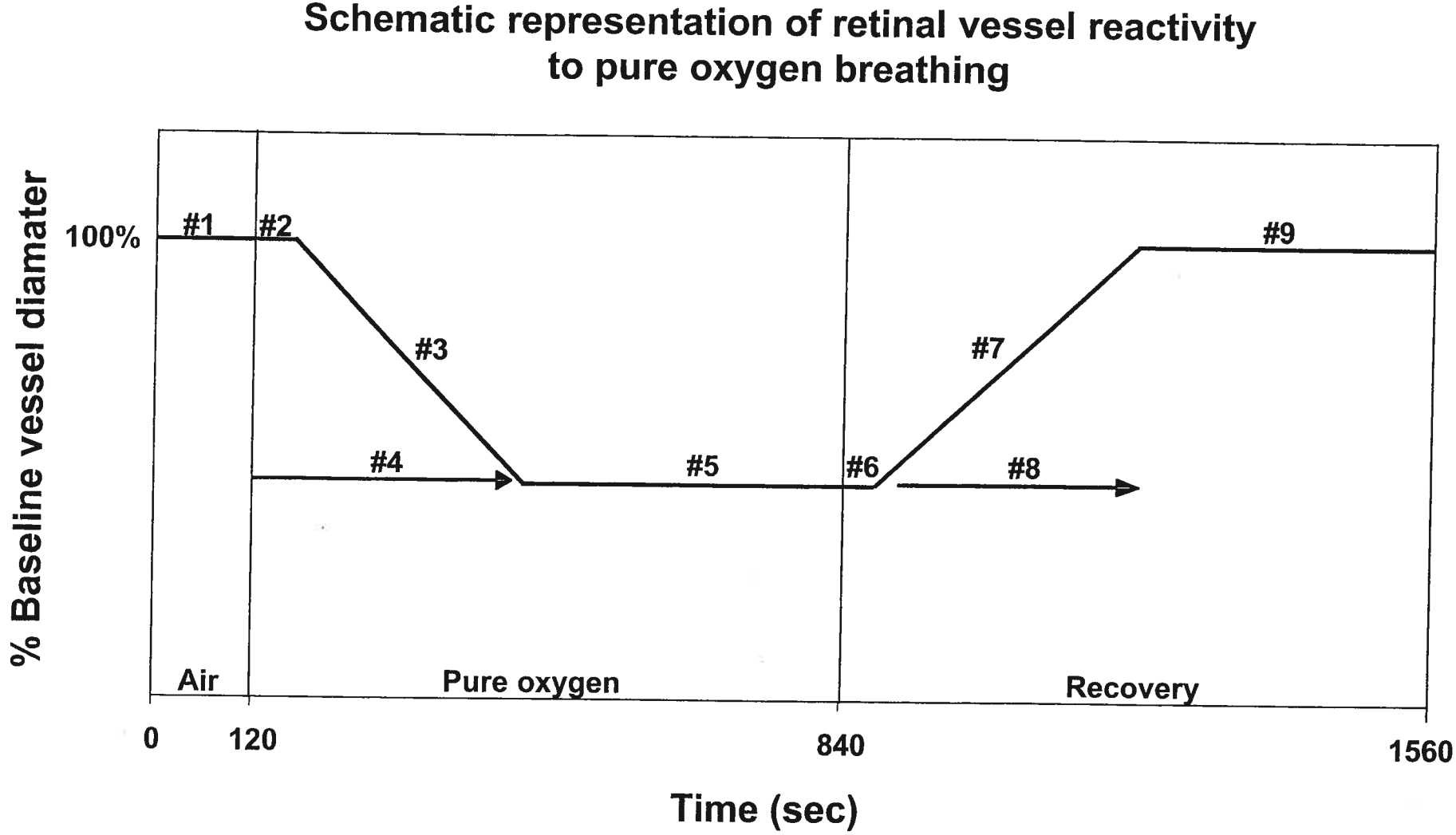

Fig 1 : Schematic representation of retinal vessel reactivity throughout the air, pure oxygen and recovery experimental phases as a function of time. The vertical lines indicate where pure oxygen breathing was started (120 sec) and stopped (840 sec), respectively. The numbers beside the schematic curve indicate the various amplitude and timing parameters of vessel dynamics measured : #1) air, #2) time delay before pure oxygen-induced vasoconstriction, #3) slope of vasoconstriction, #4) latency before the plateau during pure oxygen, #5) plateau during pure oxygen, #6) time delay before the recovery from vasoconstriction, #7) slope of the recovery, #8) latency before the plateau in recovery, and #9) plateau of recovery.

