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ESTUDO DA CINÉTICA DAS CATECOLAMINAS PLASMÁTICAS, GLICOSE E LACTATO SANGÜÍONEOS DURANTE O TESTE DE LACTATO MÍNIMO

Tese apresentada ao Instituto de Biologia para Obtenção do Título de Doutor em Biologia Funcional e Molecular, na área de Fisiologia.

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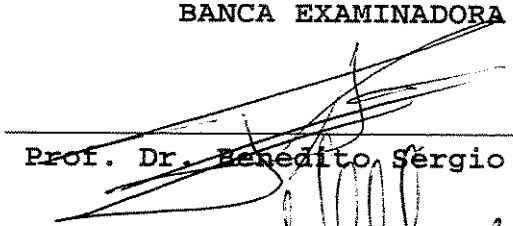

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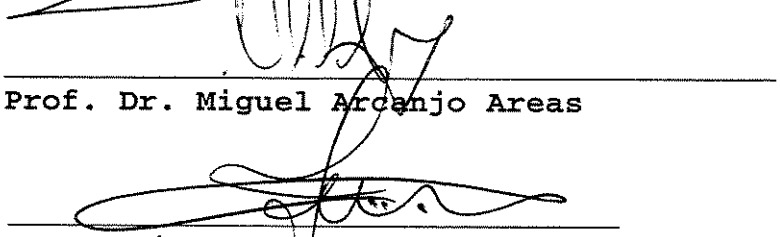

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SUMÁRIO

ABREVIAÇÕES

$\%VO_2max$ = Percentual do consumo máximo de oxigênio

$[Epi]_{min}$ = Concentração mínima de epinefrina plasmática

$[Glic]_{min}$ = Concentração mínima de glicose sangüínea

$[Lac]_{min}$ = Concentração mínima de lactato sangüíneo

$[Nor]_{min}$ = Concentração mínima de norepinefrina plasmática

AMP = Adenosina Monofosfato

ATP = Adenosina Trifosfato

E_{MI} = Intensidade de epinefrina mínima

FC = Freqüência cardíaca

FCmax = Freqüência cardíaca máxima

G_{MI} = Intensidade de glicemia mínima

G_{MS} = Velocidade de glicemia mínima

GMT = Glucose Minimal Test

IAT = Limiar anaeróbio individual

LACmin = Lactate minimum test

Laer = Limiar aeróbio

LAn = Limiar anaeróbio

LDH = Lactato Desidrogenase

LL = Limiar de Lactato

L_{MI} = Intensidade de lactato mínimo

L_{MS} = Velocidade de lactato mínimo

LMT = Lactate minimal test

MSSL = Máxima fase estável de lactato

MSSL = Maximal stead state of lactate

NAD^+ = Nicotinamida-Adenina-Dinucleotideo

NADH = Nicotinamida-Adenina-Dinucleotideo-Hidrogênio

N_{MI} = Intensidade de norepinefrina mínima

OBLA = On set of blood lactate accumulation

OPLA = Onset of plasma lactate accumulation

PO_2 = Pressão Parcial de Oxigênio

VO_2 = Consumo de oxigênio

VO_2max = Consumo máximo de oxigênio

W = Potência de trabalho expressa em Watts

RESUMO

Utilizando o teste de lactato mínimo (TLM), o presente trabalho teve como objetivos analisar: 1) a relação entre as intensidades de esforço correspondentes ao lactato mínimo e glicemia mínima em cicloergômetro; 2) a sensibilidade das variáveis acima citadas em identificar os efeitos do treinamento aeróbio; 3) o efeito do bloqueio beta-adrenérgico sobre as respostas lactacidêmica e glicêmica e 4) a relação entre o comportamento das catecolaminas (epinefrina e norepinefrina) plasmáticas e o lactato sangüíneo. Para as avaliações em cicloergômetro, foram voluntários deste estudo ciclistas e triatletas. Em todas as situações foram aplicados esforços crescentes após a indução de acidose lática (teste de lactato mínimo). Os dados encontrados confirmam a possibilidade de determinação da resposta lactacidêmica durante o exercício a partir da análise do comportamento glicêmico. Além disso, este estudo verificou pela primeira vez a alta sensibilidade do lactato e glicemia mínimos em determinar os efeitos adaptativos do treinamento. A resposta do lactato e da glicose parece estar associada ao comportamento das catecolaminas durante o exercício de cargas progressivas, realizado após um exercício anaeróbio. Sustentando tal afirmação, verificamos alterações dos comportamentos lactacidêmico e glicêmico após bloqueio ß-adrenérgico, além de identificarmos alta correlação entre a resposta das catecolaminas plasmáticas e do lactato sangüíneo durante o TLM. Esses dados sugerem que, pelo menos parte, este comportamento é dependente da estimulação adrenérgica.

ABSTRACT

Using lactate minimum test (LMT) as the experimental protocol, the present study was conducted to analyze: 1) the relationship between lactate and glucose minimum intensities during cycloergometer exercise; 2) the sensitivity of above cited variables to the adaptative effects of endurance training; 3) the effect of beta-adrenérgic blockade on the blood lactate and glucose response to exercise and 4) the relationship between plasma catecholamines (epinephrine and norepinephrine) and blood lactate behavior and. Cyclists, triathletes and runners took part in this study on a voluntary basis. In all situations it was employed graded exercise test after supra-maximal efforts (lactate minimum test). Our findings confirm the possible use of blood glucose behavior to predict the lactate response to exercise. In addition for the first time it was showed that both lactate and glucose minimum tests are sensitive parameters to adaptations resulting from training. Blood lactate and glucose responses seems to be related to catecholamines behavior during graded exercise after an anaerobic effort. Supporting this, ß-adrenergic blockade evoked significant changes in both variables, and high correlation were found between plasma catecholamines and blood lactate response during LMT. These data suggest that blood lactate and glucose responses to exercise depend, at least partially, on the adrenergic stimulation.

1.INTRODUÇÃO

O consumo máximo de oxigênio (VO_2max) foi considerado durante muito tempo, o melhor índice para avaliação da capacidade de realização de atividades de longa duração (TAYLOR et al., 1955; MITCHELL et al., 1958). Em função disso, muitos programas de treinamento físico apresentam como principal objetivo, a melhora do VO_2max. Nestes programas, o controle da intensidade do exercício, normalmente é baseado em um determinado percentual do VO_2max, da freqüência cardíaca máxima ou da reserva da freqüência cardíaca. Entretanto, a utilização do VO_2max como preditor da performance em provas com predomínio aeróbio ou para o controle da intensidade do treinamento, tem sido questionada (COYLE, 1995; WELTMAN, 1995).

Estudos recentes, têm sugerido que alguns parâmetros obtidos durante intensidades submáximas de exercício são melhores preditores da performance do que o VO_2max. Entre estes parâmetros, está o comportamento do lactato sangüíneo durante o exercício progressivo, o qual parece ser altamente relacionado à performance em vários tipos de exercícios de endurance (COYLE, 1995; DENADAI & BALIKIAN JÚNIOR, 1995; BALIKIAN JÚNIOR & DENADAI, 1996).

Para a descrição do comportamento do lactato durante o exercício, WASSERMAN & McLLORY (1964) propuseram inicialmente o termo "Limiar Anaeróbio". Para a proposição deste termo, os autores basearam-se em dados obtidos no início do século por HILL & LUPTON (1923), que indicavam ser a produção de ácido láctico, causada unicamente pela hipóxia tecidual. Mais recentemente porém, tem-se demonstrado que a hipóxia pode não ser a única causa da produção de lactato durante o exercício o que tem

levado alguns autores (JOBSIS & STAINSBY, 1968; BROOKS, 1985), a questionar os mecanismos propostos por WASSERMAN et al. (1973), e principalmente a mudar a terminologia que identifica a resposta do lactato durante o exercício. Entre as muitas terminologias utilizadas podemos citar: limiar de lactato (WELTMAN, 1995); OBLA - início da acúmulo do lactato sangüíneo (SJODIN & JACOBS, 1981) e; MSSL - máxima fase estável de lactato (HECK et al., 1985).

Embora exista ainda muita controvérsia entre os pesquisadores sobre seus mecanismos básicos (WASSERMAN et al., 1973; HAGBERG, 1986; GAESSER & POOLE, 1986; BROOKS, 1991) e também em torno da sua terminologia, como citado anteriormente, o limiar anaeróbio (LAn), tem sido amplamente utilizado por pesquisadores, fisiologistas, preparadores físicos e médicos, seja com finalidade esportiva ou clínica.

Devido ao fato de a atividade física tender a provocar distúrbios devastadores no ambiente corporal interno, muitos mecanismos fisiológicos estão envolvidos na tarefa de manter a homeostase durante o exercício (GREENHAF & TIMMONS, 1998). De acordo com PINHEIRO (1997), o momento do limiar anaeróbio não é um fato fisiológico isolado durante o esforço crescente, sendo que nesse ponto ocorrem mudanças gerais no estado metabólico, que implicam num conjunto de ajustes. O sistema nervoso autonômico exerce papel essencial nesses ajustes, estando entre eles a regulação da concentração sangüínea de glicose, ou glicemia.

Durante altas intensidades de esforço, as catecolaminas, epinefrina e norepinefrina, apresentam papel fundamental no ajuste orgânico em função da homeostasia. Especificamente, através da ativação dos receptores beta adrenérgicos, a epinefrina é conhecida por estimular a glicogenólise muscular durante os processos de contração, aumentando a oferta de substrato para a produção de energia e realização de trabalho

(MAZZEO & MARSHALL, 1989; CHWALBÍNSKA et al, 1996). Conseqüentemente, o aumento na concentração da epinefrina, tem sido associado a uma maior capacidade glicogenolítica durante o exercício (ISSEKUTZ, 1984; WELTMAN et al, 1994), sendo que estudos têm demonstrado a existência de alta correlação entre os pontos de inflexão de lactato com glicose (NORTHUIS, 1995; SIMÕES et al, 1999) durante o exercício progressivo.

STAINSBY et al (1984), demonstraram que a infusão de epinefrina implica em aumento da produção de lactato a partir da contração do músculo gastrocnêmio em cães. Estudos utilizando bloqueadores beta-adrenérgicos demonstraram uma menor degradação de glicogênio muscular, e conseqüentemente uma menor produção de lactato durante o exercício, em humanos e animais (GALBO, 1976; ISSEKUTZ, 1984; MAZZEO & MARCHAL, 1989).

A associação entre as catecolaminas plasmáticas e produção de lactato tem sido sugerida (MAZZEO et al, 1991; WELTMAN et al, 1994; CHWALBÍNSKA et al, 1996), entretanto, a extensão desta relação permanece em questão, principalmente no que diz respeito a humanos.

1.1 CONTROLE DA PRODUÇÃO DE LACTATO NO EXERCÍCIO

A resposta do lactato ao exercício se apresenta como objeto de grande número de pesquisas e revisões (KATZ & SAHLIN, 1990; STAINSBY & BROOKS 1990; BROOKS, 1991; FITTS, 1994). O aumento abrupto da concentração sangüínea de lactato a partir de uma determinada intensidade de trabalho físico é fato comprovado pela literatura desde o início do século XX, sendo que os fatores e mecanismos associados à inflexão da

lactacidemia durante o exercício progressivo têm sido de interesse fisiológico há tempos (PODOLIN et al., 1991).

Descrito pela primeira vez na literatura por WASSERMAN & McILROY, em 1964, o limiar anaeróbio se tornou tema de grande polêmica na história recente da fisiologia do exercício. Os mecanismos responsáveis pelo aumento abrupto da concentração sangüínea de lactato em determinada intensidade de trabalho físico, bem como a terminologia e metodologias utilizadas para sua identificação, têm gerado muita controvérsia. (WASSERMAN et al., 1973; HAGBERG, 1986; GAESSER & POOLE, 1986; DAVIS, 1985)

A primeira hipótese importante para a elevação da lactacidemia com o incremento da intensidade de esforço é a da hipóxia muscular, proposta por WASSERMAN et al (1964). Seus autores sugerem que o aumento da concentração sangüínea de lactato se deve a uma maior produção de ácido lático pela musculatura ativa devido a limitação da respiração mitocondrial pela oferta insuficiente de O_2. Essa teoria, conhecida como teoria da hipóxia explica a utilização do termo "anaeróbio" para a denominação desse limiar.

Apesar de alguns estudos terem demonstrado que a redução de oferta de oxigênio para a musculatura ativa era capaz de aumentar a produção de lactato (WASSERMAN et al, 1973, KATZ & SAHLIN, 1990; DAVIS, 1985), outros têm questionado ser o défcit de O_2 a única causa do acúmulo de lactato durante o exercício (BROOKS, 1985; BROOKS, 1991). GLADDEN (1996) apresenta evidências de uma complexa interação entre vários fatores capazes de gerar um aumento da lactacidemia durante o exercício submáximo. A principal hipótese contra a inadequação da oxigenação muscular tem como principal argumento o fato de que a oferta de oxigênio para a musculatura ativa é adequada para o ótimo funcionamento mitocondrial e que a elevação da produção de lactato se deve à

interação de vários fatores. Estes fatores incluem a regulação bioquímica, atividade simpato-adrenal, recrutamento de unidades motoras e o equilíbrio entre a produção e remoção do lactato sangüíneo. Basicamente existem duas correntes: autores que propõem a hipóxia tecidual como responsável por essa produção; e autores que apontam outros fatores, excluindo destes, a hipóxia tecidual.

KATZ & SAHLIN (1990) estão entre os que sustentam que a produção de lactato durante o exercício submáximo, ocorre em função da diminuição da oferta de O_2 para a atividade mitocondrial. Seus dados mostram que até o exercício submáximo (40% VO_2max), existe uma queda da concentração do NADH mitocondrial e manutenção dos valores de lactato. No exercício mais intenso (>40% VO_2max), há um aumento do NADH acima dos valores de repouso, o qual é acompanhado por um aumento do lactato muscular e sangüíneo. Estes resultados, de acordo com os autores, sugerem que a oferta de O_2, mais do que a limitação da conexão malato-aspartato (responsável pela introdução de equivalentes de redução do NADH citoplasmático na cadeia de transporte de elétrons da mitocôndria), estaria associado ao aumento da produção do lactato durante o exercício.

KATZ & SAHLIN (1990) propõem que existindo a diminuição da oferta de O_2, a respiração mitocondrial é estimulada pelo aumento da adenosina-difosfato (ADP), do fosfato inorgânico (Pi) e pelo NADH extramitocondrial. Estes mesmos fatores estimulam a glicólise, a qual aumenta a formação de NADH extramitocondrial. Estas modificações combinadas com o aumento do NADH mitocondrial, resultam em aumento ainda maior do NADH citoplasmático, o qual desvia a ação da lactato-desidrogenase (LDH) em direção a formação de lactato.

Por outro lado, baseados principalmente em estudos que utilizaram modelos de contração muscular de cães *in situ*, STAINSBY & BROOKS (1990) e BROOKS (1991) sustentam que a produção de lactato não está associada a hipóxia mitocondrial. JOBSIS & STAINSBY (1968) utilizando uma técnica de fluorescência, verificaram que o músculo sendo estimulado a se contrair em uma intensidade suficiente para se atingir o VO_2max e liberar uma grande quantidade de lactato, o estado de redox mitocondrial, mostrado pela proporção $NADH/NAD^+$, foi mais oxidado do que comparado com o repouso. Os autores concluem que a tensão crítica de O_2 mitocondrial não foi atingida. Posteriormente, STANLEY & CONNETT (1991) medindo a tensão de O_2 em músculos *in situ* produzindo lactato, não encontraram áreas onde a PO_2 aproximou-se da tensão crítica de O_2 mitocondrial, nem durante o exercício, nem durante a passagem do repouso para o exercício. Neste estudo, os autores concluem que o estado de anoxia não esteve presente em músculos que acumulam lactato.

Os mesmos fatores que controlam a produção de lactato *in situ*, parecem operar também durante a contração muscular *in vivo*, ou seja, durante o exercício realizado por um indivíduo. ROWELL et al (1986), estudando um grupo de indivíduos que, durante o exercício incremental, respiravam uma mistura contendo apenas 11% de O_2, verificaram que durante a hipóxia o fluxo de sangue femural aumentou para compensar a queda da diferença artério-venosa de O_2, mantendo o VO_2 e a eficiência muscular (equivalente calórico da carga / equivalente calórico do VO_2). Mesmo com os resultados indicando que a oferta de O_2 não limitou o metabolismo, foi observado que a hipoxia determinou um aumento da liberação de lactato (3 vezes maior). Associado a este aumento, ocorreu também um aumento da epinefrina circulante.

Baseados principalmente nestes estudos, STAINSBY & BROOKS (1990) e BROOKS (1991) concluem que a liberação de lactato pelo músculo é um pobre indicador de deficiência de O_2, já que o produção de lactato ocorre por outros motivos, provavelmente por ação de massa, e não pela queda na tensão de O_2.

1.2 INFLUÊNCIA DAS CATECOLAMINAS NA PRODUÇÃO E LIBERAÇÃO DE LACTATO PELO MÚSCULO ESQUELÉTICO

Embora o músculo esquelético seja o maior sítio de produção e liberação de lactato durante o exercício, outros órgãos (intestino, fígado, pele) podem também produzir e liberar este metabólito (ISUJI & BURINI, 1989; STAINSBY & BROOKS, 1990). Como o músculo esquelético é capaz de produzir e consumir lactato ao mesmo tempo (STANLEY et al., 1986), a liberação de lactato não pode ser confundida com a sua produção total (BROOKS, 1991).

Quando o músculo esquelético é estimulado a se contrair *in situ* (freqüência mantida entre 0,5 a 10 contrações/seg), a liberação líquida de lactato (concentração venosa - concentração arterial), é caracterizada por um rápido aumento, atingindo valores máximos após 3-7 min., declinando posteriormente a zero, entre 10 e 20 min de estimulação. Algumas vezes, quando a contração é mantida constante por um tempo maior (40-60 min), o consumo total de lactato pode ultrapassar sua liberação, ou seja, a concentração venosa passa a ser menor do que a arterial (WELCH & STAINSBY, 1967).

Durante o aumento progressivo da freqüência da estimulação elétrica sobre músculo até que se atinjam contrações tetânicas, ocorre aumento contínuo da liberação de lactato, não existindo sinal de quebra ou limiar na relação lactato/intensidade de estimulação.

Nestas condições, a liberação máxima de lactato é baixa, sendo insuficiente para justificar os aumentos encontrados durante o exercício progressivo realizado em humanos. Uma possível explicação para este comportamento, pode ser a ausência da estimulação adrenérgica durante a contração muscular *in situ*. Nestas preparações, a infusão de potentes agonistas β-adrenérgicos (epinefrina e isoproterenol) aumentam a liberação de lactato pelo músculo (STAINSBY et al., 1984). Por outro lado, o bloqueio dos receptores β-adrenérgicos, diminuem o lactato muscular e sangüíneo.

Concordando com os estudos realizados *in situ*, autores têm encontrado uma alta correlação durante o exercício progressivo, entre a concentração plasmática de catecolaminas e a concentração muscular e sangüínea de lactato (MAZZEO & MARSHALL, 1989, CHWALBÍNSKA et al, 1996). Outros têm demonstrado que a infusão de epinefrina aumenta a concentração de lactato sangüíneo (STAINSBY et al., 1984), enquanto que o bloqueio dos receptores β-adrenérgicos, determina uma diminuição da utilização do glicogênio muscular, assim como um declínio do lactato sangüíneo durante o exercício (AHLBORG, 1985). TWENTYMAN et al (1981), investigando os efeitos de β-bloqueadores adrenérgicos sobre a produção e remoção de lactato durante o exercício em cães, determinaram que as catecolaminas aumentam a glicogenólise e o metabolismo de glicose em preferência aos derivados de lipídios, bem como a gliconeogênise hepática a partir de lactato e piruvato resultantes do metabolismo anaeróbio.

O glicogênio é a maior fonte de energia no músculo esquelético durante a atividade física intensa. Duas enzimas chaves estão envolvidas respectivamente na degradação e formação deste substrato energético: a glicogênio fosforilase e a glicogênio sintetase (CHASIOTIS et al, 1983; STANLEY & CONNETT, 1991). A fosforilase existe em duas

formas enzimáticas interconvertíveis, forma "*a*" e "*b*". A forma "b" se encontra ativa somente na presença do AMP, entretanto a forma "a" está ativada também na ausência do AMP (FITTS & METZGER, 1988; REN & HULTMAN, 1989). A enzima glicogênio sintetase também existe em duas formas interconvertíveis, podendo ser encontrada na forma "I" e na forma "D". A atividade da enzima sintetase na forma "D" é totalmente dependente da concentração de glicose 6-fosfato, entretanto a enzima glicogênio sintetase na forma "I" se encontra também ativada na ausência da glicose 6-fosfato. Geralmente acredita-se que o aumento da atividade gicogenolítica no tecido muscular esquelético é iniciada pela transformação da enzima fosforilase da forma "a" para a forma "b".

Essa transformação pode ser determinada por um mecanismo hormonal mediado pelo cAMP, mas também pode sofrer influência em função do aumento da concentração Ca^{2+} no sarcoplasma durante a contração muscular (GREENHAF, P.L. & TIMMONS, 1998).

As catecolaminas, principalmente a epinefrina se caracteriza como indutora da transformação da fosforilase da forma "b" para a forma "a" no músculo esquelético determinado por uma seqüência de reações químicas, tendo como início um aumento da atividade da adenil ciclase. Como conseqüência, o aumento da concentração de cAMP, determina a ativação da proteína quinase, a qual tem a propriedade de catalisar a conversão da fosforilase "b" quinase para a forma ativa. Uma vez ativada, a fosforilase "b" quinase, catalisa a transformação da fosforilase "b" para "a" (KJAER et al, 1990).

Estudos realizados determinaram que a transformação da fosforilase "b" para "a" ocorreu no músculo esquelético humano durante a contração isométrica, sendo concluído que este fato fora determinado pela ativação da fosforilase "b" quinase pela liberação de Ca^{2+} durante o processo de contração (CHASIOTIS et al, 1983; KJAER et al, 1990).

Entretanto, em estudos realizados *in vitro* a atividade da fosforilase "a" foi menor do que a freqüência do processo glicogenolítico encontrado no tecido muscular *in vivo* (CHASIOTIS et al, 1983).

Além disso, foi observado durante o exercício com incrementos de cargas, que a concentração plasmática de epinefrina e norepinefrina, aumentam de modo similar ao lactato sangüíneo, sugerindo a existência de um limiar de catecolaminas (MAZZEO & MARSHALL, 1989; CHWALBÍNSKA et al, 1996). MAZZEO & MARSHALL (1989) encontraram uma alta correlação (r = 0,97) entre limiar de epinefrina e o limiar de lactato, mostrando ainda que o limiar de catecolaminas, não sofre influência do tipo de ergômetro (bicicleta ou esteira) e do estado de treinamento. PODOLIN et al. (1991) afirmam também que tal limiar não sofre influência da concentração de glicogênio muscular.

Em função destes resultados, muitos autores tem sugerido uma relação de causa e efeito, entre a concentração de catecolaminas e o comportamento do lactato sangüíneo durante o exercício.

1.3 CINÉTICA DO LACTATO NO EXERCÍCIO

Embora exista controvérsia sobre os mecanismos que controlam a produção de lactato, é consenso na literatura o fato da concentração de lactato no sangue variar muito pouco em relação aos valores de repouso, quando se realizam esforços correspondentes à até 50-75% VO_2max. Acima desta intensidade, existe um aumento exponencial da concentração de lactato no sangue e no músculo.

A despeito da forte correlação entre a concentração de lactato muscular e sangüíneo, informações existentes na literatura mostram que é um erro interpretar-se que o acúmulo de lactato no sangue reflete apenas a sua produção muscular. Na realidade, a concentração sangüínea desse metabólito depende do balanço entre a sua liberação (influenciada principalmente pela produção muscular, não refletindo porém, sua produção total) e sua remoção do sangue (BROOKS, 1991).

O fato do lactato sangüíneo praticamente não se modificar em relação aos valores de repouso durante o exercício leve e moderado, não significa necessariamente que a sua produção de lactato neste tipo de exercício seja pequena. Na realidade, estudos realizados em animais (ISSEKUTZ, 1984 ; DONOVAN & BROOKS, 1983) têm demonstrado que a liberação de lactato pelo músculo aumenta com a intensidade do exercício. Este aumento pode ser linear, como o encontrado em músculos isolados (STAINSBY et al, 1984), ou exponencial, durante a contração muscular *in vivo*, pelo aumento da estimulação adrenégica e/ou maior recrutamento das fibras do tipo II. Como mesmo durante o exercício submáximo a liberação de lactato pelo músculo pode ser de 3 a 4 vezes maior do que durante o repouso (DONOVAN & BROOKS, 1983), a ausência do aumento sanguíneo desse metabólito, pode ser justificada pelo aumento da capacidade de remoção que ocorre durante o exercício, comparado aos valores de repouso (DONOVAN & BROOKS, 1983).

Deste modo, autores como BROOKS (1985) tem sugerido que o aumento exponencial do lactato sangüíneo que ocorre a partir de determinada intensidade submáxima de esforço, pode refletir um aumento exponencial da sua liberação pelo músculo e/ou uma diminuição da capacidade de remoção. Esta menor remoção pode ocorrer pela diminuição do fluxo de sangue para a região esplâncnica (fígado e rins) com o aumento da intensidade de esforço, como demonstrado por ROWELL (1974), e também

por uma incapacidade dos músculos em extrair e oxidar o lactato na mesma freqüência na qual ele é liberado.

1.4. TERMINOLOGIAS E CRITÉRIOS UTILIZADOS NA AVALIAÇÃO DA RESPOSTA DO LACTATO AO EXERCÍCIO

Um dos maiores problemas relacionados a determinação e utilização da resposta do lactato ao exercício ocorre em função do grande número de terminologias e critérios empregados pelos pesquisadores para identificar fenômenos iguais ou semelhantes (WELTMAN, 1995).

Nesse sentido, podemos classificar os estudos sobre tal tema em duas categorias: a) estudos que indicam o início do acúmulo de lactato no sangue e ; b) estudos que indicam a Máxima Fase Estável de Lactato (MSSL). É importante ressaltar que nestas duas categorias, existem autores que se utilizam de concentrações fixas, e outros que se utilizam de concentrações variáveis de lactato, para identificar o fenômeno definido por sua terminologia.

1.4.1 ESTUDOS QUE IDENTIFICAM O INÍCIO DO ACÚMULO DO LACTATO NO SANGUE

FARREL et al. (1979) propuseram o termo OPLA (onset of plasma lactate accumulation) como sendo a intensidade de exercício anterior ao aumento exponencial do lactato no sangue. Embora alguns autores utilizem basicamente o mesmo referencial do estudo anterior, eles definem esta intensidade de exercício, como sendo o Limiar de Lactato (LL) (IVY et al., 1980 ; WELTMAN et al., 1994).

Outros autores porém, utilizando a mesma terminologia (LL), apresentam outra referência para sua determinação. COYLE et al. (1983) definiram o LL como sendo a intensidade de exercício que determina aumento de 1 mM no lactato sangüíneo, acima dos valores da linha de base (Δ1mM). COYLE (1995) justifica sua metodologia por encontrar no LL, intensidades de exercício que são 5% maiores do que as encontradas no OPLA, sendo estas muito próximas as velocidades selecionadas pelos atletas durante a prova de maratona. Além disso, em ciclistas o emprego da intensidade correspondente ao LL resulta em uma freqüência muito similar da glicogenólise muscular, resultando num tempo de fadiga, em função da depleção de glicogênio, também muito similar entre os sujeitos (3 horas) (COGGAN & COYLE, 1991).

As metodologias citadas anteriormente para determinação do OPLA e do LL, utilizam-se de concentrações variáveis de lactato sangüíneo, para determinar o fenômeno por elas definido, encontrando geralmente intensidades de exercício que correspondem a uma concentração de lactato entre 1,5-3,0 mM.

KINDERMANN et al. (1979) diferentemente dos estudos anteriores, propõem o termo Limiar Aeróbio (LAer), utilizando para sua determinação uma concentração fixa de lactato. Deste modo, os autores definem o LAer como sendo a intensidade de exercício correspondente a 2 mM de lactato no sangue. KINDERMANN et al. (1979) propõem que a intensidade mínima de exercício que deve ser utilizada para a melhora da capacidade aeróbia, deve ser aquela correspondente ao LAer.

1.4.2 ESTUDOS QUE IDENTIFICAM A MÁXIMA FASE ESTÁVEL DE LACTATO NO SANGUE

A máxima fase estável de lactato (MSSL), definida como a maior velocidade de corrida ou carga de trabalho na qual existe um equilíbrio entre a taxa de aparecimento de lactato no sangue e sua remoção (HECK et al., 1985; JONES & DOUST, 1998), tem sido extensivamente utilizada por pesquisadores e profissionais de saúde seja para fins clínicos ou esportivos. Um grande número de estudos, realizados principalmente por investigadores Alemães e Escandinavos, têm proposto a identificação da intensidade de exercício correspondente a MSSL, utilizando principalmente concentrações fixas de lactato (4mM), porém com diferentes terminologias. O grupo de cientistas alemães propõem o termo limiar anaeróbio (KINDERMANN et al., 1979) ou limiar aeróbio-anaeróbio (MADER et al., 1976), enquanto o grupo escandinavo propõem o termo OBLA (onset of blood lactate accumulation) (SJODIN & JACOBS, 1981), para identificar a intensidade de exercício correspondente a 4mM de lactato no sangue. HECK et al. (1985) justificam a escolha desta concentração fixa, em função da maioria dos sujeitos por ele estudados apresentarem nesta intensidade de exercício, o máximo balanço entre a produção e remoção de lactato. Embora HECK et al. (1985) terem proposto o uso de uma concentração fixa (4mM) para identificar a MSSL, os mesmos mostram que a concentração de lactato correspondente a esta intensidade pode variar entre 3 -5,5 mM.

STEGMANN et al. (1981) ressaltam que, embora a concentração de lactato no MSSL seja aproximadamente 4mM, grande variação individual pode existir (1,5 - 7,0 mM). Assim, os autores introduzem o termo limiar anaeróbio individual (IAT), propondo uma

metodologia que identifique a MSSL de maneira individualizada (STEGMANN et al., 1981).

Entre os protocolos utilizados para a predição da MSSL, o teste de lactato mínimo (LACmin), isto é, uma sessão de exercício incremental é executada após a indução da acidose lática através de esforços supramáximos (TEGTBUR et al., 1993), tem recebido especial atenção nos últimos 5 anos (SIMÕES et al., 1999; CAMPBELL et al., 1998; JONES & DOUST, 1998; BALIKIAN et al., 1999; CARTER et al., 1999a; 1999b).

De acordo com o artigo original de TEGTBUR (1993), uma vez que a concentração sangüínea de lactato sofre decréscimo nas cargas iniciais de trabalho e volta a crescer em determinada intensidade, esta representa a mais alta intensidade na qual é observada um equilíbrio entre o aparecimento e remoção de lactato da corrente sangüínea, ou seja a MSSL.

Entre suas vantagens o LACmin proporciona a avaliação do metabolismo aeróbio e anaeróbio em uma única sessão, além disso, tem sido verificado que seus resultados não sofrem influência da disponibilidade de substratos (TEGTBUR et al., 1993; DOUST et al., 1996), e não dependem da análise subjetiva do curva lactacidêmica durante o exercício progressivo.

No entanto estudos recentes têm questionado a validade do LACmin para a determinação da MSSL (JONES & DOUST, 1998) e a sensibilidade deste teste em determinar adaptações decorrentes de um programa de treinamento fisico(CARTER et al., 1999a). Além disso, por se tratar de uma metodologia relativamente nova, são poucos os estudos que tenham testado sua reprodutibilidade.