Fundus image from the RVA

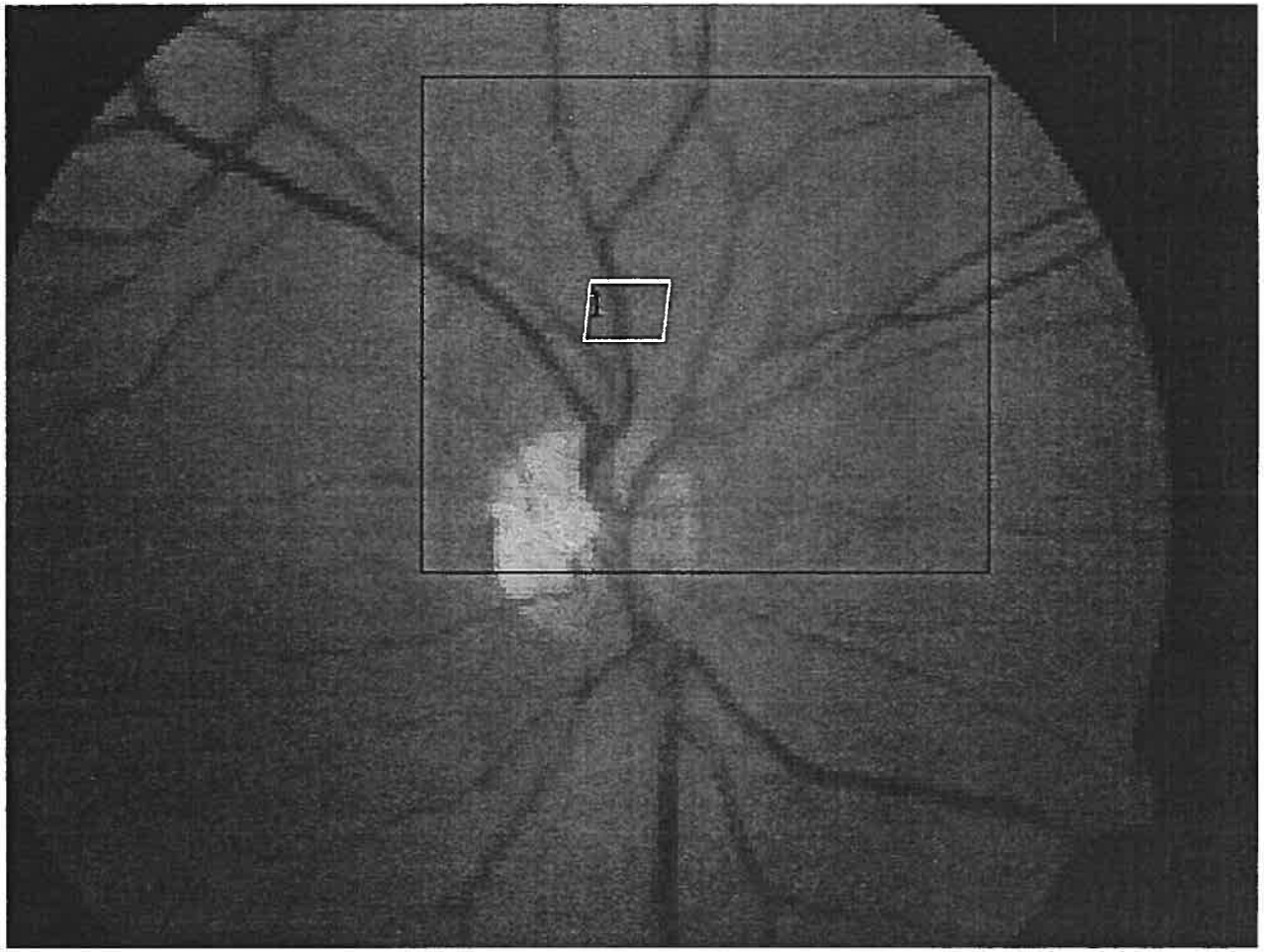

Fig 2 : Fundus image as seen on the RVA monitor, the square box represents the selected region of interest, whereas the parallelogram identifies the vessel under analysis.