1.5 DETERMINAÇÃO DA INTENSIDADE CORRESPONDENTE A MSSLAC PELO VALOR DE MENOR GLICEMIA

Como a avaliação direta da concentração de lactato durante o exercício nem sempre é possível, seja por falta de equipamento, características da população a ser avaliada ou em função das condições da realização do exercício, diferentes metodologias tem sido propostas na tentativa de predizer a resposta do lactato ao exercício (WASSERMAN et al., 1973 ; CONCONI et al., 1982 ; MAZZEO & MARSHALL, 1989).

NORTHIUS et al. (1995), observaram que o ponto de inflexão do lactato sangüíneo era coincidente com o ponto de menor valor da glicemia durante o exercício incremental em corredores exercitando-se na esteira. Os autores verificaram nesse estudo, pela primeira vez, a possibilidade da resposta glicêmica, predizer a resposta do lactato sangüíneo durante o esforço crescente. Ao avaliar indivíduos sedentários, ciclistas e nadadores em teste crescente em cicloergômetro, PINHEIRO (1997), observou alta correlação ($r = 0.92$) entre os limiares determinados através da lactacidemia e glicemia, concluindo ser este um parâmetro seguro e válido para a identificação do LAn.

SIMÕES et al. (1999) em um estudo recente realizado em associação com nosso laboratório, analisaram a possibilidade do comportamento da glicemia, ser utilizado para identificar a intensidade de exercício correspondente a MSSL. Neste estudo, 15 corredores do sexo masculino foram submetidos a dois testes para determinar a intensidade (m/min) correspondente a MSSL. O primeiro protocolo foi realizado de acordo com o proposto por TEGTBUR et al. (1993), que é conhecido como "lactate minimum test" (LACmin). O segundo, foi realizado de acordo com o proposto por STEGMANN et al. (1981), denominado pelos autores de "individual anaerobic threshold" (IAT). Nos dois testes, além da medição da concentração de lactato sanguíneo, conforme o proposto em cada protocolo,

determinou-se também, a partir da mesma amostra de sangue, o valor da glicemia. Não foram observadas diferenças entre a velocidade (m/min) correspondente ao LACmin (284,7) e ao IAT (282,5). Interessantemente, a velocidade de corrida onde foi observado o menor valor de glicemia (G_{MS}) no protocolo do LACmin (286,9) e do IAT (280,6), não foram significantemente diferentes entre si, e em relação aos valores obtidos através do lactato sanguíneo. Em função disso, os autores concluíram que foi possível, nos sujeitos estudados, predizer a velocidade equivalente a MSSL, a partir da G_{MS} obtida nos dois protocolos investigados.

Em exercícios de intensidades baixas e moderadas, a glicemia diminui com o crescimento do trabalho físico, sendo que essa queda ocorre até o momento do limiar anaeróbio, à partir do qual há um aumento da glicemia.

O limiar anaeróbio identificado pela glicemia pode facilitar muito no que tange, principalmente, ao treinamento físico, constituindo procedimento mais prático e barato, quando comparado à análise lactacidêmica. Entretanto, a dosagem de glicose sangüínea é também um método invasivo pela necessidade de coleta de amostras de sangue, seja em catéteres, veias ou artérias, ou através de amostras obtidas do lóbulo da orelha ou da polpa dos dedos.

Os autores ressaltam entretanto, que a validade e reprodutibilidade da metodologia, precisa ainda ser investigada, para que se possa confirmar ou não, a possibilidade da utilização do comportamento da glicemia, para predizer a resposta do lactato sanguíneo durante o exercício.

1.6 EFEITOS ADAPTATIVOS INDUZIDOS PELO TREINAMENTO FÍSICO

A determinação de variáveis fisiológicas relacionadas com o rendimento físico, representam um foco importante nos estudos direcionados a fisiologia do exercício (READY & QUINNEY, 1982; KORTH et al, 1989; O'TOOLE et al, 1989; BELMANN & GAESSER, 1991). Um grande número de estudos se apresentam na identificação de fenômenos fisiológicos ocorridos durante a atividade física, que possam estar relacionados com a performance (FARREL et al, 1979; BALIKIAN JUNIOR & DENADAI, 1996; ROECKER et al, 1998). Tais acontecimentos podem ser aplicados na determinação da intensidade adequada das cargas de trabalho, proporcionando maior eficiência nos processos adaptativos determinados pelo treinamento, uma vez que, entre os fatores determinantes das adaptações, a intensidade do esforço que, por sua vez, representa a via metabólica predominante durante a atividade, merece especial atenção (MAGLISCHO, 1999).

O VO_2max, que representa a capacidade máxima do organismo em captar, transportar e utilizar o oxigênio, foi durante muito tempo considerado o melhor índice para determinar a existência ou não de adaptação do treinamento aeróbio (ASTRAND, 1956; TAYLOR, 1955). Entretanto, estudos mais recentes tem verificado que o comportamento do lactato sanguíneo durante o esforço apresenta maior sensibilidade que o VO_2max, para detectar as alterações orgânicas impostas pelo treinamento de longa duração (COYLE, 1995; RIBEIRO, 1995).

Alguns autores propõem que o VO_2max relaciona-se mais com fatores cardiovasculares, como o débito cardíaco máximo, enquanto que a Máxima Fase Estável de Lactato (MSSL) e parâmetros lactacidêmicos correlatos, estão mais relacionados à fatores

metabólicos, como por exemplo a atividade das enzimas oxidativas (O'TOOLE et al, 1989; RIBEIRO, 1995).

Além da intensidade de trabalho, o percentual de melhora determinado pelo treinamento aeróbio, é dependente de vários fatores, dentre os quais podemos citar: o volume e a freqüência semanal de treinamento, a duração do programa, o nível inicial de condicionamento, a hereditariedade e a idade e sexo dos sujeitos analisados (WILMORE & COSTILL, 1994), o que torna difícil a comparação dos diferentes estudos. Deste modo, são encontrados na literatura, percentuais de melhora do Lan com o treinamento de ciclismo que vão de 5% até 16-20% (KORHT et al, 1989).

Em estudo recente realizado em nosso laboratório BALIKIAN & DENADAI (1996), compararam dois protocolos utilizados para a determinação do LAn, sendo um realizado em laboratório através de esforço contínuo e progressivo em cicloergômetro (T1) e outro realizado em campo com cargas intermitentes, utilizando a própria bicicleta de competição (T2). Os dois protocolos se mostraram sensíveis aos efeitos de um programa de treinamento aeróbio de12 semanas, imposto à um grupo de ciclistas altamente treinados. As melhoras percentuais para o LAn foram de 4,2 $\pm$ 1,6 % para a velocidade em T1 e 4,6 $\pm$ 1,2% para a carga de trabalho (Watts) em T2, sendo verificada correlação significante ($r = 0,94$; $p < 0,05$) entre tais melhoras. Além disso, não houve diferença significante entre os dois protocolos em relação à sensibilidade.

Apesar da grande utilização dos parâmetros lactacidêmicos para a identificação dos efeitos do treinamento aeróbio apenas um estudo analisou a sensibilidade do lactato mínimo para tal fim (CARTER et al, 1999). Sendo que neste, os autores não verificaram alteração

significante na velocidade de corrida (11.0 ± 1.7 vs 10.9 ± 1.7 Km/h) correspondente ao lactato mínimo, após 6 semanas de treinamento em 16 estudantes.

2.OBJETIVOS

Uma vez que a literatura especializada nos traz questões em aberto acerca da realação catecolaminas-lactato e da utilização da glicemia como metodologia alternativa para a predição da resposta lactacidêmica ao exercício, o presente estudo teve como objetivos:

- Analisar a correlação entre as intensidades de exercício (Watts) correspondentes ao menor valor lactacidêmico (L_{MI}) e glicêmico (G_{MI}) durante teste de lactato mínimo (teste de carga progressiva em cicloergômetro precedido de esforço anaeróbio máximo);
- Determinar a sensibilidade das metodologias L_{MI} e G_{MI} em identificar os efeitos adaptativos de um programa de treinamento físico;
- Verificar os efeitos do bloqueio agudo dos receptores beta-adrenérgicos com propranolol sobre o comportamento da concentração sangüínea de lactato e glicose durante o teste de lactato mínimo;
- Determinar a relação entre a concentração sangüínea de lactato e catecolaminas (epinefrina e norepinefrina) plasmáticas durante teste de lactato mínimo.

3. ARTIGO 1

EFFECT OF ENDURANCE TRAINING ON THE LACTATE AND GLUCOSE MINIMUM INTENSITIES

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ABSTRACT

The present study evaluated the correlation between lactate minimum (L_{MI}) and glucose minimum (G_{MI}) intensities [both expressed in Watts (W) and %VO2max] during the cycloergometer lactate minimum test (LACmin), and the sensitivity of these parameters to changes in fitness resulting from endurance training. Eight trained male cyclists (21.4 ± 1.9 years, 67.6 ± 7.5 Kg, 172.1 ± 9.5 cm, 60.5 ± 4.2 $ml.Kg^{-1}.min^{-1}$) underwent evaluation in a mechanically braked cycloergometer (Monark) on two different occasions: January (pre training) and May (post training) situations. L_{MI} and G_{MI} intensities were identified by respectively, the lowest blood lactate and glucose levels attained during incremental exercise (125 W starting load and 25 W increases every 3 minutes until reaching voluntary exhaustion), preceded by an all out 30 second Wingate test. For direct determination of $VO2_{max}$, subjects carried out a maximal test with a 50 W initial load, increased by 25 W loads every minute. L_{MI} and G_{MI}, both expressed in W, $\%VO_2max$ and VO_2max, increased significantly ($p < 0.05$) after 12 weeks of endurance training. Pre training power output (215.0 ± 18.6 W), relative VO_2 (71.5 ± 2.6 $\%VO_2max$) and heart rate (166.0 ± 1.3 bpm) at L_{MI} were not significantly different ($p > 0.05$) from those at G_{MI} (218.2 ± 22.1 W; 71.8 ± 2.51 $\%VO_2max$ and 166.1 ± 1.2 bpm). Such non-significant differences were also found in the post-training situation (L_{MI}: 237.5 ± 18.8 W; 72.6 ± 1.92 $\%VO_2max$; 166.2 ± 1.4 bpm vs G_{MI}: 240.6 ± 22.9 W; 72.6 ± 1,92 $\%VO_2max$; 166.1 ± 1.0 bpm. In addition, significant correlations between L_{MI} and G_{MI} intensities expressed both in W ($r = 0.92$ and $r = 0.93$) and %VO2max ($r = 0.90$ and 0.91) in pre-and post-training situations respectively, were found. In conclusion, our findings confirm G_{MI} as a good

predictor of L_{MI} during cycloergometer exercise. However, both L_{MI} and G_{MI} were, for the first time, found to be sensitive parameters of adaptation consequent to endurance training.

KEY WORDS: Lactate minimum test, Training, Glucose minimum intensity, aerobic power.

INTRODUCTION

Mechanisms and terminology associated with the blood lactate break point during exercise, have been the subject of much controversy in Exercise Physiology's recent history (BROOKS, 1985; DAVIS, 1985; KATZ & SAHLIN, 1988; STAINSBY & BROOKS, 1990; BROOKS, 1991).

However, Maximal Lactate Steady State (MSSL), defined (HECK et al., 1985; JONES & DOUST, 1998), as the highest constant running speed or external power output at which a balance between the rate of appearance of lactate in, and the rate of its removal from the blood exists, has been extensively used by researchers, physiologists, physicians and doctors for sport or clinical purposes. In spite of the lengthy nature of the MSSL assessment, several procedures, (lactate threshold (WELTMAN et al., 1990), individual anaerobic threshold (STEGMANN et al., 1981) and OBLA (SJÖDIN et al., 1982)) determinations, have been proposed to allow for its estimation from the response of blood lactate to the single incremental exercise test.

Among the applications of lactate related parameters, are the diagnostic of aerobic capacity (WELTMAN et al., 1978; COYLE, 1995), endurance performance prediction (HAGBERG & COYLE, 1983; ROECKER et al., 1998), determination of optimal training intensities (DWYER & BYBEE, 1983), verification of endurance training effects (KORHT et al., 1989) and a diagnostic aid for certain degenerative disorders (WASSERMAN et al., 1987).

The lactate minimum test (LMT), initialy proposed by DAVIS & GASS (1979) and subsequently modified by TEGTBUR et al. (1993), has been extensively employed for the identification of MSSL. Its protocol involves a graded continuous exercise test after

induction of lactic acidosis by supra-maximal efforts. Once the blood lactate concentration has decreased in the initial load and starts increasing for a given power output, the exercise intensity associated with the minimum lactate concentration (L_{MI}) represents in theory, the maximal exercise intensity where a balance between the rate of appearance of lactate in the blood and its rate of removal from the blood, i.e. MSSL, exists (TEGTBUR et al., 1993).

Among its advantages, LMT provides anaerobic and aerobic evaluation during a single session. It has been also verified that its results are not changed by substrate availability (TEGTBUR et al., 1993; DOUST et al., 1996), and does not depend on the subjective analysis of the lactate response curve during graded exercise. However, recent studies have questioned the validity of the LMT for MSSL determination (JONES & DOUST, 1998) as well as the sensitivity of this test to changes in endurance fitness resulting from training interventions (CARTER et al., 1999a).

Although blood lactate determination during exercise may not always be possible due to lack of adequate equipment or exercise conditions, many authors have proposed the use of alternative methodologies to predict lactate responses to exercise (CONCONI et al., 1982; FOSTER et al., 1995; BALIKIAN et al., 1999b; SIMÕES et al., 1999).

NORTHUIS et al. 1995; PINHEIRO, 1997; CAMPBELL et al., 1998; SIMÕES et al., 1999, have recently proposed the use of serum glucose behavior (i.e. the lowest glucose value) to predict blood lactate break point during incremental exercise. However, the authors point that this relatively new methodology should be extensively examined to confirm the possibility of its use to predict blood lactate response to graded exercise. In addition, no study has as yet applied this physiological variable to quantify adaptations caused by an endurance-training program.

Therefore, the aims of the present study were: 1) to analyze the correlation between the lactate minimum (L_{MI}) and glucose minimum (G_{MI}) intensities during cycloergometer LMT; 2) to verify the sensitivity of L_{MI} and G_{MI} to changes in endurance fitness resulting from endurance training.

METHODS

Subjects

After approval of the procedures to be used, by the Campinas State University Ethics Committee, eight well-trained male endurance cyclists or triathletes volunteered to take part in this study. The subjects gave their written informed consent to the experimental procedures after having had possible benefits and risks of participation in the study fully explained to them. The mean ± SD age, weight, height, VO_2max and training volume of the subjects were 21.4 ± 1.9 years, 67.6 ± 7.5 Kg, 172.1 ± 9.5 cm, 60.5 ± 4.2 $ml.Kg^{-1}.min^{-1}$ and 312.6 ± 12.3 $km.week^{-1}$, respectively.

Experimental methods

All subjects underwent two graded exercise tests in a mechanically braked cycloergometer (Monark) on two different occasions, January (pre-training) and May (post-training) situations. A maximum of 48 h separated the two exercise tests. All tests were performed at the same time of the day by a given subject. The first exercise test was always employed for VO_2max determination, and the second for L_{MI} and G_{MI} determinations.

VO_2max determination

For VO_2max determination, the subjects carried out a continuous incremental cycloergometer test which began at 50 Watts (W) and was increased by 25 W every minute until exhaustion. Gas exchange and ventilator parameters were continuously measured from expired air using a Vista CPX system (Vacumed, 1996). Oxygen uptake (VO_2), carbon dioxide production (VCO_2) and ventilation rate (Ve) were measured every 30 seconds with an Oxygen Analyser OM-11, Carbon Dioxide Analyser LB-2 and Flow Transducer K – 520, respectively. All data were immediately processed through Vista CPX software. VO_2max achievement was confirmed as proposed by SHEPHARD et al., (1968).

L_{MI} and G_{MI} determination

For L_{MI} and G_{MI} determination, subjects underwent a continuous incremental exercise test preceded by an all out 30 second Wingate test (BAR-OR, 1987), with a 0.075 Kp/Kg body mass load. Prior to the Wingate test, a warm up period of ten minutes cycling at 50 W and a stretching session were performed.

Eight minutes after the Wingate test, the athletes started cycling at 125 W with 25 W increases every 3 minutes until voluntary exhaustion. Blood samples were taken 7 minutes after the Wingate test and at the end of each stage during the incremental phase. VO_2 was continuously measured during the test as described earlier. For L_{MI} and G_{MI} identification both in Watts and relative VO_2 (%VO_2max), the lowest blood lactate and glucose levels respectively attained during incremental exercise were considered (Figure 1).

Blood analysis and heart rate determination

Capillary blood samples (25 µl) were taken from the athlete's earlobes; for blood lactate determination the electroenzymatic method (YLS 2700 STAT, Yellow Spring Co., USA) was used. Five ml blood samples were simultaneously taken from an antecubital vein continuously flushed with NaCl 0,85 %, and immediately placed in polyethylene tubes containing 1% NaF, for posterior enzymatic determination of blood glucose the glucose oxidase method (Cobas Mira Plus, Roche).

During the graded tests heart rate was continuously monitored using a Polar Vantage XL heart rate monitor (Polar Electro, Finland).

Figure 1

Statistics

Mean and standard deviation (SD) values were calculated for all variables studied. Pearson Product Moment correlation coefficients were employed to analyze the relationship between L_{MI} and G_{MI} , expressed in Watts; Wilcoxon's test was employed to test differences between these variables expressed in relative VO_2. Comparison were made using Student's t test for paired samples; statistical significance was set at $P < 0.05$.

RESULTS

Post-training blood lactate levels after maximal exercise (12.21±1.71 mM) were significantly higher ($p < 0.05$) than those found in the pre-training situation (11.71±1.60 mM). On the other hand, glucose maximal values after the Wingate test (90.37 ± 2.99 and

91.50 ± 3.02 mg/dl) respectively, were not significantly different ($P > 0.05$) between pre- and post-training situations.

No significant differences ($p > 0.05$) between L_{MI} and G_{MI}, expressed either in Watts or $\%VO_2max$ were found in the pre- and post-training situations. In addition, no significant differences ($p > 0.05$) were found between heart rate related to L_{MI} and G_{MI} in both situations (Table 1). L_{MI} and G_{MI}, expressed either in Watts or $\%VO_2max$, showed significant increases ($p < 0.05$) after 12 weeks of endurance training (Table 1); this was also true for VO_2max (60.50±4.20 vs 62.00±4.00 $ml.Kg^{-1}.min^{-1}$). However, L_{MI} and G_{MI} increases were significantly greater ($p < 0.05$) than those of VO_2max (Figure 2).

Significant correlations ($p < 0.05$) between L_{MI} and G_{MI} expressed either in watts or $\%VO_2max$, were found in both situations (Table 2); improvement of these parameters was significantly correlated ($p < 0.05$) (Table 3). On the other hand, no significant correlation between VO_2max and L_{MI} or G_{MI} improvement was found (Table 3).

Table 1

Table 2

Table 3

DISCUSSION

Validity of the lactate minimum test for determination of the maximal lactate steady state

Several approaches aiming to quantify the aerobic/anaerobic transition during incremental exercise using characteristics of blood lactate level, exist. Some authors (HECK et al., 1985) have proposed the use of fixed blood lactate concentrations (i.e., 4.0 mM); others showed that these may represent arbitrary values (YEH et al., 1983). In addition, fixed blood lactate protocols seem to be influenced by prior muscle glycogen content (MAASSEN & BUSSE, 1989), a fact that may diminish the validity of this methodology.

As alternative protocols, the use of certain characteristics of lactate/power output curves to identify the exercise intensity when there exists a marked increase in blood lactate concentration, have been suggested (STEGMANN et al., 1981). However, high interindividual differences have been found when different investigators tried to identify the lactate inflection point during incremental exercise (YEH et al., 1983).

Introducing the "lactate minimum test" (LMT), DAVIS & GASS (1979) found that during the graded exercise test initiated during lactic acidosis, blood lactate concentration at first decreased to a minimum and subsequently increased. The authors did not however, check the possibility that lactate minimum intensity (L_{MI}) represents the MSSL. Years afterwards, TEGTBUR et al. (1993) adapted the LMT to track runs, and verified that when subjects exercised at the lactate minimum speed (L_{MS}) for eight kilometers, MSSL was reached. However, when this velocity was increased by 0.2 $m.s^{-1}$, MSSL was never attained and many subjects couldn't finish the race. In addition, prior glycogen depletion did not cause significant changes in the L_{MS} although it lowered lactate concentrations throughout the test.

Recently, controversial results have been reported by researchers who tested the validity of the LMT to identify MSSL (JONES & DOUST, 1998; SIMÕES et al., 1999). In our laboratory, SIMÕES et al. (1999), reproduced the results of TEGTBUR et al. (1993), although the L_{MS} (282,6 $m.s^{-1}$) did not differ significantly from the 4 mM velocity (288,9 $m.s^{-1}$) determined by interpolation according to MADER et al., (1978).

On the other hand, JONES & DOUST (1998) found the L_{MS} (14.9 ± 0.2 $Km.h^{-1}$) to be significant lower than the MSSL speed (15.7 ± 0.3 $Km.h^{-1}$), although the authors did not find significant differences between L_{MS} and lactate or ventilator threshold speeds. They suggested that the discrepancy between L_{MS} and MSSL could be explained by the definition of MSSL used in their study (no more than a 1 mM increase in blood lactate concentration between minutes 10 and 30 of the constant velocity run), which could have led to an overestimation of MSSL.

Factors that could affect lactate minimum intensity (L_{MI}) determinations have also been recently studied. CAMPBELL et al. (1998), tested the possible influence of oral caffeine or glucose ingestion on the lactate minimum power output during cycloergometer exercise, after earlier studies had shown that these manipulations could alter lactate response to graded exercise (YOSHIDA, 1984; GAESSER & RICH, 1985). Evaluating 11 physically active subjects, CAMPBELL et al. found that blood lactate behavior during cycloergometer exercise was similar to that found during running (TEGTBUR et al., 1993; SIMÕES et al., 1999). In addition, they did not find significant differences between L_{MI} under placebo, caffeine or glucose conditions.

These results, besides confirming the possible use of cycloergometer LMT, have showed that factors which can alter lactate response to exercise, do not interfere with the

L_{MI} (Watts), suggesting the validity of the test employed. In contrast, CARTER et al., (1999b) found that the L_{MS} in treadmill runs could be influenced by the initial velocity used in the incremental phase of the test.

Although we did not evaluate MSSL directly, and in spite of the limitations proposed by CARTER et al. (1999b) for treadmill LMT, the results of the present study confirm the possibility of the use of LMT during cycloergometer exercise. Both pre- (215,00±18,60 W) and post- (237,50±18,80 W) training L_{MI}s found in this study were greater than those found by CAMPBELL et al. (1998). This difference can be easily explained by the greater fitness of our subjects, who where highly trained cyclists and triathetes as confirmed by their VO_2max values (60,0 $ml.Kg^{-1}.min^{-1}$), which were very close to those of national level triathetes (DENADAI et al., 1994) and cyclists (MOREIRA COSTA et al., 1989).

Glucose minimum value as a predictor of lactate minimum intensity

The lowest serum glucose level was recently described as a good predictor of the aerobic-anaerobic intensity transition during graded exercise. NORTHUIS et al. (1995), verified that the lactate threshold coincided with the lowest serum glucose value (zero tangent gradient), in runners exercising on a treadmill; they suggested for the first time, that glucose behavior could be used to predict blood lactate responses to incremental exercise. Confirming this observation, SIMÕES et al. (1999) found that glucose behavior permitted the identification of the Individual Anaerobic Threshold (IAT), L_{MS} and MSSL in track runs.

The glucose minimum (GMT) test has also been validated in cycloergometer testing (PINHEIRO, 1997; CAMPBELL, 1998). PINHEIRO (1997) found a high

correlation (r = 0.92) between lactate threshold and minimum glucose power output (G_{MI}) during graded cycloergometer exercise in sedentary subjects, cyclists and swimmers. In addition, CAMPBELL et al. (1998) found no significant differences between L_{MI} and G_{MI}, suggesting that the type of the exercise does not affect this relationship.

However, the above-cited authors point out that the validity and reproducibility of this methodology must be better investigated in order to confirm the possibility of using serum glucose behavior to predict blood lactate response to exercise. We found a high correlation and no significant differences between L_{MI} and G_{MI}, expressed both in Watts and $\%VO_2max$, in the pre-and post-training situations. Furthermore, the two variables showed correlated increases after performance of the training program.

In the present study, G_{MI} was higher than that observed by CAMPBELL et al. (1998) for moderately active subjects, and higher than the anaerobic threshold found by PINHEIRO (1997) for sedentary subjects (103.1 ± 20.9 W), swimmers (167.9 ± 23.8 W) and trained cyclists (193.7 ± 25.9 W). In her study, this author used a graded protocol instead of LMT. Nevertheless, differences between our results and those listed above, can be explained by the better fitness of our subjects. Although PINHEIRO also employed atlethes in her study, the training volume of the cyclists (80 – 150 $Km.week^{-1}$) was considerably lower than that of our cyclists or triathletes.

Our results as well as those of others, suggest that G_{MI} is a safe and valid measure for the identification of lactate parameters associated with MSSL during graded exercise. Although of an invasive nature, GMT presents several advantages over tests involving lactate both in terms of cost and of analytical methodology. Consequently, it could be used

by a large number of coaches, researchers and other professionals, both in the laboratory and the field.

Since during exercise, serum glucose levels are mainly governed by factors that control liver glucose production (GAp) and glucose uptake by active muscle mass (GD) (KJAER, 1992), the explanation for such glucose behavior may be the imbalance between glucose uptake by active muscle and glucose production by the liver. It is known that several hormones involved in liver glycogenolysis show marked increases following exercise of high intensity. Direct autonomic neural activity on the liver may also contribute to this phenomenon (GLADDEN, 1996). More detailed investigations are needed to explain the causes and mechanisms responsible for the existence of the G_{MI} during incremental exercise and its possible relationship with lactate-related parameters like L_{MI}, IAT and lactate threshold.

Effect of training on the L_{MI}, G_{MI} and VO_2

Maximal oxygen uptake (VO_2max), has been traditionally considered as being the best index for the evaluation of adaptation to endurance training (ASTRAND, 1956). However, recent studies suggest that during submaximal exercise, blood lactate-related parameters are more sensitive than VO_2max to endurance training derived adaptation (COYLE, 1995, BALIKIAN & DENADAI, 1996), especially during longitudinal accompaniment (KORHT et al., 1989).

Among the blood lactate parameters used for the identification of training effects, are anaerobic and lactate thresholds, OBLA and MSSL itself. However, we found only one study (CARTER et al., 1999) which used LMT to verify an endurance training program. In addition, the sensitivity of GMT to endurance training does not appear to have been

analyzed in previous work. The results of the present study show significant increases of both L_{MI} and G_{MI} after 12 weeks of endurance training, and that these increases were highly correlated.

Power output related to minimum lactate and glucose values, increased by 10.28 ± 4.29 % and 9.89 ± 4.35%, respectively, while VO_2max increased by only 2.52 ± 1.80%. This can in part, be explained in part, by the fact that the latter variable is determined primarily by central factors (i.e. maximum cardiac output), being a less sensitive parameter for the identification of training effects. In contrast, blood lactate and probably glucose responses to exercise, seem to be closely related to peripheral factors (i.e. biochemical alterations in the trained musculature), which are in constant adaptation to exercise training (HAGBERG, 1984; O'TOOLE et al., 1995). Although we have not examined the influence of training on more traditional lactate parameters, the larger L_{MI} and G_{MI} increases compared to VO_2max, suggests that they could be successfully used to monitor parameters during a training session.

In contrast to our results, CARTER et al. (1999) did not find significant changes in L_{MS} (from 11.0 ± 1.7 to 10.9 ± 1.7 $Km.h^{-1}$) and VO_2 at the L_{MS} (from 2.42 ± 0.8 to 2.40 ± 60 $l.min^{-1}$) after 6 weeks of endurance training in 16 sport science students. Furthermore, these authors verified significant increases in VO_2max (9.9%), VO_2 (7.8%) and velocity (6.3%) at lactate threshold, VO_2 (9%) and velocity (6%) at a 3mM lactate reference value and MSSL velocity. Using treadmill running instead of a cycloergometer exercise protocol, these authors furthermore suggest that L_{MS} is not a valid measurement of endurance capacity.

In their study CARTER et al. (1999) applied exactly the same exercise test protocols prior to, and after training. This resulted in lower blood lactate concentrations prior to the incremental phase of the test in the post-training situation due to the lower relative intensities of the supramaximal bouts (from 120 to 111% VO_2max). It is our belief, that this could have influenced the L_{MS} determinations, since as we have previously found, lower lactate values prior to the incremental phase of the LMT consequent to beta-adrenergic blockade, cause a significant decrease in L_{MI} (BALIKIAN et al., 1999a, 1999b). CARTER et al. (1999) have also pointed out that it is possible that L_{MS} could have shifted to the right if they had taken the increased fitness of the participants after the training program into account, and started the incremental part of the test at a faster running speed. Other methodological problems (i.e. training intensity and duration) could also have minimized training adaptations, diminishing the LMT test's sensitivity.

In the present study, subjects underwent a maximal 30 seconds cycloergometer test prior to the incremental exercise protocol, in both the pre- and post-training situations. Improvement of fitness due to training did not cause a decrease in the relative intensity of the anaerobic bout of exercise, a conclusion confirmed by lactate concentration data taken immediately prior to graded exercise.

To conclude, our findings confirm that G_{MI} is a good predictor of L_{MI} during cycloergometer LMT. In addition, we have for the first time, found that both L_{MI} and G_{MI} are sensitive parameters of adaptations due to endurance training. More studies will be required to elucidate the mechanisms responsible for changes in these parameters during graded exercise.

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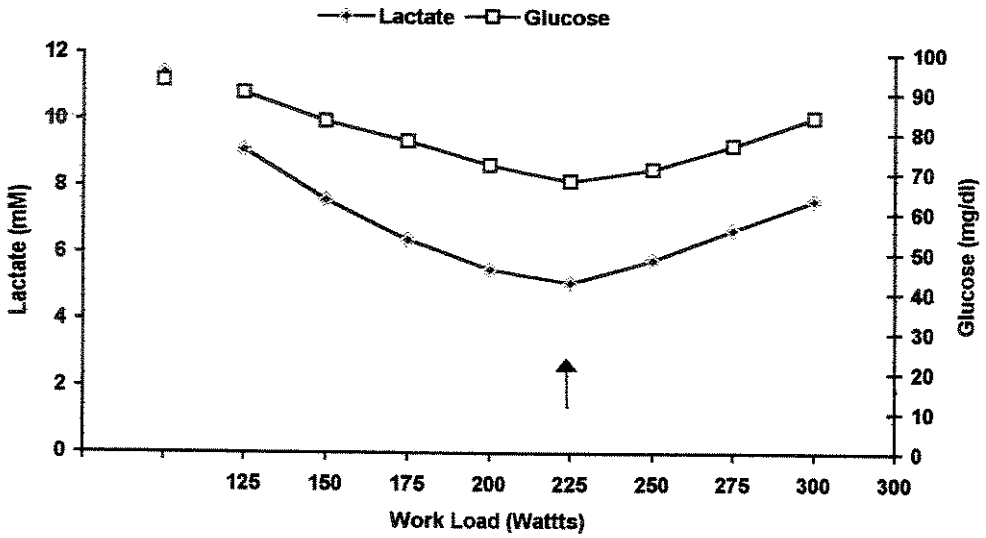

Figure 1. A single subject's data showing the determination of L_{MI} and G_{MI} power output (W). In this case, a work load of 225 Watts (arrow) was related to both parameters.