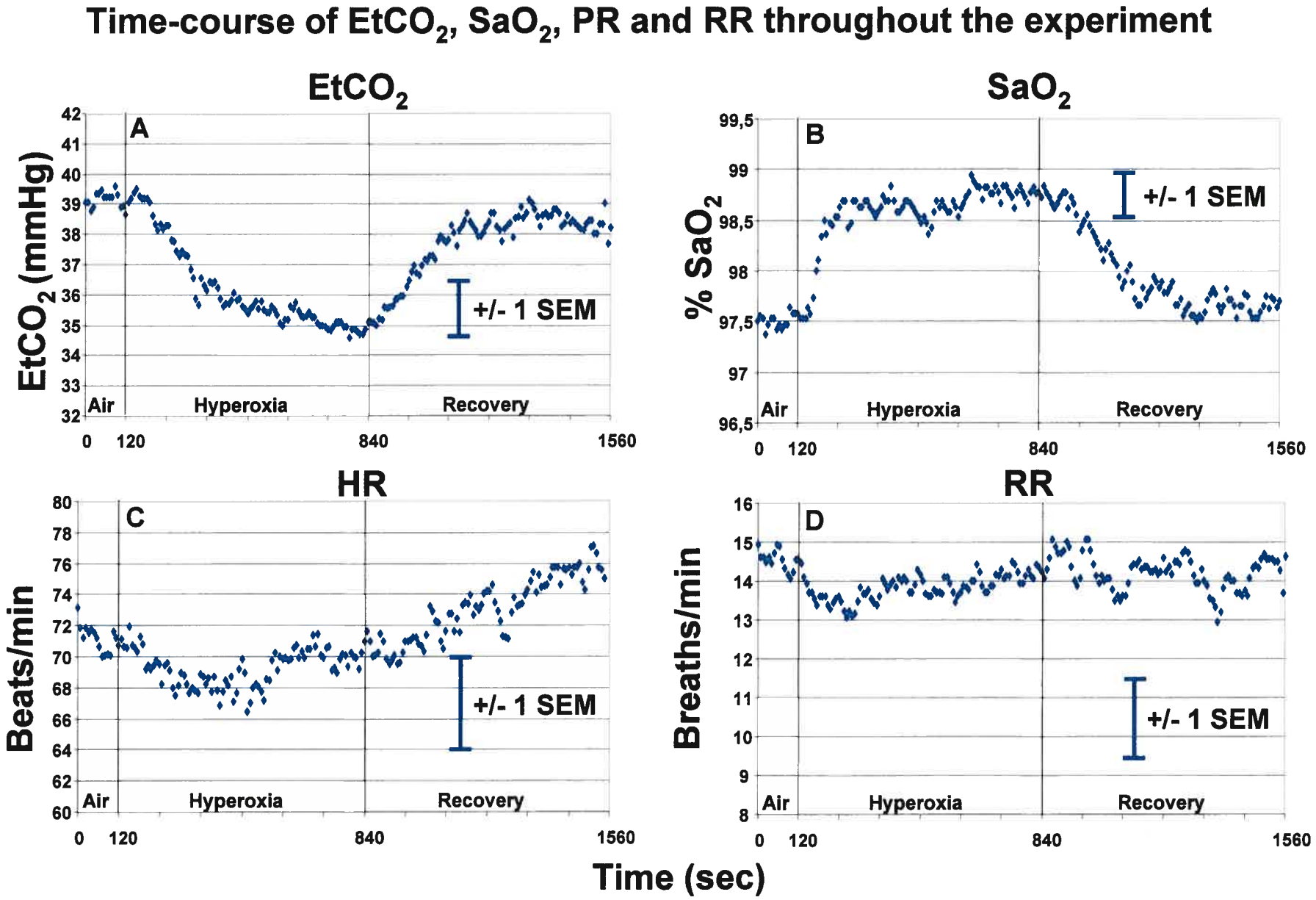

Fig 3 : Group-averaged $ETCO_2$ pressure, SaO_2 pourcentage, HR and RR combined across all subjects (n=20). The vertical line further indicate where pure oxygen breathing was started (120 sec) and stopped (840 sec), respectively.