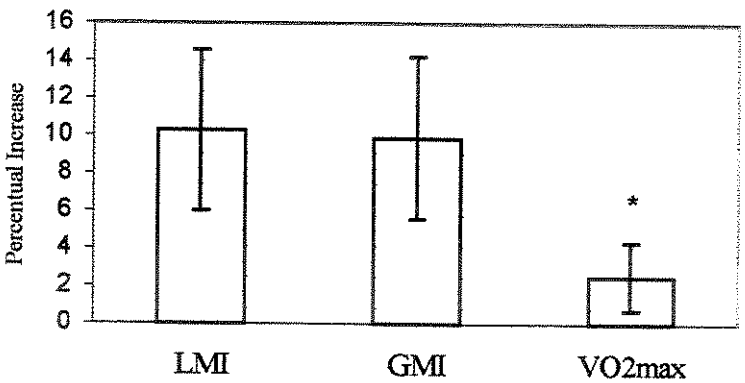

Figure 2. Lactate (L_{MI}) and glucose (G_{MI}) minimum intensities (Watts) and VO_2max ($ml.Kg^{-1}.min^{-1}$) alterations after a 12-week training period. *P < 0.05 from L_{MI} and G_{MI}

Table 1. Mean ± SD values for L_{MI} and G_{MI} expressed in Watts (W), relative oxygen uptake (%VO_2max) and Heart Rate (HR) in pre- and post-training situations

	Pre-training			Post-training		
	W	%$VO2_{max}$	HR (bpm)	W	%$VO2_{max}$	HR (bpm)
LACmin	215.0 ± 18.6	71.5 ± 2.6	166.0 ± 1.3	237.5 ± 18.8*	72.6 ± 1.92*	166.2 ± 1.4
GLICmin	218.2 ± 22.1	71.8 ± 2.5	166.1 ± 1.2	240.6 ± 22.9*	73.0 ± 1.51*	166.1 ± 1.0

* $p < 0.05$ from pre-training situation

Table 2 Correlation coefficients (r), between L_{MI} and G_{MI} work load (W) and relative oxygen uptake (%VO_2max) in the pre-training situation (N = 8).

		Pre-training		Post-training	
		L_{MI}		L_{MI}	
		W	%VO_2max	W	%VO_2max
G_{MI}	W	0.92 *	-	0.93*	-
	%VO_2max	-	0.90 *	-	0.91*

*P < 0.05

Table 3. Spearman correlation coefficients (r) between percent differences in the improvement in Lactate Mínimum (%LACmin), Glycemia Mínimum (%GLICmin) e Maximal Oxygen Consumption (%VO_2max), determined at two training períods, basal and competition. (N=08)

	%GLICmin	%VO_2max
%LACmin	0.97*	0.29
%GLICmin	_	0.43

*$p < 0.05$

4. ARTIGO 2

Effect of an acute β-adrenergic blockade on the blood glucose response during lactate minimum test

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Abstract

The aim of this study was to analyze na accute effect of β-adrenergic blockade on the lactate and glucose minimum intensities during an incremental test after exercise induced lactic acidosis. Eight fit males (cyclists or triathletes) performed a protocol to determine the intensity corresponding to the individual equilibrium point between lactate entry and removal from the blood (incremental test after exercise induced lactic acidosis), determined from the blood lactate (Lacmin) and glucose (Glucmin) response. This protocol was performed twice in a double-blind randomized order by ingesting either propranolol (80 mg) or a placebo, 120 min prior to the test. The blood lactate and glucose concentration obtained 7 minutes after anaerobic exercise (Wingate test) was significantly lower during the acute β-adrenergic blockade (8.6 ± 1.6 mM; 3.9 ± 0.1 mM) than placebo condition (11.7 ± 1.6 mM; 5.0 ± 0.1 mM), respectively. There was no difference between the exercise intensity determined by Lacmin (215.0 ± 18.6 W) and Glucmin (218.2 ± 22.1 W) during exercise performed without acute β-adrenergic blockade. The exercise intensity at Lacmin was lowered from 215.0 ± 18.6 to 184.0 ± 18.6 W and heart rate at Lacmin was reduced from 166.0 ± 1.3 to 132.1 ± 2.0 beats min^{-1} as a result of the blockade. It was not possible to determine the exercise intensity corresponding to Glucmin with β-adrenergic blockade, since the blood glucose concentration presented a continuous decrease during the incremental test. We concluded that the blood glucose response can be used to estimate the intensity corresponding to Lacmin, during cycling exercise. This association is not present during β-adrenergic blockade suggesting that, at least in part, this behavior depends upon adrenergic stimulation.

Introduction

Despite the lack of agreement among researchers about the underlying mechanisms and terminology (Wasserman et al., 1973; Brooks, 1985; Gaesser and Poole, 1986), the blood lactate response during incremental exercise has been widely used in sport and medical research. Practical applications of the blood lactate response include the measurement of aerobic capacity training effects (Kohrt et al., 1989; Weltman et al., 1992) and prescription of appropriate exercise intensity (Kindermann et al., 1979; Billat, 1996). Many studies have proposed protocols to determine the exercise intensity corresponding to the maximal lactate steady state (MSSL), i.e., the highest constant workload that can be performed with equilibrium between lactate entry and removal from the blood (Stegmann et al., 1981; Heck et al, 1985).

Tegtbur et al. (1993) have proposed an interesting protocol (incremental test after exercise induced lactic acidosis or Lacmin) to identify the intensity corresponding to the individual MSSL. The authors found that MSSL could be obtained for all subjects during long term exercise at Lacmin intensity. Moreover, differently from others protocols (Maassen and Busse, 1989; Berry et al., 1991) the intensity corresponding to the Lacmin is not influenced by muscle glycogen stores (Tegtbur et al., 1993) nor glucose or caffeine ingestion (Campbell et al., 1998).

Although the blood lactate determination during exercise is not always possible due to the lack of equipment, many authors have propose the use of alternative methodologies, which could predict the lactate response to exercise (Wasserman et al., 1973; Conconi et al., 1982; Northuis et. al., 1995; Weltman, 1995; Dantas et al., 1999).

Recently, Simões et al. (1999) reported that it was possible to predict the MSSL intensity from the plasma glucose response (Glucmin) during a Lacmin test in endurance

runners. Moreover, Campbell et al. (1998) have demonstrated that the relationship between blood lactate and glucose during Lacmin test is not altered by glucose or caffeine ingestion. These findings suggest the possibility to use the plasma glucose response to estimate the Lacmin intensity. However, these authors point that this relatively new methodology must be extensively examined to confirm the possible use of serum glucose to predict the blood lactate response to graded exercise.

Although its invasive nature, blood glucose analysis presents several advantages over lactate envolving tests due to cost reduction and more accessible analytical methodology. Consequently, it could be used by a large number of coaches, researchers and other professionals, both in the laboratory and the field.

However, the factors and mechanisms responsible for blood lactate and glucose behavior during exercise are not completely understood. A possible mechanism is the catecholamine response during exercise, since epinephrine and norepinephrine have a critical role in the body's adjustment to stressful activities. In muscle, through β-adrenergic receptors, epinephrine initiates a cascade of events that stimulates the degradation of glycogen and an increase in lactate production (Podolin et al., 1991). Moreover, many studies have demonstrated that circulating epinephrine is an important controller of both hepatic glucose production and peripheral glucose uptake during exercise (Kjaer, 1992; Moneta et al, 1996; Schneider et al, 2000). Therefore, the main purpose of this study was to investigate the effect of an acute β-adrenergic blockade with propranolol on the lactate and glucose minimum intensities during the Lacmin test.

Methods and Procedures

Subjects

Eight healthy, physically active male volunteers participated in the study: age (SD) = 21.1 (1.7) yr; height = 171.4 (8.5) cm; weight = 64.7 (9.5) Kg; and $\dot{V}O_{2max}$ = 60.5 (4.2) $ml.kg^{-1}.min^{-1}$. Six were competitive triathletes, and two were competitive cyclists. None of them took regular medication or had any remarkable medical history. The nature of the study was explained to each subject before written informed consent was obtained.

Experimental protocol

The participants were instructed to arrive at the laboratory in a rested and fully hydrated state, at least 3 h post-prandial and to avoid strenuous exercise during the 48 h preceding the test session. For each subject, the tests took place at the same time of the day to avoid the effects of diurnal biological variation.

Subjects reported to the laboratory three times, at 2-3 days intervals between test sessions. At the first visit, in order to determine the $\dot{V}O_{2max}$, a maximal exercise test was performed on an electrically braked cycle ergometer (Lifestyle 5500). The initial workload was 50 W and the intensity was increased by 25 W every 1 min until voluntary exhaustion. Respiratory gas exchange data were determined continuously throughout the exercise tests (Vista CPX, Vacumed).

In the two subsequent sessions, the intensity corresponding to the Lacmin and Glicmim were determined in a double-blind randomized order with the subject ingesting either propranolol (80 mg) or a placebo (glucose) 120 min prior to the test. In order to

determine the intensity corresponding to the Lacmin and Glicmim, the subjects were submitted initially to the Wingate test (Bar-Or, 1987), for lactic acidosis induction. At 8 min of recovery after the Wingate test, a subsequent incremental exercise test was performed. The initial workload was 100 W and the intensity was increased by 25 W every 3 min until exhaustion. After 7 min of recovery and at the end of each stage, 25 µl of blood was collected from the ear lobe, into microcentrifuge tubes containing 50 µl NaF (1%), for lactate measurement (YSL 2700 STAT). Simultaneously, 5 ml of blood was sampled at 7 min of recovery and during the last 30 seconds of each workload from an antecubital vein via an indwelling catheter for glucose measurement (glucose oxidase – Cobas Mira Plus-Roche). The lowest blood lactate and glucose concentration during the incremental test and its respective intensity were calculated using a spline function, and were considered Lacmin and Glucmin, respectively (Tegtbur et al., 1993; Simões et al., 1999) (Fig. 1 and 2).

Heart rate determination (HR)

At the end of each stage of progressive testing, HR was determined with a frequency meter (Polar Vantage XL).

Statistical analysis

Results are reported as means ± SD. Comparisons were analyzed by the Student *t*-test and the Pearson product moment coefficient was employed for correlation analysis. Statistical significance was set at $P \leq 0.05$.

Results

The blood lactate and glucose concentration obtained 7 minutes after the Wingate test were significantly lower with acute β-adrenergic blockade (Table 1). The exercise intensity and heart rate corresponding to the Lacmin were significantly lower with acute β-adrenergic blockade (Table 1). There was no difference between the exercise intensity determined by Lacmin and Glucmin during the protocol performed without acute β-adrenergic blockade. It was not possible to determine the exercise intensity corresponding to Glucmin with β-adrenergic blockade, since the blood glucose concentration of all subjects decreased continuously during the incremental test. Example for one subject is presented in Figure 2.

There was a significant correlation ($r = 0.93$; $P<0.01$) between the exercise intensity determined by Lacmin and Glucmin in tests without β-adrenergic blockade (Fig. 3). However, there was no significant correlation ($r = 0.31$; $P>0.05$) between the exercise intensity corresponding to the Lacmin with and without acute β-adrenergic blockade (Fig 4).

Discussion

This investigation was designed to analyze the effect of β-adrenergic blockade on the lactate and glucose minimum intensities during an incremental test after exercise induced lactic acidosis. The results of this study indicate two significant findings. Firstly, β-adrenergic blockade had significant effects on the blood lactate and glucose response to the Lacmin test. Secondly, the glucose response can be used to predict the intensity corresponding to Lacmin during cycling exercise in normal conditions.

Although drug plasma concentration was not directly measured, propranolol caused a 26% reduction of blood lactate after the Wingate test and a 20% reduction of the heart rate value corresponding to Lacmin, indicating adequate blockade of β-adrenoceptors (Jansson et al, 1986). β-adrenergic blockade studies (propranolol) have shown drastic decrease in plasma lactate (Galbo et al, 1976; Jansson et al, 1986). Moreover, epinephrine infusion has been found to produce an increase in lactate output from contracting gastrocnemius muscle in dogs (Stainsby et al, 1984).

On the other hand, some studies have shown ß-adrenergic blockade to have no effect on blood [Lac] during incremental (Hughson et al.,1981; Tesch & Kaiser, 1981) or constant load exercise (Jensen et al., 1993), thereby demonstrating that the ß-adrenergic system is not obligatory for the blood [Lac] response to exercise.

The results of this study support the possibility that the blood glucose response can be used to predict the Lacmin intensity, being consistent with previous findings (Campbell et al., 1998; Simões et al., 1999). Simões et al. (1999) verified in well-trained endurance runners, that the velocity determined by Glucmin, was coincident with the velocity corresponding to MSSL, determined by two different incremental tests performed in track: individual anaerobic threshold (Stegmann et al., 1981), and lactate minimum test (Tegtbur et al., 1993). This phenomenon could, to some extent, be explained by the catecholamines influence on the metabolism, particularly during the strenuous part of a graded exercise test.

Catecholamines have a potent effect on a variety of physiological and metabolic proccess, mainly during intense exercise. Particulary, epinephrine plays an important role in muscle glycogenolysis control by its stimulatory effect on ß-adrenergic receptors located in

skeletal muscle membrane. Once activated, ß-adrenergic receptors start a series of cascading reactions that lead to the activation of phosphorilase *a* (the regulating enzime for glycogenolysis) and consequently increase in muscle lactate production and blood lactate concentration (Issekutz, 1985).

Mazzeo and Marshall (1989), manipulated the lactate threshold (T_{LA}) by using training specificity over two testing modalities, treadmill running and cycloergometer, both whit graded work load, and finding that the inflection in plasma epinephrine (T_{EPI}) shifted in an identical manner and occurred simultaneously with that of T_{La} ($r = 0.97$) regardless of the testing protocol or training status.

In another study, Podolin et al. (1991), examined under normal and glycogen-depleted conditions the relationships between the T_{LA} and plasma catecholamines, and found high correlations for both, epinephrine ($r = 0.964$) and norepinephrine (0.965).

Schneider et al., (2000), demonstrated that the lactate, epinephrine and norepinephrine thresholds shifted between exercise testing modes depending on the size of the muscle mass utilized. The blood lactate and catecholamines thresholds were found to be significantly lower for arm than for leg exercise. Furthermore, the breakpoint in plasma catecholamines moved in an identical manner and occurred simultaneously with that of T_{LA} regardless of the mode of exercise (arm or leg).

In addition, the relationship between catecholamines and lactate production has been suggested by several authors under various animals experimental conditions (Issekutz, 1985; Stainsby & Brooks, 1990). Although it doesn't represent an obligatory cause-effect relationship, this could be pointed by the statistical treatment.

In relation to glucose metabolism, some studies have found that epinephrine is directly involved in regulation of both hepatic glucose production (Ra) and peripheral

glucose uptake (Rd) during exercise. Ra increases exponentially with workload in parallel with the rise in plasma epinephrine (Kjær, 1992; Weltman, 1995). During exercise performed in hypoxia, the increase of the catecholamines and Ra is higher compared to normoxia, whereas response of pancreatic hormones were similar between the two conditions. Rd also seems to be under influence of catecholamines during exercise (Kjaer, 1992). Kjaer et al. (1991) found that during combined arm and leg exercise, both catecholamines response as well Ra rose more markedly compared with the period of leg exercise only. However, the increase of glucose delivery only resulted in a small increase in Rd. The authors suggested that this phenomenon could be determined by the high concentration of epinephrine in plasma, as epinephrine has been shown to reduce muscular glucose uptake during exercise (Issekutz, 1985; Hoelzer et al., 1986). Therefore, the catecholamine, particularly epinephrine may play an important role in the control of blood lactate and glucose response during incremental exercise.

In the present study, the blood glucose response was modified by acute β-adrenergic blockade, making it impossible to identify an inflection in the blood glucose curve. There are no studies in the literature which have analyzed the β-adrenergic blockade effect on the blood glucose response using a similar protocol, which makes it difficult to compare our results to others existent. However, Galbo et al. (1976) reported a more rapid decline of blood glucose during submaximal exercise after β-adrenergic blockade. Moreover, the authors found an increase of the carbohydrate combustion rate and less muscle glycogen utilization after β-adrenergic blockade. Galbo et al. (1976) suggested that during β-adrenergic blockade, a smaller inhibition of hexokinase by glucose-6-phosphate derived

from glycogen possibly accounted for the larger glucose uptake, and a more rapid decline of blood glucose.

Hoelzer et al. (1986) have verified that the hypoglycemia observed during exercise with β-adrenergic blockade, is not determined by a lower hepatic glucose production. Even though adrenergic stimulation could be important for hepatic glucose production, the fall in insulin levels associated with exercise is not affected by pharmacological β-blockade (Hoelzer et al., 1986). Moreover, Hoelzer et al. (1986) also verified an increase of muscular glucose uptake after adrenergic blockade, indicating the importance of catecholamines in hypoglycemia prevention during exercise. The fall in blood glucose may result from the lack of catecholamine action in skeletal muscle (Issekutz, 1985) or indirectly due to lower free fatty acid availability, since lipolysis is depressed under β-adrenergic blockade. Thus, the increase in muscular glucose uptake may explain the constant decline in blood glucose observed during our protocol with β-adrenergic blockade.

In conclusion, β-adrenergic blockade caused a significant decrease in Lacmin intensity and a continuous decrease in blood glucose during the graded phase of Lacmin test, suggesting that, at least in part, blood lactate and glucose behavior depends upon adrenergic stimulation during exercise. In addition, we found the Glucmin to be a good predictor of Lacmin under normal condition. However, more studies are needed to elucidate the relationship between the sympathetic activity, blood lactate and glucose behavior during exercise.

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Table 1 – Blood lactate and glucose 7 minutes after anaerobic exercise and the intensity (Watts) and heart rate (HR) corresponding to lower blood lactate (Lacmin) and glucose (Glucmin) concentration during incremental test, with and without β-adrenergic blockade (n = 8)

	Placebo	β-adrenergic blockade	Difference (%)
Lactate (mM)	11.7 ± 1.6	8.6 ± 1.6 *	- 26.71 ± 7.60
Glucose (mM)	5.0 ± 0.1	3.9 ± 0.1 *	- 21.62 ± 3.54
Lacmin (Watts)	215.0 ± 18.6	184.0 ± 18.6 *	- 14.27 ± 9.77
Glucmin (Watts)	218.2 ± 22.1	-	-
HR - Lacmin (bpm)	166.0 ± 1.3	132.1 ± 2.0 *	- 20.36 ± 1.62
HR - Glucmin (bpm)	166.1 ± 1.24	-	-

Values are means ± SD. * $p < 0.05$ in relation to placebo

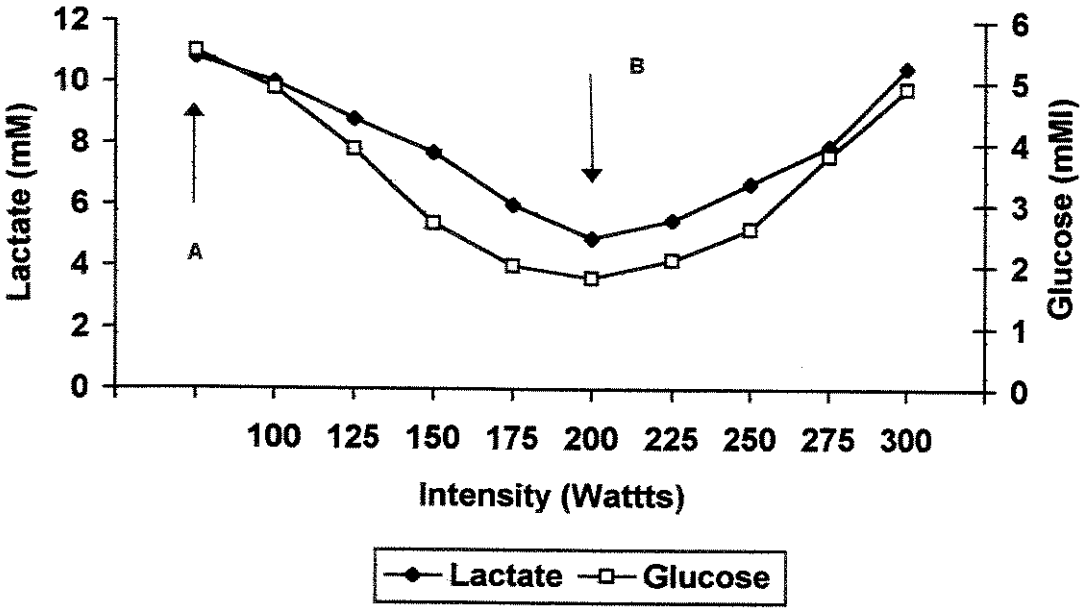

Figure 1 - Determination of intensities corresponding to the lower lactate (Lacmin) and glucose (Glucmin) concentration during the incremental test (single subject) without beta-adrenergic blockade. A = blood lactate and glucose 7 minutes after anaerobic exercise (Wingate test).

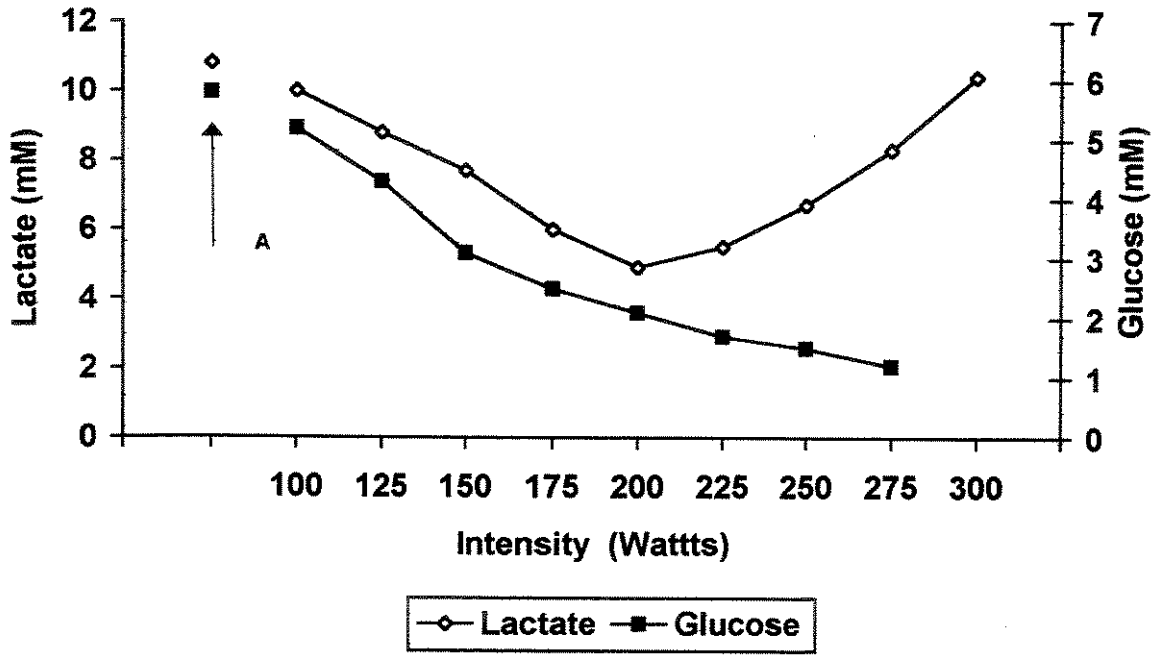

Figure 2 - Determination of intensity corresponding to the lower lactate (Lacmin) concentration during the incremental test (single subject) with beta-adrenergic blockade. A = blood lactate and glucose 7 minutes after anaerobic exercise (Wingate test).

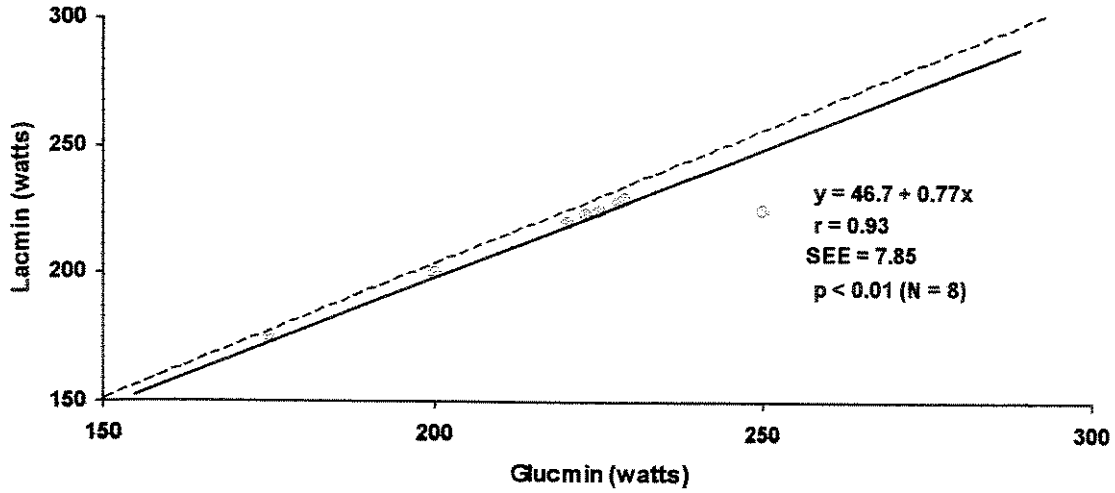

Figure 3 - Relationship between exercise intensity at lowest blood lactate (Lacmin) and glucose (Glucmin) concentration, without β-adrenergic blockade. Dashed line is line of identify, solid line is regression equation.

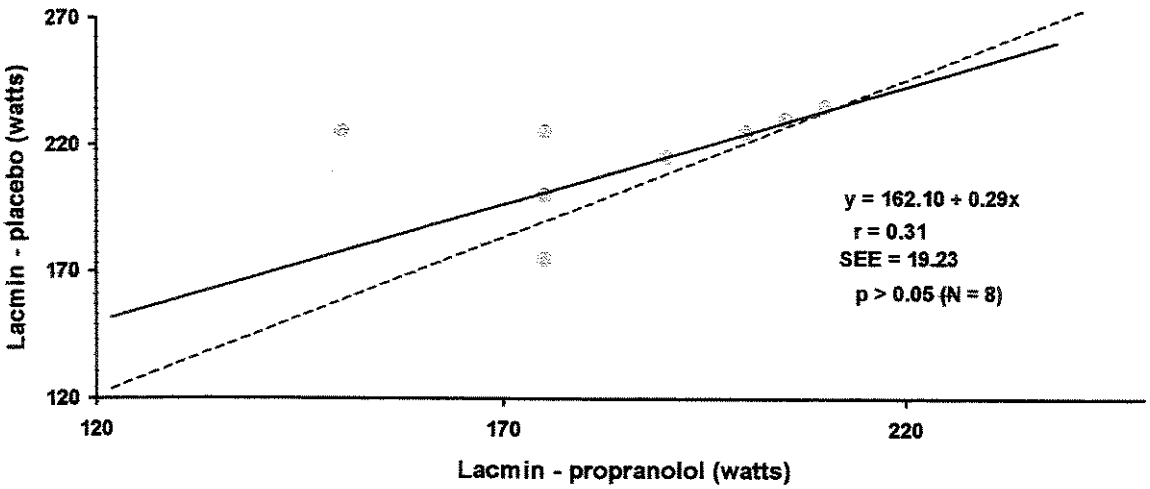

Figure 4 - Relationship between exercise intensity at lowest blood lactate (Lacmin) concentration, with and without β-adrenergic blockade. Dashed line is line of identify, solid line is regression equation.

5. ARTIGO 3

CATECHOLAMINE AND LACTATE RESPONSES TO INCREMENTAL WORK AFTER MAXIMAL EXERCISE

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ABSTRACT

The relationships between the plasma epinephrine minimum (EPImin), the norepinephrine minimum (NORmin) and blood lactate minimum (LACmin) were examined during incremiental cycling after a preceding bout of maximum exercise (Wingate test), when blood lactate initially decreases to an individual minimum and then increases again. 07 male trained cyclists participated in the study. Significant correlations ($p < 0.05$) were found between peak lactate, norepinephrine and epinephrine concentrations, after Wingate test. When oxygen uptake measured at each variable was expressed as a percent of VO_2max, the minimum values ocurred at 71.70±2.70; 72.00±3.10; 71.70±2.70 for LACmin, NORmin and EPImin respectively, being these values not significantly different ($p > 0.05$). In addition, heart rate and power output related to lactate, norepinephrine and epinephrine minimum values were not found to be significantly different ($p > 0.05$). Significant correlations were found between lactate and catecholamines responses ($p < 0.05$).

INTRODUCTION

Them human subjects perform progressive exercise in which the work rate (W) is increased until the maximal O_2 uptake (VO_2max) is achieved, the concentration of lactate in the arterial blood rises. During exercise up to ~50% of VO_2max, blood lactate rises slowly. However, above ~50% the maximal work rate it rises progressively more rapidly, and the break in the rate of rise of blood lactate has been referred to as the anaerobic threshold (T_{la}) (STAINSBY et al, 1985; TANAKA et al, 1997). The factors and mechanisms associated with the inflection in blood lactate during progressive incremental exercise have long been of physiological interest. Muscle anaerobiosis (WASSERMAN et al, 1989), fiber recruitment (BROOKS, 1991), mitochondrial saturation (ISSEKUTZ, 1984), and hormonal control (GLADDEN, 1996; GREENHAFF & TIMMONS, 1998; SIMÕES et al, 1999; STROBEL et al., 1999) are among the more prominent variables thought to have a contributing role. Concentrations of free plasma epinephrine ([Epi]) and norepinephrine ([Nor]) are known to increase during exercise (PODOLIN et al, 1991; MAZZEO et al., 1991), with moderate to strong correlations reported between plasma [Epi] and [Nor] and blood lactate concentrations ([Lac]) (POKAN et al., 1995; MONETA et al, 1996; SCHNEIDER et al, 2000). During high intensity exercise, the catecholamines, epinephrine and norepinephrine, play an integral role in the adjustment to disturbances in homeostasis. Specifically, through the action of the β-adrenergic receptors, epinephrine is known to stimulate muscle glycogenolysis during contraction (GREENHAFF & TIMMONS, 1998; SCHNEIDER et al, 2000). Consequently, elevated levels of epinephrine have been associated with increased rates of muscle glycogen breakdown and lactate production

during exercise. Infusion of β-adrenergic blockade (propranolol) drastically decreased plasma lactate (JANSSON et al, 1986), and experiments using [^{14}C]glucose indicated that some 90% of the lactate originated from plasma glucose and not from other sources (muscle glycogen) (ISSEKUTZ, 1984). Moreover, epinephrine infusion has been found to produce an increase in lactate output from contracting gastrocnemius muscle in dogs (STAINSBY et al, 1984). Plasma [Epi] and [Nor] are also known to demonstrate infletion point (or thresholds) during incremental exercise (JANSSON et al, 1986;). In addition, the abrupt increases im plasma [Epi] and blood [Lac] have been reportes to occur at identical work rates during incremental exercise (MAZZEO & MARSHALL, 1984; SCHNEIDER et al, 2000). On the other hand, some studies have shown ß-adrenergic blockade to have no effect on blood [Lac] during incremental (HUGHSON et al.,1981; TESCH & KAISER, 1981) or constant load exercise (JENSEN et al., 1993), thereby demonstrating that the ß-adrenergic system is not obligatory for the blood [Lac] response to exercise. Thus an associantion has been suggested between plasma catecholamines and lactate production, but the extent of this relationship still remains a question, particularly in humans. To elucidate the relationships between the plasma catecholamines and blood lactate, were performed an incremental exercise test after a preceding bout of maximum exercise (WINGATE test), when blood lactate initially decreases to an individual minimum and then increases again (LACmin) (TEGTBUR et al, 1993; SIMÕES, et al, 1999).

METHODS

A total of 07 male subjects participated in the study. All subjects were examined for possible contra-indications to the study. The details of the experimental procedures and the possible risks were explained in detail before the subjects signed an informed consent form approved by the Campinas State University Ethics Committee. The subjects were competitive cyclists for the University Team - SP, considered healthy after clinical examination, non-smokers and didn't take any medication on a regular basis. The characteristics of the subjects are in Table 1.