Systemic blood pressure and ocular perfusion pressure throughout obtained the experiment

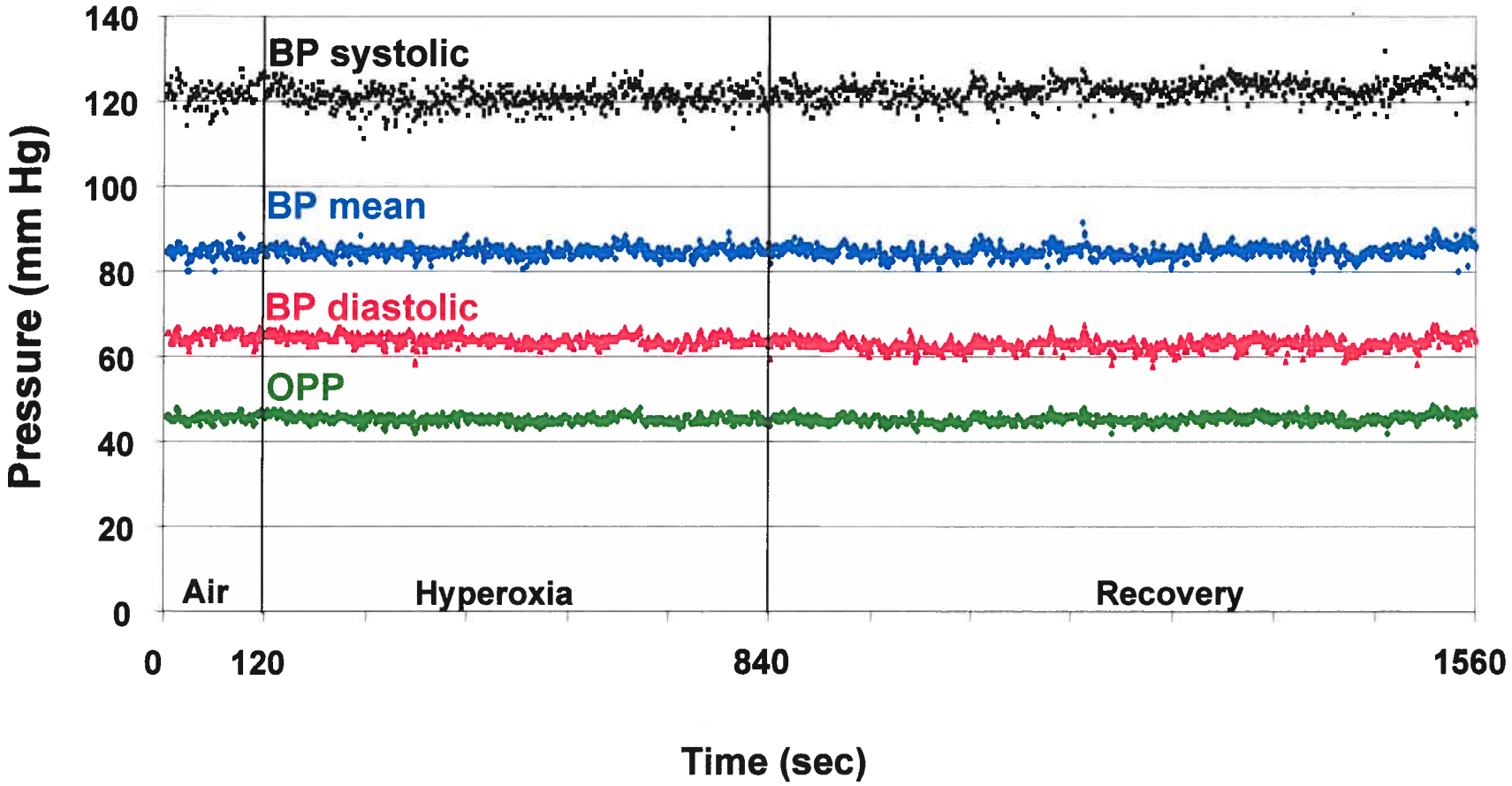

Fig 4 : Group-averaged (n=20) mean, systolic and diastolic blood pressure (BP) and ocular perfusion pressure (OPP) as a function of time into the experiment. Each experimental phase is identified at the bottom of each graph. The vertical lines further indicate where pure oxygen breathing was started (120 sec) and stopped (840 sec), respectively.

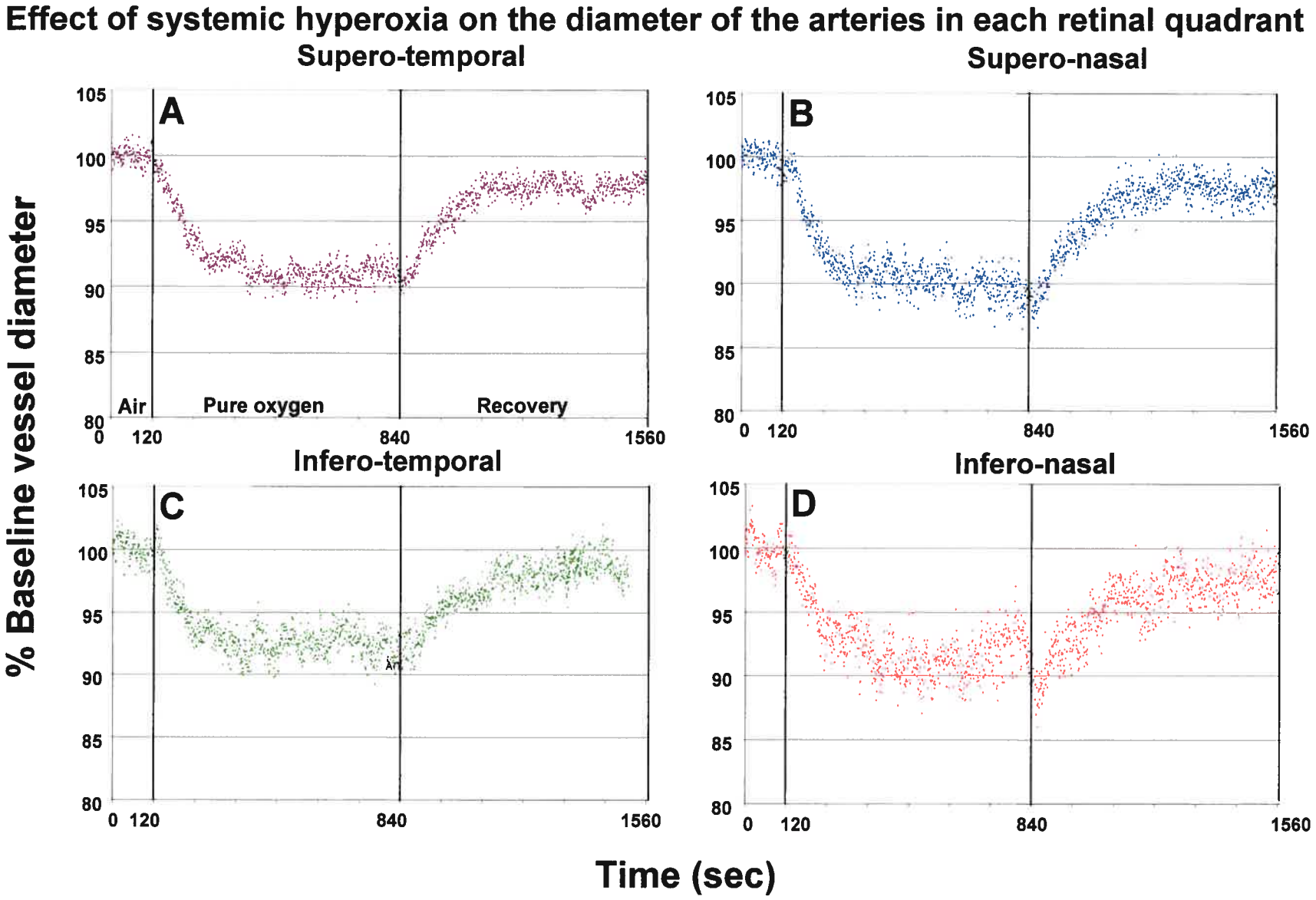

Fig 5 : Percent change in group-averaged diameter for the arteries combined across all subjects (n=20) for each retinal quadrant as a function of time into the experiment. Each experimental phase is identified at the bottom of each graph. The vertical lines further indicate where pure oxygen breathing was started (120 sec) and stopped (840 sec), respectively.