Experimental protocol.

All of the subjects studied went to the lab in two different occasions, with a 3 day interval from the first to the last time. On the first time, they were submitted to a clinical evaluation to eliminate any possible disturb that could unable them of participating of the experiment. After these procedures, they were submitted to a protocol to determine the VO_2max. On the second time for the determination of the LACmin, NORmin and EPImin exercise intensities.

Measurements.

Determination of VO_2max For the VO_2max determination the subjects carried out a continuous incremental cycloergometer test which began at 50 W and increased 25 W every minute until voluntary exaustion. Gas exchange and ventilatory parameters were continuously measured from expired air using a Vista CPX system (Vacumed, 1996). Oxygen uptake (VO_2), carbon doixide production (VCO_2) and ventilation (Ve) were measured each 30 seconds through an Oxygen Analyser OM-11, Carbon Dioxide Analyser LB-2 and Flow Transducer K – 520, respectively. All data were imediately processed

through a Vista CPX "software". VO_2max achievment was confirmed as proposed by SHEPHARD et al., (1968).

Determination of the lactate minimum (L_{MI}), norepinephrine minimum (N_{MI}) and epinephrine minimum (E_{MI}) intensities. For the L_{MI} , N_{MI} and E_{MI} intensities determination subjects underwent a continuous incremental exercise test preceded by an all out 30 seconds Wingate test (BAR-OR, 1987), with 0.075 Kp/Kg body mass load. Before the Wingate test, a warm up of ten minutes cycling at 50 W and a stretching session were performed.

8 minutes after the Wingate test, subjects started cycling at 125 W with 25 W increases each 3 minutes until voluntary exaustion. Blood samples were taken 7 minutes after the Wingate test and at the end of each stage during incremental test. In addition, VO_2 was continuously measured during the test as described early. For the identification of power output (W) and relative VO_2 (%VO_2max) at lactate, norepinephrine and epinephrine minimum, it was considered the lowest blood lactate and catecholamines levels respectively attained during incremental exercise (Figure 1).

Figura 1

Catecholamine analysis. Approximately 5 ml of blood were sampled at rest, 7 min after the Wingate Test and during the last 30s of each work load from an antecubital vein via an indwelling catheter. One milliliter of blood was immediately deproteinized with 4.5 ml of iced 0.8% perchloric acid, vortexed, and centrifuged.

The blood were placed in a tube containing reduced glutathione to control the oxidation of catecholamenes, vortexed, and centrifuged. The plasma was then stored at -70 °C for catecholamine analysis. Plasma norepinephrine and epinephrine concentrations were determined by means of high-pressure liquid chromatography (HPLC) with electrochemical detection (Bio-Rad HPLC pump, model 1330; Bio-Rad electrochemical detector) as modified by HALLMAN et al, 1978. An internal standard was prepared by adding appropriate concentrations of dihydroxybenzlamine (Sigma) in 50 µl of 0.1 N $HClO_4$ to the supernatant fluid. The solution was pH adjusted to above 8.0 with 1.5 M tris (hydroxymethyl) aminomethane buffer at pH 8.6 in 2% EDTA (Sigma Chemical). Twenty-five milligrams of acid-washed alumina (Woelm, ICN Pharmaceuticals) were added, followed by 10 min of vigorous shaking. The alumina wos then woshed three times with 3 ml of distilled water with brief centrifugation between washes. The catecholamines were extracted with 100 µl of N $HCLO_4$ for 3 min with shaking and final centrifugantion at 12,000 g. One-hundred microliters of eluant were then injected into the HPLC column (recerse phase, Bio- Sil ODS-5S, Bio-Rad) and eluted with mobile phase (6.9 g sodium acetate-anhydrous, 0.8 g Na_2EDTA, 45 ml acetonitril, 1.2 g sodium heptane sulfonate in 1 liter, pH adjusted to 4.8). The flow rate was 1.1 ml/min at 2,000 psi with a potential of 0.65 V. The chromatogram was analyzed by computer integration (model C-R3A, Shimadzu).

Blood lactate analysis. Simultaneously to the sample collection to analyse the catecholamines, samples were collected from the ear-lap, without hyperemia, 25µl of blood, which was immediately transferred to plastic tubes with lid - Eppendoff type- 1,5 ml, containing 50µl of NaF1% solution and stored in ice. The lactate analysis was done in

duplicates, by the electrochemical analyzer model YSL 2700 STAT (Yellow Spring Co., USA).

Statistical analyses. The statistical significance of the difference between the inflections in plasma catecholamines and blood lactate and glucose was determined using mean differences and Pearson product-moment correlations.

RESULTS

Significant correlations ($p < 0.05$) were found between maximal blood lactate (11.75 ± 1.72 mM) and plasma norepinephrine [Nor] (14.99 ± 1.85 ng/ml) and epinephrine [Epi] (2.33 ± 0.11 ng/ml) concentrations obtained 7 minutes after Wingate test (Table 2). Significant correlations ($p < 0.05$) were also found between L_{MI}, N_{MI} and E_{MI} expressed in $\%VO_2max$ (Table 2).

Table 2

T test showed no significant differences ($p > 0.05$) between L_{MI}, N_{MI} and E_{MI}, expressed both in Watts (214.28 ± 19.66, 217.85 ± 23.77 and 214.28 ± 19.66, respectively) (Figure 2) and $\%VO_2max$ (71.71 ± 2.75; 72.00 ± 3.10 and 71.42 ± 2.57, respectively) (Figure 3).

Heart rate values related to the minimum lactate (165.00 ± 1.33 bpm), norepinephrine (166.28 ± 0.95 bpm) and epinephrine (165.28 ± 1.60 bpm) concentrations obtained during the incremental phase of the lactate minimum test were not significant different ($p > 0.05$) (Figure 4).

Figure 2

Figura 3

Figura 4

DISCUSSION

Based on the blood lactate response, several criterion have been employed in the accessment of aerobic/anaerobic transition during graded exercise (BROOKS, 1991; WELTMANN, 1995). Fixed blood lactate concentrations (i.e., 4.0mM) (HECK et al, 1985) are tradittionaly used, but some authors point that this could led to arbitrary values (YEH et al, 1983) and be influenced by prior muscle glycogen content (MAASSEN & BUSSE, 1989).

Mechanisms and terminology associated to the blood lactate break point during exercise has been subject of great controversy in Exercise Physiology's recent history (BROOKS, 1985; DAVIS, 1985; KATZ & SAHLIN, 1988; STAINSBY & BROOKS, 1990; BROOKS, 1991). Among the possible causes of increased lactate concentrations during intense exercise are: biochemistry regulation, relative tissue hipoxia, motor unit recruitment, an imbalance between lactate production and removal and enhanced sympathetic activity (ISSEKUTZ, 1984; WASSERMAN et al, 1989; BROOKS, 1991; GLADDEN, 1996; GREENHAFF & TIMMONS, 1998; SIMÕES et al, 1999).

Due to its objectivity and independence of previous nutrition status, lactate minimum test is becoming popular in athletics evaluation. Introducing the "lactate minimum test" (LMT), DAVIS & GASS (1979) found that during graded exercise test initiated during latic acidosis, blood lactate concentration decreased to a minimum first and then increased. The authors however, did not check the possibility of the lactate minimum intensity (LACmin) represents the MSSL. Years after, TEGTBUR et al. (1993) adapted the LMT to track run, and verified that when subjects exercised at the lactate minimum speed for eight kilometers, MSSL was reached. However, when this velocity was increased by 0.2 m/s, MSSL was never attained and many subjects could not finish the race. In addition,

prior glycogen depletion did not cause significant changes in the lactate minimum speed although lower lactate concentrations thorough the test.

In our lab, SIMÕES et al. (1999), reproduced the results of TEGTBUR et al. (1993), although the LACmin speed (282.6 m/s) did not significant differ from the 4 mM velocity (288.9 m/s) determined by interpolation (MADER et al., 1978).

Factors that could affect the lactate minimum intensity determination have also been studied recently during cycloergometer exercise. CAMPBELL et al. (1998), tested the possible influence of oral caffeine or glucose ingestion on the lactate minimum power output, once prior studies showed that these manipulations could alter the lactate response to graded exercise (YOSHIDA, 1984; GAESSER & RICH, 1985). Evaluating 11 physical active subjects, CAMPBELL et al.(1998) found that blood lactate behavior during cycloergometer exercise was similar to that found during running (TEGTBUR et al., 1993; SIMÕES et al., 1999). In addition, they did not found significant differences between lactate minimum power output in placebo (155.0 W), caffeine (160.0 W) or glucose (160.0 W) conditions.

During high intensity exercise, the catecholamines, epinephrine and norepinephrine, play an integral role in the adjustment to disturbances in homeostasis. In the present study we employed the LMT to evaluate the relationship between plasma catecholamines and blood lactate response during exercise.

Our results showed high correlation ($r = 0.85$ to $r = 0.98$) between maximal [NOR], [EPI] and [LAC] obtained 7 min after Wingate test. In addition no significant differences were found between L_{MI}, E_{MI} and N_{MI}, expressed both in Watts and % VO_2max. High correlation were also found between L_{MI} and N_{MI} ($r = 0.97$) and L_{MI} and E_{MI} ($r = 0.96$) when these intensities were expressed in $\%VO_2max$.

Once for the first time in the literature LMT was employed to evaluate the relationship between catecholamines and lactate behavior during exercise, comparison with other's results are limited by protocol differences. However, our results are in accordance with previous human studies that found catecholamines inflexion point to coincide with the lactate break point during simple graded exercise (LEHMANN et al, 1985; MAZZEO & MARSHALL, 1989; PODOLIN et al, 1991; MONETA et al, 1996; SCHNEIDER et al, 2000).

MAZZEO and MARSHALL (1989), manipulated the lactate threshold (T_{La}) by using training specificity over two testing modalities, treadmill running and bicycle ergometry, both whit graded work load, and finding that the inflection in plasma epinephrine shifted in an identical manner and occurred simultaneously with that of T_{La} ($r = 0.97$) regardless of the testing protocol or training status.

In another estudy, PODOLIN et al. (1991), examined under normal and glycogen-depleted conditions the relationships between the T_{La} and plasma catecholamines, and found high correlations for both, epinephrine ($r = 0.964$) and norepinephrine (0.965).

SCHNEIDER et al. (2000) demonstrated that the lactate, epinephrine and norepinephrine thresholds shifted between exercise testing modes depending on the size of the muscle mass utilized. The blood lactate and catecholamines thresholds were found to be significantly lower for arm than for leg exercise. Furthermore, the breakpoint in plasma catecholamines moved in an identical manner and occurred simultaneously with that of T_{La} regardless of the mode of exercise (arm ou leg)

In addition, the relationship between catecholamines and lactate production has been suggested by several authors under various animals experimental conditions

(ISSEKUTZ, 1984; STAINSBY et al, 1987). Although it does not represent an obligatory cause-effect relationship, this could be pointed by the statistical treatment.

Catecholamines have a potent effect on a variety of physiological and metabolic proccess, mainly during intense exercise. Particulary, EPI plays an important role in muscle glycogenolysis control by its stimulatory effect on ß-adrenergic receptors located in skeletal muscle membrane. Once activated, ß-adrenergic receptors start a series of cascading reactions that lead to the activation of phosphorilase *a* (the regulating enzime for glycogenolysis) and consequently increase in muscle lactate production and blood lactate concentration (ISSEKUTZ, 1984).

Norepinephrine has the same stimulatory effect on ß-adrenergic receptors, but it acts not only as an hormone but as the main sympathetic neurotransmitter. High intensity exercise promotes a great sympathetic activation, leading to a great NOR appearance in circulation and consequent EPI (80%) and NOR (20%) release from adrenal medulla (LEHMANN et al., 1985; MAZZEO & MARSHALL, 1989). This could be used to explain the non-linear response of plasma catecholamines to graded exercise.

Thus, the finding in the present study that plasma catecholamines and blood lactate minimum concentrations occurred simultaneously during the LMT is compatible with the concept that elevation in plasma epinephrine elicited during exercise contributes to the increase in muscle glicogenolysis. Consequently, this evokes an increase in lactate production in muscle as well as in the rate of appearance of lactate in the blood.

Contrary to our and other's findings, some authors have shown no effect of ß-adrenergic blockade on blood [Lac] during graded (HUGHSON et al.,1981; TESCH & KAISES, 1981) or constant load exercise (JENSEN et al., 1993), thereby demonstrating that the ß-adrenergic system is not obligatory for the blood [Lac] response to exercise.

According to the authors, these controversial results could be explained by the fact that during muscular contraction, there is an increase in citoplasmic Ca^{++} concentration as the result of its release from sarcoplasmic reticulum, once it has been demonstrated to control the phosphorylase *a* activation (CHASIOTIS et al., 1983). Although this mechanism contributes to the breakdown of glycogen during muscular activity, these appears to be a transient response (RENNIER et al., 1982; ISSEKUTS, 1984). Another possible mechanism pointed by some authors is the decrease in muscle pH, due to increased lactic acid, stimulated a reflex increase in sympathetic outflow and a subsequent rise in catecholamine levels (SCHNEIDER, 1992; WELTMAN, 1994).

In conclusion, our findings suggest a causal relationship between plasma catecholamines and blood lactate response to incremental work after maximal exercise. However, once sympathetic activity is only one of several components acting on the blood lactate response to exercise (BROOKS, 1991; GLADDEN, 1996), its relative contribution must be well understood.

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Table 1 - Characteristics of the subjects

N = 07 Male	Age (years)	Weight (kg)	Height (cm)	VO_2max ($ml.kg^{-1}.min^{-1}$)
M	21.4	66.6	171.1	60.2
DP	1.9	7.4	9.3	4.4

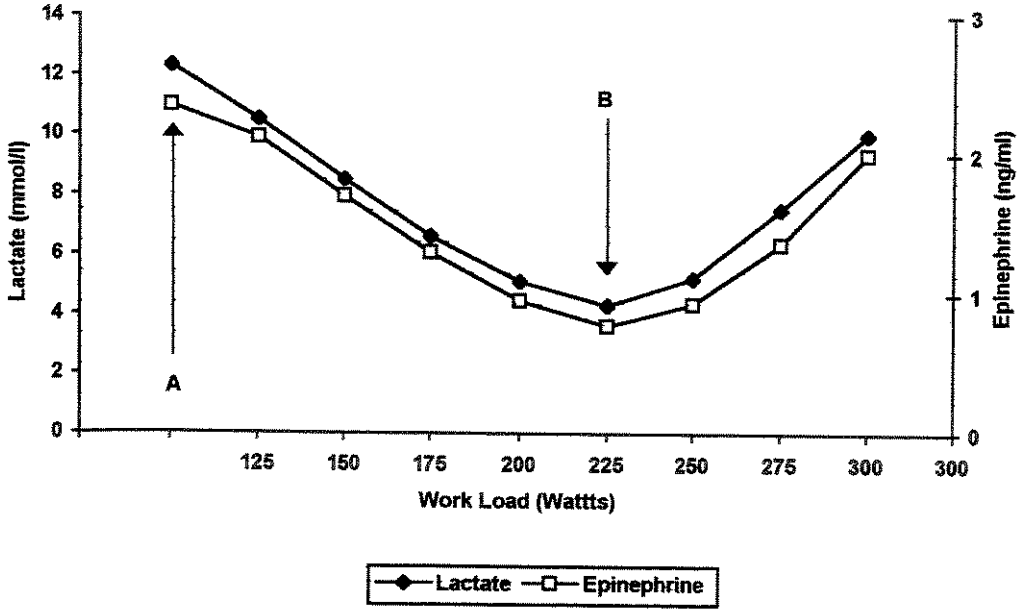

Figura 1 – Determination of exercise intensity corresponding to lactate and epinephrine minimum. Example for one subject, where the intensity found by either criterion corresponds to 225 Watts (B). A = blood lactate and epinefrine values 7 min following Wingate's test.