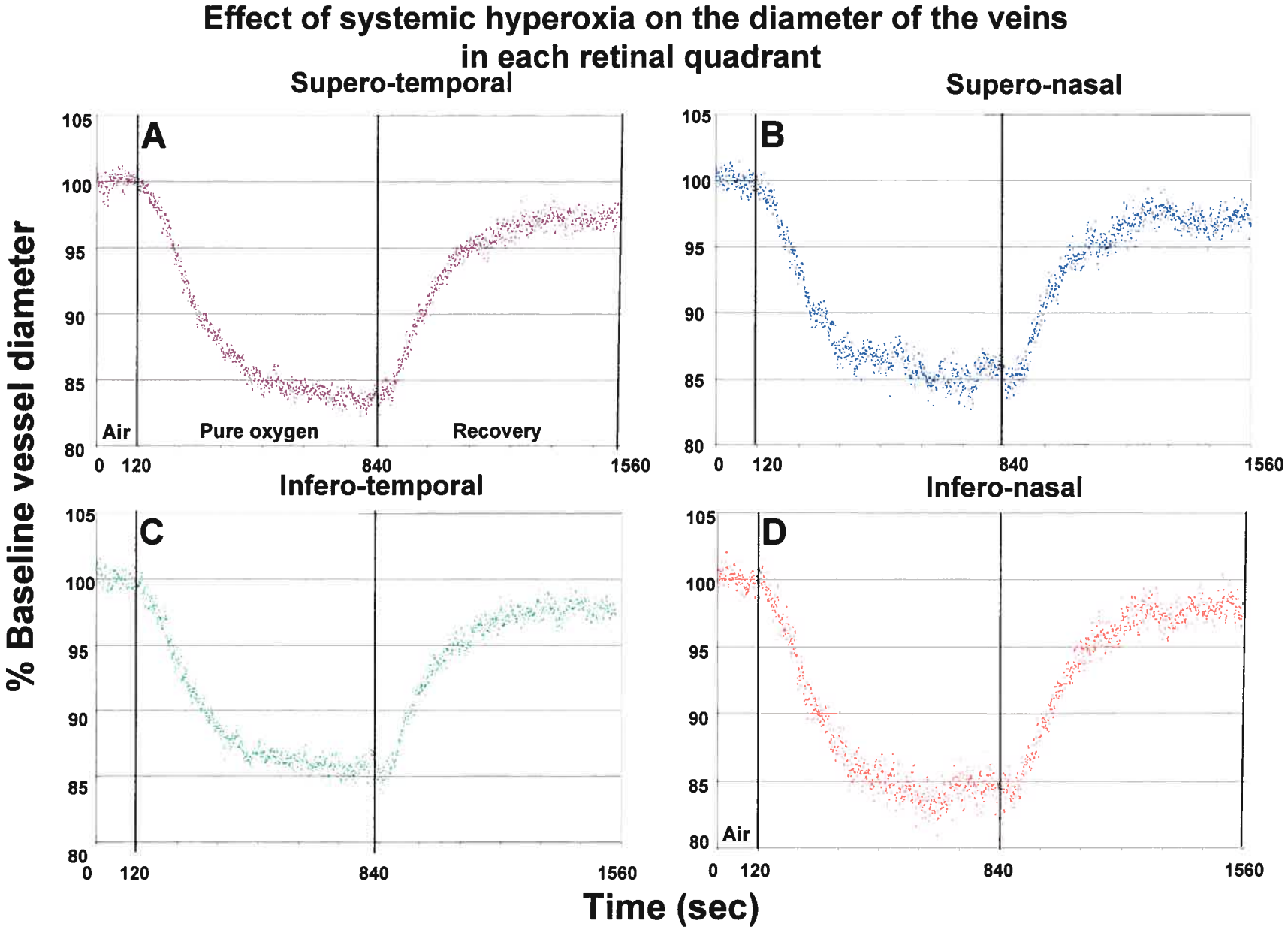

Fig 6 : Percent change in group-averaged diameter for the veins combined across all subjects (n=20) for each retinal quadrant as a function of time into the experiment. Each experimental phase is identified at the bottom of each graph. The vertical lines further indicate where pure oxygen breathing was started (120 sec) and stopped (840 sec), respectively.

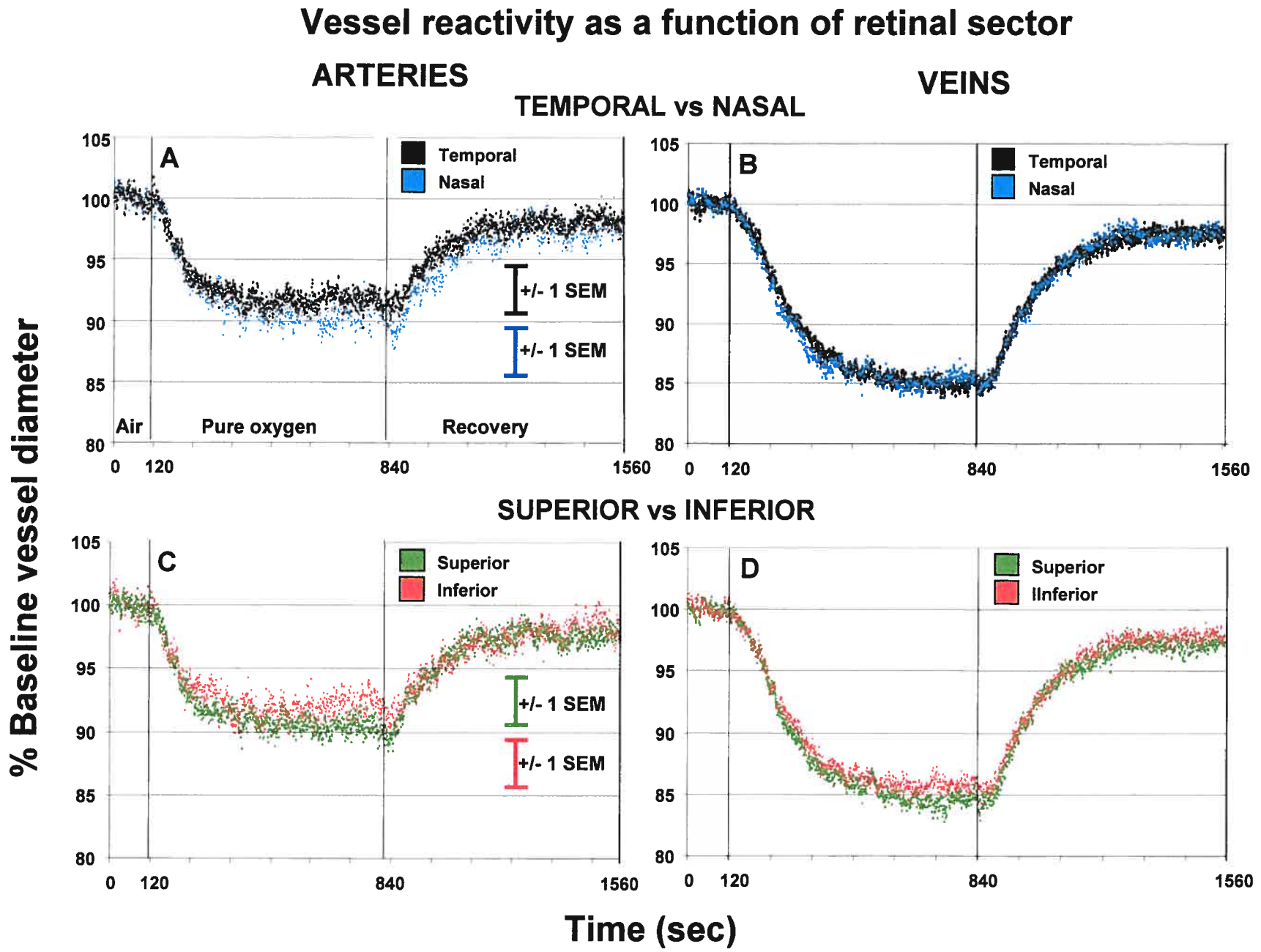

Fig 7 : **Percent change in group-averaged diameter for the arteries (left panel) and veins (right panel) combined across all subjects (n=20) for each retinal sector as a function of time into the experiment. Each experimental phase is identified at the bottom of each graph. The vertical lines further indicate where pure oxygen breathing was started (120 sec) and stopped (840 sec), respectively.**