Tabela 2 – Pearson correlation coefficient (r) between maximal blood lactate ([Lac]max) and plasma norepinephrine ([Nor]max) and epinephrine ([Epi]max) concentrations obtained 7 minutes after Wingate test and between lactate (L_{MI}), norepinephrine (N_{MI}) and epinephrine (E_{MI}) minimum intensities expressed in $\%VO_2max$ (N = 11).

	[Lac]max	[Epi]max	N_{MI}	L_{MI}
[Epi]max	0.85*	-	-	-
[Nor]max	0.98*	0.88*	-	-
L_{MI}	-	-	0.97*	-
E_{MI}	-	-	0.88*	0.96*

* $p < 0,05$

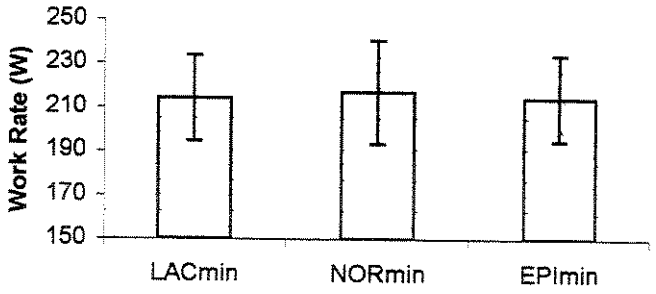

Figura 2. Lactate (L_{MI}), norepinephrine (N_{MI}) and epinephrine (E_{MI}) minimum intensities, expressed in Watts (W)

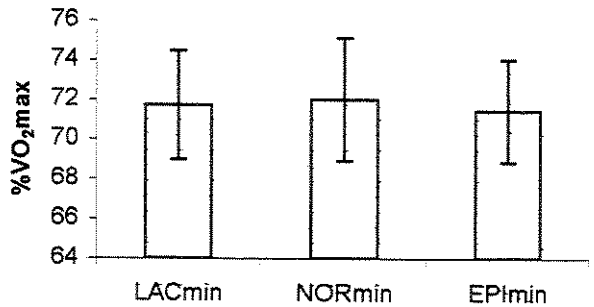

Figure 3. Lactate (L_{MI}), norepinephrine (N_{MI}) and epinephrine (E_{MI}) minimum intensities, expressed in $\%VO_2max$.

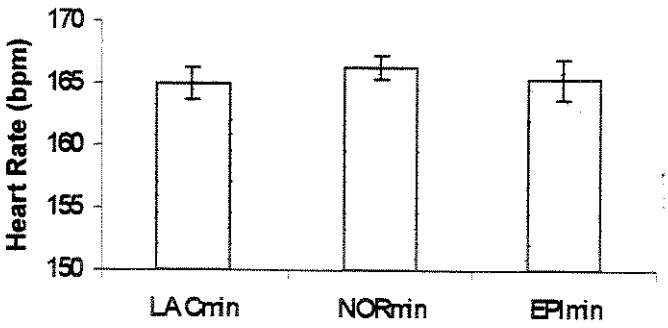

Figure 4. Heart rate values related to the minimum lactate (LACmin), norepinephrine (NORmin) and epinephrine (EPImin) concentrations during the incremental phase of lactate minium test.

6. CONCLUSÃO GERAL

Em função dos resultados obtidos nos estudos realizados, foram elaboradas as seguintes conclusões:

1) Confirmação da possibilidade de determinação da resposta lactacidêmica durante o exercício a partir da análise do comportamento glicêmico;
2) Identificação pela primeira vez da alta sensibilidade do lactato e glicemia mínimos para determinar os efeitos adaptativos do treinamento;
3) Quanto à resposta do lactato e da glicose é possível que a mesma esteja associada ao comportamento das catecolaminas durante o exercício de cargas progressivas, realizado após um exercício anaeróbio;
4) Verificação de alterações dos comportamentos lactacidêmico e glicêmico após bloqueio ß-adrenérgico;
5) Identificação de alta correlação entre a resposta das catecolaminas plasmáticas e do lactato sangüíneo durante o TLM, sugerindo que, pelo menos parte, este comportamento é dependente da estimulação adrenérgica.

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8. ANEXO

TABELAS DE RESULTADOS REFERENTES AO ARTIGO 1.

Valores individuais, médias e desvios padrão do consumo máximo de oxigênio (VO_2max) expresso em $ml.kg^{-1}.min^{-1}$ e Watts (W), nas condições pré e pós treinamento. N = 8

SUJEITO	VO_2max ($ml.kg^{-1}.min^{-1}$)		Carga (W) VO_2max	
	Pré	Pós	Pré	Pós
1	61,00	64,00	325,00	350,00
2	56,00	58,00	275,00	300,00
3	66,00	68,00	300,00	300,00
4	62,00	62,00	300,00	325,00
5	53,00	55,00	225,00	250,00
6	64,00	65,00	300,00	325,00
7	60,00	62,00	300,00	325,00
8	62,00	62,00	300,00	325,00
Média	60,50	62,00	290,60	312,50
DP	4,20	4,00	29,60	29,88

Valores individuais, médias e desvios padrão do consumo máximo de oxigênio (VO_2max) e $\%VO_2max$, carga de trabalho (W), freqüência cardíaca (bpm) correspondentes às intensidades de lactato mínimo e glicemia mínima, nas condições pré e pós treinamento. N = 8.

SUJEITO	VO_2max ($ml.kg^{-1}.min^{-1}$)		% VO_2max L_{MI}		Carga (W) L_{MI}		FC (bpm) L_{MI}		% VO_2max G_{MI}		Carga (W) G_{MI}		FC (bpm) G_{MI}	
	Pré	Pós	Pré	Pós	Pré	Pós	Pré	Pós	Pré	Pós	Pré	Pós	Pré	Pós
1	61,00	64,00	75,00	75,00	225,00	250,00	165,00	166,00	75,00	75,00	225,00	250,00	167,00	167,00
2	56,00	58,00	69,00	71,00	200,00	225,00	166,00	167,00	69,00	71,00	200,00	225,00	166,00	167,00
3	66,00	68,00	74,00	75,00	225,00	250,00	167,00	167,00	74,00	74,00	225,00	250,00	166,00	167,00
4	62,00	62,00	72,00	73,00	225,00	250,00	168,00	168,00	72,00	74,00	225,00	250,00	168,00	167,00
5	53,00	55,00	68,00	70,00	175,00	200,00	164,00	164,00	68,00	71,00	175,00	200,00	165,00	165,00
6	64,00	65,00	74,00	74,00	225,00	225,00	165,00	165,00	74,00	74,00	225,00	225,00	164,00	165,00
7	60,00	62,00	70,00	71,00	225,00	250,00	166,00	166,00	70,00	72,00	225,00	250,00	166,00	166,00
8	62,00	62,00	70,00	72,00	225,00	250,00	167,00	168,00	73,00	73,00	250,00	270,00	167,00	168,00
Média	60,50	62,00	71,50	72,60	215,00	237,50	166,00	166,20	72,10	73,00	218,00	240,60	166,10	166,50
DP	4,20	4,00	2,60	1,92	18,60	18,80	1,30	1,40	2,70	1,50	22,10	22,90	1,20	1,00

Valores individuais, médias e desvios padrão das concentrações mínimas de lactato [Lac] e glicose [Glic], encontradas nas condições pré e pós treinamento.

SUJEITO	[Lac]min (mM)		[Glic]min (mg/dl)	
	Pré	Pós	Pré	Pós
1	4,30	4,10	66,00	65,00
2	4,80	4,70	66,00	66,00
3	3,70	3,60	63,00	65,00
4	4,10	4,20	62,00	61,00
5	3,50	4,00	65,00	63,00
6	4,10	4,20	63,00	64,00
7	4,60	4,80	64,00	63,00
8	5,10	5,20	68,00	67,00
Média	4,27	4,35	64,62	64,25
DP	0,54	0,51	1,99	1,90

Valores individuais, médias e desvios padrão das concentrações máximas de lactato [Lac] e glicose [Glic], encontradas 7 min após o teste de Wingate, nas condições Pré e Pós-treinamento.

SUJEITO	[Lac] Wingate (mM)		[Glic] Wingate (mg/dl)	
	Pré	Pós	Pré	Pós
1	12,30	13,10	94,00	96,00
2	13,50	14,00	90,00	91,00
3	11,50	12,00	88,00	90,00
4	14,40	15,00	94,00	92,00
5	10,40	11,00	86,00	90,00
6	9,80	9,60	91,00	88,00
7	10,40	11,00	88,00	89,00
8	11,40	12,00	92,00	96,00
Média	11,71	12,21	90,37	91,50
DP	1,60	1,71	2,99	3,02

TABELAS DE RESULTADOS REFERENTES AO ARTIGO 2.

Valores individuais, médias e desvios padrão do consumo máximo de oxigênio (VO_2max) expresso em $ml.kg^{-1}.min^{-1}$ e Watts (W), nas condições placebo (Plac) e propranolol (Prop). N = 8

SUJEITO	VO_2max ($ml.kg^{-1}.min^{-1}$)		Carga (W) VO_2max	
	Plac	Prop	Plac	Prop
1	61,00	55,00	325,00	300,00
2	56,00	48,00	275,00	250,00
3	66,00	59,00	300,00	275,00
4	62,00	55,00	300,00	275,00
5	53,00	47,00	225,00	225,00
6	64,00	58,00	300,00	275,00
7	60,00	54,00	300,00	275,00
8	62,00	57,00	300,00	275,00
Média	60,50	54,12	290,60	268,75
DP	4,20	4,42	29,60	22,16

Valores individuais, médias e desvios padrão do consumo máximo de oxigênio (VO_2max) e $\%VO_2max$, carga de trabalho (W), frequência cardíaca (bpm) correspondentes às intensidades de lactato mínimo e glicemia mínima, nas condições placebo (Plac) e propranolol (Prop). N = 8.

SUJEITO	VO_2max ($ml.kg^{-1}.min^{-1}$)		% VO_2max L_{MI}		Carga (W) L_{MI}		FC (bpm) L_{MI}		% VO_2max G_{MI}		Carga (W) G_{MI}		FC (bpm) G_{MI}	
	Plac	Propr	Plac	Propr	Plac	Propr	Plac	Propr	Plac	Propr	Plac	Propr	Plac	Propr
1	61,00	55,00	75,00	66,00	225,00	200,00	165,00	131,00	75,00	-	225,00	-	167,00	-
2	56,00	48,00	69,00	60,00	200,00	175,00	166,00	135,00	69,00	-	200,00	-	166,00	-
3	66,00	59,00	74,00	56,00	225,00	175,00	167,00	133,00	74,00	-	225,00	-	166,00	-
4	62,00	55,00	72,00	49,00	225,00	150,00	168,00	129,00	72,00	-	225,00	-	168,00	-
5	53,00	47,00	68,00	65,00	175,00	175,00	164,00	133,00	68,00	-	175,00	-	165,00	-
6	64,00	58,00	74,00	65,00	225,00	200,00	165,00	130,00	74,00	-	225,00	-	164,00	-
7	60,00	54,00	70,00	64,00	225,00	200,00	166,00	135,00	70,00	-	225,00	-	166,00	-
8	62,00	57,00	70,00	66,00	225,00	200,00	167,00	131,00	73,00	-	250,00	-	167,00	-
Média	60,50	54,12	71,50	61,50	215,00	184,00	166,00	132,10	72,10	-	218,00	-	166,10	-
DP	4,20	4,42	2,60	6,00	18,60	18,60	1,30	2,00	2,70	-	22,10	-	1,24	-

Valores individuais, médias e desvios padrão das concentrações máximas de lactato [Lac] e glicose [Glic], encontradas 7 min após o teste de Wingate, nas condições placebo e propranolol.

SUJEITO	[Lac] Wingate (mM)		[Glic] Wingate (mg/dl)	
	Plac	Prop	Plac	Prop
1	12,30	9,20	94,00	76,00
2	13,50	10,20	90,00	71,00
3	11,50	8,70	88,00	71,00
4	14,40	11,20	94,00	71,00
5	10,40	7,40	86,00	71,00
6	9,80	8,30	91,00	66,00
7	10,40	6,10	88,00	71,00
8	11,40	7,70	92,00	69,00
Média	11,71	8,60	90,37	70,75
DP	1,60	1,61	2,99	2,76

Valores individuais, médias e desvios padrão das concentrações mínimas de lactato [Lac] e glicose [Glic], encontradas nas condições placebo e propranolol.

SUJEITO	[Lac]min (mM)		[Glic]min (mg/dl)	
	Plac	Prop	Plac	Prop
1	4,30	4,10	66,00	-
2	4,80	4,20	66,00	-
3	3,70	3,70	63,00	-
4	4,10	3,80	62,00	-
5	3,50	3,10	65,00	-
6	4,10	3,80	63,00	-
7	4,60	3,30	64,00	-
8	5,10	3,80	68,00	-
Média	4,27	3,72	64,62	-
DP	0,54	0,36	1,99	-

TABELAS DE RESULTADOS REFERENTES AO ARTIGO 3.

Valores individuais, médias e desvios padrão do consumo máximo de oxigênio (VO_2max) expresso em $ml.kg^{-1}.min^{-1}$ e Watts (W). N = 7

SUJEITO	VO_2max ($ml.kg^{-1}.min^{-1}$)	Carga (W) VO_2max
1	61,00	300,00
2	56,00	275,00
3	66,00	325,00
4	62,00	300,00
5	53,00	225,00
6	64,00	300,00
7	60,00	300,00
Média	60,28	289,28
DP	4,49	31,81

Valores individuais, médias e desvios padrão das concentrações máximas de lactato [Lac], norepinefrina [Nor] e epinefrina [Epi] encontradas 7 min após o teste de Wingate

SUJEITO	[Lac] Wingate (mM)	[Nor] Wingate (ng/ml)	[Epi] Wingate (ng/ml)
1	12,30	16,21	2,35
2	13,50	16,83	2,41
3	11,50	14,24	2,28
4	14,40	17,53	2,50
5	10,40	13,82	2,33
6	9,80	12,63	2,12
7	10,40	13,67	2,32
Média	11,75	14,99	2,33
DP	1,72	1,85	0,11

Valores individuais, médias e desvios padrão do percentual do consumo máximo de oxigênio (%VO_2max) associado as menores concentrações de lactato [Lac]min, norepinefrina [Nor]min e epinefrina [Epi]min encontradas durante o teste incremental realizado após o teste de Wingate

SUJEITO	%VO_2max [Lac]min	%VO_2max [Nor]min	%VO_2max [Epi]min
1	75,00	75,00	75,00
2	69,00	69,00	69,00
3	74,00	74,00	74,00
4	72,00	72,00	72,00
5	68,00	68,00	68,00
6	74,00	76,00	72,00
7	70,00	70,00	70,00
Média	71,71	72,00	71,42
DP	2,75	3,10	2,57

Valores individuais, médias e desvios padrão da carga de trabalho (W) associada as menores concentrações de lactato [Lac]min, norepinefrina [Nor]min e epinefrina [Epi]min encontradas durante o teste incremental realizado após o teste de Wingate

SUJEITO	W - [Lac]min	W - [Nor]min	W - [Epi]min
1	225,00	225,00	225,00
2	200,00	200,00	200,00
3	225,00	225,00	225,00
4	225,00	225,00	225,00
5	175,00	175,00	175,00
6	225,00	250,00	225,00
7	225,00	225,00	225,00
Média	214,28	217,85	214,28
DP	19,66	23,77	19,66

Valores individuais, médias e desvios padrão da frequência cardíaca (FC) associada as menores concentrações de lactato [Lac]min, norepinefrina [Nor]min e epinefrina [Epi]min encontradas durante o teste incremental realizado após o teste de Wingate

SUJEITO	FC - [Lac]min	FC - [Nor]min	FC - [Epi]min
1	165,00	166,00	165,00
2	166,00	167,00	166,00
3	167,00	166,00	166,00
4	168,00	168,00	168,00
5	164,00	165,00	164,00
6	165,00	166,00	163,00
7	166,00	166,00	165,00
Média	165,00	166,28	165,28
DP	1,33	0,95	1,60