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Conclusion

Conclusion

Cette étude nous aura permis d'enregistrer les modifications du diamètre des vaisseaux rétiniens, en temps réel, lors d'un stress vasculaire induit par l'inspiration d'oxygène pur chez le jeune adulte en santé. De plus, cette étude nous aura permis de corréler les changements survenant dans le diamètre des artères et veines de la rétine avec diverses variables physiologiques telles que la saturation d'oxygène, le dioxide de carbone de fin d'expiration, le rythme respiratoire, la fréquence cardiaque, la pression sanguine systémique et la pression de perfusion oculaire.

Nos résultats indiquent que l'hyperoxie systémique induite par l'inspiration d'oxygène pur entraîne une augmentation de la saturation d'oxygène et une diminution du dioxide de carbone de fin d'expiration, mais n'altère pas significativement le rythme respiratoire, la fréquence cardiaque, la pression sanguine systémique ou la pression de perfusion oculaire.

L'inhalation d'oxygène pur a induit une vasoconstriction des artères et des veines dans tous les quadrants de la rétine. La vasoconstriction moyenne induite lors de l'hyperoxie systémique était de 8.8% pour les artères et de 14.0 % pour les veines. Même si on ne connaît pas encore le mécanisme d'action précis de l'hyperoxie systémique sur la constriction des vaisseaux rétiniens, il serait raisonnable de penser que des récepteurs sensibles aux variations d'oxygène et de dioxide de carbone, logés dans la paroi des vaisseaux, pourraient être impliqués. Des études ultérieures devront être entreprises afin de mieux comprendre les mécanismes modulant la réactivité vasculaire en période de stress vasculaire induit par l'hyperoxie systémique.

Notre étude a révélé la capacité des artères et des veines rétiniennes à constricter en présence d'hyperoxie systémique. Elle a de plus démontré que cette capacité d'autorégulation vasculaire rétinienne était semblable et uniforme dans les quatre quadrants de la rétine, dans la rétine supérieure *vs* inférieure, et dans la rétine nasale *vs* temporale, chez le jeune adulte en santé. Nos résultats ont de plus indiqué que l'autorégulation vasculaire rétinienne ne différait pas entre les hommes et les femmes. De plus, nos données indiquent que le temps de délai avant la vasoconstriction des vaisseaux rétiniens correspondait relativement bien au temps requis pour développer une hyperoxie systémique. Le temps requis pour que les vaisseaux atteignent leur niveau maximal de constriction était d'environ 3 à 4 minutes, alors que le temps de recouvrement de la constriction était d'environ 5 minutes, indiquant une plus grande habileté des vaisseaux à constricter qu'à dilater.

En résumé, notre étude confirme que les artères et les veines de la rétine constrictent en présence d'hyperoxie systémique. Notre étude fournit de plus des résultats originaux et importants indiquant que: 1) l'autorégulation vasculaire rétinienne est uniforme dans tous les quadrants de la rétine, de même que dans les hémi-rétines supérieure *vs* inférieure et temporale *vs* nasale, 2) l'autorégulation vasculaire rétinienne ne diffère pas entre les hommes et les femmes, et 3) les vaisseaux rétiniens reviennent progressivement à leur valeur de base après une période d'environ 5 minutes. Ces résultats sont importants car ils révèlent la capacité d'autorégulation vasculaire rétinienne, par secteur, chez le jeune adulte en santé. Des études ultérieures pourront être planifiées, sur la base de ces résultats, afin d'étudier plus en détail l'effet du

vieillissement physiologique normal, ou de diverses pathologies oculaires d'origine vasculaire, sur la capacité d'autorégulation vasculaire rétinienne.

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